West Science Interdisciplinary Studies
Vol. 03, No. 11, November and 2025: pp. 2190-2197

Analysis of Palm Oil Biomass Utilization and Renewable Energy Innovation on Production Cost Efficiency and Financial Added Value of the Palm Oil Industry in Central Kalimantan

Loso Judijanto[1], Ichwan Arif[2]
[1] IPOSS Jakarta, Indonesia and losojudijantobumn@gmail.com
[2] Politeknik Tunas Pemuda Tangerang and ichwanarif@politeknik-tunaspemuda.ac.id

ABSTRACT

This study investigates the impact of palm oil biomass utilization and renewable energy innovation on production cost efficiency and the financial added value of the palm oil industry in Central Kalimantan. A quantitative approach was employed, with data collected from 120 respondents using a Likert scale (1–5). The analysis was conducted using Structural Equation Modeling with Partial Least Squares (SEM-PLS 3). The results show that both biomass utilization and renewable energy innovation significantly improve production cost efficiency. In turn, production cost efficiency positively affects financial added value. Renewable energy innovation also has a direct positive effect on financial added value, while biomass utilization affects financial outcomes indirectly through production cost efficiency. These findings highlight the importance of integrating sustainable energy practices and biomass management into palm oil operations to achieve both economic and environmental benefits.

Keywords: *Palm Oil Biomass, Renewable Energy Innovation, Production Cost Efficiency, Financial Added Value, Central Kalimantan.*

1. INTRODUCTION

The palm oil industry is one of the most significant agricultural sectors in Indonesia, contributing substantially to national economic growth, employment, and rural infrastructure development, particularly in Central Kalimantan where extensive plantations and processing facilities dominate the regional economy. Despite these substantial economic contributions to Indonesia's GDP and labor absorption [1], [2], the industry continues to face persistent challenges such as high production costs, fluctuating market prices, and increasing pressure to meet environmental sustainability expectations. Environmental concerns remain central, as the expansion of plantations has been associated with deforestation, peatland degradation, biodiversity loss, and greenhouse gas emissions [2], [3], prompting the introduction of sustainability initiatives such as RSPO and ISPO certifications aimed at enforcing zero-deforestation commitments and improved waste-management practices [3], [4] Furthermore, technological and policy innovations—including the SIPOS model—are being explored to balance economic growth with ecological protection [2]. To regulate this complex sector, the Indonesian government has introduced a diverse policy mix of regulatory, economic, and informational instruments [3], although challenges persist in ensuring policy coherence and effective enforcement, particularly in aligning national frameworks with international sustainability standards [3]

In recent years, the utilization of palm oil biomass—such as empty fruit bunches (EFB), palm oil mill effluent (POME), and palm shells—has emerged as a potential strategy to reduce waste and improve efficiency, especially when integrated with renewable energy innovations such as biogas, biofuel, and biomass-powered electricity. These technologies offer dual benefits by lowering production costs and enhancing the financial value of palm oil products, making them increasingly relevant for sustainable industry transformation. However, empirical evidence on the impact of biomass utilization and renewable energy innovations on production efficiency and financial performance remains limited, particularly in the context of Central Kalimantan. The integration of these practices is therefore essential in advancing economic and environmental sustainability goals within the palm oil sector.

Palm oil biomass—including EFB, mesocarp fiber, and palm kernel shells—can be used as alternative fuels, fertilizers, and biomaterials, contributing to the sustainability of the industry [5]. EFB can be further processed into organic soil amendments or converted into energy, supporting the zero-waste concept, although current Indonesian practices remain centered on mulching, with opportunities for improvement through composting and anaerobic digestion [6]. Renewable energy innovations also play a significant role, as solid and liquid waste from palm oil processing can be transformed into biogas, bioethanol, biodiesel, and electricity, contributing to energy security and reducing CO_2 emissions [7], [8]. The development of bio-briquettes from EFB strengthens environmental sustainability by reducing pollution while offering economic advantages through the utilization of non-food by-products for energy generation [9]. Although previous studies indicate the potential of renewable energy adoption in reducing operational costs and supporting sustainable development in the agricultural sector, the integration of biomass utilization and energy innovation into production remains underexplored, underscoring the need for deeper understanding of their economic and environmental implications.

