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The Impact of Gross Domestic Product, Exports, And Palm Oil Prices on the Ecological Footprint in Indonesia, 1995–2025

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ABSTRACT: Economic development almost always goes hand in hand with increasing pressure on the environment. Output growth requires greater use of natural resources, energy, and land, while ecosystems have limited capacity to provide resources and absorb waste. This economic growth also increases pressure on the environment. Furthermore, the expansion of oil palm plantations has made Indonesia the world's largest producer and exporter of palm oil, but it has also increased environmental pressure, and the country's ecological footprint has exceeded its biocapacity. This study aims to analyze the impact of Gross Domestic Product (GDP) per capita, palm oil exports, and palm oil prices on Indonesia's production ecological footprint in both the short and long term, and to test for a cointegration relationship among these variables. The study uses annual time-series data for the period 1995–2025. All variables were transformed into natural logarithms and analyzed using the Autoregressive Distributed Lag (ARDL) approach. The results show that all variables are stationary in first differences and that a cointegration relationship exists at the 5% significance level. In the short term, an increase in GDP raises the ecological footprint in the current year, and this effect is partially offset in the following period; palm oil exports have a positive effect with a lag of one to two years, while palm oil prices have a significant negative effect on the ecological footprint. In the long run, only GDP has a positive and significant effect, while exports and palm oil prices are not significant at the 5 percent level. Diagnostic and parameter stability tests indicate that the model is suitable for interpretation. These findings imply that Indonesia's ecological pressures are more strongly influenced by income growth and short-term export dynamics than by price fluctuations.

KEYWORDS: Ecological Footprint, Gross Domestic Product, Palm Oil Exports, Palm Oil Prices, ARDL, Indonesia.
JEL Classification: Q56, Q17, C22

1. INTRODUCTION

Economic development almost always goes hand in hand with increasing pressure on the environment. Output growth requires greater use of natural resources, energy, and land, while ecosystems have limited capacity to provide resources and absorb waste. This economic growth increases pressure on the environment.

One indicator commonly used to measure environmental pressure is the ecological footprint (EF), which measures the consumption of natural resources and the capacity to assimilate waste generated by a human population or economic entity, and relates these to the carrying capacity of available land (Dapas, 2015). In terms of production, the EF calculates the area of bioproductive land and water required to produce all goods and services within a given region. Indonesia is in an ecological deficit because its EF exceeds its biocapacity (Idroes et al., 2024). This condition is illustrated in Figure 1, which shows that Indonesia's ecological footprint has exceeded its biocapacity. This situation indicates that Indonesia is consuming natural resources and generating waste at a rate that exceeds the Earth's ability to regenerate them.

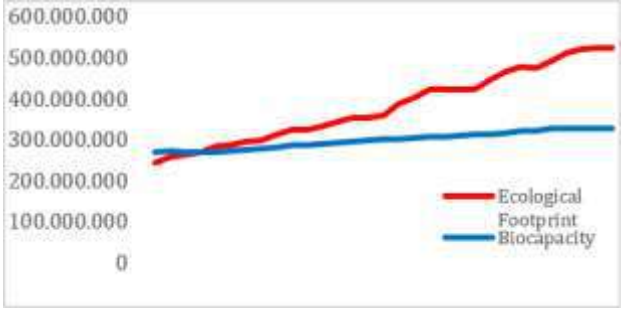

Figure 1. Ecological footprint and biocapacity levels in Indonesia, 1995–2025
Source: National Ecological Footprint and Biocapacity Accounts, 2026 Edition

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Until now, the primary measure of a country's progress has been its economic growth. Although the relationship between the two is not always linear, the emphasis on economic growth often overlooks harmful environmental impacts, such as an increased ecological footprint. Rising Gross Domestic Product (GDP) in the early stages of growth is usually accompanied by increased energy consumption, carbon emissions, and massive exploitation of natural resources—all of which significantly enlarge the ecological footprint. As the largest economy in Southeast Asia, Indonesia has experienced dynamic GDP growth year after year, as shown in Figure 2.

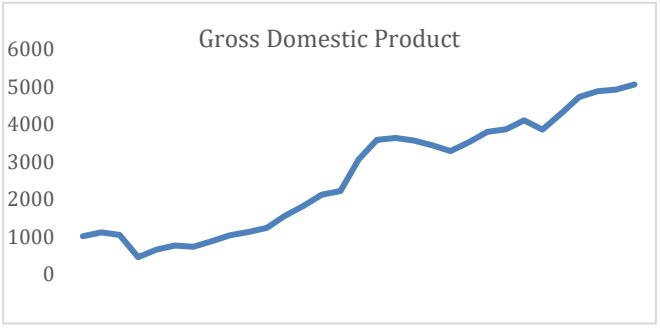

Figure 2. Gross Domestic Product Levels in Indonesia, 1995–2025
Source: World Bank (2026).

In environmental economics, Gross Domestic Product (GDP) is the most commonly used variable to explain changes in environmental quality. Theoretically, the relationship between the two is explained by the Environmental Kuznets Curve (EKC) hypothesis, which states that environmental degradation increases during the early stages of growth and only begins to decline once per capita income surpasses a certain tipping point (Güler et al., 2025).

