

Analyzing the Market Conditions and Long-Term Dynamics in the Biodiesel Industry

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Abstract

The Indonesian energy industry is working towards achieving net zero emissions by reducing energy composition between renewables and non-renewables. Based on this background, this study investigates the biodiesel market conditions and its long-term sustainability using monthly data from January 2014 to October 2023. The study applies the 3SLS, Johansen and bound test approach to cointegration for estimations. Findings from the study show that demand for biodiesel in Indonesia is price inelastic, which implies that the response of demand on small price changes is high due to the availability of substitute products. The Walrasian coefficient is negative and statistically significant, suggesting a partial disequilibrium in the biodiesel market. Furthermore, the blending mandatory of biodiesel is found to be sustainable in the long run as shown by the bound f-statistics and Johansens' trace statistics. The increasing prices of crude palm oil, catalysts, methanol, and glycerin have a devastating effect on biodiesel production. Exchange rate depreciation is also a negative function of biodiesel production. These findings are crucial for industry stakeholders and policymakers to make informed decisions about resource allocation, cost management, and strategies to enhance the sustainability and efficiency of biodiesel production processes.

Keywords: Biodiesel, CPO, Bound Test, 3SLS, Exchange Rate

1. Introduction

Global warming poses a serious challenge to the planet. It is highly driven by the excessive fossil fuel consumption by industries, sectors, governments and households. However, combustion from the fuel releases carbon emissions into the earth's atmosphere as the global temperature is rising more than required for human and non-human species (Samaras, 2019; Lee, 2015). A report from the Intergovernmental Panel on Climate Change (2018) determined that there is an increased likelihood of around one million species facing extinction if the average global temperature rises by a minimum threshold of 1.5 °C. To mitigate this effect, there is a serious need for low-carbon technologies and a transition to renewable energy. Biofuels represent an essential component in addressing the imperative quest for renewable energy and mitigating the consequences of fossil fuel usage on a global scale (Damian et al., 2024). Reflecting on the development made so far in biodiesel production, in 2016, the global biodiesel market was estimated to be \$34.1 billion and is projected to reach 42.1 billion in 2021 (M&M Reports, 2022). The expansion of the biodiesel industry is primarily driven by the increasing desire for an environmentally sustainable ecosystem

that is free from pollution resulting from excessive usage of fossil fuels. This aligns with the international agreement and individual nations' undertaking to annually decrease greenhouse gas emissions. This circumstance has prompted several countries to develop strategies aimed at expediting the production and use of biofuel as a potential solution for achieving worldwide net zero emissions by the year 2050.

As the world's fourth-fastest growing economy, Indonesia requires a large energy supply to meet its demand. This energy supply is mostly fulfilled from fossil sources, where coal, oil and natural gas accounted for over 60% of the total energy mix or about 5% of Indonesian GDP in 2021 (IEA, 2022; and IESR, 2022). As a result, Indonesia's total energy sector CO₂ emissions have escalated by more than doubled between the year 2000 and 2021, of which coal dominates for more than 70% of that increase (IEA, 2022). On the other hand, Indonesia has been renowned as both the largest producer and consumer of biodiesel products globally. Its implementation is essential to substitute the large combustion of fossil fuels activities. As a product type of biofuel, biodiesel implementation is remarked as one of the key strategies to achieve the renewable energy mix target of 23% in the year 2025 and 31% in the year 2050 (MEMR, 2022). Based on its national mandatory program, the mixture of biodiesel with that of gasoil product is obliged¹.

In the Indonesian transportation sector, between the years 2020 and 2022, the mandate of biodiesel mixture in gasoil fuel was 30% (or called B30), which consumed about 8.40 million, 9.3 million, and 10.15 million kiloliters (KL), respectively (MEMR, 2022; Halimatussadiyah, *et al.*, 2021). In the year 2023, the percentage blending is increasing even more by 35% (B35), which is projected to reach 13.15 million KL².

The inception of biodiesel production in Indonesia was started in 2006 to address its net-import status of crude oil including its petroleum products. The initial policy draft was encapsulated in the National Energy Policy given in Presidential Regulation No. 5/2006 – which was replaced by Government Regulation No. 79/2014. A clear roadmap for an improved mandatory program of biodiesel was enacted in year Minister Regulation No. 32/2008 which sets the minimum blending requirement for biodiesel and vegetable oil. Despite encountering numerous challenges, the primary obstacle that emerged during the inception of biodiesel production was the significant price competition in the market, which proved to be unmatched when compared to petroleum, even with government subsidies. Furthermore, in 2015, there was a notable evaluation of the biodiesel pricing, along with the establishment of the Oil Palm Plantation Fund (OPPF) to provide incentives for biodiesel production in the Public Service Obligation (Adiatma and Prasojo, 2022).

Indonesia has a comparative advantage in the production of biodiesel due to its blessing of large palm oil resources. Compared to other feedstock types, the utilization of crude palm oil for biodiesel production offers an advantage, in that it possesses a diverse range of phytonutrients that

¹ Minister of Energy and Mineral Resources (MEMR) Regulation No. 32/2008 regarding the Provision, Utilization, and Trading System of Biofuels as Other Fuels – which was amended by Minister of Energy and Mineral Resources Regulation No. 12 of 2015 regarding the Third Amendment of the Regulation of the Minister of Energy and Mineral Resources Number 32 of 2008.

² MEMR Decree No. 205.K/EK.05/DJE/2022 regarding the Establishment of Biodiesel Allocation in Period January – December 2023.

can be extracted before the synthesis of biodiesel. The market value of these phytonutrients is economically substantial, which effectively reduces the entire production cost of palm biodiesel. Indeed, this particular advantage has not been anticipated for alternative edible oil crops (Lam & Lee, 2011). According to Akor et al (1983) cited in Alkabbashi et al (2009), under huge subsidy payments and fluctuating fossil oil prices, FAME (Fatty Acid Methyl Ester) could be used as a perfect substitute for diesel or other fuels. Since blending and production through palm oil is considered viable in light of the energy transition target of the Indonesian government, the cost implication is of great importance concerning global fossil prices.