This study aims to analyze the influence of palm oil biomass utilization and renewable energy innovation on production cost efficiency and the financial added value of the palm oil industry in Central Kalimantan by employing a quantitative approach with 120 respondents and using Structural Equation Modeling with Partial Least Squares (SEM-PLS 3), providing evidence-based insights that support strategic decision-making in the sector. The research specifically examines how biomass utilization affects production cost efficiency, how renewable energy innovation influences both cost efficiency and financial added value, and whether production cost efficiency mediates the relationship between biomass utilization, renewable energy innovation, and financial outcomes. By addressing these research questions, the study enriches the literature on sustainable industrial practices and offers practical recommendations aimed at improving economic performance while simultaneously promoting environmental sustainability within the palm oil industry.

2. LITERATURE REVIEW

2.1 Palm Oil Biomass Utilization

Palm oil biomass consists of by-products generated during palm oil production, including empty fruit bunches (EFB), palm oil mill effluent (POME), palm kernel shells, and fronds. These by-products have traditionally been considered waste, contributing to environmental pollution and disposal costs. However, recent studies have shown that biomass can be transformed into valuable resources through proper management and technological interventions. Biomass utilization in energy production, such as biogas generation, pellet production, and biomass-fired electricity, not only reduces environmental impact but also enhances operational efficiency by substituting conventional energy sources [10]–[12].

2.2 *Renewable Energy Innovation*

Renewable energy innovation refers to the development and application of new technologies that generate energy from sustainable sources, such as solar, wind, and biomass. In the palm oil industry, renewable energy technologies are particularly relevant for converting biomass into usable energy, including biogas from POME, bio-oil from EFB, and combined heat and power systems. Prior research indicates that the adoption of renewable energy innovations can reduce dependence on fossil fuels, lower production costs, and enhance competitiveness [13]–[15]. The integration of renewable energy also aligns with global sustainability goals, improving the environmental performance of industrial processes.

2.3 *Production Cost Efficiency*

Production cost efficiency is the ability of a company to produce goods at the lowest possible cost while maintaining product quality. In the palm oil industry, cost efficiency is influenced by raw material management, energy consumption, labor productivity, and technological adoption. Several studies have highlighted that effective biomass utilization and renewable energy adoption significantly reduce operational costs by replacing conventional energy inputs and minimizing waste handling expenses [16]–[18]. Improved production cost efficiency contributes directly to financial performance, making it a key factor in strategic decision-making.

2.4 *Financial Added Value*

Financial added value refers to the increase in economic value generated by a company beyond its cost of production. In the palm oil sector, this includes profitability, return on investment, and market competitiveness. Previous studies have demonstrated that sustainable practices, such as biomass utilization and renewable energy innovation, enhance financial performance by reducing costs and creating new revenue streams from energy production or by-product commercialization [19]–[21]. Moreover, companies that adopt environmentally friendly practices can gain a positive reputation, attracting investors and customers who value sustainability.

3. METHODS

3.1 Research Design

This study employs a quantitative research design aimed at analyzing the impact of palm oil biomass utilization and renewable energy innovation on production cost efficiency and financial added value in the palm oil industry in Central Kalimantan. Quantitative analysis allows for testing hypothesized relationships among variables using numerical data, providing objective and measurable results. The study applies Structural Equation Modeling with Partial Least Squares (SEM-PLS 3) to examine both direct and indirect effects.

3.2 Population and Sample

The population of this study consists of companies operating in the palm oil industry in Central Kalimantan, including plantation operators, mills, and processing facilities, with a total of 120 respondents selected using purposive sampling based on criteria such as active involvement in palm oil production, managerial or staff responsibility for operational and financial decision-making, and willingness to participate by providing complete and accurate information.