Indonesia is currently recognized as the world's largest producer and exporter of palm oil, making a significant contribution to the global vegetable oil trade (Vijay et al., 2016). The high global demand for palm oil products is driven not only by food needs but also by increased use in the energy and cosmetics industries. These conditions make palm oil exports a key factor in driving national economic growth, particularly through increased government revenue and economic activity in the plantation sector (Erwinsyah, 2024). Palm oil's contribution to the economy is inextricably linked to various complex environmental issues resulting from its expansion. Palm oil expansion, driven by high global demand, has led to massive land clearing. The expansion of palm oil plantations is not solely due to productivity constraints but is driven by economic signals such as rising exports and prices that create incentives to continue clearing new land. Consequently, this land clearing directly contributes to increased pressure on tropical forest ecosystems and exacerbates the ecological deficit already experienced by Indonesia (Idroes et al., 2024).

This situation places pressure on the environment, particularly through deforestation and land-use change, which contribute to an increased ecological footprint. The ecological footprint represents environmental limits and the extent to which human activities exceed the Earth's regenerative capacity. It reflects the burden that a population places on the natural environment, encompassing the amount of land required to support that population's level of resource consumption and waste disposal (Budihardjo et al., 2013). In the palm oil industry, increases in exports are often linked to the expansion of plantation land, which changes land use. This expansion has been shown to contribute to deforestation, land degradation, and increased carbon emissions resulting from the conversion of forests into oil palm plantations (Erwinsyah, 2024). This expansion has been shown to contribute to deforestation, land degradation, and increased carbon emissions resulting from the conversion of forests into oil palm plantations (Carlson et al., 2013).

The dynamics of environmental degradation driven by international trade provide a clear picture of how anthropogenic pressure on ecosystems continues to increase. The relationship between economic activity in the palm oil sector and ecological conditions is visually illustrated in Figure 3.

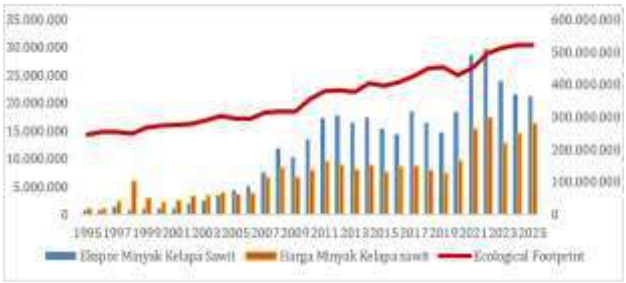

Figure 3. Palm oil export volumes, prices, and ecological footprint in Indonesia, 1995–2025
Source: Global Footprint Network, Global Price of Palm Oil, Bank Indonesia (2026).

As shown in Figure 3, rising exports and fluctuations in global commodity prices have spurred efforts to intensify production, directly contributing to deforestation and a decline in biocapacity through the conversion of peatlands and primary forests (Manulusi et al., 2026). The surge in exports directly created production pressures that drove producers to expand their plantation areas to meet global demand. Under these conditions, clearing forests for oil palm plantations was not only a response to market demand but was also influenced by factors such as the price of crude palm oil, interest rates, and exchange rates, which significantly drove forest conversion (Pridananti, 2022). This finding is also supported by research by

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Xin et al. (2021), which shows that the expansion of oil palm plantations in Indonesia, particularly in Kalimantan, is significantly driven by the export value of oil palm products, with expansion patterns favoring regions with better land suitability and infrastructure accessibility. In the context of globalization, this interconnection also reflects an unequal ecological exchange, in which most environmental impacts from Indonesia's palm oil production are shifted abroad through exports and final consumption in other countries (Rulli et al., 2019).

This type of ecological trade imbalance aligns with findings that most tropical deforestation linked to the agriculture and forestry sectors is concentrated in Brazil and Indonesia (Bausano et al., 2023), meaning that Indonesia's environmental footprint does not fully reflect actual domestic consumption. Therefore, an analysis of Indonesia's ecological footprint must incorporate the dimension of teleconnections, that is, how foreign market demand shapes changes in domestic land use (Henders et al., 2015; Meyfroidt et al., 2013).

Figure 3 also shows that palm oil prices are relatively volatile. Prices act as a one-way signal for expansion, driving land clearing when they rise but not triggering a recovery when they fall. This is consistent with Gaveau's research (2022) A 1 percent increase in the price of palm oil is associated with a 1.08 percent increase in the establishment of new plantations. Erwinsyah, (2024) shows that global palm oil prices positively affect Indonesia's export volume, such that rising prices drive an increase in exports to international markets. The resulting changes in land use and carbon emissions are among the primary mechanisms linking these economic activities to an increase in the ecological footprint; thus, any rise in prices or exports that drives land conversion ultimately contributes to an expansion of Indonesia's ecological footprint.

