JPPIPA 11(11) (2025)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Analysis of The Impact of Infrastructure on Palm Oil Production in Smallholder Plantations

Susan Novrini[1*], Mhd. Ilham Riyadh[1], Mhd. Sofyan Harahap[2]

[1] Department of Agribusiness, Agriculture Faculty, Universitas Islam Sumatera Utara, Medan, Indonesia
[2] Alumni of Department of Agriculture, Agribisnis Faculty, Universitas Islam Sumatera Utara, Medan, Indonesia

Received: September 06, 2025
Revised: October 07, 2025
Accepted: November 25, 2025
Published: November 30, 2025

Corresponding Author:
Susan Novrini
susan.novrini@gmail.com

DOI: 10.29303/jppipa.v11i11.13053

Abstract: This study aims to analyze the influence of infrastructure and economic factors including accessibility, construction, electricity availability, land area, and Gross Regional Domestic Product (GRDP) on smallholder palm oil production in Muko-Muko Regency, Bengkulu Province. Using secondary data from 2005 to 2020 obtained from the Central Bureau of Statistics, the research employs multiple linear regression analysis based on the Ordinary Least Squares (OLS) method. The F-test results indicate that the five independent variables collectively have a significant effect on palm oil production (F = 4.00; Sig. 0.029), confirming that the model is statistically valid in explaining production variation. However, partial t-tests reveal that accessibility, construction, electricity, land area, and GRDP do not individually exhibit significant effects. These findings suggest that production performance is not driven by a single factor but rather shaped by the combined interaction of infrastructure conditions and regional economic dynamics. The discussion highlights that inconsistent infrastructure development, declining land area, and limited technological adoption among smallholders contribute to suboptimal production despite rising electrification and economic growth. Overall, the study underscores the importance of integrated infrastructure development, effective land-use planning, and technological support for smallholders to sustainably enhance palm oil productivity and strengthen regional economic resilience.

Keywords: Infrastructure; Accessibility; Electricity; Land Area; GRDP; Smallholder Palm Oil Production; Multiple Linear Regression; Indonesia

Introduction

The development of oil palm commodities continues to play a pivotal role in driving rural economies in Indonesia, with smallholder plantations contributing significantly to national production. While the expansion of oil palm areas by smallholders has increased household income, it has not always translated into higher productivity per hectare. This indicates the presence of structural constraints within upstream value chains, particularly in relation to physical infrastructure and regional economic conditions (Jelsma et al., 2017)

One of the most critical infrastructure aspects directly linked to yield is accessibility, particularly the quality and availability of road networks as well as distance to palm oil mills (PKS). Good road access reduces transportation costs, shortens delivery time for fresh fruit bunches (FFB), and helps maintain fruit quality, thus securing better prices for farmers. Conversely, damaged roads often push smallholders to rely on middlemen, which leads to price losses (Molenaar et al., 2013).

How to Cite:
Novrini, S., Riyadh, M. I., & Harahap, M. S. (2025). Analysis of The Impact of Infrastructure on Palm Oil Production in Smallholder Plantations. *Jurnal Penelitian Pendidikan IPA*, *11*(11), 1396–1405. https://doi.org/10.29303/jppipa.v11i11.13053

Table 1. Economic Growth in Bengkulu Province

Year	Economic Growth (%)
2020	4.31
2021	3.24
2022	4.31
2023	4.28
2024	4.62

Sumber : BPS Provinsi Bengkulu

The table above shows that although in 2021 Bengkulu's economic growth declined to 3.24% due to the impact of the COVID-19 pandemic, during the 2022–2024 period the province's economy rebounded and stabilized within the range of 4.3–4.6%. This condition indicates that improvements in infrastructure and the contribution of the plantation sector, particularly palm oil, may play a significant role in supporting regional economic growth. However, the extent to which infrastructure factors (accessibility, construction, electricity), land area, and regional GDP (GRDP) directly contribute to smallholder palm oil production at the district level has not been extensively studied.

Yet, it is not only the presence of roads that matters, but also the quality of construction (e.g., paved vs. dirt roads, the existence of bridges and drainage systems). Roads constructed with higher standards reduce seasonal transportation disruptions—an important factor in high-rainfall areas—ensuring continuity of FFB supply to mills and improving aggregate productivity. Local empirical studies confirm a strong correlation between the quality of road networks and crude palm oil (CPO) production efficiency (Arnol et al., 2025).

A third factor, electricity availability, enhances farmers' ability to adopt productive technologies (irrigation pumps, dryers, ICT for market information) and supports the operations of small- and medium-scale PKS. Development literature notes that rural electrification significantly raises both non-farm activities and agricultural productivity when complemented by market access and financing mechanisms (Finucane et al., 2021). Hence, electricity functions not only as a household necessity but also as a crucial agricultural input.

Another determinant is land area, which remains a key driver of gross output more hectares generally lead to higher total production. However, without adequate infrastructure and market access, land expansion often results in diminishing marginal returns. Several studies in Sumatra highlight the importance of balancing land expansion with per-hectare investment to achieve sustainable gains (Euler et al., 2016a).

Finally, regional GDP (PDRB) serves as an indicator of both economic capacity and public investment in infrastructure. A higher PDRB often correlates with greater public infrastructure provision, increased local capital availability, and more vibrant market activities, all of which incentivize farmers to enhance production and adopt more productive practices. Nevertheless, this PDRB–agrarian production linkage has often been overlooked in smallholder studies despite its relevance to policy-making (Bakhtary et al., 2021).