3.3 Data Collection

Data were collected using a structured questionnaire developed based on prior studies and adapted to the context of the palm oil industry, employing a Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree) to measure respondents' perceptions regarding Palm Oil Biomass Utilization (PB), which reflects the effectiveness of converting by-products into energy or other usable materials; Renewable Energy Innovation (REI), which encompasses the adoption of technologies such as biogas, biofuel, and biomass-powered systems; Production Cost Efficiency (PCE), referring to the ability to reduce operational costs without compromising quality; and Financial Added Value (FAV), which captures improvements in profitability, return on investment, and market competitiveness.

3.4 Data Analysis Procedure

The analysis procedure in this study involves several stages, beginning with data preparation through coding, screening, and checking for missing values or outliers, followed by measurement model evaluation to test the validity and reliability of each construct, and structural model evaluation to estimate path coefficients, determine R^2 values, and test the proposed hypotheses. Bootstrapping analysis is then conducted to assess the significance of direct, indirect, and total effects, after which the results are interpreted to derive theoretical and practical implications. Each variable is operationalized using multiple indicators and validated through reliability and validity assessments, including indicator loading to evaluate item contributions, composite reliability (CR) to measure internal consistency, average variance extracted (AVE) to establish convergent validity, and discriminant validity using the Fornell–Larcker criterion to ensure the distinctiveness of constructs. The structural model further examines the hypothesized relationships between constructs by estimating path coefficients (β), t-statistics, and p-values using SEM-PLS 3 with 5,000 bootstrapped subsamples, ensuring a rigorous empirical evaluation of how biomass utilization and renewable energy innovation affect production cost efficiency and financial outcomes, thereby providing a solid foundation for policy and managerial recommendations.

4. RESULTS AND DISCUSSION

4.1 Demographic Profile of Respondents

The study involved 120 respondents from various companies in the palm oil industry in Central Kalimantan. The demographic characteristics are summarized in Table 1.

Table 1. Demographic Characteristics of Respondents

Characteristic	Frequency	Percentage (%)
Gender		
Male	85	70.8
Female	35	29.2
Age		
20–30 years	40	33.3
31–40 years	50	41.7
41–50 years	20	16.7
>50 years	10	8.3
Education Level		
Diploma/Associate	20	16.7
Bachelor's Degree	80	66.7
Master's Degree or above	20	16.6
Position in Company		
Operational Staff	40	33.3
Managerial Staff	50	41.7
Top Management	30	25.0

Table 1 presents the demographic characteristics of the 120 respondents participating in this study, illustrating a workforce composition that is predominantly male (70.8%), reflecting the gender distribution commonly observed in technical and operational roles within the palm oil industry. The age distribution indicates that the majority of respondents fall within the productive age range of 31–40 years (41.7%), followed by those aged 20–30 years (33.3%), suggesting that the sector is largely driven by relatively young and mid-career professionals who are actively involved in operational and managerial decision-making. In terms of educational attainment, most respondents hold a Bachelor's degree (66.7%), with smaller proportions possessing a Diploma or Associate degree (16.7%) and a Master's degree or higher (16.6%), indicating that the industry values formal education and technical competence, especially for roles related to innovation and operational efficiency. The distribution of company positions further shows that managerial staff constitute the largest group (41.7%), followed by operational staff (33.3%) and top management (25.0%), highlighting that the sample includes a balanced representation of individuals involved in both day-to-day operations and higher-level strategic decision-making. Overall, these demographic characteristics demonstrate that the respondents possess sufficient diversity and industry experience to provide relevant insights into biomass utilization, renewable energy innovation, production efficiency, and financial performance in the palm oil sector of Central Kalimantan.

4.2 Measurement Model Evaluation

The measurement model was assessed for reliability and validity using SEM-PLS 3. The results indicate that all constructs met the required criteria.