Wang et al. (2025) show that palm oil production in Indonesia has a relatively high carbon footprint, and that the increase in palm oil exports also contributes to rising embodied carbon emissions in global trade. The expansion of plantations into forest and peatland areas significantly increases carbon emissions, reaching up to 26 metric tons of CO_2e (carbon dioxide equivalent) per metric ton of production under certain conditions (Lam et al., 2019). The increase in palm oil export volumes reflects steadily rising global demand. Approximately 53 percent of total trade in CPO and its derivatives on the international market originates from Indonesia (Pacheco et al., 2017). Every metric ton of Refined Palm Oil (RPO) exported carries an ecological footprint that spans the entire supply chain from cultivation to shipment, including emissions from land-use change, which account for approximately 32.82 percent of the total carbon footprint of production (Wang et al., 2025).

Several studies have examined the environmental impacts of the palm oil industry using a life cycle assessment approach (Wang et al., 2025) or deforestation analysis, as in the studies by Austin et al. (2017) and Gaveau et al. (2022). Destek et al., (2018) and Durkaya & Kaya (2024) indicate that the ecological footprint has become a crucial research topic in recent years; however, the focus has primarily been on the relationship between overall economic growth and the ecological footprint, so there has not yet been a study specifically examining the palm oil sector as one of Indonesia's leading export commodities in relation to the dynamics of the national ecological footprint. This is consistent with the fact that in 2023, Indonesia produced 47 million metric tons of crude palm oil, solidifying its position as the world's largest exporter of palm oil, accounting for 54 percent of global exports. The palm oil industry has grown to become a vital part of Indonesia's economy, accounting for 4.5 percent of GDP, making a deep understanding of the ecological pressures on oil palm cultivation essential. The palm oil commodity serves as the backbone of the national economy while also carrying serious ecological consequences. This tension between these two realities makes this research important.

Many previous studies have examined the ecological footprint and its relationship to economic indicators, using different methods, time frames, and locations. Naturally, these studies have yielded varying conclusions. Therefore, the author seeks to identify the impact of gross domestic product and, specifically, to examine the palm oil sector as one of Indonesia's leading export commodities on the dynamics of the national ecological footprint. Without a quantifiable understanding of the extent to which GDP, exports, and palm oil prices influence the ecological footprint, the resulting policies will tend to prioritize the economy while neglecting environmental sustainability. This study aims to: (1) analyze the impact of GDP, exports, and palm oil prices on Indonesia's ecological footprint in the short and long term, and (2) test for the existence of a long-run cointegration relationship between GDP, exports, and palm oil prices and Indonesia's ecological footprint.

2. RESEARCH METHOD

2.1 Data and Variables

This study uses annual time-series data for the period 1995–2025. The dependent variable is Indonesia's Ecological Footprint of Production (EFP), measured in global hectares (gha), which quantifies the biologically productive land and water area required to produce all goods and services generated within a given region. The data are sourced from the 2026 Edition of the National Ecological Footprint and Biocapacity Accounts, compiled by the Ecological Footprint Initiative at York University (n.d.), covering 1995–2025. Data for 1995–2023 are final figures calculated from officially reported statistics. Meanwhile, data for 2024 and 2025 are estimates provided by the data provider.

Furthermore, the independent variables consist of: (1) gross domestic product (GDP) per capita, which is the total income generated through the production of goods and services in an economic region during a specific accounting period, sourced from the World Bank, (2) palm oil exports (POX) in thousands of metric tons per year, sourced from Bank Indonesia, and (3) the international price of palm oil (PP) in USD per metric ton, converted to rupiah, sourced from the International Monetary Fund. All variables were transformed into natural logarithms to allow the coefficients to be interpreted as elasticities and to stabilize the data variance.

2.2 ARDL Model Specifications

The ARDL model used in this study is formulated as follows: the ARDL model (p, q1, q2 q3):

$$\Delta \mathrm{LEFP}_t = \beta_0 + \sum_{i=0}^{p} \beta_{1i} \Delta \mathrm{LEFP}_{t-i} + \sum_{i=0}^{q1} \beta_{2i} \Delta \mathrm{LPDB}_{t-i} + \sum_{i=0}^{q2} \beta_{3i} \Delta \mathrm{LPOX}_{t-i} + \sum_{i=0}^{q3} \beta_{4i} \Delta LPP_{t-i} + \theta_1 LEF_{t-1} + \theta_2 LPDB_{t-1} + \theta_3 LPOX_{t-1} + \theta_4 LPP_{t-1} + \varepsilon_t \quad (1)$$

Description:

LEFP = *Ecological Footprint Log*

LPDB, LPOX, LPP= *Gross Domestic Product Log, Palm Oil Exports Log, and Palm Oil Price Log*

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Δ = *Opertor first difference*
β_0 = Constant
$\beta_{1i} - \beta_{3i}$ = Short-term coefficient
$\theta_1 - \theta_3$ = Long-term coefficient
p, q1, q2 = Optimal lag of the variable
ε_t = *Error term*

2.3 Estimation Procedures

The analysis steps include: (1) Stationarity test using the Augmented Dickey-Fuller (ADF) test, (2) Cointegration test using the Bounds Test by comparing the F-statistic to the critical values of I(0) and I(1) from Pesaran et al. (2001), (3) Estimation of the short-run (ECM) and long-run ARDL models, (4) Diagnostic tests, including tests for normality (Jarque-Bera), heteroscedasticity (Breusch-Pagan-Godfrey), and autocorrelation (Breusch-Godfrey LM Test), and (5) Tests for parameter stability using CUSUM and CUSUM of Squares. All estimations were performed using EViews software.