The processes of biodiesel production depend on the chosen technology - pyrolysis for instance involves use of high temperature in the absence of oxygen for conversion into gaseous and liquid fuels. In the microemulsion mixing technique, both reactants are initially micellized separately within two distinct microemulsions. They are then combined, facilitating the reaction through intermicellar exchange (Sankumgon, et al., 2018; Aktaş et al.,(2021). Other methods are the family of transesterification, they include catalytic and noncatalytic transesterification, supercritical methanol transesterification, ultrasound- and radio frequency-assisted transesterification, microwave irradiation-assisted transesterification, and in situ assisted transesterification (Amirthavalli et al., 2022). Whereas in Indonesia, the transesterification reaction method has been used mostly. It begins with the refining of palm oil and is then converted into biodiesel through a chemical reaction. In this reaction, the triglycerides (fats and oils) in palm oil are broken down into methyl esters (biodiesel) and glycerin. This process involves mixing the palm oil with an alcohol (usually methanol or ethanol) and a catalyst (typically sodium hydroxide or potassium hydroxide). The reaction typically occurs in a reactor vessel, and it produces two main products: biodiesel and glycerin (Abdullah et al., 2017; Alkabbashi et al., 2009; Nduwayezu et al., 2015). Thus, the cost factor plays a crucial role in the biodiesel production process, since it directly influences the production volume in response to market demand. Significantly, the procurement of essential components such as methanol and catalysts for biodiesel production is reliant on imports, rendering them susceptible to the impact of exchange rate fluctuations. The market prices are determined by the cost of production per kiloliter, which is influenced by government subsidies aimed at reaching net zero emissions and reducing the effect of fossil fuel price volatility on the national economy.

Figure 1 illustrates the mean monthly price fluctuations of biodiesel in Indonesia, indicating a certain degree of volatility in reaction to market dynamics. The price attained its maximum value during the first quarter of 2022 and then had a continual decline. However, figure 2 depicts a notable growth in the production and use of biodiesel over a certain time frame. Both curves have an upward trend, demonstrating a rise in both production and consumption. The observed phenomenon may be primarily attributed to the implementation of government subsidies aimed at promoting the transition from mostly imported fossil fuels to alternative energy sources.

This study delves into the disequilibrium modelling of the demand for and supply of biodiesel fuel and gasoline in Indonesia as well as looks into the mechanism establishing the state of the long-run equilibrium in the market. To design macroeconomic tax and subsidy policies, policymakers are interested in aggregate demand and supply as well as market clearing conditions. Considering the Indonesian government's commitment and interventions in promoting not only the production

but also the consumption of domestic biodiesel in the country, studying market efficiency and allocation is imperative for policymakers. The novelty of this paper is two-fold. Firstly, to the best of the authors' knowledge, it is the first attempt to establish the state of equilibrium in the biodiesel market, emphasizing the importance of price stability. Secondly, the paper introduces a long-term dynamic model for assessing the sustainability of biodiesel production in Indonesia. By employing advanced modelling techniques such as the autoregressive distributed lag model, the study offers a unique perspective on understanding the dynamics of biodiesel production over time.



Figure 1. Monthly Average Price of Biodiesel in Indonesia



Figure 2. Monthly Production and Consumption of Biodiesel in Indonesia

2. Literature Review

This section delves into the review of previous related studies on biodiesel production, and market potentials by analyzing its technological advancements, economic potentials, and environmental challenges. Additionally, it explores the imperative of ensuring long-term sustainability amidst the country's reliance on crude palm oil-based biodiesel. Beginning with the study of Abila, (2015) who considered biofuel especially ethanol as not a new technology, believes that the recent concern towards renewables is explained by the government's attention towards net zero emissions. However, enforcement of the blending rate using gasoline and diesel was to reduce the impact of the oil price shock on the domestic economy. Similarly, Algieri, (2014) asserts that biofuel production is the key strategy to mitigate the effect of climate change, and promote energy security and green energy economies in general. This has been the basis for frequent changes in biofuel policies. However, the production has a consequence such as an increase in demand for feedstocks and an increase in the food items. In a nutshell, the policy may cause conflict between energy and food security. Using computable general equilibrium on EU data, (De Lucia & Bartlett, 2014) found that presence of the biorefineries has the potential to increase the amount of crop production in Eastern Europe. However, it is worth noting that the sectoral GDP may experience a fall. Significantly, there will be a decrease in carbon emissions, albeit falling short of the established targets.

Damian et al. (2024) examined the paces achieved in technological advancements, prospects, and prevailing challenges to biodiesel production in India. The findings highlighted significant improvements in biofuel production within the nation, attributing this progress largely to synergistic collaborations across various entities within the energy sector. Such concerted endeavours have notably contributed to a substantial reduction in India's reliance on imported fossil fuels for both transportation and manufacturing purposes. Similarly, Liu et al. (2024) reviewed microalgae biodiesel production by examining the cultivation method for efficient growth and oil production. The study documented the hydrothermal liquefaction method as the most efficient process that has recently replaced the traditional transesterification although the cost implication could serve as a setback towards production in commercial quantities.

Utilizing the emission benefits of biodiesel under the "polluter pays" principle has the potential to establish it as a compelling substitute for traditional diesel fuel (Wirawan et al., 2024). This approach emphasizes the importance of holding those responsible for environmental pollution accountable for its costs, thereby incentivizing the adoption of cleaner alternatives like biodiesel. By integrating biodiesel into this framework, not only can emissions be reduced, but it also fosters a transition towards more sustainable energy practices (Wirawan & Tambunan, 2006).