Although international and diagnostic studies emphasize that road access, mill proximity, infrastructure quality, and electricity are influential in determining smallholder yields (Cramb & Mccarthy, 2016). Empirical research that simultaneously examines the combined effects of accessibility (X1), infrastructure quality (X2), electricity (X3), land area (X4), and regional GDP (X5) on smallholder oil palm production at the district level remains scarce. Most existing research is either macro in scope or focuses on one or two factors only, often neglecting spatial variation (e.g., distance to roads/mills) and household heterogeneity (e.g., ownership patterns, tree age, financial access).

The urgency of this research lies in the need to understand the role of infrastructure and regional economic dynamics in ensuring the sustainability of smallholder palm oil production, particularly in Muko-Muko Regency, which possesses distinct geographic characteristics and land ownership structures compared to major production centers in Sumatra. Although this sector serves as a key driver of the local economy, various indicators show that improvements in electrification and regional economic growth do not automatically translate into higher smallholder output, while declining land area and inconsistent infrastructure development continue to hinder productivity. These conditions indicate a structural gap that has not been adequately addressed by regional development policies or previous studies, which are generally macro-oriented and rarely examine the simultaneous influence of multiple infrastructure variables at the district level. Therefore, this research is essential to provide empirical evidence on how accessibility, construction quality, electricity, land area, and GRDP collectively contribute to production, offering a stronger basis for formulating more targeted and effective infrastructure strategies aimed at enhancing smallholder productivity and improving local livelihoods.

For the case of Muko-Muko District, Bengkulu Province a region with distinct geographical features, land ownership structures, and mill networks compared to major production centers in Sumatra—findings from other areas cannot be directly generalized. The absence of spatial analysis that maps infrastructure access while controlling for household-level endogeneity highlights a clear research gap. This study therefore seeks to fill that gap by: (1) quantifying the contribution of each infrastructure and economic variable (X1–X5) to smallholder oil palm production in Muko-Muko, and (2) estimating production elasticities to provide evidence-based recommendations for infrastructure investment priorities aimed at improving productivity and farmer welfare.

Method

Research Method

This study applied a case study approach focusing on smallholder palm oil production in Desa Tanah Harapan, Kecamatan Kota Muko-Muko, Kabupaten Muko-Muko, Bengkulu Province. The case study method was considered appropriate because it enables an in-depth exploration of a phenomenon within its real-life context, which is essential in answering "how" and "why" questions (Yin, 2018). Previous studies on agricultural productivity have also used similar approaches to understand regional economic dynamics in relation to infrastructure (Vaishar and Šťastná, 2021).

The data utilized were secondary data obtained from the Central Statistics Agency (Badan Pusat Statistik/BPS), regional government publications, and related institutions covering the period 2005–2020. These data included palm oil production, accessibility (measured by road length), construction sector value, electricity access, land area, and Gross Regional Domestic Product (GRDP). The use of secondary data is widely recognized as reliable for time-series analysis and has been employed in agricultural economic studies both in Indonesia and internationally (Space, 2013). Data processing and statistical analysis were conducted using SPSS version 26.

The analytical framework employed was multiple linear regression analysis, which allows the estimation of relationships between one dependent variable and several independent variables (Gujarati & Porter, 2009). The dependent variable was smallholder palm oil production (tons), while the independent variables included accessibility (district road length), construction (value of construction sector), electricity (percentage of households with electricity access), land area (hectares of palm oil), and GRDP at constant prices. The regression model was estimated using the Ordinary Least Squares (OLS) method, which provides efficient and unbiased estimators under the assumptions of linear regression (Koutsoyiannis, 1977). In addition, elasticity analysis was applied to evaluate the responsiveness of palm oil production to changes in each independent variable, as suggested in econometric studies by (Wooldridge, 2016).

Experimental Design

The experiment employed a Non-Factorial Completely Randomized Design (CRD), which is commonly used in agricultural and biological research due to its simplicity and statistical reliability (Freeman et al., 1985). A total of seven treatments were tested, with each treatment replicated three times to ensure statistical validity and minimize experimental error. The treatments consisted of:

The analytical method applied in this study is multiple linear regression using the Ordinary Least Squares (OLS) approach to examine the influence of infrastructure and economic variables on smallholder palm oil production in Muko-Muko Regency. The regression model is formulated as:

$$Yt=\alpha+\beta1X1t+\beta2X2t+\beta3X3t+\beta4X4t+\beta5X5t+\varepsilon t \quad (1)$$

where:

- YtY_tYt = Smallholder palm oil production (tons) in year t,
- α\alphaα = Constant,
- β1,β2,β3,β4,β5\beta_1, \beta_2, \beta_3, \beta_4, \beta_5β1,β2,β3,β4,β5 = Regression coefficients of the independent variables,
- X1tX_{1t}X1t = Accessibility (road length in km),
- X2tX_{2t}X2t = Construction (GRDP value of the construction sector in Rp),
- X3tX_{3t}X3t = Electricity (percentage of households with electricity access),
- X4tX_{4t}X4t = Smallholder plantation area (ha),
- X5tX_{5t}X5t = Gross Regional Domestic Product (GRDP) at constant prices (Rp),
- εt\varepsilon_tεt = Error term.