3. RESULTS AND DISCUSSION

3.1. Stationarity Test

In time series analysis, determining whether the data is stationary is the first step. Given that time series data often contains trends or patterns that, if not stationary, can lead to spurious regression results, a stationarity test is initially conducted in levels to determine whether the data is stationary in its original form. The first stationarity test is performed at the level to determine whether the data is stationary in its original form, because time series data often contains trends or patterns that can lead to spurious regression if the data is not stationary. In this study, the ADF (Augmented Dickey-Fuller) test was used because it can identify unit roots while accounting for the lags of the independent variables.

Table 1. Results of the Stationarity Test for the Data

Variables	*At Level*		*First Difference*		Conclusion
	Statistics	p-value	Statistics	p-value	
LEFP (Production Ecological Footprint)	-3.521431	0.0557	-5.004589	0.0022	I(1)
LPDB (Gross Domestic Product)	-2.276029	0.4334	-5.502828	0.0006	I(1)
LPOX (Palm Oil Exports)	-0.768002	0.9577	-6.509203	0.0000	I(1)
LPP (Palm Oil Price)	-3.370963	0.0802	-6.501256	0.0001	I(1)

Source: Estimated results (processed), 2026

Based on Table 1, the results of the stationarity test using the Augmented Dickey-Fuller (ADF) test show that the four variables in this study, LEFP, LPDB, LPOX, and LPP, are not stationary at the first order, as all ADF probability values are greater than 0.05; therefore, the null hypothesis of the presence of a unit root cannot be rejected. After first-order differentiation, all variables became stationary at the 1% significance level. Thus, all variables are integrated of order one (I(1)), and no variables are integrated of order two (I(2)). According to Pesaran et al. (2001) first-order integrated variables (I(1)) are suitable for use in an ARDL (Autoregressive Distributed Lag) model.

3.2 Cointegration Test *(Bounds Test)*

After confirming that the data meet the stationarity criteria, the next step is to test whether a long-run relationship (cointegration) exists among the variables in the model. The cointegration test is conducted using the Bounds Test approach introduced by Pesaran et al. (2001). This procedure compares the F-statistic value of the restricted ARDL model with the critical bounds, which consist of the lower bound I(0) and the upper bound I(1). If the F-statistic value exceeds the upper bound, it can be concluded that there is cointegration among these variables, without the need to know the exact order of integration for each variable.

Table 2. Results of the Cointegration Test (Bounds Test)

Test Statistic	Value	Signif	I(0) Bound	I(1) Bound
F-statistic	5.460672	10%	3.770	4.535
K = 3		5%	4.535	5.415
		1%	6.428	7.505

Source: Estimated results (processed), 2026

Based on Table 2, the Bounds Test results show an F-statistic of 5.460 with k = 3 regressors. This value is greater than the upper limit of I(1) at the 10% (4.535) and 5% (5.415) significance levels but remains below the lower limit of I(0) at the 1% level (6.428). Thus, the null hypothesis of no long-run relationship is rejected at the 5% level, whereas at the 1% level, the hypothesis cannot yet be rejected. In conclusion, there is cointegration among GDP, exports, palm oil prices, and the ecological footprint, significant at the 5% level but not at the 1% level. Thus, the ARDL model can be estimated to obtain the short-run and long-run elasticities of each variable with respect to the ecological footprint in Indonesia (Huda & Widodo, 2017). These results are consistent with the findings of other studies using the ARDL approach, in which an F-statistic value exceeding the upper critical limit serves as a strong indication of a long-run cointegration relationship among the variables (Maulidar et al., 2024).

3.3 Determining the Optimal Lag

Selecting the optimal lag is a crucial step in ARDL model development because it directly affects the model's ability to capture the dynamics of the relationships among variables. Lags that are too short can result in an underfitted model that fails to represent the dynamic structure of the

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data, while lags that are too long can lead to overfitting and the loss of valuable degrees of freedom, especially in small samples (Pesaran et al., 2001).

In this study, the optimal lag was selected automatically based on the Akaike Information Criterion (AIC), considering up to a maximum of four lags for each variable. EViews selected the model with the smallest AIC value as the best model. The selection results indicate the following ARDL model (1,3,3,1).