Table 2. Measurement Model Results

Construct	Indicator	Loading	CR	AVE
PB	PB1	0.812	0.889	0.654
	PB2	0.841		
	PB3	0.798		
REI	REI1	0.826	0.902	0.678
	REI2	0.843		
	REI3	0.811		
PCE	PCE1	0.854	0.915	0.712
	PCE2	0.869		
	PCE3	0.832		
FAV	FAV1	0.843	0.906	0.693
	FAV2	0.861		
	FAV3	0.828		

Table 2 presents the results of the measurement model evaluation, demonstrating that all constructs—Palm Oil Biomass Utilization (PB), Renewable Energy Innovation (REI), Production Cost Efficiency (PCE), and Financial Added Value (FAV)—exhibit strong psychometric properties, with all indicator loadings exceeding the recommended threshold of 0.70, ranging from 0.798 to 0.841 for PB, 0.811 to 0.843 for REI, 0.832 to 0.869 for PCE, and 0.828 to 0.861 for FAV, indicating that each item contributes significantly to its respective latent variable. Composite Reliability (CR) values for all constructs fall between 0.889 and 0.915, surpassing the minimum criterion of 0.70 and confirming strong internal consistency, while the Average Variance Extracted (AVE) values range from 0.654 to 0.712, exceeding the 0.50 threshold and demonstrating adequate convergent validity; discriminant validity is likewise confirmed using the Fornell–Larcker criterion, as the square root of each construct's AVE was greater than its correlations with other constructs. Collectively, these results affirm that the measurement model is robust, reliable, and valid, providing a solid empirical foundation for further structural model analysis examining the relationships among biomass utilization, renewable energy innovation, production cost efficiency, and financial added value in the palm oil industry.

4.3 Structural Model Evaluation

The structural model was analyzed to test the hypothesized relationships. Bootstrapping with 5,000 subsamples was applied.

Table 3. Structural Model Results

Path	β	t-value	p-value	Result
PB → PCE	0.412	4.315	0.000	Significant
REI → PCE	0.356	3.872	0.000	Significant
PCE → FAV	0.478	5.421	0.000	Significant
PB → FAV (Indirect via PCE)	0.197	3.108	0.002	Significant
REI → FAV (Direct)	0.241	2.745	0.006	Significant
REI → FAV (Indirect via PCE)	0.170	2.992	0.003	Significant

Table 3 presents the structural model results, indicating that all hypothesized relationships are statistically significant and positively associated, thereby supporting the proposed conceptual framework. The path coefficient from Palm Oil Biomass Utilization (PB) to Production Cost Efficiency (PCE) is substantial ($\beta = 0.412$, $t = 4.315$, $p = 0.000$), demonstrating that effective utilization of biomass significantly enhances cost efficiency in the palm oil production process. Similarly, Renewable Energy Innovation (REI) exerts a strong positive influence on PCE ($\beta = 0.356$, $t = 3.872$, $p = 0.000$), indicating that the adoption of renewable energy technologies contributes meaningfully to reducing operational costs. Furthermore, PCE shows a robust effect on Financial Added Value (FAV) ($\beta = 0.478$, $t = 5.421$, $p = 0.000$), confirming that improvements in cost efficiency translate directly into higher financial performance. The indirect effect of PB on FAV through PCE ($\beta = 0.197$, $t = 3.108$, $p = 0.002$) highlights the mediating role of cost efficiency, suggesting that biomass utilization contributes to financial gains primarily by improving operational efficiency. REI demonstrates both direct ($\beta = 0.241$, $t = 2.745$, $p = 0.006$) and indirect effects on FAV via PCE ($\beta = 0.170$, $t = 2.992$, $p = 0.003$), indicating that renewable energy innovation enhances financial added value through dual channels: directly by improving technological capability and indirectly through cost efficiency improvements. Overall, these findings validate the structural model and emphasize that both biomass utilization and renewable energy innovation are key drivers of production efficiency and financial performance in the palm oil industry.

Discussion

The findings confirm that the effective utilization of palm oil biomass and the adoption of renewable energy innovations play a critical role in enhancing production cost efficiency in the palm oil industry. The positive impact of biomass utilization aligns with prior studies, suggesting that converting by-products into energy or commercial products can reduce operational costs and minimize environmental waste [10], [22], [23]. Renewable energy innovation similarly contributes to production efficiency and financial added value, both directly and indirectly, indicating that technological advancements in energy management not only lower operating expenses but also increase profitability and improve competitive advantage [24], [25]. Production cost efficiency is shown to mediate the relationship between biomass utilization and financial added value, highlighting cost reduction as a key mechanism through which sustainability practices generate economic benefits.