Harahap et al. (2019) critically examine the cost-effectiveness of CPO and biodiesel production in Indonesia. The findings indicate that the combined approach involving an enhanced crude palm oil (CPO) facility and biodiesel processing plant (biorefinery), which generates biodiesel, electricity, heat, and biofertilizer concurrently, can yield an extra revenue of 14 USD per metric ton of fresh fruit bunches (FFB) compared to the conventional system. They further suggested that biorefinery setup will not only reduce reliance on governmental subsidies for biodiesel manufacturing but also reduce the industry's exposure to fluctuations in fossil diesel prices.

The sustainability of crude palm oil-based biodiesel in Indonesia is considered to be facing a daunting challenge. Dharmawan et al. (2020) examined these challenges using three interconnected approaches of sustainability. The economic profitability, ecological argument and social acceptability could constitute a big challenge for the sustainability of biodiesel production in Indonesia, especially from the upstream of CPO cultivation to the downstream. They further argued that the ecological parameter is the most daunting challenge to the sustainability of biodiesel production in Indonesia. Although, Halimatussadiah et al., (2021) scrutiny of CPO-centered biodiesel production in Indonesia reveals a dual-edged impact. While it proves advantageous in terms of import savings and mitigating emissions, it casts a shadow over the anticipated foreign exchange gains from crude palm oil sales, thus posing a challenge to governmental revenue streams. Consequently, substantial governmental funds allocated for subsidizing FAME (Fatty Acid Methyl Ester) and diesel could potentially be redirected towards more impactful endeavors. In light of these findings, the study advocates for the formulation of lucid policy frameworks to ascertain an optimal blending ratio conducive to long-term sustainability. In addition, Farobie and Hartulistiyoso (2021) did a comprehensive check of biodiesel implementation since 2006, surrounding both techno-economic and socio-political dimensions. While acknowledging the commendable employment opportunities and foreign

exchange gains attributed to the biodiesel policy, their analysis highlights a notable oversight regarding environmental risks and the comparative profitability of exports, aspects often neglected by policymakers and implementers. Similarly, Widrian et al. (2022) echoed these sentiments in their assessment of biodiesel implementation in Indonesia, emphasizing concerns about environmental ramifications and the generation of economic value.

A stand-alone study by (Zhang et al., 2016) used a bottom-up equilibrium optimization to study the biofuel market supply chain. They posit that the biofuel market has the potential to reduce greenhouse gas emissions in the transport sector. Also, subsidies to the farmer have a pass-through effect on biofuel production because they reduce the selling prices of the biomass to the biofuel producers.

Biofuel production has been linked to economic growth (Zaman et al., 2016). For instance, Ozturk and Bilgili (2015) established a strong correlation between the biomass production and aggregate economic output. Similarly, in the study of G-7 countries, Bilgil and Ozturk (2015) found evidence of a significant positive impact of biomass consumption on economic growth. In another study by Al-mulali and Ozturk (2015) the impact of the socio-economic factors such as political and environmental factors are evaluated on the environment for sustainability in MENA region. They proved that biofuel system is driving renewable towards green society in the long run.

3. Methodology

3.1 Disequilibrium Conditions of Indonesian Biodiesel Market

As previously explained, in Indonesia, the implementation for biodiesel mandatory is given for a certain percentage mixture between biodiesel and gasoil product which currently generate a B35 fuel. Therefore, since biodiesel product is not purely sold to the final consumers, we take into consideration that the disequilibrium state exists between its corresponding price of demand and supply side. By considering this assumption, we then develop the description of the regression model as follows.

In general, market dynamics involve the study of demand for and supply of goods and services constitute the major framework for government policies regarding tax and subsidy. In regulating the consumption of certain commodities, the government could impose high commodity tax, while excise duties are largely used to protect the infant industries. More importantly, in the energy sector, where many exogenous and endogenous factors play a prominent role in maintaining the state of balance or equilibrium, monetary and fiscal authorities constantly intervene to ensure fairness and balance among the players. Market demand, for instance, explains the volume of biodiesel consumed by individuals, firms and governments, while the market supply of biodiesel depicts the volume produced from the mixture and supply to the market. At equilibrium, as assumed by John B. Says cited in Blaug (1997) stated that the market always clears, meaning that demand equals supply to establish prices. A state of disequilibrium exists, and natural forces will reestablish the equilibrium in the market. It follows that for all biodiesel markets, the demand tends to equate with the supply;

$$QD_t^{bio} = f(P_t, X_t) \dots [1]$$

$$QS_t^{bio} = f(P_t, Z_t) \dots [2]$$

Where, the aggregated demand for biodiesel at time, t, is represented by QD_t^{bio} in equation 1, similarly QS_t^{bio} stands for the quantity supplied to the market at time t, while P_t is the price and X_t and Z_t are the vector of covariates.

