The Impact of Crude Palm Oil Downstreaming Policies on the Indonesian Palm Oil Industry

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Abstract. The Indonesian palm oil industry plays a strategic role in the national economy, both as a source of foreign exchange, a major employer, and a driver of regional growth. However, the dominance of crude palm oil (CPO) exports raises concerns about the resilience of domestic value addition and vulnerability to global price fluctuations. To address this, the government is promoting downstreaming policies through mandatory biodiesel use as a means of strengthening the industry's structure. This study aims to analyze the performance of biodiesel policies in supporting CPO downstreaming, identify the factors influencing biodiesel development, and evaluate their impact on the Indonesian palm oil industry. This study employed a simultaneous equation model with nine structural equations estimated using the Two Stage Least Squares (2SLS) method, validated using RMSPE and U-Theil. Time series data from 2000 to 2024 were used to analyze key variables such as oil palm plantation area, domestic CPO prices, biodiesel production, and exports. The analysis results indicated that the B35 and B40 mandatory policies had driven increases in biodiesel prices and exports, but on the other hand, they had reduced CPO exports and crude palm oil production. This signified a shift in the industry's orientation from raw material exports to domestic value-added utilization. These policies had important implications for energy distribution, price stability, and the competitiveness of the national industry. Therefore, further policy support is needed in the form of incentives, infrastructure strengthening, and a balance between energy, food, and environmental needs to achieve sustainable palm oil downstreaming.

1 Introduction

The palm oil industry holds a strategic position in Indonesia's economy as a major source of foreign exchange, employment, and regional development. As the world's largest palm oil producer, Indonesia contributes more than 62% of global output. In 2023, the country

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managed 16.83 million hectares of plantations and produced 47.08 million tons of Crude Palm Oil (CPO) and 9.41 million tons of palm kernel, with exports totaling 27.54 million tons and generating USD 24.01 billion in foreign exchange. These achievements demonstrate Indonesia's central role in meeting global demand for vegetable oils and strengthening its leadership in international markets. However, despite this strong production base, the national industry still faces major challenges, including sustainability concerns, farmer welfare, and high dependence on raw material exports.

To address these issues, the Indonesian government has emphasized a downstreaming strategy aimed at increasing domestic value addition and reducing reliance on unprocessed CPO exports. One key measure is the export levy policy, designed to encourage the shift from raw CPO exports toward higher value-added products such as cooking oil, oleochemicals, and biodiesel. The downstream policy is supported by Presidential Regulation No. 61 of 2015 on the Collection and Use of Palm Oil Plantation Funds, which outlines mechanisms for collecting, managing, and allocating industry-related funds. The Palm Oil Plantation Fund Management Agency (BPDPKS) administers these funds to support infrastructure development, research, sustainability initiatives, and other downstream-supporting programs. Through these policies, the government seeks to expand domestic processing capacity, increase job creation, improve industrial competitiveness, and enhance the contribution of palm oil to sustainable economic development.

Failure to accelerate downstreaming would result in a substantial loss of potential value, especially considering the wide price gap between raw CPO and processed derivatives. Raw exports remain vulnerable to fluctuations in global prices and trade barriers, including the European Union's deforestation regulations[1]. Heavy reliance on CPO exports limits the country's ability to capture higher value from processed goods that are generally more competitive and price-stable in the global market. Conversely, domestic processing can increase foreign exchange earnings, generate employment, and strengthen national industry performance. Prioritizing downstreaming therefore provides an opportunity to optimize the economic potential of the palm oil sector while reducing exposure to international market volatility.

To promote downstream development, the government has introduced numerous tariff and non-tariff policies. A key non-tariff measure is the mandatory adoption of CPO-based biodiesel. This program, established under Ministry of Energy and Mineral Resources Regulation No. 12 of 2015, requires diesel fuel to be blended with biodiesel. The mandate has progressively expanded from B20 to B30 and, since early 2023, to B35, representing a 35% biodiesel blend. This initiative stimulates domestic CPO absorption, supports energy diversification, reduces dependency on fossil fuel imports, and increases domestic value addition. The policy illustrates how downstreaming can deliver tangible benefits not only for national energy security but also for rural economies and industrial development.

The increasing allocation of CPO for biodiesel production has significant implications across economic, environmental, and social dimensions. Higher biodiesel demand may raise domestic CPO prices [2], as demonstrated by the implementation of the B20 mandate, which increased biodiesel production and exports but decreased raw CPO exports [3]. From an environmental perspective, biodiesel production can contribute to greenhouse gas emission reductions relative to fossil fuels [4,5]. aligning with national commitments under the Paris Agreement. However, this redirection of CPO toward fuel uses may create tensions with food security objectives by reducing the supply of palm oil available for household consumption, potentially contributing to higher cooking oil prices [6]. Consequently, policy strategies must balance food, energy, and trade priorities to prevent adverse socioeconomic impacts.

Despite its positive effects, biodiesel-driven downstreaming also raises concerns regarding sustainability. Expansion of palm oil plantations to meet growing biodiesel demand risks contributing to deforestation and land-use change [7], creating potential indirect environmental consequences. Furthermore, technological and regulatory challenges persist, including the need to ensure compatibility between higher biodiesel blends and existing vehicle technology, as well as the need for consistent and long-term policy frameworks to safeguard investment certainty and sustainability goals [8].

