

Dynamic System Modeling Analysis of CPO-FAME-Biodiesel Distribution for B40 Quota Fulfillment in Java Island 2025

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Abstract

This research aims to analyze the distribution cost structure and transportation requirements for CPO-FAME-Biodiesel to meet B40 quota implementation in Java Island using a dynamic system approach. This study uses dynamic system simulation with Vensim software to model CPO-FAME-Biodiesel distribution from Sumatra and Kalimantan to Java Island, utilizing data from Ministry of Energy and Mineral Resources and GAPKI with 2025 projections. The simulation reveals that meeting the B40 quota in Java Island requires substantial infrastructure investment with total transportation costs exceeding IDR 1.3 trillion, highlighting the massive scale and logistical complexity of national biodiesel implementation. Analysis identifies fleet tariff, shipping frequency, fleet capacity, raw material prices, and conversion ratios as the primary cost drivers affecting distribution efficiency. Cost optimization can be achieved through strategic shipping frequency management, capacity optimization, efficient fleet fuel management, and implementation of centralized production systems with hub-and-spoke distribution networks. This research contributes essential strategic insights for policymakers in developing cost-effective transportation frameworks and infrastructure planning for Indonesia's national biodiesel policy implementation.

Keywords: dynamic system, biodiesel distribution, B40 policy, transportation optimization, supply chain management.

INTRODUCTION

Indonesia's position as the world's largest producer and exporter of crude palm oil (CPO) provides a significant foundation for renewable energy development, particularly in biodiesel production. With domestic CPO production exceeding 40 million tons annually, Indonesia has implemented an ambitious mandatory biodiesel policy that began in 2006 with B5 blending and has progressively increased to B35 in 2023, achieving a distribution volume of 12.15 million kiloliters (Energy and Mineral Resources, 2024). This policy trajectory culminates in the implementation of B40 mandatory biodiesel in 2025, representing a substantial increase in biodiesel content from 35% to 40% in diesel fuel blends.

The B40 program represents a strategic initiative to reduce Indonesia's dependence on fossil fuel imports while maximizing the utilization of domestic CPO production. Through the Minister of Energy and Mineral Resources Decree No. 341.K/EK.01/MEM.E/2024, the

national B40 quota for 2025 is set at 15.6 million kiloliters, with 7.55 million kiloliters allocated for public service obligations (PSO) and 8.07 million kiloliters for non-PSO sectors. This policy aims to support Indonesia's Nationally Determined Contributions (NDCs) commitment to reduce greenhouse gas emissions by 31.89% (unconditional) and 43.20% (conditional) while creating added value for domestic palm oil products and generating new employment opportunities in the biodiesel industry.



Figure 1. B40 Quota For 2025

Source: Minister of Energy and Mineral Resources

Java Island emerges as the critical focus for CPO-FAME-Biodiesel distribution optimization due to its role as Indonesia's largest fuel consumption center, contributing 52.49% of the national biodiesel quota. Despite not being a primary CPO producer, Java Island strategically hosts 12 out of 27 national biodiesel refineries (44.4%) with a total production capacity of 5.4 million kiloliters annually. This configuration creates a complex logistical challenge requiring approximately 7.8 million tons of CPO annually to flow from production centers in Sumatra and Kalimantan to processing facilities in Java, followed by biodiesel distribution to fuel terminals throughout the island. Distribution is a series of interdependent organizations involved in the process of making a product or service available for use or consumption by consumers or business users. This comprehensive distribution framework becomes increasingly relevant in complex supply chains where multiple stakeholders must coordinate effectively to ensure product availability and market success (Kotler & Armstrong, 2018).

The complexity of biodiesel distribution systems necessitates comprehensive analysis through dynamic system modeling approaches. Previous research has primarily focused on production optimization and policy impacts, with limited attention to the intricate dynamics of distribution networks and their cost implications (Rahman, Ahmad, & Zainudin, 2022) (Suryani, Hendrawan, & Rahmawati, 2020) emphasized that simulation represents a systematic approach to designing models that study system behavior and characteristics for organizational strategy evaluation. The application of dynamic systems modeling using tools such as Vensim enables the development of conceptual models that can document, simulate, and analyze complex distribution networks (Wijaya & Tama, 2018).