Thus, the structural equation for 1 and 2 above is given as;

$$QD_t^{bio}(P_t, X_t) = \delta_0 + \delta_1 P_t + \delta_2 X_t + \varepsilon_t \dots [3]$$

$$QS_t^{bio}(P_t, Z_t) = \delta_0 + \delta_1 P_t + \delta_2 Z_t + \varepsilon_t \dots [4]$$

$$QD_t^{bio}(P_t, X_t) = QS_t^{bio}(P_t, Z_t) \dots [5]$$

[5] is the biodiesel market clearing equation, while [3] and [4] are the structural form of the linear biodiesel market. We expect that $\delta_1 < 0$ in [3], $\delta_1 > 0$ in [4] based on the theory of demand and supply respectively. From the foregoing therefore, we expect correlation between the regressors and error term, because it is possible that price is also being influence by the quantity demand and supply, hence the reduced form of [3] and [4] in which the equilibrium price (P_t^{eq}) and quantity of the biodiesel (Q_t^{eq}) could be a linear function of the covariates in the model are presented thus:

$$P_t^{eq} = \pi_x^p X_t' + \varepsilon_t^p \dots [6]$$

$$Q_t^{eq} = \pi_x^q X_t' + \varepsilon_t^q \dots [7]$$

According to Goldberger (1991), equations 3 and 4 cannot be estimated using ordinary least squares because prices are endogenously determined. In addition, the identification of the equation for estimation is key in the system of simultaneous equations such as the ones above, ignoring this assumption will lead to inconsistent and inefficient estimators unless we use some instrument outside the model. In the Ruud (2000)'s wisdom, estimating individual equation using ordinary least square suffers from the problem of identification and correlation between the explanatory variables and error term, it is important to estimate the equations jointly, hence, we specify the demand and supply equations below;

$$QD_t^{bio} = f(P_t, P_{t-1}, P_{t-2}, P_{t-k}, \pi_t) \dots [8]$$

[8] could be econometrically expressed as:

$$QD_t^{bio} = \beta_0 + \beta_1 P_t + \beta_2 P_{t-1} + \beta_3 P_{t-2} + \beta_n P_{t-k} + \phi_m \pi_t \dots [9]$$

Equation 9 is a distributed lag model, thus, to operationalize the equation, we follow the Koyck's transformation cited in Klein (1956). Under the transformation, it is assumed that $\beta_0 = \beta_0 \gamma k$, where $k = 0, 1, 2, \dots$ γ represents the coefficient of the decay with $0 < \gamma < 1$, by imposing the restrictions impose by koyck, the following equation is arrived at;

$$QD_t^{bio} = \beta_0 + \beta_1 \gamma P_t + \beta_2 \gamma^2 P_{t-1} + \beta_2 \gamma^3 P_{t-2} + \beta_n \gamma^n P_{t-k} + \phi_m \pi_t) \dots [9]$$

One period lag from [9] produces [10] as follows;

$$QD_t^{bio} = \beta_0 + \beta_1\gamma P_{t-1} + \beta_2\gamma^2 P_{t-2} + \beta_2\gamma^3 P_{t-3} + \beta_n\gamma^n P_{t-k} + \phi_m \pi_t) \dots [10]$$

By multiplying [10] by γ we get [11]

$$\gamma QD_t^{bio} = \gamma\beta_0 + \beta_2\gamma^2 P_{t-1} + \beta_2\gamma^3 P_{t-2} + \beta_2\gamma^4 P_{t-3} + \beta_n\gamma^n P_{t-k} + \phi_m \pi_t) \dots [11]$$

Eliminating [9] from [11] we obtain [12] as follows;

$$QD_t^{bio} = \beta_0(1 - \gamma) + \beta_1\gamma P + \gamma QD_{t-1}^{bio} \dots [12]$$

Hence, we can rewrite [12] as [13] where $\alpha_0 = \beta_0(1 - \gamma)$, $\alpha_1 = \beta_1\gamma$, $\alpha_2 = \gamma$

$$QD_t^{bio} = \alpha_0 + \alpha_1 P + \alpha_2 QD_{t-1}^{bio} + \varepsilon_t \dots [13]$$

It is important to note that [13] is the demand equation for biodiesel market. However, we can introduce the vector of the control or other explanatory variables as shown in [8].

Supply of biodiesel is equally explained by prices and other explanatory variables. In the initial stage of this analysis, we assume that supply is a function of the price at time t and the lagged prices. This could be written as;

$$QS_t^{bio} = f(P_t, P_{t-1}, P_{t-2}, P_{t-k}, \pi_t) \dots [14]$$

Explicitly following the moment generating the [13] in the demand equation, the Koyck's transformation could generate [15] as supply function.

$$QS_t^{bio} = \mu_0 + \mu_1 P + \mu_2 QS_{t-1}^{bio} + \varepsilon_{2t} \dots [15]$$

The current price of a commodity is assumed to be influence by the previous period prices all other things being equal. The price equation in this regard can be formulated as:

$$P_t = f(P_{t-1}, P_{t-2}, P_{t-3}, \dots) \dots [16]$$

Which could be further expressed as;

$$P_t = \vartheta_0 + \vartheta_1 P_{t-1} + \vartheta_2 P_{t-2} + \vartheta_3 P_{t-3} \dots [17]$$

In the similar manner, we apply Koyck's transformation to obtain equation [18] as follows:

$$P_t = \vartheta_0 + \vartheta_1 P_{t-1} + \vartheta_2 (QD_t^{bio} - QS_t^{bio}) + \varepsilon_{3t} \dots [18]$$

From the foregoing therefore, we generate a complete three system of equations namely: equation [13], [15] and [18]. These equations contain endogenous variables and we hold constant all other factors that may influence each equation in the first estimation, while introduce them in the second model.

Individual estimation of the three equations using ordinary least square yield inconsistent and bias estimators because of endogeneity problem. However, we utilize the three-stages least squares estimation (3SLS). This method involves three major steps; in the first step, instrument values are developed for endogenous variables, secondly, the covariance matrix of the disturbance equation

are composed, in the final stage, using the covariance matrix in the second stage the generalized least square is estimated.

3.2 Long Term Dynamic Model

The second key contribution of this study centered on the examination of the long-term dynamics for biodiesel sustainability. To achieve this objective, employed the autoregressive distributed lagged model extended by Pesaran et al. (2001). These methods have advantages over other families of long run modelling. It utilizes the lags value of both endogenous and exogenous variables unlike other models that are strictly, endogenous or exogenous. It also allows specification of linear model with combination of stationary and non-stationary time series provided that the non-stationary could be stationary after first difference only. Further, the model is efficient and unique in the presence of small and finite sample data size and the long run estimates are consider to be unbiased. (Mah, 2000, Abubakar et al. (2023).