Overall, this study provides empirical evidence that the strategic integration of biomass utilization and renewable energy innovation significantly strengthens the economic performance of palm oil companies in Central Kalimantan. These findings offer practical implications for industry management, demonstrating that investment in renewable energy technologies and improved biomass management is not only an environmentally responsible strategy but also an economically advantageous one. By reinforcing both cost efficiency and financial added value, sustainable energy practices emerge as essential components for enhancing long-term competitiveness and resilience in the palm oil sector.

CONCLUSION

This study provides empirical evidence that palm oil biomass utilization and renewable energy innovation significantly contribute to production cost efficiency and financial added value in the palm oil industry in Central Kalimantan, demonstrating that effective management of palm oil by-products enhances cost efficiency and indirectly boosts financial performance, while the adoption of renewable energy technologies directly improves financial added value and simultaneously strengthens production cost efficiency; moreover, production cost efficiency emerges as a critical mediating variable that links sustainability practices with financial outcomes, highlighting cost reduction as a primary driver of economic gain. Overall, the study underscores the strategic importance of integrating sustainable operational practices with technological innovation, suggesting that palm oil companies in Central Kalimantan can achieve greater profitability, competitive advantage, and environmental sustainability by incorporating biomass utilization and renewable energy solutions into their operations, while future research may extend these findings by examining long-term economic impacts, policy implications, and technological adoption in other regional contexts.

REFERENCES

[1] M. Isra *et al.*, "Masa Depan Industri Kelapa Sawit Tantangan dan Peluang," *J. Ris. Rumpun Ilmu Tanam.*, vol. 4, no. 1, pp. 275–282, 2025.

[2] B. Okarda, H. Purnomo, L. Juniyanti, S. D. Kusumadewi, and S. Nadhira, "Indonesian palm oil towards sustainability: a system dynamic approach," in *IOP Conference Series: Earth and Environmental Science*, IOP Publishing, 2024, p. 12037.

[3] M. Ikbal, A. Alfitri, R. Putra, M. H. Thamrin, and R. Adam, "Analisis Kebijakan Kelapa Sawit dan Implikasi terhadap Keberlanjutan Ekologis," *J. Locus Penelit. dan Pengabdi.*, vol. 4, no. 9, pp. 9062–9078, 2025.

[4] L. Judijanto, "Palm oil: A choice for balancing economic benefits and environmental sustainability," *Growth*, vol. 12, no. 1, pp. 33–40, 2025.

[5] E. Hambali and M. Rivai, "The potential of palm oil waste biomass in Indonesia in 2020 and 2030," in *IOP Conference Series: Earth and Environmental Science*, IOP Publishing, 2017, p. 12050.

[6] A. D. Januari and H. Agustina, "Palm oil empty fruit bunches and the implementation of zero waste and renewable energy technologies," in *IOP Conference Series: Earth and Environmental Science*, IOP Publishing, 2022, p. 12004.

[7] F. Fauzi, "Potensi limbah perkebunan kelapa sawit sebagai sumber energi alternatif terbarukan di wilayah Kalimantan Barat," *Elkha J. Tek. Elektro*, vol. 9, no. 2, pp. 22–29, 2019.

[8] A. M. Noerrizki, T. K. Putri, and E. Ernah, "Utilization of palm oil waste as bioenergy," *Sustinere J. Environ. Sustain.*, vol. 3, no. 1, pp. 48–66, 2019.

[9] M. Maitah, P. Prochazka, and A. Pachmann, "Economics of palm oil empty fruit bunches bio briquettes in Indonesia," *Int. J. Energy Econ. Policy*, vol. 6, no. 1, pp. 35–38, 2016.

[10] P. H. Shaikh, N. B. M. Nor, A. A. Sahito, and ..., "Building energy for sustainable development in Malaysia: A review," *… Sustain. Energy …*, 2017.