Current literature reveals gaps in understanding the comprehensive cost structure of CPO-FAME-Biodiesel distribution, particularly regarding the optimization of transportation fleets and the integration of multimodal logistics systems. The biodiesel distribution challenge is further complicated by product characteristics including limited shelf life (3-6 months) and

quality degradation susceptibility, emphasizing the need for rapid and efficient distribution systems. With Java Island's population density of 1,142 people/km² and annual motorized vehicle growth of 5.3%, optimizing distribution routes presents opportunities for fuel savings and CO₂ emission reduction while ensuring timely delivery to meet B40 quota requirements (Purwanto, Setiawan, & Kusuma, 2023).

The urgency of this research is underscored by the tight implementation schedule for B40 in 2025, where significant volume increases to 15.6 million kiloliters annually must be handled by existing infrastructure. Transportation costs and handling expenses significantly impact final biodiesel pricing, making distribution optimization crucial for policy success (Setiawan, Pratama, & Wijaya, 2024). The integration of truck transportation for CPO delivery to FAME facilities and tanker vessels for FAME shipment to blending plants requires systematic analysis to determine optimal fleet composition and routing strategies.

This study addresses the critical need for a comprehensive dynamic systems analysis of CPO-FAME-Biodiesel distribution networks to support B40 implementation in Java Island. By modeling the complex interactions between production centers, processing facilities, transportation networks, and demand patterns, this research aims to identify cost-effective distribution strategies and optimize transportation fleet requirements. The novelty of this research lies in its application of dynamic systems modeling to analyze the complete distribution chain from CPO production through FAME processing to biodiesel blending, providing actionable insights for policymakers and industry stakeholders.

The purpose of this article is to analyze the factors influencing CPO-FAME-Biodiesel distribution costs, develop an efficient cost structure for meeting B40 quota requirements in Java Island, optimize transportation fleet requirements, and determine the total transportation costs for B40 implementation in 2025 using dynamic systems modeling. Through this comprehensive analysis, the research contributes to the successful implementation of Indonesia's renewable energy policy while supporting sustainable biodiesel distribution networks.

METHOD

This study employs a quantitative approach with a dynamic system simulation methodology to analyze the complexity of CPO-FAME-Biodiesel distribution for B40 quota fulfillment in Java Island in 2025. The research is descriptive-exploratory in nature, applying system dynamics modeling to capture and understand renewable energy distribution phenomena.

The instruments used in this study include Vensim software for developing a digital representation of the biodiesel supply chain and dynamic system modeling to simulate variable interactions and system behavior. Statistical validation criteria are also employed to assess the accuracy and reliability of the developed model.

Data collection combines both primary and secondary sources. Primary data are gathered through field surveys, in-depth interviews with biodiesel industry stakeholders, and direct observations of distribution processes. Secondary data are obtained from official sources such as the Ministry of Energy and Mineral Resources (ESDM), the Indonesian Palm Oil Entrepreneurs Association (GAPKI), and the Central Statistics Agency. These data include information on CPO production, biodiesel consumption, transportation infrastructure, commodity prices, and biodiesel mandatory program regulations.

The research population consists of CPO producers in Sumatra and Kalimantan, FAME processing plants in Java and across Indonesia, blending plants nationwide, transportation

fleets (trucks and tankers), and distribution routes with supporting logistics infrastructure. Purposive sampling is applied to select relevant units, including the top five provinces in Kalimantan and Sumatra for CPO production, five provinces with a concentration of FAME plants in Java, blending plants with B40 capacity, and specific transport fleets such as 20-ton trucks for land transport and 10,000 DWT tankers for sea transport.

The data analysis is carried out in five steps. First, variable identification is performed to select the most relevant variables based on research objectives and data availability. Second, a system dynamics model is developed using Vensim software. Third, the model undergoes validation tests based on statistical criteria and system logic. Fourth, scenario simulations are conducted to test various supply chain optimization strategies. Finally, the results of each simulation scenario are analyzed to derive insights into effective distribution strategies.