As earlier mentioned, Pesaran et al. (2001) methods allowed for linear combination of the I(0), I(1) and the mixture of both to examine the cointegration. To clearly understand the stationarity status of the underlying variables, we used augmented dickey fuller and kpss test of unit root.

To study the long run dynamic relationship in biodiesel market, we specify the following mathematical relations;

$$bio_t = f(katalis, methanol, glycerin, crudepalmoil, exchnage rate, gasoil, bioprice)$$

To test for the long run level relationship among the aforementioned variables, we formulated the symmetric ARDL model as follows;

$$\begin{aligned} \Delta lnbio_t = & \delta_0 + \delta_1 lnkt_{t-1} + \delta_2 lnme_{t-1} + \delta_3 cp_{t-1} + \delta_4 op_{t-1} + \delta_5 ex_{t-1} + \delta_6 gs_{t-1} + \delta_1 pr_{t-1} \\ & + \sum_{i=1}^p \partial_1 \Delta lnkt_{t-i} + \sum_{i=1}^p \partial_2 \Delta lnme_{t-i} + \sum_{i=1}^p \partial_3 \Delta ln cp_{t-i} + \sum_{i=1}^p \partial_4 \Delta ln op_{t-i} \\ & + \sum_{i=1}^p \partial_5 \Delta ex_{t-i} + \sum_{i=1}^p \partial_6 \Delta ln gs_{t-i} + \sum_{i=1}^p \partial_1 \Delta ln pr_{t-i} + \varepsilon_t \dots [19] \end{aligned}$$

To capture the short run dynamics, the error correction version of [19] is specify below;

$$\begin{aligned} \Delta lnbio_t = & \sum_{i=1}^p \partial_1 \Delta lnkt_{t-i} + \sum_{i=1}^p \partial_2 \Delta lnme_{t-i} + \sum_{i=1}^p \partial_3 \Delta ln cp_{t-i} + \sum_{i=1}^p \partial_4 \Delta ln op_{t-i} \\ & + \sum_{i=1}^p \partial_5 \Delta ex_{t-i} + \sum_{i=1}^p \partial_6 \Delta ln gs_{t-i} + \sum_{i=1}^p \partial_1 \Delta ln pr_{t-i} + ect_{t-1} + \varepsilon_t \dots [20] \end{aligned}$$

Where δ and ∂ are the long run and short run parameters respectively. However, Δ and ect_{t-1} are the difference operator and error correction term. The bound test hypothesis that specifies whether long run relationship exist or variables are cointegration, can be specify as;

$$H_0: \delta_i = 0$$

$$H_0: \delta_i \neq 0$$

Where $i = 1, 2, 3..$

3.3 Data and Variables

This study relied on data retrieved from the ministry of energy and mineral resources, Indonesia. It is monthly data spanning the period January 2014 to October 2023. The demand for biodiesel is represented by the total biodiesel consumption in thousand kilo-liters, similarly, the supply in the model is the total biodiesel production in thousand kilo-liters. We consider the price of the biodiesel per liter as the monthly average price computed market index price in Indonesian rupiah. In the later model, we include the, price of methanol, catalyst, glycerin and crude palm oil. We control for exchange rate which has indirect effect on the production of biodiesel. With exception of exchange rate, all other variables were converted into natural logarithm.

[Table 1](#) displays the descriptive statistics derived from the analysis of mean, standard deviation, minimum, and maximum values for the level data. The results indicate that the average price of biodiesel is 9073.907 with a standard deviation of 1951.163, and the price fluctuated between a minimum of 8.55 and a maximum of 9.65 during the observed period. The average production for the investigated period is 580995.09 liters, accompanied by a standard deviation of 311138.82. The historical minimum and maximum production values are 54608.548 liters and 1185541.4 liters, respectively.

Additionally, the average consumption of biodiesel during the period is 475823.94, with a standard deviation of 326283. The minimum and maximum biodiesel consumption levels are 29718.049 and 1129087, respectively. Notably, the average production exceeds consumption, suggesting a consistent surplus and indicating a potential absence of supply shocks in the long run.

4. Result and Discussions

This section presents the outcomes of different estimations, commencing with the iterative three-stage least square estimations, followed by the autoregressive distributed lag model, and concluding with the Johansen test of cointegration.

4.1 Biodiesel Equilibrium Market Conditions

It could be recalled that the classical theory of demand and supply is presented in a simultaneous form in which endogenous variables are expressed as a function of the set of endogenous and exogenous variables. To resolve this fundamental issue, we use iterative 3SLS popularly used in estimating simultaneous models, the outcome of which is reported in [Table 2](#).

Estimating the demand equation has revealed that price exerts a negative and statistically insignificant influence on the demand or consumption of biodiesel in Indonesia. Holding all other factors constant in the model, a percentage increase in price results in a marginal decrease in demand by 0.05%, albeit lacking statistical significance. Conversely, lagged demand emerges as a pivotal variable shaping the progressive trajectory of biodiesel demand. Furthermore, the model accounts for 95% of systematic variation in biodiesel demand through its explanatory variables. These findings align with market theory and further validate the study conducted by Chanthawong

et al. (2016), who identified the price of biodiesel as a key determinant of demand in Thailand. Also reported in Table 2, is the estimate of the supply equation. The results uphold the popular supply theory, where the price is a positive and significant function of the supply. This implies that as the price of biodiesel rises, firms are motivated to produce more if all other things are kept constant. A percentage rise in the price will increase supply by 0.15% this is statistically significant at 1% level. Interestingly, the last period supply or lag has a positive and significant impact on the current supply. More intuitively, last month's production of the biodiesel determines what will be produced in the current month, especially, when firms take into account the volume of sales and price dynamics. Inspection of the Supply model against the diagnostic test shows that 92% of the variation in the supply of biodiesel can be attributed to the explanatory variables in the model. This aligns with the conceptualization of the biofuel supply chain analysis in the context of institutions extended by Moncada et al., (2017).