This model aims to identify how infrastructure and economic factors contribute to palm oil production, while providing a statistical basis to measure both the magnitude and direction of the relationships among variables.

To test the hypotheses, the F-test was used to examine the simultaneous effects of all independent variables, and the t-test was conducted to assess the individual significance of each explanatory variable at a 95% confidence level ($\alpha = 0.05$) (Ghozali, 2018). The coefficient of determination (R^2) was employed to assess the explanatory power of the model, with higher R^2 values indicating stronger predictive accuracy (Hair et al., 2019). To ensure the robustness of the findings, classical assumption tests were performed, including multicollinearity testing using the Variance Inflation Factor (VIF), heteroscedasticity testing with scatterplots, and normality testing using probability plots and the Kolmogorov–Smirnov test (Field, 2017).

Production Elasticity

In addition to measuring the influence of each independent variable, this study also calculates production elasticity to determine the extent to which palm oil production responds to changes in each independent variable. The elasticity of regression is formulated as follows (Koutsoyiannis, 1977):

$$Exi = \beta . \frac{\dot{X}i}{\bar{Y}} \quad (2)$$

Where :
Exi = Elasticity of the i-th variable,
Bi = Regression coefficient of the i-th independent variable
$\overline{Xi}$ = Mean value of the i-th independent variable
$\bar{Y}$ = Mean value of the dependent variable (palm oil production).
If Exi > 1, palm oil production is considered elastic with respect to that variable; if 0 < Exi < 1, it implies that the variable has no effect on production.

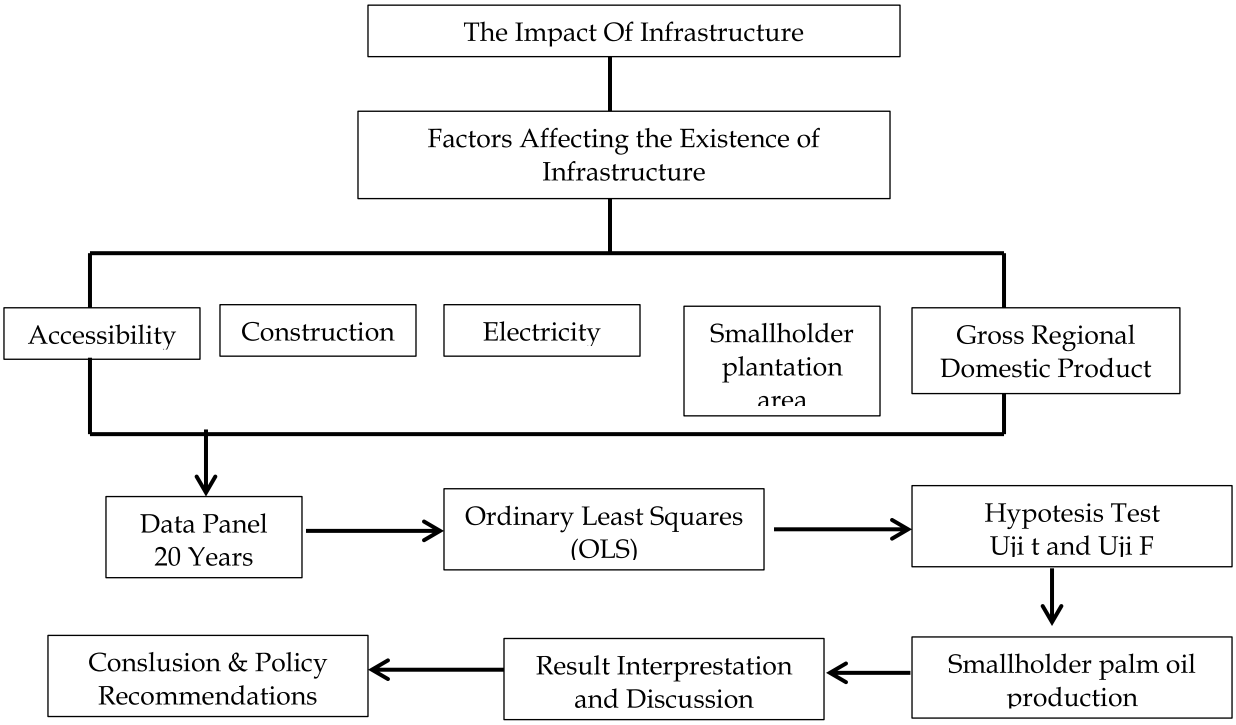

Figure 1. Research Flow

Result and Discussion

The Impact of Infrastructure on Palm Oil Production in Smallholder Plantations

People

The type of culture media was influential in increasing the growth rate of Metarhizium sp fungal colonies and each culture medium showed differences in growth. Corn culture medium + O.rhinoceros extract (A4) produced the best growth of 95 mm, while PDA media and rice media produced the smallest growth with values of 79.83 mm and 83 mm at the observation of 23 HSI, for the pathogenicity test of Metarhizium sp fungus in causing O. rhinoceros larval mortality in the laboratory all types of culture media were equally good.