Nonetheless, biodiesel remains a central component of Indonesia's renewable energy transition and downstream industrial policy. The government's systematic escalation of mandatory biodiesel blending—from 2.5% in 2008 to 35% in 2023—demonstrates strong political commitment to enhancing domestic energy security, reducing fossil fuel imports, and maximizing national value addition from palm oil. The B35 program alone has been credited with saving significant foreign exchange, supporting improvements in environmental quality, and increasing employment.

Given the scale of these policy interventions, assessing their effectiveness is essential. Therefore, this study aims to evaluate the performance of Indonesia's biodiesel policy in advancing palm oil downstreaming, identify factors influencing biodiesel development, and analyze their broader impacts on the national palm oil industry. A comprehensive analysis is needed to determine the extent to which downstreaming through biodiesel production has strengthened industrial performance, enhanced sustainability, and positioned Indonesia more competitively in the global palm oil economy.

2 Research Methods

The research methods section of this study comprehensively describes the specification of the econometric model used to analyze the impact of biodiesel policy on Indonesia's palm oil industry, detailing the relationships between endogenous and exogenous variables, including production, demand, prices, exports, and other determining factors. This section outlines the model identification process, validation procedures using the RMSPE and Theil's U statistics, and policy simulation scenarios covering the implementation of mandatory biodiesel policies from B30 to B35 and B40 for the 2021–2024 period. It also explains the types and sources of time-series data employed, along with an expanded interpretation of p-values in regression t-tests to ensure the accuracy of directional hypotheses. Through this approach, the model is expected to accurately represent actual conditions and simulate policy impacts effectively, providing an evidence-based foundation for informed policy decision-making.

2.1 Model Specifications

An econometric model was a simplified representation of interrelated real phenomena within a system. In this model, exogenous variables were linked to endogenous variables through parameters that reflected the magnitude and direction of the relationship in accordance with the underlying theory. To ensure the reliability of the model, a series of validity tests were required to ensure that the estimation results not only explained actual conditions but also had good predictive power for the population. The developed model must meet economic and statistical criteria, including goodness of fit (R^2) and statistical significance tests. Meeting these criteria will result in a model that was unbiased, consistent, sufficient, and efficient. In this study, the model specification was designed to analyze the impact of biodiesel policy on the palm oil industry in Indonesia.

2.2 Palm Oil Plantation Area in Indonesia

The area of palm oil plantations in Indonesia can be influenced by several factors, including domestic palm oil prices, domestic rubber prices, urea fertilizer prices, and credit interest rates in Indonesia. An increase in domestic palm oil prices tends to encourage farmers to expand their plantation areas in an effort to increase fresh fruit bunch (FFB) production. This relationship is formulated structurally in an econometric model through the following equation for the palm oil plantation area in Indonesia:

$$LASI_t = a_0 + a_1 HDSI_t + a_2 HDKI_t + a_3 HPUI_t + a_4 SBI_t + U_{1t} \quad (1)$$

where:
$\mathrm{LASI_t}$: Indonesian palm oil plantation area in year t (1,000 ha)
$\mathrm{HDSI_t}$: Domestic palm oil price in year t (Rp/ton)
$\mathrm{HPUI_t}$: Domestic rubber price in year t (Rp/ton)
$\mathrm{SBI_t}$: Indonesian credit interest rate in year t (%)
$\mathrm{U_{1t}}$: error term
The expected signs and magnitudes of the estimated parameters were a_1>0 and $a_2, a_3, a_4 < 0$

2.3 Indonesian Palm Oil Production

Palm oil production in Indonesia was formulated as an identity equation stating that total production in year t is the product of the area of palm oil plantations and the productivity of palm oil in the same year. Mathematically, this relationship can be expressed as follows:

$$PROSI_t = LASI_t * TIVSI_t \quad (2)$$

where:
$\mathrm{PROSI_t}$: Indonesian palm oil production in year t (1,000 tons)
$\mathrm{TIVSI_t}$: Indonesian palm oil productivity in year t (tons/ha)

2.4 Domestic Palm Oil Prices

Domestic palm oil prices can be influenced by several factors, including domestic biodiesel prices, domestic cooking oil prices, and palm oil export prices. The functional relationship between these variables can be expressed mathematically as follows:

$$HDSI_t = b_0 + b_1 HBIOI_t + b_2 HMGDI_t + b_3 HXSI_t + U_{2t} \quad (3)$$

where:
$HDSI_t$: Domestic palm oil price in year t (Rp/ton)
$HBIOI_t$: Harga biodiesel Indonesia tahun t (Rp/liter)
$HMGDI_t$: Indonesian biodiesel price in year t (Rp/liter)
$HXSI_t$: Domestic cooking oil price in year t (Rp/kg)
U_{2t} : error term

The signs and magnitudes of the expected estimation parameters were $b_1 > 0 \; and \; b_2, b_3 < 0$

2.5 Indonesian Palm Oil Exports

Indonesian palm oil exports can be influenced by several factors, including Indonesian palm oil production, domestic palm oil prices, Indonesian palm oil export prices, Indonesian palm oil export taxes, and the exchange rate of the rupiah against the dollar. Mathematically, this can be expressed as follows:

$$XSI_t = c_0 + c_1 PROSI_t + c_2 HDSI_t + c_3 HXSI_t + c_4 TXSI_t + c_5 NTRP_t + U_{3t} \quad (4)$$

where:
XSI_t : Indonesian palm oil exports in year t (1,000 tons)
$PROSI_t$: Indonesian palm oil production in year t (1,000 tons)
$HDSI_t$: Domestic palm oil price in year t (Rp./ ton)
$HXSI_t$: Indonesian palm oil export price in year t (US$/ ton)
$TXSI_t$: Indonesian palm oil export tax in year t (%)
$NTRP_t$: Exchange rate of rupiah against dollar in year t (Rp./ US$)
U_{3t} : error term

The sign and magnitude of the estimated parameters were expected to bec_1> 0 and $c_2, c_3, c_4 < 0$.