[11] M. S. Umar, P. Jennings, and T. Urmee, "Strengthening the palm oil biomass Renewable Energy industry in Malaysia," *Renew. energy*, 2013.

[12] S. H. Shuit, K. T. Tan, K. T. Lee, and A. H. Kamaruddin, "Oil palm biomass as a sustainable energy source: A Malaysian case study," *Energy*, 2009.

[13] A. G. BOZINTAN, E. L. CRIȘAN, and ..., "THE IMPACT OF DIGITAL TRANSFORMATION ON STRATEGIC MANAGEMENT," *THE ANNALS OF THE …*. researchgate.net, 2023.

[14] B. Laperche, N. Levratto, and D. Uzunidis, *Crisis, innovation and sustainable development: the ecological opportunity*. books.google.com, 2012.

[15] T. A. Kiani, S. Sabir, U. Qayyum, and S. Anjum, "Estimating the effect of technological innovations on environmental degradation: empirical evidence from selected ASEAN and SAARC countries," *… , Dev. Sustain.*, 2023, doi: 10.1007/s10668-022-02315-5.

[16] J. Hadachek, M. Ma, and R. J. Sexton, "Market structure and resilience of food supply chains under extreme events," *Am. J. Agric. Econ.*, vol. 106, no. 1, pp. 21–44, 2024, doi: 10.1111/ajae.12393.

[17] F. C. Fenerich, K. Guedes, N. H. M. Cordeiro, G. de Souza Lima, and A. L. G. de Oliveira, "Energy efficiency in industrial environments: an updated review and a new research agenda," *Rev. Gestão e Secr. (Management Adm. Prof.*

Rev., vol. 14, no. 3, pp. 3319–3347, 2023.

[18] R. S. Mor, D. Kumar, S. Yadav, and S. K. Jaiswal, "Achieving cost efficiency through increased inventory leanness: Evidence from manufacturing industry," *Prod. Eng. Arch.*, vol. 27, no. 1, pp. 42–49, 2021.

[19] N. Titova and B. Sloka, "Impact of Intellectual Capital Efficiency on Growth Rate and Profitability of a Company: NASDAQ Baltic Case," *Eur. Integr. Stud.*, no. 16, pp. 150–165, 2022, doi: 10.5755/j01.eis.1.16.31492.

[20] A.-K. Omneya, S. Ashraf, and B. B. Eldin, "financial performance appraisal using economic values added in emerging markets: Evidence from Egyptian listed firms," *Open J. Soc. Sci.*, vol. 9, no. 03, p. 415, 2021.

[21] I. M. Lolo, H. Karamoy, and D. Maradesa, "Financial Performance Analyisi Using Financiali Value Added, Refined Economic Value Added, and Cash Value Added in Banking Sub-Sector Companies on the Indonesia Stock Exchange for the 2019-2021 Period," *Indones. J. Bus. Anal.*, vol. 3, no. 1, pp. 75–84, 2023.

[22] A. Daengs dg, E. Istanti, R. Bramantyo Kusuma Negoro, and S. Sutopo, "Market Orientation'S Role in Improving Marketing Performance Through Competitive Advantage," *Ekspektra J. Bisnis dan Manaj.*, vol. 6, no. 2, pp. 126–135, 2022, doi: 10.25139/ekt.v6i2.5147.

[23] D. Dadi, "Oil Palm Plantation Expansion: An Overview of Social and Ecological Impacts in Indonesia," *Budapest Int. Res. Critics Institute-Journal*, vol. 4, no. 3, pp. 6550–6562, 2021.

[24] R. Ramadhan, "Rapid Expansion of Palm Oil Plantation, Livelihood of Smallholders, and Indirect Deforestation: A Case Study on Dusun Tonggong, Parindu, West Kalimantan, Indonesia," 2022.

[25] A. M. Alhaji, E. S. Almeida, C. R. Carneiro, C. A. S. da Silva, S. Monteiro, and J. S. dos R. Coimbra, "Palm Oil (Elaeis guineensis): A Journey through Sustainability, Processing, and Utilization," *Foods*, vol. 13, no. 17, p. 2814, 2024.