Accessibility (X1)

The accessibility graph shows a significant spike around 2006 and 2012, followed by stability and a gradual decline afterwards. This decline after the peak indicates that although there were efforts to improve road networks or accessibility conditions, maintenance and expansion were inconsistent. Accessibility is crucial because road conditions directly affect the distribution of fresh fruit bunches (FFB) from smallholders to mills. Poor access raises transport costs, reduces fruit quality upon arrival at mills, and limits farmers' income. Hermansyah et al., (2025) found that farmers in Bengkulu perceived road quality as a critical factor influencing production management and marketing efficiency.

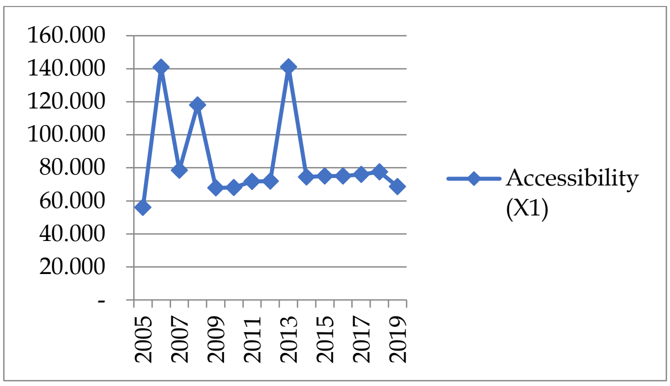

Figure 1. Accessibility

Construction (X2)

The construction index increased strongly until 2012 and then dropped significantly, implying that investments in physical infrastructure such as bridges, drainage, and road improvements declined. Poor construction conditions may worsen access, increase fruit damage during transport, and lower production efficiency. Ismiasih & Afroda, (2023) highlighted that infrastructure conditions, especially roads and access to markets and processing facilities, are significant determinants of smallholder oil palm production in Riau Province.

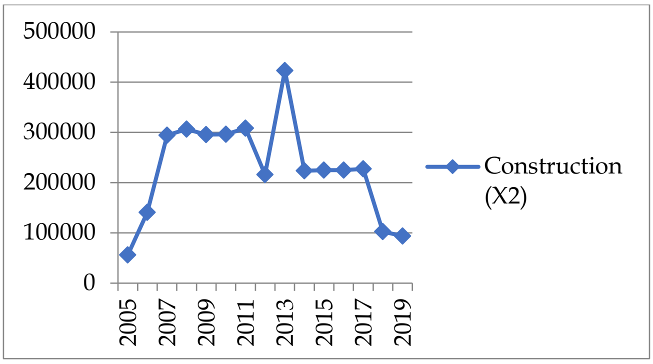

Figure 2. Construction

Electricity (X3)

The graph demonstrates a clear upward trend in electricity access between 2005 and 2019. This supports literature showing that electrification boosts agricultural productivity by enabling irrigation pumps, storage, and other supporting technologies. For instance Ariyanto et al., (2020) on smallholder oil palm plantations in Riau and West Kalimantan provides strong empirical evidence that technology adoption is a key determinant of technical efficiency and productivity among smallholders. Using an efficiency analysis framework, their findings demonstrate that farmers with adequate access to technological tools, improved cultivation practices, and basic processing equipment achieve significantly higher levels of efficiency compared to those facing technological constraints. The study further highlights that access to technology is closely linked to the availability of supporting infrastructure, particularly stable and reliable electricity, which is essential for operating modern agricultural tools, on-farm processing equipment, and electrically powered irrigation systems. Consequently, limited access to electricity directly restricts farmers' ability to adopt and utilize technology, creating structural barriers that hinder productivity improvements. These findings provide strong justification that electricity access, technological availability, and smallholder productivity are interconnected through the mechanism of technical efficiency, meaning that deficiencies in one of these components will negatively affect overall farm performance.

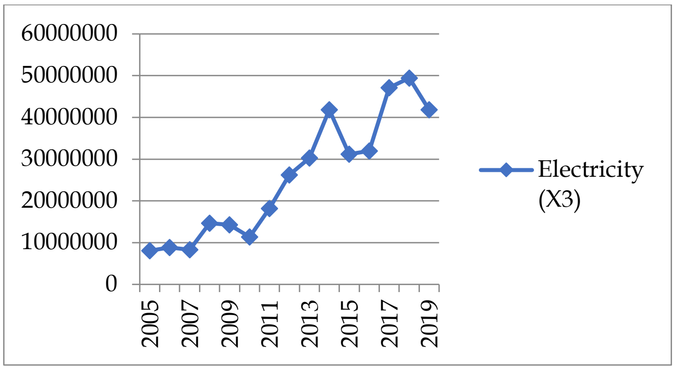

Figure 3. Electricity

Land Area (X4)

The land area graph shows stability until around 2011, followed by a gradual decline until 2019. This may reflect land conversion, limited replanting efforts, or issues related to land tenure. Land reduction inevitably affects total production. Sari et al., (2021) revealed that many smallholder plantations in Indonesia face "land use inefficiency," where the potential output per hectare is not achieved due to suboptimal management.