2.6 Indonesian Palm Oil Demand

Indonesian palm oil demand can be influenced by several factors, including domestic palm oil prices and Indonesian biodiesel prices. Mathematically, this can be expressed as follows:

$$QDSI_t = d_0 + d_1 HDSI_t + D_2 HBIOI_t + U_{4t} \quad (5)$$

where:
$QDSI_t$: Indonesian palm oil exports in year t (1,000 tons)
$HDSI_t$: Domestic palm oil prices in year t (Rp/ton)
$HBIOI_t$: Indonesian biodiesel prices in year t (Rp/liter)
U_{4t} : error term

The expected sign and magnitude of the estimated parameters were d_1, d_2<0

2.7 Biodiesel Production in Indonesia

Biodiesel production in Indonesia can be expressed as an identity equation, which was the product of total palm oil demand and a conversion coefficient of 0.16. This conversion value reflected that approximately 16% of total national palm oil demand was allocated to meet biodiesel production needs. Mathematically, this relationship can be written as follows:

$$PRODI_t = 0.16 * QDSI_t \quad (6)$$

where:
$PRODI_t$: Indonesia's biodiesel production in year t (1,000 tons)
$QDSI_t$: Indonesia's palm oil demand in year t (1,000 tons)

2.8 Indonesian Biodiesel Prices

Indonesian biodiesel prices can be influenced by several factors, including global biodiesel prices, the exchange rate of the rupiah against the dollar, domestic palm oil prices, and Indonesian biodiesel exports. Mathematically, this can be expressed as follows:

$$HBIOI_t = e_0 + e_1 HBIOD_t + e_2 NTRP_t + e_3 HDSI_t + e_4 XBIO_t + U_{5t} \tag{7}$$

where:
$HBIOI_t$: Indonesia's biodiesel price in year t (Rp/liter)
$HBIOD_t$: World biodiesel price in year t (US$/barrel)
$NTRP_t$: Exchange rate of rupiah against dollar in year t (Rp/US$)
$HDSI_t$: Domestic palm oil price in year t (Rp/ton)
$XBIO_t$: Indonesian biodiesel exports (1,000 tons)
U_{5t} : error term
The sign and magnitude of the estimated parameters are expected to be $e_1, e_3, e_4 > 0;\ dan\ e_2 < 0$

2.9 Indonesian Biodiesel Demand

Indonesian biodiesel demand can be influenced by several factors, namely Indonesian biodiesel prices, global biodiesel prices, and Indonesian biodiesel exports. Mathematically, this can be expressed as follows:

$$QDBIO_t = f_0 + f_1 HBIOI_t + f_2 HBIOD_t + f_3 XBIO_t + U_{6t} \tag{8}$$

where:
$QDBIO_t$: Indonesian biodiesel demand in year t (BOE)
$HBIOI_t$: Indonesian biodiesel price in year t (Rp/liter)
$HBIOD_t$: World biodiesel price in year t (US$/barrel)
$XBIO_t$: Indonesian biodiesel exports (1,000 tons)
U_{6t} : error term

The signs and magnitudes of the estimated parameters were $f_1, f_2 < 0$ and $f_3 > 0$.

2.10 Indonesian Biodiesel Exports

Indonesian biodiesel exports can be influenced by several factors such as Indonesian biodiesel production, world biodiesel prices, and the exchange rate of the rupiah against the dollar. Mathematically, this can be written as follows:

$$XBIO_t = g_0 + g_1 PRODI_t + g_2 HBIOD_t + g_3 NTRP_t + U_{7t} \tag{9}$$

Where:
$XBIO_t$: Indonesian biodiesel exports (1,000 tons)
$PRODI_t$: Indonesian biodiesel production in year t (1,000 tons)
$HBIOD_t$: World biodiesel price in year t (US$/barrel)
$NTRP_t$: Exchange rate of the rupiah against the dollar in year t (Rp/US$)
U_{7t} : error term
The signs and magnitudes of the estimated parameters were expected to be $g_1, g_2 > 0\ dan\ g_3 < 0$

2.11 Model Identification

The econometric model identification process was carried out before the estimation stage to ensure that the model can be estimated accurately. This identification must meet two main conditions, namely the order condition and the rank condition, with the formula $(\mathrm{K} - \mathrm{M}) > (\mathrm{G} - 1)$. In this case, K represented the total number of variables in the model, both endogenous and exogenous; M was the number of variables (endogenous and exogenous) in a particular equation; and G indicated the total number of equations in the model, which also represented the number of endogenous variables. The criteria used to determine the identification status of the model were explained as follows:

(K-M)>(G-1) : the equation was overidentified
(K-M)=(G-1) : the equation was exactly identified
(K-M)<(G-1) : the equation was unidentified

In a structural equation model, each equation must satisfy the condition of being exactly identified or overidentified so that the parameter estimated of each variable can be performed accurately. In this study, the developed model consisted of nine equations, including seven structural equations and two identity equations. The total number of variables, both endogenous and exogenous (K), was 18 variables, while the number of variables in one equation (M) was six variables, and the total number of equations (G) was nine. Based on the model identification criteria, all equations in this system were classified as overidentified, so they can be estimated using appropriate econometric methods.