The last column of Table 2 displays the estimates of the price equation. It could be observed that the Walrasian coefficient (D-S) which determines whether a market condition is in equilibrium or not is found to be negative and statistically significant. Two distinctive conclusions are drawn from this, firstly, there exists a disequilibrium in the biodiesel market in Indonesia, and secondly, there exists an excess supply of biodiesel over demand in demand. These empirical findings are in agreement with the government policies in promoting the biodiesel industry in Indonesia through which net zero emissions could be achieved by gradual withdrawal from the consumption of fossil fuels. Further, the last period's price is a significant factor in the current prices. This implies that the biodiesel price is likely to increase in the coming month when we take a historical cognizance of what happened in the last month. The coefficient of determination revealed that 80% variation in the price of biodiesel is explained by the variation in the lagged price and supply-demand fluctuations.

We observe the overall performance of the model by checking for serial correlation, heteroscedasticity and over-identification tests. The Harvey LM test for serial correlation indicates the non-rejection of the null hypothesis at all conventional significance levels, signifying the absence of serial correlation in the demand model. Similarly, the null hypothesis of homoskedasticity remains unrejected, affirming the absence of heteroskedasticity in the demand model. Moreover, a thorough examination of the model attests to the absence of over-identification, as indicated by the Harsen Segan test.

Table 1. Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
bioprice	118	9073.907	1951.163	5180	15559
bioconsum	118	475823.94	326283	29718.049	1129087
bioproduc	118	580995.09	311138.82	54608.548	1185541.4
cpo	118	8989.029	2290.278	5872	16665
exchr	118	13893.143	976.938	11427.05	16047
methanol	118	4994.859	1083.423	3019.54	8277
glyserin	118	5112.749	3007.863	2180.157	14760.505
Katalis	118	10521.552	1750.114	7416.864	14636.495

Source: Author' Computations

Table 2. Biodiesel Equilibrium Market Conditions Estimates

Variables	Demand Equation	Supply Equation	Price Equation
Price	-0.046	0.152*	
D(-1)	0.960*		
C	0.120	-0.417	1.208*
S(-1)		0.927*	
D-S			-0.052**
P(-1)			0.869*
Diagnostic tests			
R ²	0.95	0.92	0.80
Harvey LM statistics	0.1271		
Harsen sagan (overid)	121.100		
BP LM test (hetero)	30.35		

Note: * P<0.01 **P<0.05, ***P<0.1 Source: Author' Computations

4.2 Unit Root Test and Cointegration Test

One of the key contributions of this paper is to determine the long-term dynamics of the biodiesel market. To achieve this objective, we relied on the dynamic model put forward by Pesaran et al. (2001). The first and foremost step in the estimation of the dynamic model is to determine the stationarity status of the variables under investigation. This is to ensure that all the variables are either stationary at level or at first difference which is the key assumption underlying estimating the autoregressive distributed lag model extended by Pesaran et al. (2001). Table 3 reports the outcome of the Augmented Dickey-Fuller (ADF) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) unit root tests. The null hypothesis for ADF states that a series has a unit root or it is non-stationary, while the null of KPSS states that a series is stationary. The price of biodiesel is found to be a stationary series at the level under ADF because we reject the null hypothesis at 5% level. contrarily, the null was rejected in the case of KPSS and the first difference became stationary. Similarly, there is disagreement between ADF and KPSS on the order of integration of methanol. Where ADF shows that it is a level stationary, while KPSS revealed that it is a difference stationary series. Aside from these two scenarios, all other variables are stationary after the first difference under both tests.

To examine the cointegration among the variables, we utilized two different cointegration approaches for efficient outcomes. The integration order of the variables is found to satisfy conditions for each method. Table 5 presents the results of the Johansen cointegration test. Trace statistics indicate that there are at most three cointegrating equations at 5% level of significance. This implies that there is a significant interdependence among various factors in the long-term dynamics of the biodiesel production process. Similar findings are reported by (Elobeid et al. 2006; Zhang et al., 2016).

Specifically, it indicates that the production of biodiesel, as well as the prices of biodiesel, methanol, catalyst, crude palm oil (CPO), glycerin, and exchange rates, exhibit a collective movement and have the potential to influence each other. Essentially, this implies a systemic

relationship where changes in one variable can trigger corresponding adjustments in others within the production framework. Furthermore, the current composition or blending of these components in the biodiesel production process is deemed to be sustainable over an extended period. The interconnected nature of these variables suggests that any alterations or fluctuations in one element, such as biodiesel production or its pricing, may have a cascading effect on the entire system. This coherence among the different aspects underscores the importance of considering the holistic dynamics of the biodiesel production ecosystem for effective long-term planning and sustainability.