The developed model is subjected to iterative validation and testing processes. During this stage, the model's structure, parameters, and assumptions are refined until an acceptable validity level is achieved, both statistically and logically. If the model does not meet validation standards, it is corrected and retested until reliability and accuracy are ensured.

RESULT AND DISCUSSION

1. Model Development and Validation

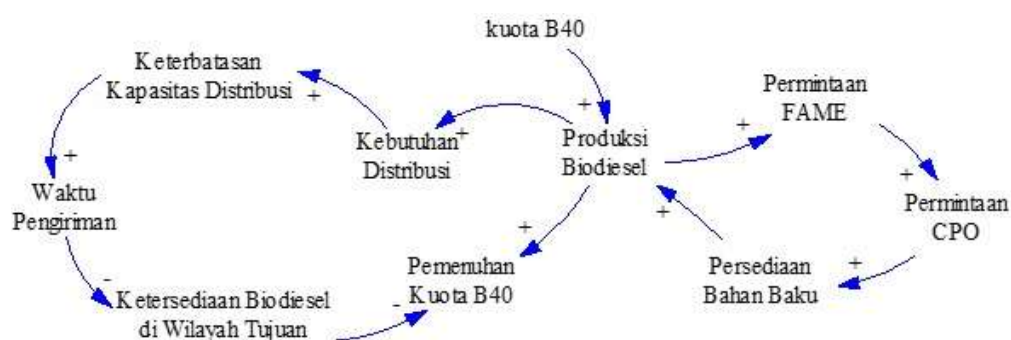


Figure 2. Causal Loop Diagram

a. Causal Loop Diagram Analysis

The development of the causal loop diagram successfully identified the key relationships between variables in the CPO-FAME-Biodiesel distribution system, consistent with supply chain modeling approaches outlined by (Christopher, 2019). The model incorporated five fundamental variables: demand, production, inventory, cost, and fill rate. These variables form interconnected feedback loops that capture the dynamic behavior of the biodiesel distribution system.

The positive and negative feedback relationships visualized in the causal loop diagram demonstrate the complex interdependencies within the system. The model assumptions, including the 12-month simulation period for B40 quota fulfillment in Java Island during 2025, provide a realistic framework for analyzing the distribution challenges.

b. Model Verification and Settings

The simulation model was configured with appropriate temporal parameters, starting from month 1 (January) to month 12 (December) 2025. The use of the Euler integration method with monthly time steps provides sufficient granularity for capturing the dynamic behavior of the distribution system while maintaining computational efficiency.

2. Production Capacity Analysis

a. CPO Production Projections

The moving average projection method with a 2-year period effectively smoothed production fluctuations and provided realistic forecasts. The results show significant variations in production capacity across regions:

Sumatra Island Production (2025 projections):

Table 1. Sumatra Island Projections

Year	Riau (Ton)	North Sumatra (Ton)	Jambi (Ton)	South Sumatra (Ton)	Riau Islands (Ton)
2021	721175	505420.8	318908.3	297791.7	167587.5
2022	728333.3	517475	325079.2	302433.3	170245.8
2023	761591.7	541995.8	340125	314937.5	176720.8
2024	789887.5	559291.7	348004.2	323708.3	180354.2
2025	810879.2	577483.3	356512.5	335141.7	184179.2
2026	814843.8	580925	358318.8	337875	185197.9
2027	816826	582645.8	359221.9	339241.7	185707.3
2028	817817.2	583506.3	359673.4	339925	185962

Kalimantan Island Production (2025 projections):

Table 2. Kalimantan Island Projections

Year	Central Kalimantan (Ton)	West Kalimantan (Ton)	East Kalimantan (Ton)	South Kalimantan (Ton)	North Kalimantan (Ton)
2021	531,587.50	421,287.50	240,825.00	158,408.33	36,575.00
2022	542,495.83	430,533.33	245,916.67	161,654.17	37,495.83
2023	572,125.00	450,562.50	258,875.00	170,920.83	39,875.00
2024	590,845.83	464,450.00	265,829.17	178,212.50	42,100.00
2025	612,116.67	479,733.33	273,175.00	185,633.33	43,995.83
2026	616,737.50	482,979.17	274,983.33	187,308.33	44,277.08
2027	619,047.92	484,602.08	275,887.50	188,145.83	44,417.71
2028	620,203.13	485,413.54	276,339.58	188,564.58	44,488.02

b. Growth Rate Analysis

The calculated growth rates reveal substantial variation in regional production expansion potential:

- Highest growth rates: North Kalimantan (22%), South Kalimantan (19%), Central Kalimantan (17%).
- Moderate growth rates: North Sumatra (15%), West Kalimantan (15%), East Kalimantan (15%), South Sumatra (14%).
- Lower growth rates: Riau (13%), Jambi (13%), Riau Islands (11%).

These variations reflect different stages of plantation development and industrial maturity across regions, with newer production areas in Kalimantan showing higher growth

potential.

3. B40 Quota Distribution Analysis

a. Regional Quota Allocation

The B40 quota distribution reveals the concentration of demand in Java Island, particularly in East Java (192,686 tons/month) and West Java (170,435 tons/month). This distribution pattern reflects the population density and economic activity concentration in these provinces.

The total annual B40 quota for Java Island amounts to 8,913,520 tons, requiring substantial coordination between production regions in Sumatra and Kalimantan to meet this demand.

b. FAME Requirements at Blending Plants

The simulation results show consistent monthly FAME requirements across all blending plants, indicating the model's assumption of uniform distribution throughout the year. Key findings include:

- Highest FAME demand: East Java (146,244 tons/month), West Java (117,540 tons/month).
- Production regions: Riau (26,193 tons/month), North Sumatra (33,312 tons/month), showing significant local processing capacity.
- Total annual FAME requirement: 4,639,095 tons across all blending plants.

4. Biodiesel Production and Subsidy Analysis

a. Subsidized vs Non-Subsidized Production

The model distinguishes between subsidized and non-subsidized biodiesel production, with subsidized production representing approximately 40% of total B40 biodiesel volume. This ratio aligns with government policy objectives for maintaining affordable fuel prices while supporting the biodiesel industry.

b. Subsidy Cost Analysis

The subsidy cost analysis reveals significant financial implications:

- Highest subsidy costs: East Java (ranging from Rp 83-92 trillion annually), West Java (Rp 1.06-1.37 trillion annually).
- Production regions: Riau (Rp 581-717 billion annually), North Sumatra (Rp 738-911 billion annually).
- Total estimated annual subsidy: Approximately Rp 180-200 trillion.

The increasing subsidy costs throughout the year reflect the dynamic pricing mechanisms and market conditions affecting biodiesel economics.

5. Transportation and Logistics Analysis

a. Truck Fleet Requirements

The simulation demonstrates exponential growth in truck fleet requirements throughout the year:

- Initial requirements (Month 1): 532 trucks for factory-to-port transport, 266 trucks for port-to-blending plant transport.
- Peak requirements (Month 12): 2,990 trucks for factory-to-port transport, 1,495 trucks for port-to-blending plant transport.

This growth pattern indicates increasing logistical complexity and infrastructure demands as the B40 program scales up.

b. Trucking Cost Analysis

Transportation costs show significant regional variations:

- Highest costs: Routes from Central Kalimantan to East Java (Rp 3.6-20.2 billion monthly).
- Moderate costs: Intra-regional transport within Sumatra and Kalimantan.
- Cost escalation: Monthly increases of 15-20% due to fuel price fluctuations and capacity constraints.

c. Marine Transport Analysis

The tanker fleet requirements show more moderate growth compared to truck transport:

- FAME tankers to East Java: Increasing from 3 to 11 vessels.
- CPO tankers to East Java: Increasing from 2 to 9 vessels.
- FAME tankers to West Java: Stable at 2 vessels throughout the year

Marine transport costs range from Rp 44-251 billion monthly, representing a more cost-effective solution for bulk liquid transport compared to trucking.