2.12 Model Validation

Model validation was conducted to evaluate the reliability (robustness) of the constructed model, particularly in explaining and simulating the impact of biodiesel policy on the palm oil industry in Indonesia. This process aimed to ensure that the model was able to adequately represent actual conditions. In this study, the statistical criteria used to measure the accuracy of the model are Root Mean Square Percentage Error (RMSPE) and Theil's Inequality Coefficient (U-Theil).

$$RMSPE = \sqrt{\frac{1}{n}\sum_{t=1}^{n}\left(\frac{Y_t^p - y_t^a}{y_t^a}\right)^2} \; x\; 100\% \tag{10}$$

$$U - Theil = \frac{\sqrt{\frac{1}{n}\sum_{t=1}^{n}\left(Y_t^p - y_t^a\right)^2}}{\sqrt{\frac{1}{n}\sum_{t=1}^{n}\left(Y_t^p\right)^2} + \sqrt{\frac{1}{n}\sum_{t=1}^{n}\left(y_t^a\right)^2}} \tag{11}$$

Where:
Y_t^p = predicted value of endogenous variable
y_t^a = actual value of endogenous variable
t = simulation period (2021-2024)

The Root Mean Square Percentage Error (RMSPE) statistic was used to measure the extent of deviation between the predicted values of endogenous variables and their actual values in relative terms (percentage). Meanwhile, the Theil's Inequality coefficient (U-Theil) had a value ranging from 0 to 1, where a value of U = 0 indicated a perfect estimate, while a value close to 1 indicated low model quality. The smaller the RMSPE and U-Theil values, the better the model performance in performing simulations.

2.13 Model Simulation

Models that had undergone validation and meet statistical criteria can be used as a basis for simulating various policy change scenarios. In this study, simulations were conducted to evaluate the impact of biodiesel policies in Indonesia, covering the historical period from 2021 to 2024. Two simulation scenarios were designed, which were presented in detail in Table 1:

Table 1. Simulation Basics

No.		Simulation Scenarios	Basic Considerations
1.	SIM-1	The implementation of the biodiesel policy from mandatory B30 to B35 has resulted in a 32% increase in palm oil demand by the biodiesel industry.	The 32% increase in demand reflected the gradual impact of the implementation of the mandatory B30 biodiesel policy towards B35 during the 2021–2024 period. This growth was driven by increased domestic biodiesel consumption, the readiness of the distribution infrastructure, and government regulatory support in promoting the sustainable use of palm oil-based renewable energy.
2.	SIM-2	The implementation of the mandatory B40 policy has resulted in a 50% increase in palm oil demand by the biodiesel industry.	The 50% increase reflected an aggressive expansion scenario that included accelerated adoption of mandatory B40 policies, increased national biodiesel production capacity, and expansion of export markets. This projection took into account full support for national energy policies, industry incentives, and commitments to reduce dependence on fossil fuels through the optimal utilization of palm oil as a feedstock for biodiesel.

2.14 Types and Sources of Data

This study used time series data from 2000 to 2024, which was secondary data obtained from several related agencies such as the Central Statistics Agency, the Ministry of Energy and Mineral Resources, the Ministry of Agriculture, the Food and Agriculture Organization (FAO), UN Comtrade, and other publications.

2.15 Expanded Interpretation of P-Values in Regression t-Tests

In regression analysis, significance testing of independent variables on dependent variables was generally performed using a t-test. It should be noted that, by default, almost all statistical software uses a two-tailed test approach. This meant that the resulting p-value measured the probability of the independent variable having a positive or negative effect on the dependent variable.

However, if the specific objective of the research was to test the direction of a particular effect—for example, to determine whether a variable has a positive or negative effect—then the appropriate approach was a one-tailed test. In this context, the p-value from the t-test estimation results needed to be adjusted by dividing the p-value generated by the software in half. This adjustment aimed to ensure that the decision on the null hypothesis (H_0) was in line with the intended direction of the test. Without this adjustment, the interpretation of the test results could be inaccurate, potentially leading to errors in drawing conclusions.

In this article, the level of significance was indicated by the following symbols: i) **** for a significance level of 1%; ii) *** for a significance level of 5%; iii) ** for a significance level of 10%; and iii) * for a significance level of 15%. The selection of the appropriate test type and a thorough understanding of the meaning of the p-value were crucial to ensuring that research conclusions are valid and scientifically sound.