Table 3. Unit Root Test Results

Variable	ADF		KPSS		Order of integration
	level	First difference	level	First difference	
lnpr	-3.448**	-	1.21	0.0293*	I(0), I(1)
lngas	-1.380	-7.989*	1.15	0.0598*	I(1)
lncpo	-1.772	-10.048*	1.27	0.0423*	I(1)
lnbiopr	-3.326***	-10.950*	0.388	0.0414*	I(1)
lnmet	-2.908**	-	0.499	0.0851*	I(0), I(1)
lngly	-1.423	-6.607*	0.555	0.0802*	I(1)
lnkat	-2.493	-9.014*	0.783	0.0615*	I(1)
exchr	-3.604**	-	0.347	0.0378*	I(1)

Note: * P<0.01 **P<0.05, ***P<0.1 Source: Author' Computations

Table 4. Estimate of the Long-Term Biodiesel Model

Variables	Coefficients	Standard error
Lon Run Estimates		
Lnpr	7.411**	3.287
Lngas	0.591	0.399
lncpo	-7.188**	3.251
lnmet	-0.117**	0.771
lngly	-0.397	0.372
lnkat	-1.772**	0.851
Exchr	0.007*	0.001
C	8.261	7.295
Short run dynamics estimates		
lncpo	-0.948*	0.225
lnkat	-0.179	0.248
lnkat(-1)	0.310	0.247
lnkat(-2)	0.636**	0.251
Ect	-0.187*	0.024
Bound (F- statistics)	6.008*	
BP serial correlation	0.522	
White's test of Heteros	2.577	
Cusum square test	Stable	
Selected model (AIC)	(1,0,1,0,0,3,0,0)	

Note: * P<0.01 **P<0.05, ***P<0.1 Source: Author' Computations

4.3 Long Term Biodiesel Market Dynamics

This section presents the outcome of the baseline model. The results are displayed in [Table 4](#). Having established through the Johansen test that there is a long-run relationship among the variables of the study, it could be further affirmed by looking at the bound F-statistics. However, we proceed to the long-run estimates of the ARDL where the price of gas oil has a positive and significant effect on the production of biodiesel, this implies that a rise in the price of gasoil is a signal to firms to increase the production as a substitute oil to the gas. It could be seen that a rise in the price of crude palm oil has a significant devastating effect on the production of biodiesel. This constitutes important empirical findings because crude palm oil is an important component in the production of biodiesel, government regulations about the composition of export and local consumption should not jeopardize the aim and objective of the production of biodiesel in Indonesia. this finding is in agreement with the study of Dermawan et al (2022).

Furthermore, the findings reveal insights into the specific impact of glycerin and methanol prices on biodiesel production. The analysis indicates that glycerin exerts a negative effect on biodiesel production, and this influence is deemed statistically insignificant. In practical terms, a percentage increase in the price of glycerin is projected to result in a reduction of 0.019% in biodiesel production. While this effect may be considered relatively small, it signifies that changes in glycerin costs have a limited but apparent impact on the overall biodiesel production output.

Similarly, the study highlights a consistent negative and statistically significant relationship between the catalyst price and biodiesel production in the long run. In more concrete terms, a percentage escalation in the price of the catalyst is linked to a more substantial decline in biodiesel production, amounting to 0.0192%. This indicates that variations in catalyst prices play a significant role in influencing the production levels of biodiesel compared to glycerin. Understanding these relationships is crucial for industry stakeholders and policymakers, as it enables them to make informed decisions about resource allocation, cost management, and strategies for enhancing the sustainability and efficiency of biodiesel production processes.

Table 5. Johansen Cointegration Test

Hypothesis	eigenvalue	Trace statistics	0.05 critical value
None	0.350349	156.3357*	125.6154
At most 1	0.265157	107.5965*	95.75366
At most 2	0.221343	72.78139**	69.81889
At most 3	0.152094	44.51050***	47.85613

Note: * P<0.01 **P<0.05, ***P<0.1 Source: Author' Computations

Incorporating the exchange rate as a control variable in the model comes from its role in exerting an indirect influence on biodiesel production. The relationship is revealed through the blending composition, which necessitates imported petroleum diesel. Consequently, fluctuations in the exchange rate, specifically the dollar value against the Indonesian rupiah, become pivotal factors influencing the overall biodiesel production dynamics.

The exchange rate exhibits a significant negative impact on biodiesel production in the model. This implies that when the exchange rate is high, indicating a stronger dollar relative to the Indonesian rupiah, biodiesel production experiences a decline. Conversely, when the exchange rate is lower, reflecting a weaker dollar, biodiesel production sees an upturn. This correlation highlights

the sensitivity of biodiesel production to currency fluctuations and underscores the importance of considering external economic factors in optimizing production strategies. Policymakers and industry stakeholders can leverage this insight to implement measures that mitigate the adverse effects of exchange rate fluctuations on biodiesel production, fostering a more resilient and sustainable production framework.

In the short run, however, crude palm oil remains an important input affecting biodiesel production negatively and this is statistically significant at 1% level. Moreover, the catalyst appears to be a significant factor in increasing production in the short run. The error correction term is found to be negative and statistically significant as required. It pinpoints the speed of adjustment to the long-run equilibrium in case of distortion in the market, however, 18.7% correction towards the long run is achieved monthly in case of endogenous and exogenous shocks.

Upon closer examination of the lower section of [Table 4](#), it is evident that the bound F-statistics surpass both the lower and upper bounds. It is statistically significant at the 1% level. This suggests that the model's variables are cointegrated, indicating a consistent movement together in the long run. Furthermore, the outcomes of the Breusch-Pagan test for serial correlation do not provide sufficient evidence to reject the null hypothesis of no serial correlation. Concurrently, White's test affirms the homoscedasticity of the residuals. The stability of the estimated coefficients is upheld by the CUSUM squared test as shown in [Figure 1](#).

5. Conclusions

This study delves into the equilibrium conditions within Indonesia's biodiesel industry, examining its long-term dynamics through the bound approach to cointegration and the Johansen test. The results unveil a state of disequilibrium in the biodiesel market, as evidenced by Walrasian coefficients, indicating a consistent excess supply over demand. These findings underscore the government's persistent efforts to leverage biofuel policies as a pathway toward achieving net-zero emissions in the future. Additionally, the behaviour of biodiesel prices, as observed in both the demand and supply models, aligns with the well-established Marshallian theory in the short run. Notably, the study highlights the significance of the previous month's average prices in determining the current biodiesel price.