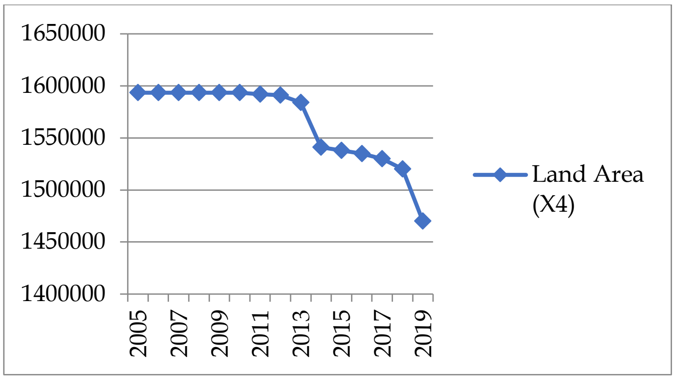

Figure 4. Land Area

PDRB (X5)

The PDRB trend increased consistently from 2005 to 2019, reflecting broader regional economic growth. Higher PDRB likely contributes positively to palm oil production by providing capital flow and public investment in supporting infrastructure. A study by Raharja et al., (2020) on smallholder expansion in Kampar District, Riau, emphasized that regional economic dynamics and land-use planning significantly shape smallholder oil palm expansion and its impacts on production.

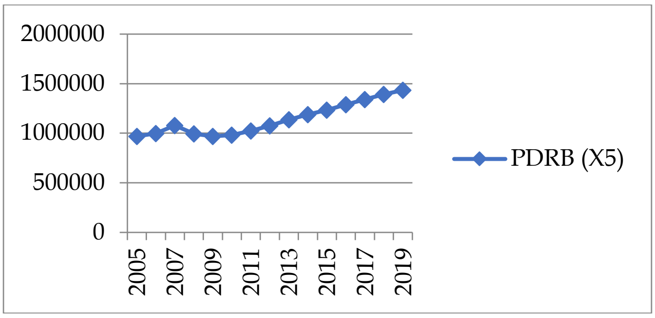

Figure 5. PDRB

Production (Y)

Smallholder palm oil production shows a downward trend since 2015/2016, with a slight recovery in 2018–2019. Despite improvements in electricity access and regional economic growth, declining production indicates that other factors—such as road access, construction quality, and land availability—play a crucial role. Sokoastri et al., (2021) found that smallholder productivity in West Kalimantan and West Sumatra averages only 2–3 tons of CPO/ha/year due to constraints in technology, infrastructure, and market access.

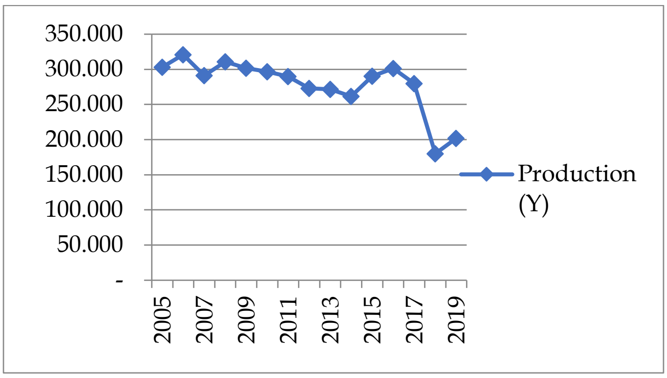

Figure 6. Production

Data Sources

Table 1. Data Sources

Tahun	Production (Y)	Accessibility (X1)	Construction (X2)	Electricity (X3)
2005	302.977	56.065	56.065	8.077.772
2006	320.879	140.845	140.845	8.807.640
2007	290.988	78.440	294.362	8.326.000
2008	310.665	118.138	306.260	14.633.739
2009	301.567	67.910	295.960	14.285.433
2010	296.788	68.033	296.660	11.380.000
2011	289.654	71.650	308.511	18.160.000
2012	272.933	71.950	215.850	26.191.000
2013	271.426	141.054	423.162	30.285.772
2014	261.765	74.514	223.542	41.828.000
2015	290.345	74.934	224.802	31.223.000
2016	300.999	75.029	225.088	31.972.000
2017	279.909	75.952	227.856	47.089.000
2018	180.002	77.637	102.659	49.440.000
2019	201.723	68.678	93.700	41.868.000
2020	302.977			49.939.000

Between 2005 and 2020, smallholder palm oil production in Muko-Muko Regency fluctuated with a declining trend after 2017. Production dropped sharply to 180,002 tons in 2018 before slightly recovering in 2019–2020. Accessibility (X1) and construction infrastructure (X2) showed volatility, peaking in 2006 and 2013 before declining, suggesting inconsistent investment in supporting infrastructure. Such conditions directly affect logistics costs and harvesting efficiency. Hermansyah et al., (2021)highlight that road and construction quality are decisive factors for smallholder palm oil production and marketing efficiency.

Table 2. Data Sources

Year	Land Area (X4)	PDRB (X5)
2005	15.934.50	970.154
2006	15.934.50	998.657
2007	15.934.50	1.078,114
2008	15.934.50	995.145
2009	15.934.50	970.650
2010	15.934.50	981.412
2011	15.920	1.022.817
2012	15.910	1.075.248
2013	15.840	1.136.727
2014	15.410	1.188.510
2015	15.380	1.234.394
2016	15.350	1.288.131
2017	15.300	1.339.411
2018	15.200	1.391.845
2019	14.700	1.434.031
2020	14.500	1.449.783

In contrast, listrik (X3) showed significant growth from 8 million in 2005 to nearly 50 million in 2020, reflecting broader rural electrification programs. As Sukiyono et al., (2023) argue, electrification facilitates mechanization and post-harvest processing, although in this case it did not directly lead to increased smallholder production. Land area (X4) decreased from 15,934 hectares in 2005 to 14,500 hectares in 2020, pointing to land conversion or degradation. This supports Sari et al., (2021) findings that limited land availability and inefficiency constrain smallholder productivity despite input improvements.