3 Results and Discussion

Over the past ten years, biodiesel development in Indonesia has undergone significant transformation as part of the national commitment to renewable energy. Policy initiatives from the Ministry of Energy and Mineral Resources (*Kementerian Energi dan Sumber Daya Mineral*/ESDM) have accelerated the implementation of biofuel use through mandatory biodiesel policies. Indonesia's biodiesel policy began with Presidential Regulation No. 5 of 2006, which aimed to diversify energy sources and reduce greenhouse gas emissions. This policy has evolved to mandate an increase in biodiesel content, reaching B30 by 2020 [9].

Despite the increase in production capacity, utilization rates remain low due to several factors, including the availability of raw materials and production costs. The main raw material, palm oil, faces competition from food production and environmental issues, such as deforestation [10]. Technological advancements in production techniques, such as the use of non-edible oils and innovative catalytic systems, offer potential solutions to enhance efficiency and reduce costs, thereby increasing capacity utilization.

The increase in domestic consumption of biodiesel has become more apparent since the establishment of the Palm Oil Plantation Fund Management Agency (Badan Pengelola Dana Perkebunan Kelapa Sawit/BPDPKS) in 2015. With the incentive scheme offered, domestic consumption rose from around 860,000 kiloliters in 2015 to 3 million kiloliters in 2016. However, challenges remain, one of which is the failure to achieve the targeted blend rate under national policy. According to USDA reports and CIFOR studies, the implementation of B20 in 2016 was not fully achieved due to limited uptake in key sectors such as non-PSO transportation and industry.

This situation indicated that biodiesel's contribution to the national energy mix was still not optimal. Biodiesel refineries were not operating at full capacity, resulting in uneven distribution of biodiesel across regions and sectors. The industrial and commercial sectors still showed low absorption rates compared to the transportation sector. Therefore, stronger policy coordination, along with improvements to distribution systems and incentives, were needed to ensure that biodiesel was not merely an export commodity or energy subsidy, but an integral part of Indonesia's sustainable energy transition.

3.1 Results of the Indonesian Biodiesel Model Estimation

The Indonesian biodiesel estimation model had been adequately constructed, as indicated by the coefficient of determination values for each structural equation, which ranged from 0.76429 to 0.97290. This indicated that the explanatory variables in the model were able to explain 76% to 97% of the variation in the endogenous variable. Each structural equation showed parameter values and directions consistent with economic theory and logically acceptable. To test the influence of explanatory variables on the endogenous variable, the t-statistic value was used. The test results indicated that several explanatory variables had a statistically significant influence on the endogenous variable.

3.2 Indonesian Palm Oil Area and Palm Oil Production

The estimated results for the Indonesian palm oil area equation were presented in Table 2. The coefficient of determination (R^2) value of 0.96590 indicated that 96.59% of the variation in the endogenous variable, namely palm oil area, can be explained by the explanatory variables in the model. The remaining 3.41% was influenced by other factors outside the model. Parameter estimates indicated that the domestic price of Indonesian palm oil had a positive and statistically significant effect on the expansion of palm oil area. An increase in domestic palm oil prices encouraged farmers to expand their plantation areas, which in turn can increase production volume and farmers' income potential.

Table 2. Estimated Parameters of the Equation for the Total Area of Oil Palm Plantations in Indonesia

Variable	Parameters	Pr > |t|	Description
Intercept	-17006.1	0.0036	Intercept LASI
HDSI	0.279795	<.0001****	Domestic price of Indonesian palm oil (Rp/ton)
HDKI	-0.07682	0.2523	Domestic price of Indonesian rubber (Rp/ton)
HPUI	0.262677	0.3661	Domestic price of Indonesian urea fertilizer (Rp/kg)
SBI	15.65340	0.3939	Interest rate on Indonesian loans (%)
R^2=0.96590	Dw =0. 91984		F-value= 141.65

Source: own data processing

3.3 Domestic Palm Oil Prices

The estimated results for the domestic palm oil price equation were presented in Table 3. The coefficient of determination (R^2) value of 0.82117 indicated that approximately 82.12% of the variation in domestic palm oil prices can be explained by the variables in the model, while the remaining 7.88% was influenced by other factors not covered in the equation. Based on the estimation results, domestic cooking oil prices had a positive and significant effect on domestic palm oil prices. The increase in cooking oil prices in the domestic market was thought to be triggered by rising demand, which in turn drove demand for its raw material, palm oil. When palm oil production capacity was limited, this increase in demand will push up palm oil prices in the domestic market.

Meanwhile, Indonesian palm oil export prices and Indonesian biodiesel price had a negative and significant impact on domestic palm oil prices because when export prices and Indonesian biodiesel price rose, producers tent to shift supplies to more profitable foreign markets, thereby reducing the availability of palm oil in the domestic market. However, despite the decline in domestic supply, domestic prices did not immediately increase due to government policy interventions in the B35 mandate and subsidies that maintained domestic price stability. As a result, the increase in Indonesian palm oil export prices and Indonesian biodiesel price actually led to a statistical decline in domestic cooking oil prices.