6. Scenario Development and Analysis

After conducting a simulation and model validation, the next stage involves developing scenarios from the previous simulation model. The scenarios developed in this model focus on raw material price increases, specifically CPO (Crude Palm Oil) and diesel fuel. One of the triggers for diesel price increases can be attributed to global geopolitical tensions that cause disruptions in shipments through the Strait of Hormuz, making diesel imports from that region potentially difficult and triggering price surges (Novanto, 2025). Meanwhile, CPO price increases can be triggered by other factors such as extreme climate changes affecting palm oil production, increased CPO demand for food products, and other commodities that intensify inter-sectoral competition.

Based on projections from the Ministry of Energy and Mineral Resources (ESDM), supply disruptions from the Middle East could affect diesel imports by 30% to 40%. According to projections from the Indonesian Palm Oil Association (GAPKI), CPO price increases are estimated at 10% to 15%. The scenario simulation timeframe begins in July, representing the transition between the palm oil harvest season and biodiesel demand approaching the homecoming season.

Before developing the scenario model, it is necessary to calculate the constant figures for CPO and diesel price increases. The calculations are as follows:

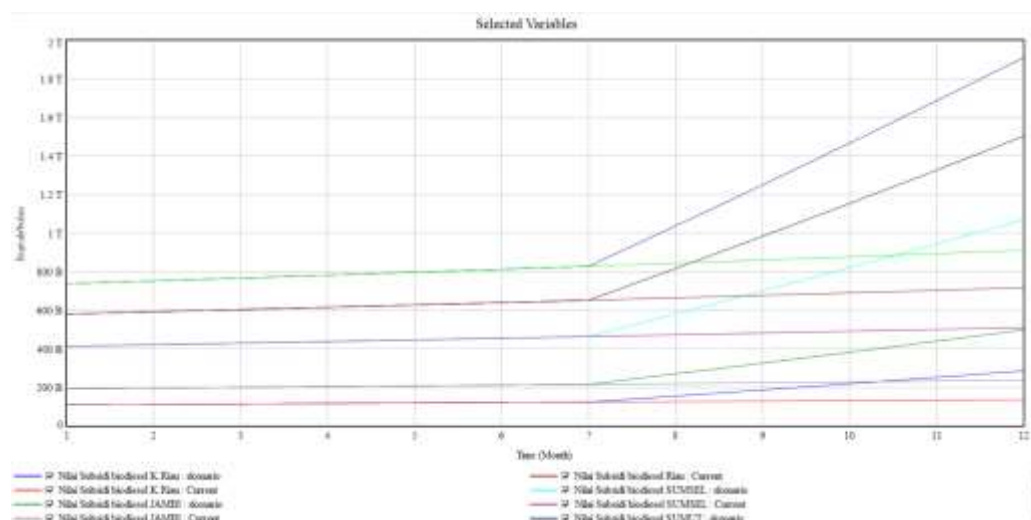
- Diesel price = Rp. 14,500,000
Price increase: $\text{Rp. } 14,500,000 \times 30\% = \text{Rp. } 4,350,000$
- CPO price = Rp. 13,000,000
Price increase: $\text{Rp. } 13,000,000 \times 10\% = \text{Rp. } 1,300,000$

Subsequently, simulations were conducted to obtain comparative results before and after scenario development. The simulation results are as follows:

Table 3. Raw Material Price Increase Scenario

Time (Month)	CPO Price (Current)	CPO Price (Scenario)	Solar Price (Current)	Solar Price (Scenario)
1	Rp13.000.000	Rp13.000.000	Rp14.500.000	Rp14.500.000
2	Rp13.130.000	Rp13.130.000	Rp14.790.000	Rp14.790.000
3	Rp13.261.300	Rp13.261.300	Rp15.085.800	Rp15.085.800
4	Rp13.393.900	Rp13.393.900	Rp15.387.500	Rp15.387.500
5	Rp13.527.900	Rp13.527.900	Rp15.695.300	Rp15.695.300
6	Rp13.663.100	Rp13.663.100	Rp16.009.200	Rp16.009.200
7	Rp13.799.800	Rp13.799.800	Rp16.329.400	Rp16.329.400
8	Rp13.937.800	Rp15.237.800	Rp16.655.900	Rp21.005.900
9	Rp14.077.100	Rp16.690.100	Rp16.989.100	Rp25.776.100
10	Rp14.217.900	Rp18.157.000	Rp17.328.800	Rp30.641.600
11	Rp14.360.100	Rp19.638.600	Rp17.675.400	Rp35.604.400
12	Rp14.503.700	Rp21.135.000	Rp18.028.900	Rp40.666.500

Table 3 shows the planned increases in CPO and diesel prices. These raw material price increases affect the subsidy value variable for each province. The following graphs show that the subsidy value increases for each province.