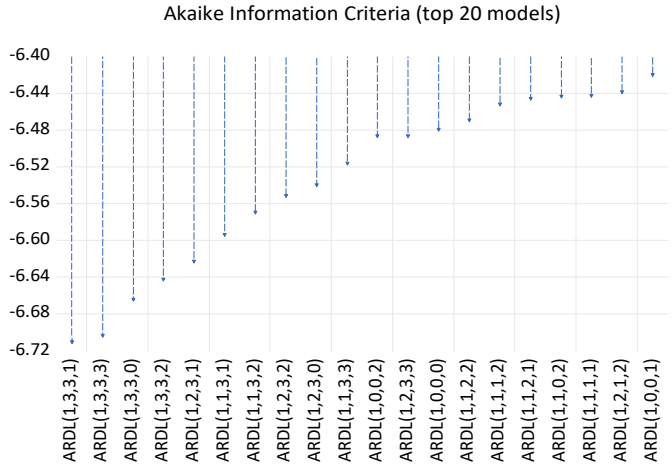

Figure 2. Best ARDL model

Source: Estimated results (processed), 2026

The best ARDL specification based on the AIC criterion is ARDL (1,3,3,1), namely ecological footprint with one lag, GDP with three lags, palm oil prices with three lags, and palm oil exports with one lag. The order of variables in EViews is LEFP, LPDB, LPOX, LPP. With a maximum lag of three, the estimation uses 28 effective observations (1998–2025).

3.4 Model Diagnostic Tests

3.4.1 Normality Test

The normality test aims to determine whether the residuals from the ARDL model are normally distributed. This test is conducted using the Jarque-Bera (JB) test, in which the null hypothesis states that the residuals are normally distributed. If the Jarque-Bera p-value is greater than the 5% significance level, the null hypothesis is not rejected, and the residuals are considered to satisfy the assumption of normality.

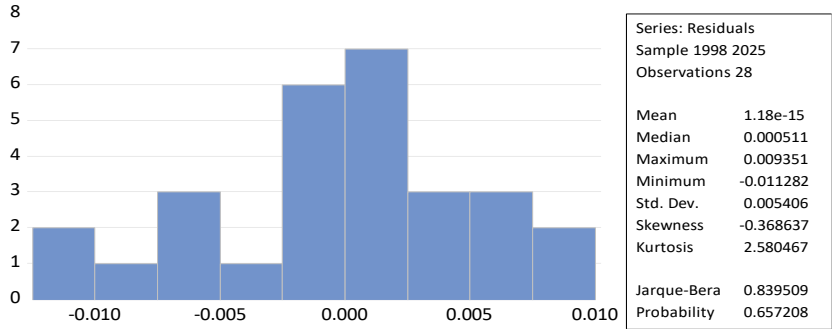

Figure 3. Normality Test

Source: Estimated results (processed), 2026

Based on the results of the Jarque-Bera test obtained from the ARDL model estimates (Figure 3), the test statistic value of 0.839509, with a p-value of 0.657208, is greater than 0.05; therefore, the null hypothesis cannot be rejected, and the residuals are normally distributed.

3.4.2 Heteroscedasticity Test

The heteroscedasticity test aims to determine whether the variance of the regression model's residuals is constant (homoscedastic) across all observations or varies (heteroscedastic). The presence of heteroscedasticity can render estimators inefficient and result in biased standard errors, thereby compromising the validity of statistical significance tests. In this study, the test was conducted using the Breusch-Pagan-Godfrey (BPG) test, with the null hypothesis that the residual variances are homoscedastic.

Table 3. Results of the Heteroscedasticity Test

F-statistic	0.375200	Prob. F (12,15)	0.9530
Obs*R-squared	6.464186	Prob. Chi-Square (12)	0.8909
Scaled explained SS	1.466006	Prob. Chi-Square (12)	0.9999

Source: Estimated results (processed), 2026

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Based on Table 3, the results of the heteroscedasticity test show that the probability values for the F-statistic (0.9530), observed R-squared (0.8909), and scaled explained SS* (0.9999) are all greater than 0.05. The null hypothesis that the residual variances are homoscedastic cannot be rejected, so the model does not suffer from heteroscedasticity. The fulfillment of the homoscedasticity assumption has important implications for the quality of the estimates. As noted by Pesaran et al., (2001) an ARDL model free from heteroscedasticity will produce efficient parameter estimates (Best Linear Unbiased Estimator, or BLUE) and valid standard errors, thereby allowing for reliable significance tests of the coefficients. Thus, the short-run and long-run estimates produced by this model can be interpreted with an adequate level of confidence.

3.4.3 Autocorrelation Test

The purpose of an autocorrelation test is to detect whether there is serial correlation among the model's residuals across different periods. Autocorrelation in a time-series regression model can result from an inappropriate model specification, omitted variables, or the inherent nature of economic data, which often exhibits continuous patterns from one period to the next. The presence of autocorrelation can result in inefficient parameter estimates and biased standard errors, which ultimately affect the validity of statistical inferences. In this study, autocorrelation was tested using the Breusch-Godfrey Serial Correlation LM Test.