Table 3. Estimated Parameters of the Domestic Palm Oil Price Equation

Variable	Parameters	Pr > |t|	Description
Intercept	38879.29	0.0001	Intercept
HBIOI	-1.00664	0.0915**	Indonesian biodiesel price (Rp/liter)
HMGDI	5.654305	0.0001****	Domestic cooking oil price (Rp/Kg)
HXSI	-20.7667	0.0127***	Indonesian palm oil export price (US$/ Ton)
R^2=0. 82117	Dw =0. 894084		F-value= 32.14

Source: own data processing

3.4 Indonesian Palm Oil Exports

The estimated results of the Indonesian palm oil export equation can be seen in Table 4. The R^2 value of the Indonesian palm oil export equation was 0.97855, meaning that 97.86 percent of the explanatory variables were able to explain the endogenous variable of Indonesian palm oil exports, while the remaining 2.14 percent was explained by other variables not included in the equation.

The results of the estimation of the Indonesian palm oil export equation showed that the price of Indonesian palm oil had a negative and significant effect on Indonesian palm oil exports. A number of studies indicate that an increase in the price of Indonesian palm oil tent to have a negative impact on export volume. This increase in prices can reduce the competitiveness of Indonesian palm oil in the international market, thereby potentially reducing demand from trading partner countries.

Meanwhile, Indonesian palm oil production had a positive and significant effect on Indonesian palm oil exports. Indonesia's palm oil production had experienced a consistent upward trend and contributed significantly to the growth in export volume. This increase was largely driven by the expansion of plantation areas, which played a role in boosting total production output. The production levels had a positive direct effect on export volume. These findings suggested that increases in production tent to be followed by increases in export volume.

Table 4. Estimated Parameters of Indonesian Palm Oil Export Equation

Variable	Parameters	Pr > |t|	Description
Intercept	-20058.1	0.3754	Intercept
PROSI	0.626329	0.1327*	Indonesian palm oil production (1,000 ton)
HDSI	0.397886	0.3172	Indonesian domestic palm oil price (Rp/Ton)
HXSI	-5.95879	0.1379*	Indonesian palm oil export price (US$/Ton)
TXSI	-150.581	0.1924	Indonesian palm oil export tax (%)
NTRP	-0.16901	0.4008	Exchange rate of the rupiah (Rp/US$)
R^2=0. 97855	Dw =1. 167028		F-value= 173.34

Source: own data processing

3.5 Indonesian Palm Oil Demand

The estimated results for the Indonesian palm oil demand equation were presented in Table 5. The coefficient of determination (R^2) value of 0.95693 indicated that approximately 95.69% of the variation in Indonesian palm oil demand can be explained by the independent variables used in the model, while the remaining 4.31% was influenced by other factors outside the model. This estimation also showed that domestic palm oil prices had a positive and significant effect on palm oil demand in Indonesia, indicating that price increases in the domestic market were accompanied by an increase in demand, possibly due to market characteristics or policy interventions that influenced this relationship.

Domestic palm oil demand in Indonesia continued to increase despite price increased, due to several strategic factors. First, the biofuel industry contributed significantly to the increase in demand, in line with the increasing use of palm oil as a feedstock for biodiesel, especially when global oil prices surged [11]. Second, the substitution effect from coconut oil to palm oil, reinforced by government policies, had also driven domestic consumption without being overly affected by price fluctuations. Third, various government policies—such as price setting, distribution, and trade policies—had actively encouraged the use of palm oil, increasing demand even when prices rose. Finally, fiscal policies such as export taxes and subsidies also played a role in maintaining the competitiveness of palm oil in the domestic market, making it more attractive than exports, thereby strengthening domestic consumption [12].

Table 5. Estimated Demand for Indonesian Palm Oil

Variable	Parameters	Pr > |t|	Description
Intercept	-10760.6	<.0001	Intercept
HDSI	0.203138	<.0001****	Domestic price of Indonesian palm oil (Rp/ton)
HBIOI	-0.03482	0. 1775	Price of Indonesian biodiesel (Rp/liter)
R^2=0. 95693	Dw =0. 977556		F-value= 244.41

Source: own data processing

3.6 Indonesian Biodiesel Prices

Estimation of biodiesel prices in Indonesia, as presented in Table 6, showed that the coefficient of determination (R^2) was 0.76429. This meant that 76.43 percent of the variation in Indonesian biodiesel prices can be explained by the explanatory variables in the model, while the remaining 23.57 percent was influenced by other factors not covered in the model. This estimation also showed that global biodiesel prices had a positive effect on biodiesel prices in Indonesia. The increase in global biodiesel prices had prompted importing countries to seek alternative supplies in the international market. As one of the main exporters, demand for Indonesian biodiesel in the global market had increased, reducing supply for the domestic market and ultimately driving up domestic biodiesel prices.

Table 6. Estimated Price of Biodiesel in Indonesia

Variable	Parameters	Pr > |t|	Description
Intercept	4735.582	0. 4126	Intercept
HBIOD	6. 305772	0.0002****	World biodiesel price (US$/barel)
NTRP	0. 395322	0. 2082	Exchange rate of the rupiah (Rp/US$)
HDSI	-0. 12289	0. 3140	Domestic price of Indonesian palm oil (Rp/ton)
XBIO	1. 495765	0. 1955	Indonesian biodiesel export (1.000 ton)
R^2=0. 76429	Dw =0. 240086		F-value= 16.21

Source: own data processing

3.7 Indonesian Biodiesel Demand

The estimated results of Indonesia's biodiesel demand can be seen in Table 7. The R^2 value of the Indonesian biodiesel demand equation was 0.87626, meaning that 87.63 percent of the explanatory variables were able to explain the endogenous variable of Indonesia's biodiesel demand, while the remaining 12.37 percent was explained by other variables not included in the equation.