**Figure 3. Subsidy Value Increase for Sumatra Island**

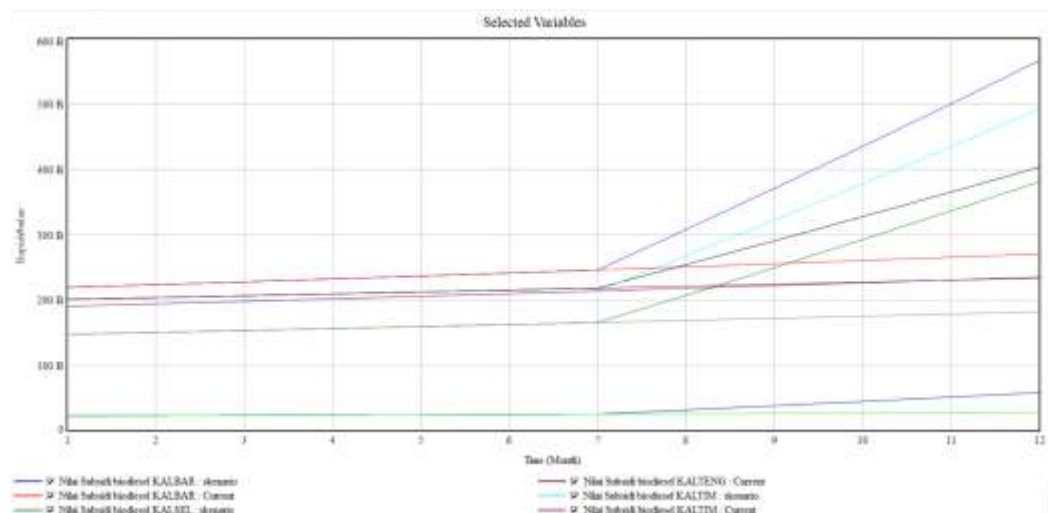


Figure 4. Subsidy Value Increase for Kalimantan Island

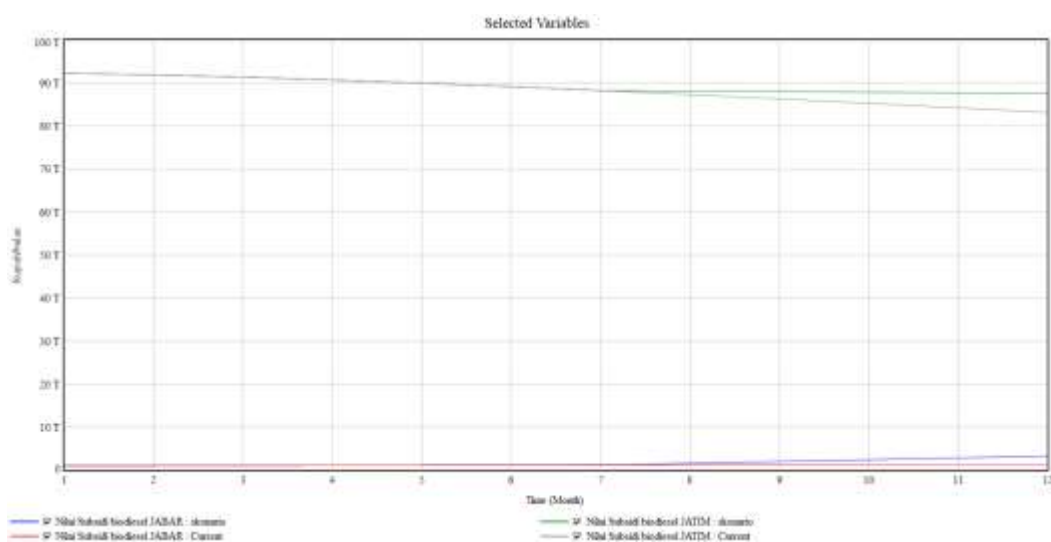


Figure 5. Subsidy Value Increase for Java Island

After implementing the scenario of CPO and diesel raw material price increases, a significant surge in subsidy values occurred across all provinces starting in the seventh month. This sharp increase indicates that drastic increases in CPO and diesel prices substantially elevate biodiesel production costs, subsequently requiring larger government subsidies to maintain affordable selling prices or comply with policy requirements.