Table 4. Autocorrelation Test Results

F-statistic	1.248779	Prob. F (2,13)	
Obs*R-squared	4.512428	Prob. Chi-Square (2)	

Source: Estimated results (processed), 2026

Based on Table 4, the results of the autocorrelation test show an F-statistic probability value of 0.3191 and an ObsR-squared* value of 0.1047, both of which are greater than 0.05. The null hypothesis that there is no serial correlation in the residuals was not rejected; therefore, the model is free from autocorrelation. The absence of autocorrelation indicates that the selected ARDL model specification has adequately captured the dynamic structure of the data, leaving no systematic information in the residuals. This is consistent with the point made by Pesaran et al.,(2001) that one of the advantages of the ARDL approach over conventional VAR methods is its ability to minimize autocorrelation issues through the selection of optimal lags. When this assumption of non-autocorrelation is met, the validity of the significance test and the confidence intervals for the model parameters can be justified.

3.5 Cointegration and the Speed of Adjustment

The estimation results indicate that the ecological footprint of production, GDP, exports, and palm oil prices in Indonesia follow a long-run equilibrium relationship. The bounds test supports the existence of a long-run relationship, and the speed of adjustment toward equilibrium can be observed from the error correction term, as indicated by COINTEQ. The magnitude of the coefficient indicates that approximately 69% of the deviation of the ecological footprint from its long-run equilibrium path is corrected within one year. This high rate of adjustment indicates that Indonesia's ecological footprint responds quickly to economic shocks. This makes sense because the ecological footprint of production is calculated using production data and land area figures that are updated annually (Lin et al., 2018). The presence of cointegration is consistent with other ARDL studies that have also found a long-run relationship between economic indicators and environmental quality (Kumaran et al., 2024; Maulidar et al., 2024).

3.6 Short-Term Forecast

The Error Correction Model (ECM) within the ARDL framework is used to identify the short-run adjustment dynamics between gross domestic product, exports, and palm oil prices in relation to Indonesia's ecological footprint. The ECM estimation follows the approach of Pesaran et al.,(2001) which allows for the simultaneous separation of short-run effects from long-run equilibrium.

Table 5. Estimation Results for the Error Correction Model

Variable	Coefficient	Std. Error	T-Statistic	Prob.	Conclusion
COINTEQ*	-0.689805	0.117297	-5.880838	0.0000	Significant
D(LPDB)	0.080570	0.034482	2.336608	0.0306	Significant
D(LPDB(-1))	-0.055511	0.022267	-2.492981	0.0221	Significant
D(LPDB(-2))	-0.048008	0.023174	-2.071594	0.0522	Significant
D(LPOX)	0.026648	0.019243	1.384789	0.1822	Not Significant
D(LPOX(-1))	0.087244	0.018465	4.724852	0.0001	Significant
D(LPOX(-2))	0.068781	0.018367	3.744886	0.0014	Significant
D(LPP)	-0.039047	0.017074	-2.286966	0.0338	Significant
C	5.823221	0.988787	5.889256	0.0000	Significant

Source: Estimated results (processed), 2026

Based on Table 5, the Gross Domestic Product (GDP) variable in the current period has a positive and significant effect on changes in the ecological footprint. This means that a 1% increase in GDP per capita in the same year is followed by an increase in the ecological footprint of approximately 0.081%. This effect reverses in the next two lags, with values of −0.056 and p = 0.022, followed by −0.048 and p = 0.052, which are significant only at the 10% level. Consequently, the initial increase was largely offset in subsequent periods. This pattern is consistent with the findings of Kumaran et al.,(2024) who reported a significant short-term relationship between Indonesia's GDP and its ecological footprint.

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Palm oil exports. Exports during the current period have no significant effect. However, exports from one and two years prior have a positive and significant effect. Thus, a 1% increase in exports increases the ecological footprint by approximately 0.18% with a lag of one to two years. This lag is consistent with the time-consuming process of oil palm expansion from land clearing and planting to production as recorded in the footprint accounts. These findings are consistent with those of Nugraha et al.,(2025) who found that Indonesia's palm oil exports reduce forest cover; with those of Xin et al.,(2021) who showed that export values drive plantation expansion; and with those of Manulusi et al.,(2026) who found that positive shocks to palm oil production worsen the ecological footprint.

Price changes during the current period had a significant negative effect: a 1% increase in price was followed by a decrease in the ecological footprint of approximately 0.039%. This finding differs from deforestation-based studies, which have found that price increases drive plantation expansion and forest clearing (Cisneros et al., 2021; Gaveau et al., 2022). Given the very small magnitude of the coefficient, this effect is better interpreted as a short-term adjustment rather than a strong policy signal.

3.7 Long-Term Estimates

Long-run estimates in the ARDL framework are derived from the cointegration coefficients, which describe the long-run equilibrium relationship among the variables in the model. The interpretation of the long-run coefficients reflects a persistent and stable structural relationship among the variables, rather than merely temporary adjustment dynamics.