The results of the estimation of the Indonesian biodiesel demand equation indicated that the volume of Indonesian biodiesel exports and the global biodiesel price had a positive and significant impact on Indonesian biodiesel demand. The Indonesian government had implemented various policies to encourage the use of biodiesel as a renewable energy source. The primary objective of these policies was to reduce dependence on fossil-based energy and enhance national energy security. The policy instruments employed include subsidies, mandates for blending biodiesel into conventional fuels, and the imposition of export taxes. Overall, these policies had led to an increase in domestic demand and had also influenced biodiesel export volumes. Global crude oil prices had a significant impact on biodiesel demand. When crude oil prices rose, biodiesel became a more competitive alternative energy source, thereby driving increased demand. The subsequent impact of this was an increase in biodiesel production and export volumes [12]. This relationship was reflected in the positive correlation between crude oil prices and biodiesel demand in Indonesia.

However, the results of the estimation of the Indonesian biodiesel demand equation further indicated that Indonesian biodiesel prices had a negative and significant effect on Indonesian biodiesel demand. The biodiesel demand in Indonesia was elastic to price changes. A decrease in price tent to increase demand as biodiesel became more competitive compared to other fuels. Conversely, an increase in price can reduce demand as consumers switched to cheaper alternatives, such as subsidized diesel or other fossil fuels.

Table 7. Estimated Demand for Biodiesel in Indonesia

Variable	Parameters	Pr > |t|	Description
Intercept	-1085.59	0.3964	Intercept
HBIOI	-3.61638	0.1035**	Indonesian biodiesel price (Rp/Liter)
HBIOD	24.04161	0.0819***	World biodiesel price (US$/Barel)
XBIO	15.55535	<0.0001****	Indonesian biodiesel exports (1,000 ton)
R^2=0.87626	Dw =0.847271		F-value= 49.57

Source: own data processing

3.8 Indonesian Biodiesel Exports

The estimated results of Indonesia's biodiesel exports can be seen in Table 8. The R^2 value of the Indonesian biodiesel export equation was 0.85774, meaning that 85.74 percent of the explanatory variables were able to explain the endogenous variable of Indonesian biodiesel exports, while the remaining 14.26 percent was explained by other variables not included in the equation.

The results of the estimation of the Indonesian biodiesel export equation indicated that the variable of Indonesian biodiesel production had a positive and significant effect on Indonesian biodiesel exports. The higher the biodiesel production, the greater the potential for Indonesian biodiesel exports in the international market. The increase in Indonesian biodiesel production had a positive and significant effect on biodiesel exports, as greater production capacity opened opportunities to meet international market demand. Government policies such as the national energy policy and the implementation of the B30 mandate had substantially boosted production growth [12,13]. On the other hand, trade policies such as export taxes and domestic market obligations helped to regulate supply balance, ensuring that exports remained stable in situations of production surplus.

Meanwhile, the results of the estimation of Indonesia's biodiesel export equation indicated that the rupiah exchange rate had a negative and significant impact on Indonesia's biodiesel exports. The rupiah exchange rate had a significant negative impact on the performance of Indonesia's non-oil and gas exports, including biodiesel. A depreciation of the rupiah can increase production and transaction costs for exports, thereby reducing the competitiveness of Indonesian products in international market.

Table 8. Estimated Indonesian Biodiesel Exports

Variable	Parameters	Pr > |t|	Description
Intercept	380.0025	0.4046	Intercept
PRODI	2.280610	0.0082****	Indonesia's biodiesel production (1,000 ton)
HBIOD	0.224956	0.2467	Harga World biodiesel price (US$/Barel)
NTRP	-0.13640	0.0658**	Exchange rate of the rupiah (Rp/US$)
R^2=0.85774	Dw =1.247905		F-value= 42.21

Source: own data processing

3.9 The Impact of Indonesia's Aggressive Downstream Expansion Policy for CPO in the Form of Biodiesel on the Indonesian Palm Oil Industry

The validation of the Indonesian biodiesel model was conducted for the period 2021-2024 to assess the condition of the Indonesian biodiesel industry. The results of the model validation were presented in Table 9. Based on the model validation results, it can be observed that the endogenous variables with an RMSPE value of less than 30% accounted for 87.5% and the U-theil value of less than 0.3 reached 100%. This indicated that during the historical simulation period of 2021-2024, the predicted values of endogenous variables were quite close to their actual values.

The RMSPE and U-theil indicator values indicated that the model met the criteria for simulating the impact of Indonesia's progressive biodiesel policy on several endogenous variables. Therefore, the model that had been developed was highly suitable for analyzing the simulation of the impact of progressive biodiesel policy on the palm oil industry in Indonesia.