Meanwhile, Gross Regional Domestic Product (GRDP, X5) consistently rose from IDR 970,154 million in 2005 to IDR 1,449,783 million in 2020, reflecting strong regional economic growth. However, this growth did not translate into higher smallholder production. Raharja et al., (2020) note that regional economic expansion often benefits large-scale plantations more than smallholders due to unequal access to infrastructure and capital. Overall, the results reveal a structural gap where improvements in electrification and economic growth alone are insufficient without complementary physical infrastructure development and sustainable land management.

Uji t (Parsial)

Table 3. Uji t

	Coefficients	*t Stat*	*P-value*
Intercept	505.6550549	0.523301463	0.612162821
Accessibility (X1)	0.007245354	0.233543786	0.820050552
Construction (X2)	0.007177576	0.748014262	0.471676565
Electricity (X3)	-1.14625E-06	-0.912518129	0.382968209
Land Area (X4)	-0.007823645	-0.147628751	0.885569932
PDRB (X5)	-8.6143E-05	-0.497718352	0.629444683

The regression results indicate that none of the independent variables significantly affect smallholder palm oil production in Muko-Muko Regency. Nevertheless, a detailed discussion of each variable provides important insights.

Accessibility (X1)

The coefficient for accessibility is positive (0.0072) but not significant (p = 0.820). This suggests that improvements in road length or quality do not automatically translate into higher palm oil output. Challenges such as poor road maintenance, high transportation costs, and limited logistics may reduce its impact. Hadi, (2015) highlighted that road infrastructure only shows tangible effects when supported by efficient supply chain systems.

Construction (X2)

Construction infrastructure also shows a positive coefficient (0.0071) but remains insignificant (p = 0.472). This implies that physical development, such as public facilities or supporting buildings, does not directly increase smallholder productivity. According to Panjaitan et al., (2020), construction contributes more to the long-term improvement of social and economic environments rather than immediate agricultural output.

Electricity (X3)

Interestingly, electricity supply has a negative coefficient (-1.14E-06) and is insignificant (p = 0.383). This indicates that electricity availability does not necessarily increase palm oil production. This could be due to the fact that most smallholders still rely on manual labor and have not fully adopted mechanized, electricity-based farming tools. Hadi et al., (2021) argue that the impact of electricity on agricultural productivity becomes significant only when modern technologies are widely adopted.

Land Area (X4)

The land area variable also shows a negative coefficient (-0.0078) and is not significant (p = 0.886). This contradicts conventional production theory, where larger cultivated areas should result in higher output. The result suggests that land expansion among smallholders may not be efficient due to limited capital, poor farm management, and low input utilization.

Land size has consistently been recognized as one of the most fundamental determinants of agricultural output, particularly within perennial crop systems such as oil palm. Larger cultivated areas provide broader opportunities for input allocation, operational optimization, and production scaling, ultimately contributing to higher aggregate yields. Empirical findings by Mina et al., (2021) Productivity and Competitiveness of Garlic Production in Pasuquin, Ilocos Norte, Philippines.. Their study indicates that the extent of land cultivated correlates directly with production levels when management practices, input application, and agronomic care are adequately maintained. Moreover, the work of Euler et al., (2016) further reinforces the centrality of land resources in shaping productivity dynamics. Their analysis of smallholder oil palm expansion in Sumatra shows that increases in cultivated land area create substantial potential for yield enhancement, particularly when supported by improved agronomic practices, access to inputs, and proper field maintenance. Complementing these findings, Hartono & Robiyanto,)2021) highlight that variations in production performance across smallholders are largely attributable to differences in land management quality, where well-maintained plots consistently generate higher yields. Collectively, these studies establish a solid empirical foundation demonstrating that land size, when accompanied by sound and consistent management, serves as a core driver of sustained productivity gains in smallholder agricultural systems.

Gross Regional Domestic Product (GRDP) (X5)

GRDP exhibits a negative coefficient (-8.61E-05) and is insignificant (p = 0.629). This indicates that regional economic growth does not directly contribute to higher smallholder productivity. It is likely that the benefits of economic expansion are absorbed more by other sectors (e.g., services and industry), while smallholder farmers continue to face barriers in terms of capital, technology, and institutional support. Shilpa, (2020) also emphasized that the link between economic growth and smallholder plantation productivity remains uneven.

Overall, these findings highlight that infrastructure development and regional economic growth are insufficient to explain variations in smallholder palm oil production in Muko-Muko. External factors such as seed quality, access to credit, institutional support, and technology adoption may play a more dominant role.

Uji F (Simultan)

Table 4. Uji F (ANOVA)

	SS	*F*	*Significance F*
Regression	16013.49107	4.002362824	0.029623609
Residual	8002.018693		
Total	24015.50976		

Based on the ANOVA results, the calculated F-value is 4.002 with a significance level (Significance F) of 0.0296, which is below the 0.05 threshold. This indicates that, collectively, the independent variables (Accessibility, Construction, Electricity, Land Area, and GRDP) have a significant influence on the dependent variable, Production. In other words, the regression model is statistically valid and can significantly explain the variation in production. The Sum of Squares (SS**)** for regression is 16,013.49, which is substantially higher than the residual value of 8,002.01, further confirming that the variation explained by the model is more dominant than the unexplained variation. This implies that even though individual independent variables may not show significant effects, together they contribute meaningfully to influencing production.