A cursory look at the long-run market conditions indicates that there is the long-run relationship among the key determinants of biodiesel production in Indonesia. The long-run coefficient revealed that crude palm oil prices have a negative effect on biodiesel production both in the short run and long run. A rise in the prices of crude palm oil is likely going to affect the production of biodiesel. This underscores the crucial and imminent need for a constant supply of CPO to ensure uninterrupted production in the face of scarcity. Additionally, the supply model highlights that the price of biodiesel is directly proportional to production, indicating a positive correlation between price and production as firms are motivated to produce more, in the same vein, the long-run price coefficient suggests the same effect on production. Moreover, the exchange rate emerges as a pivotal determinant in the long run, while shocks in glycerin and methanol exert a diminishing impact on biodiesel production.

Based on these findings, we recommend incentivizing firms in the industry to promote sustainability, facilitating a smoother transition to renewable energy. Also, policy regarding the domestic and export composition of crude oil should be properly managed in the continuous biodiesel production. However, future studies should incorporate exogenous factors that may influence the optimal blending rate in the biodiesel market.

Conflict of Interest

Authors have no conflict of interest

Data Availability

Data for this study is available on request.

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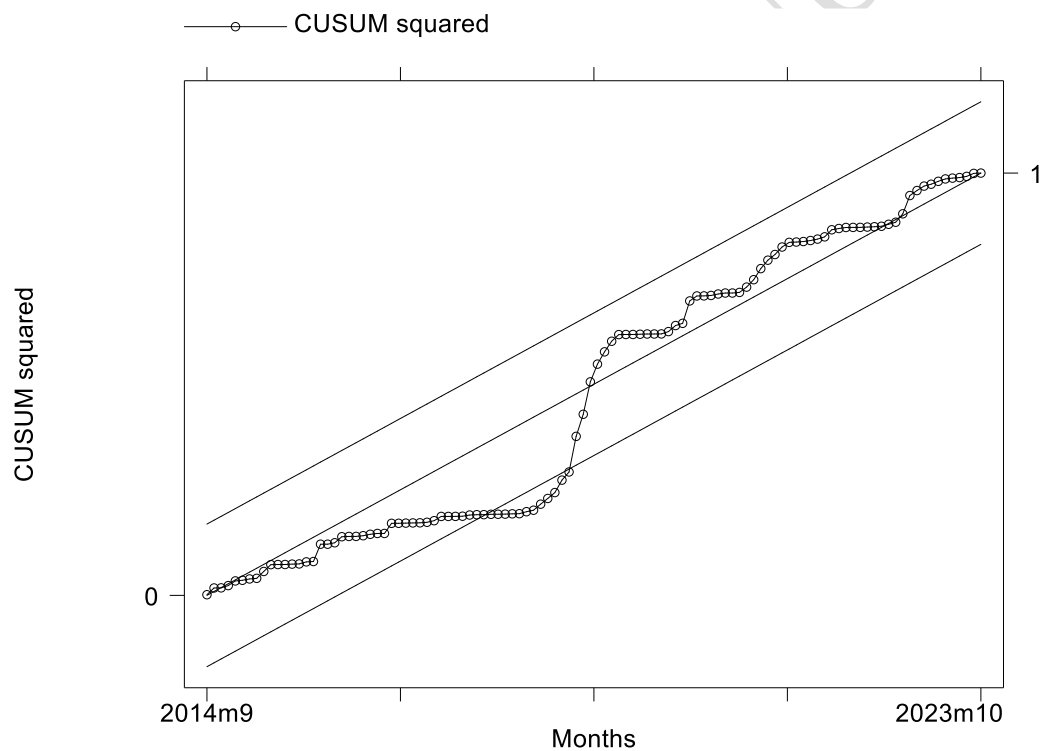


Figure 3. CUSUM Test of Residual Stability

Dear Professor Marc A. Rosen, PhD

Thank you, sir, for providing feedback on our manuscript. The issue raised has been addressed, and below, we provide a brief on how we solved the issues.

First Reviewer

Reviewer #1: There's nothing novel in this manuscript; it feels like a regurgitation of existing literature. Unfortunately, I must reject it.

As one reviewers feel there is nothing novel in this manuscript and that it feels like a regurgitation of existing literature, the authors need to ensure they make it explicitly clear in the paper what the novelty and contribution is.

Responses: we sincerely appreciate the time invested by the reviewers and the chief editor of this journal in reading and providing the necessary feedback needed to improve this manuscript. We understand your concern towards ensuring that the right thing is done on the manuscript to make it better.

However, as suggested, we look over again to explicitly state the intent of this paper. The correction is highlighted in the yellow in the last paragraph of the introduction. This could be highlighted below:

....This study delves into the disequilibrium modelling of the demand for and supply of biodiesel fuel and gasoline in Indonesia as well as looks into the mechanism establishing the state of the long-run equilibrium in the market. To design macroeconomic tax and subsidy policies, policymakers are interested in aggregate demand and supply as well as market clearing conditions. Considering the Indonesian government's commitment and interventions in promoting not only the production but also the consumption of domestic biodiesel in the country, studying market efficiency and allocation is imperative for policymakers. The novelty of this paper is two-fold. Firstly, to the best of the authors' knowledge, it is the first attempt to establish the state of equilibrium in the biodiesel market, emphasizing the importance of price stability. Secondly, the paper introduces a long-term dynamic model for assessing the sustainability of biodiesel production in Indonesia. By employing advanced modelling techniques such as the autoregressive distributed lag model, the study offers a unique perspective on understanding the dynamics of biodiesel production over time.....

Reviewer #4: The authors have addressed all the questions raised by the reviewer and revised the manuscript accordingly.

Responses: we thank you for the time spent to go over the manuscript again to ensure that all the issues raised were fully addressed.