Table 6. Long-Term Estimation Results

Variable	Coefficient	Std. Error	T-Statistic	Prob.	Conclusion
LPDB(-1)	0.392118	0.183410	2.137927	0.0429	Significant
LPOX(-1)	-0.178569	0.093386	-1.912156	0.0679	Not Significant
LPP(-1)	-0.010546	0.033708	-0.312867	0.7571	Not Significant
@TREND	0.008119	0.001633	4.973138	0.0000	Significant

Source: Estimated results (processed), 2026

The long-term results indicate that GDP has a positive and significant effect at the 5% level (0.392; p = 0.043). A 1% increase in GDP per capita over the long term increases the ecological footprint by 0.39%. Palm oil exports have a negative coefficient (−0.179; p = 0.068) that is not significant at the 5% level but becomes significant at the 10% level. Furthermore, the price of palm oil has no significant effect (−0.011; p = 0.757), so there is no evidence that price structurally shifts the ecological footprint. The deterministic trend is positive and highly significant (0.0081; p = 0.000). After controlling for GDP, exports, and price, the ecological footprint still increases by about 0.81% per year. This trend captures factors not included in the model.

3.8 Model Stability Test

Model stability tests were conducted to ensure that the estimated ARDL model parameters were stable throughout the study period and did not undergo significant structural changes. In this study, stability tests were conducted using two complementary approaches: the Cumulative Sum of Recursive Residuals (CUSUM) test and the Cumulative Sum of Squares of Recursive Residuals (CUSUM of Squares) test.

The CUSUM test detects systematic and gradual parameter instability, whereas the CUSUM of Squares test is more sensitive to random disturbances or sudden fluctuations in residual variance. Both tests present results graphically; if the statistical plot lies between the two critical bounds at a 5% significance level, the model parameters are considered structurally stable throughout the entire sample period.

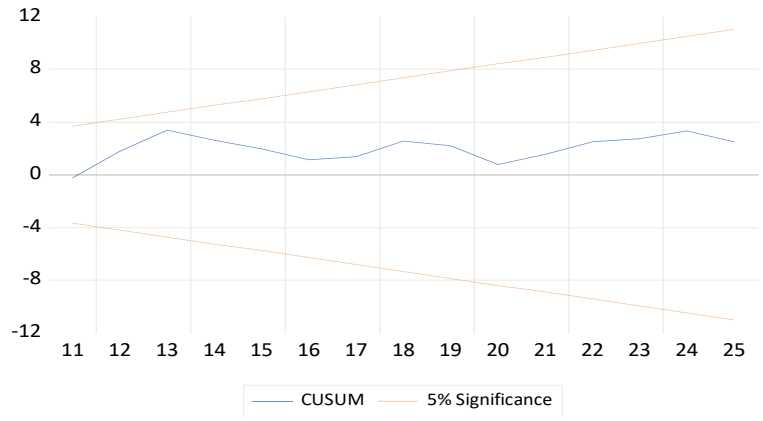

Figure 4. CUSUM Test
Source: Estimated results (processed), 2026

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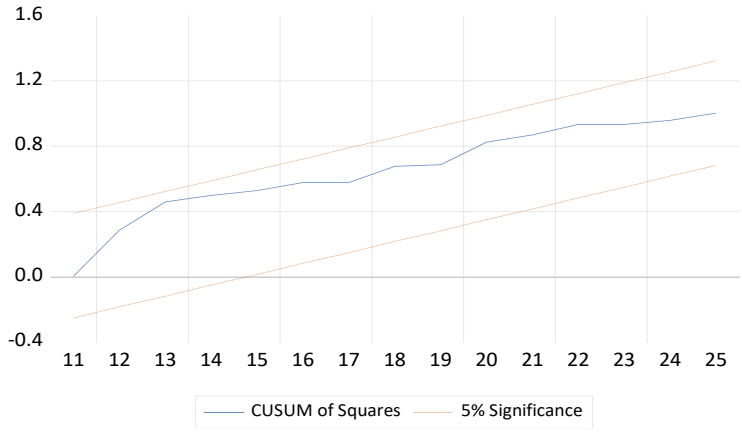

Figure 5. CUSUM of Squares Test
Source: Estimated results (processed), 2026

Based on the results of the CUSUM and CUSUM of Squares tests, the test statistic line remained within the band formed by the two critical limits at the 5% significance level throughout the observation period, although it approached the critical limits at some points. Thus, the null hypothesis regarding parameter stability cannot be rejected; therefore, the coefficients of the ARDL (1,3,3,1) model are deemed stable, with no indication of significant structural changes during the study period. This stability reinforces the model's suitability as a basis for interpretation in.

3.9 The Impact of Gross Domestic Product on the Ecological Footprint

The estimation results show that, in the short term, changes in GDP have a positive and significant coefficient, meaning that a 1% increase in GDP increases the ecological footprint by 0.08% in the same period. However, in the first and second lags, the GDP coefficient is negative and significant, indicating a decrease in environmental pressure in subsequent periods. In the long run, however, GDP has a positive and significant effect: a 1% increase in per capita GDP increases the production ecological footprint by 0.39%. The long-run elasticity in this study is lower than that reported by Idroes et al.,(2024), which was approximately 0.87. This difference is expected given differences in the sample period, footprint size, and control variables.

These findings are consistent with the Environmental Kuznets Curve hypothesis during the early stages of economic growth, when increases in national income are still accompanied by the exploitation of natural resources, energy consumption, and land-use changes that increase the ecological footprint. These findings are consistent with Kumaran et al. (2024), which found that economic growth in Indonesia significantly increases ecological pressure, and with Adebayo et al. (2021), which revealed a similar pattern between economic growth and environmental degradation in Indonesia.