Conclusion

Overall, this research emphasizes that enhancing smallholder productivity requires integrated infrastructure development, improved technological support, and strengthened land-use management to ensure sustainable increases in palm oil production at the regional level. Future research should consider integrating additional determinants such as access to credit, seed quality, agronomic practices, institutional support, and farmer-level technological adoption, which may offer a more detailed explanation of variations in smallholder production. Subsequent studies could also incorporate spatial data, geospatial land-use indicators, and household-level surveys to capture heterogeneity across farming systems more accurately. Methodological advancements—including panel data techniques, spatial econometrics, and stochastic frontier analysis—would allow for stronger causal inference and more precise measurement of efficiency. The broader scientific implication of this study is its emphasis on the interdependence between infrastructure provision, land-use dynamics, and regional economic development in shaping smallholder productivity. Nevertheless, the study is constrained by its use of aggregated secondary data and the absence of micro-level behavioral insights, indicating the need for multi-scale and mixed-methods approaches in future research.

Acknowledgments

Thank you to the Head of the Agribusiness Study Program and the Dean of the Faculty of Agriculture, Universitas Islam Sumatera Utara.

Author Contributions

S.N.: Developing ideas, analyzing, writing, reviewing, responding to reviewers' comments; M.I.R., M.S.H.: analyzing data, overseeing data collection, reviewing scripts, and writing.

Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflict of interest

References

Ariyanto, A., Syaukat, Y., Hartoyo, S., & Sinaga, B. M. (2020). Technology Adoption And Technical Efficiency Of Oil Palm Smallholder Plantation In Riau And West Kalimantan. *Jurnal Manajemen Dan Agribisnis*, *17*(3), 239–253. https://doi.org/http://dx.doi.org/10.17358/jma.17.3.239

Arnol, I., Bakhri, S., & Darsono, D. (2025). Tinjauan Kualitas Jaringan Jalan untuk Peningkatan Produksi pada Pabrik Pengolahan Kelapa Sawit. *Journal of Comprehensive Science (JCS)*, *4*(2), 708–716. https://doi.org/10.59188/jcs.v4i2.3050

Bakhtary, H., Haupt, F., Luttrell, C., Landholm, D., & Jelsma, I. (2021). Promoting sustainable oil palm production by independent smallholders in Indonesia: Perspectives from non-state actors. *Briefing Paper*. https://doi.org/https://climatefocus.com/wp-content/uploads/2022/06/Indonesian-Palm-Oil-Smallholders_Briefing-Paper

Cramb, R., & Mccarthy, J. (2016). *TY - BOOK AU - Yin, Robert K. TI - Case study research and applications: Design and methods ET - 6 PB - Sage Publications CY - Thousand Oaks, CA PY - 2018 SN - 9781506336169 ER - The Oil Palm Complex: Smallholders, Agribusiness and the State in Indonesia* . https://doi.org/10.2307/j.ctv1xz0km

Euler, M., Schwarze, S., Siregar, H., & Qaim, M. (2016a). Oil Palm Expansion among Smallholder Farmers in Sumatra, Indonesia. *Journal of Agricultural Economics*, *67*. https://doi.org/10.1111/1477-9552.12163

Euler, M., Schwarze, S., Siregar, H., & Qaim, M. (2016b). Oil Palm Expansion among Smallholder Farmers in Sumatra, Indonesia. *Journal of Agricultural Economics*, *67*(3), 658–676. https://doi.org/https://doi.org/10.1111/1477-

9552.12163

Field, A. (2017). *Discovering Statistics Using IBM SPSS Statistics* (5th ed.). Sage Publications.

Finucane, J., Besnard, J., & Golumbeanu, R. (2021). Raising Rural Productive Uses of Electricity: A Case Study of a Successful Utility-NGO Partnership in Indonesia. *Raising Rural Productive Uses of Electricity: A Case Study of a Successful Utility-NGO Partnership in Indonesia*, *119*, 1–9. https://doi.org/10.1596/36670

Freeman, G. H., Gomez, K. A., & Gomez, A. A. (1985). Statistical Procedures for Agricultural Research. In *Biometrics* (2nd ed., Vol. 41, Issue 1). John Wiley & Sons. https://doi.org/10.2307/2530673

Ghozali. (2018). *Aplikasi Ananlisis Multivariate dengan Program IBM SPSS 25.* Badan Penerbit Universitas Diponogoro.

Gujarati, D. N., & Porter, D. C. (2009). *Basic econometrics* (5th ed.). McGraw-Hill.