Table 9. Results of the Validation of the Indonesian Biodiesel Model for 2021-2024

No.	Variable	Label	RMSPE	U-Theil
1	LASI	Area of Indonesian oil palm plantations (1,000 ha)	7.2112	0.0372
2	HDSI	Domestic price of Indonesian palm oil (Rp/ton)	3.3504	0.0171
3	PROSI	Indonesian palm oil production (1,000 ton)	7.2112	0.0368
4	XSI	Indonesian palm oil exports (1,000 Ton)	6.2183	0.0317
5	QDSI	Indonesian palm oil demand (1,000 ton)	5.6634	0.0289
6	HBIOI	Indonesian biodiesel price (Rp/Liter)	48.0247	0.1929
7	QDBIO	Indonesian biodiesel demand (barrel of oil equivalent/BOE)	44.8222	0.2887
8	XBIO	Indonesian biodiesel exports (1,000 ton)	5.9005	0.0300

Source: own data processing

The importance of simulating CPO downstreaming policies in biodiesel derivative products lies in the need to thoroughly understand the impact of their implementation on national energy demand and distribution. A 32% increase in biodiesel demand during the 2021–2024 period reflected the gradual results of the mandatory B30 to B35 policy, driven by domestic consumption, infrastructure readiness, and government regulatory support for palm oil-based renewable energy. Meanwhile, projections of a 50% increase reflected a more aggressive expansion scenario, including accelerated implementation of B40, increased production capacity, and expanded export markets. Considering the crucial role of national policies, industry incentives, and commitments to reduce dependence on fossil fuels, policy simulations served as an essential tool for testing various scenarios and ensuring the direction of sustainable and adaptive renewable energy development.

Table 10. Results of the Simulation of the Indonesian Biodiesel Model for 2021-2024

Variable	Basic Values	Changes (%)		Description
		SIM-1	SIM-2	
LASI	8691.2	-0.0939	-0.1211	Area of Indonesian oil palm plantations (1,000 ha)
HDSI	94179.0	-0.0413	-0.0500	Domestic price of Indonesian palm oil (Rp/ton)
PROSI	41071.9	-0.0935	-0.1207	Indonesian palm oil production (1,000 ton)
XSI	34169.0	-0.0886	-0.1191	Indonesian palm oil exports (1,000 ton)
QDSI	7904.3	-0.0895	-0.1286	Indonesian palm oil demand (1,000 ton)
HBIOI	7920.9	0.9157	1.4061	Indonesian biodiesel price (Rp/liter)
QDBIO	64506.0	-0.0735	0.3382	Indonesian biodiesel demand (BOE)
XBIO	2997.4	0.7225	1.5738	Indonesian biodiesel exports (1.000 ton)

Source: own data processing

The mandatory B35 policy had a negative impact on several key indicators. This was evident from the decline in Indonesia's oil palm plantation area (LASI) by -0.0939%, as well as a decrease in palm oil production (PROSI) by -0.0935%. Domestic palm oil prices (HDSI) also fell by -0.0413%, indicating that this policy had not been sufficiently effective in boosting the domestic economic value of palm oil. As a result, there had been a decrease in Indonesia's palm oil exports (XSI) of -0.0886%, which had instead increased Indonesia's biodiesel exports (XBIO) by 0.7225%. This had led to an increase in Indonesia's biodiesel price (HBIOI) of 0.9157%, which in turn had reduced Indonesia's biodiesel demand (QDBIO) by -0.0735%.

The increase in policy ambition toward mandatory B40 showed a greater impact pattern on related variables. Palm oil plantation area (LASI) and palm oil production (PROSI) decreased by -0.1211% and -0.1207%, respectively, indicating pressure on production capacity. However, biodiesel prices increased by 1.4061%. This increase in biodiesel prices was greater than the decline in Indonesia's domestic palm oil prices (HDSI) of -0.0500, causing Indonesia's biodiesel demand (QDBIO) to also rise by 0.3382%. This indicated that the B40 mandate was able to drive more aggressive biodiesel use. The decline in Indonesian palm oil exports (XSI) and demand for Indonesian palm oil (QDSI) by -0.1191% and -0.1286%, respectively, indicated a shift in production orientation to meet domestic needs. Overall, B40 demonstrated a stronger substitution effect from exports to domestic consumption compared to B35.

4 Conclusion

This study concludes that the downstreaming policy of Crude Palm Oil (CPO) through biodiesel development has a significant impact on the dynamics of the palm oil industry in Indonesia. Based on the simultaneous estimation model constructed, it is found that variables such as domestic palm oil prices, biodiesel production, and biodiesel exports show a positive and significant relationship with downstream sector growth. Simulations of mandatory B35 and B40 policies show that despite a decline in CPO exports and demand for crude palm oil, there is an increase in biodiesel exports and domestic biodiesel prices. This reflects a shift from an export-oriented raw material focus to strengthening the domestic market and value-added products.

The policy implications of these results underscore the importance of continued regulatory and fiscal support, such as production incentives and distribution infrastructure strengthening, to ensure the smooth implementation of the biodiesel mandate. The government also needs to balance the use of CPO for food and energy to maintain domestic price stability and food security. CPO downstreaming strategies not only increase value-added and biodiesel exports but also reduce dependence on fossil fuels, create jobs, and enhance the sustainable competitiveness of the national palm oil industry.

Further research is recommended to include spatial analysis related to the distribution of benefits and impacts of biodiesel policies in various palm oil-producing regions in Indonesia. In addition, a long-term evaluation of the environmental and social impacts of downstreaming, including issues of deforestation and farmer welfare, is needed. The integration of CGE (Computable General Equilibrium) models or panel data approaches with regional dimensions can enrich the analysis and produce more comprehensive and contextual policy recommendations for the sustainability of the national palm oil industry.

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