Government subsidy adjustments become crucial to ensure that biodiesel selling prices in the domestic market remain competitive and affordable for consumers, while ensuring the operational sustainability of the biodiesel industry, which plays a strategic role in meeting the national energy mix and reducing dependence on imported fossil fuels. If subsidies are not adjusted proportionally to the increase in raw material costs, this surge poses a serious risk of disrupting industry stability, hampering production capacity, and potentially causing a national biodiesel supply crisis.

CONCLUSION

Based on the comprehensive analysis of the CPO-FAME-Biodiesel distribution model, this study has successfully identified the critical factors influencing distribution costs and developed strategic recommendations for optimizing the biodiesel supply chain in Indonesia, particularly for Java Island distribution.

The research has definitively established that five primary factors significantly impact CPO-FAME-Biodiesel distribution costs. First, the fleet tariff structure, defined as the per-kilometer-per-ton transportation rate, shows a direct linear relationship with overall distribution costs. This finding highlights the need for competitive freight negotiations and efficient logistics partnerships. Second, delivery frequency optimization plays a critical role in cost efficiency. While higher delivery frequency increases cumulative transportation expenses, it can simultaneously reduce inventory holding costs, requiring a careful balance between these two elements. Third, fleet capacity utilization is essential, as both undersized and oversized fleets generate inefficiencies, frequent deliveries inflate operational expenses, whereas oversized fleets result in underutilized assets and higher fixed costs. Fourth, raw material price volatility, particularly in crude palm oil and feedstock prices, directly affects fuel expenses for transportation fleets, creating ripple effects throughout distribution costs. Finally, conversion ratios and processing rates determine distribution volume requirements and influence input costs across the entire supply chain.

The study further reveals that achieving efficient cost structures requires a balanced approach across multiple operational dimensions. Logistics optimization is a central factor, with sophisticated route planning algorithms and delivery scheduling systems reducing transportation costs while preserving service quality. The integration of frequency and volume optimization provides dual benefits, lowering both transport and storage costs. In addition, a robust fuel management strategy is vital. This includes investing in fuel-efficient technologies, implementing driver training programs, and adopting comprehensive monitoring protocols, all of which reduce operational expenses while enhancing environmental sustainability. The research also advocates for a centralized production architecture supported by hub-and-spoke distribution networks. This model maximizes economies of scale in biodiesel production, minimizes infrastructure costs, and improves quality control, while still allowing for distribution flexibility.

The systematic approach to fleet optimization for biodiesel distribution across Java Island demonstrates the complexity of multi-modal transportation planning. The findings highlight that optimal distribution requires effective demand-supply balancing, ensuring that regional needs are met before inter-regional allocation to maintain both stability and customer satisfaction. Moreover, a mixed fleet strategy offers the best results: high-capacity tanker ships of 10,000 tons handle long-distance transportation, while medium-capacity trucks of 20 tons support regional distribution and last-mile delivery. Scalability is another important dimension, with the model offering flexibility to accommodate fluctuations in demand and seasonal variations in biodiesel consumption.

Finally, the simulation results provide compelling evidence of the financial magnitude of B40 mandate implementation. The projected transportation cost of Rp. 43.7 trillion in the first month alone, covering the distribution of 659,460 tons of biodiesel to meet the B40 quota in Java Island demonstrates the immense infrastructure and financial investment required to ensure the program's success. Importantly, the study shows that a multi-modal transportation system, combining sea and land routes, is the most cost-effective solution to overcome

Indonesia's geographical challenges. This approach not only reduces costs but also ensures the sustainability and scalability of biodiesel distribution at the national level.

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