3.10 The Impact of Palm Oil Exports on the Ecological Footprint

In the short term, the palm oil export variable has no significant effect during the current period; however, at the first and second lags, it shows a positive and highly significant effect, with coefficients of 0.0872 and 0.0688, respectively. This means that the impact of palm oil exports on increased environmental pressure does not occur immediately, but rather emerges after a time lag of approximately one to two years. Pola explained that the sustained increase in export volume is driving producers to expand their plantation areas, and the land-conversion process takes time before it has a tangible impact on the ecological footprint. Short-term trends support the argument that global demand signals expansion. Indonesia's palm oil export volume increased from approximately 14.6 to 24.8 million metric tons per year between 2006 and 2013 (Shigetomi et al., 2020)and carbon emissions from processed palm oil exports rose from 35.79 to 54.94 Mt CO_2e between 2010 and 2022 (Wang et al., 2025). These results are also consistent with Nugraha et al. (2025) who found a cointegration relationship between palm oil exports and declining forest cover.

Conversely, in the long term, the coefficient for palm oil exports is negative (-0.1786) but not statistically significant at the 5% level ($p = 0.068$). This non-significant result can be explained by several possibilities: first, efforts to develop the downstream palm oil industry, which are beginning to strengthen domestic value added, may reduce direct pressure on land conversion in the long term. Second, improving productivity through the replanting of smallholder plantations allows for increased output without the need for a proportional expansion of land area. Third, most palm oil-related deforestation is actually driven more by domestic consumption than by exports. These findings differ from initial assumptions but are consistent with the research by Benedict & Heilmayr (2024) which notes that the relationship between palm oil exports and deforestation is not always linear and weakens as sustainability policies are strengthened.

3.11 The Impact of Palm Oil Prices on the Ecological Footprint

The short-term results indicate that palm oil prices have a negative and significant effect on Indonesia's ecological footprint at the 5 percent significance level. In the long term, palm oil prices do not significantly affect the ecological footprint. These results are not entirely consistent with studies that have found a correlation between prices and oil palm land expansion. This negative finding likely reflects the fact that increased palm oil exports, accompanied by the adoption of more efficient production practices and sustainability policies, have not yet been fully reflected in the ecological footprint; therefore, this relationship should be interpreted with caution given its weak significance in similar studies (Manulusi et al., 2026). Possible explanations for the absence of such an effect include the fact that domestic palm oil prices are largely determined by government policy and global market dynamics, so fluctuations in those prices are not always reflected in production decisions that affect ecological pressure. Therefore, these findings suggest that the impact of prices on the ecological footprint in Indonesia cannot be considered

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mechanical in nature, but rather depends on policy structures and market conditions that determine how price signals are translated into production practices (Erwinsyah, 2024).

In contrast to the study by Gaveau et al. (2022) which explains that, historically, a 1% increase in price is associated with a 1.08% increase in new industrial plantations and a 0.68% loss of forest. Meanwhile, Guye & Kraus (2026) found a positive elasticity of deforestation with respect to CPO prices at the mill level. However, both studies used deforestation as the dependent variable, whereas this study uses the aggregate national ecological footprint, meaning the impact of prices on one component may be offset by another. Furthermore, the response of planting to price changes tends to occur with a long lag, as oil palm trees only become productive after several years. This lack of significance is also supported by the finding that the recent surge in palm oil prices has not been followed by the expansion of new plantations.

4. CONCLUSION

This study concludes that GDP per capita, palm oil exports, and palm oil prices have a long-run equilibrium relationship with Indonesia's production ecological footprint over the period 1995–2025. Deviations from this equilibrium are corrected rapidly by about 69 percent within one year, meaning that Indonesia's ecological footprint responds relatively quickly to economic shocks. Economic growth is the most consistent factor. In the short term, GDP growth increases the ecological footprint in the current year, although this increase is partially offset in subsequent periods. In the long term, a 1 percent increase in GDP per capita increases the ecological footprint by approximately 0.39 percent. These findings are consistent with the Environmental Kuznets Curve theory, which states that income growth is still accompanied by increased environmental pressure. Palm oil exports have no effect in the current year, but exports from one and two years prior increase the ecological footprint. This pattern reflects the lag between global demand signals, land clearing and conversion, and the recording of these impacts in the footprint accounts.

In the long run, GDP per capita has a positive and significant effect. A 1 percent increase in GDP per capita in the long run increases the ecological footprint by approximately 0.39 percent. Palm oil exports have a negative coefficient. This effect is not significant at the 5 percent level and is only significant at the 10 percent level. Palm oil prices do not have a significant effect; thus, prices are not shown to structurally shift the ecological footprint. The study's findings should be interpreted with caution because the sample size is relatively small, the 2024–2025 data are estimates, and the ecological footprint used is an aggregate measure that may obscure the dynamics of the land-use components. Future research could incorporate variables such as population size, energy consumption, and land cover, and analyze the ecological footprint components separately.

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