Hadi, M., Hidayat, M., Widiarsih, D., & Murialti, N. (2021). The Role of Electricity and Energy Consumption Influences Industrial Development between Regions in Indonesia. *International Journal of Energy Economics and Policy*, *11*, 403–408. https://doi.org/10.32479/ijeep.11082

Hadi, P. U. (2015). Manajemen Rantai Pasok Ternak dan Daging Sapi di Nusa Tenggara Timur. *Bunga Rampai Rantai Pasok Komoditas Pertanian Indonesia*, 136. https://www.neliti.com/publications/695/bunga-rampai-rantai-pasok-komoditas-pertanian-indonesia

Hartono, P., & Robiyanto, R. (2021). Can Cryptocurrency, Gold and Bonds Play a Role as a Safe Haven for the Indonesian Capital Market? *Jurnal Ekonomi Kuantitatif Terapan*, *14*(1), 1–10. https://doi.org/10.24843/JEKT.2021.v14.i01.p01

Hendra Andy Mulia Panjaitan, Sri Mulatsih, & Wiwiek Rindayati. (2020). Analisis Dampak Pembangunan Infrastruktur Terhadap Pertumbuhan Ekonomi Inklusif Provinsi Sumatera Utara. *Jurnal Ekonomi Dan Kebijakan Pembangunan*, *8*(1), 43–61. https://doi.org/10.29244/jekp.v8i1.29898

Hermansyah, D., Sukiyono, K., & Romdhon, M. M. (2025). Palm Oil Farmers' Perception On The Impact Of Farm Roads Development In Bengkulu Selatan Regency. *Journal of Agri Socio Economics and Business*, *7*(01 SE-Articles). https://doi.org/10.31186/jaseb.07.1.117-136

Hermansyah, H., Sukiyono, K., & Romdhon, A. (2021). The influence of road infrastructure on the efficiency of palm oil smallholders in Bengkulu Province. *Jurnal Agro Ekonomi*, *39*(2), 75–89. https://doi.org/10.21082/jae.v39n2.2021.75-89

Ismiasih, I., & Afroda, H. (2023). Faktor Penentu Produksi Kelapa Sawit Rakyat Di Provinsi Riau. *Jurnal Penelitian Pertanian Terapan*, *23*(2), 211–218. https://doi.org/10.25181/jppt.v23i2.2726

Jelsma, I., Schoneveld, G. C., Zoomers, A., & van Westen, A. C. M. (2017). Unpacking Indonesia's independent oil palm smallholders: An actor-disaggregated approach to identifying environmental and social performance challenges. *Land Use Policy*, *69*, 281–297. https://doi.org/https://doi.org/10.1016/j.landusepol.2017.08.012

Koutsoyiannis, A. (1977). *Theory of Econometrics* (2nd ed.). Macmillan.

Mina, C. S., Catelo, S. P., & Jimenez, C. D. (2021). Productivity and Competitiveness of Garlic Production in Pasuquin, Ilocos Norte, Philippines. *Asian Journal of Agriculture and Development*, *18*(1), 50–63. https://doi.org/10.37801/ajad2021.18.1.4

Molenaar, J. W., Persch-Orth, M., Lord, S., Taylor, C., & Harms, J. (2013). *Diagnostic Study on Indonesian*.

Raharja, S., Setiawan, B., & Firmansyah, R. (2020). Economic growth, land use planning, and smallholder palm oil expansion in Kampar District, Riau. *Journal of Regional and Rural Development Planning*, *4*(2), 121–135. https://doi.org/10.29244/jp2wd.2020.4.2.121-135

Sari, D. P., Hidayat, M., & Abdul, R. (2021). Land use efficiency and productivity challenges of smallholder oil palm plantations in Indonesia. *Asian Journal of Agriculture and Development*, *18*(1), 55–67. https://doi.org/10.37801/ajad2021.18.1.4

Sari, D. W., Hidayat, F. N., & Abdul, I. (2021). Efficiency of land use in smallholder palm oil plantations in indonesia: A stochastic frontier approach. *Forest and Society*, *5*(1), 75–89. https://doi.org/10.24259/fs.v5i1.10912

Shilpa, S. (2020). Emergence Of Producer Companies as Innovative Institutuions for Agriculture Development In India : Issues And Challanges. *Asian Journal of Agriculture and Development*, *17*(2), 79–92. https://doi.org/https://doi.org/10.37801/ajad2020.17.2.5

Sokoastri, M., Setiadi, A., & Hakim, R. (2021). Productivity gap of independent smallholders: Evidence from West Kalimantan and West Sumatra. *Journal of Agribusiness and Rural Development*, *60*(2), 145–158. https://doi.org/10.17306/J.JARD.2021.01567

Space, W. L. (2013). Research Methods for Business: A Skill-Building Approach. In *Leadership & Organization Development Journal* (Vol. 34, Issue 7). https://doi.org/10.1108/lodj-06-2013-0079

Sukiyono, K., Yuliarso, M. Z., Nabiu, M., Romdhon, M. M., Puspitasari, M. S., Trisusilo, A., Sugiardi, S., Mulyasari, G., Masliani, Nugroho, Y., Reflis, Arifudin, & Napitupulu, D. M. (2023). *Sawit Rakyat Dan Sustainable Development Goals* (Vol. 17). PT. Penerbit IPB Press.

Vaishar, A., & Šťastná, M. (2021). Accessibility of services in rural areas: Southern moravia case study. *Sustainability (Switzerland)*, *13*(16). https://doi.org/10.3390/su13169103

Wooldridge, J. M. (2016). *Introductory Econometrics: A Modern Approach* (6th ed.). Cengage Learning.

Yin, R. K. (2018). *Case study research and applications: Design and methods* (6th ed.). Sage Publications.