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The Relationship between Farmer Empowerment, Technological Innovation, and Economic Sustainability in the Oil Palm Farming Sector in Kalimantan

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ABSTRACT

This study investigates the relationships among Economic Sustainability, Farmer Empowerment, and Technological Innovation and their collective impact on the Farming Sector in the oil palm plantation context of Kalimantan. Using a quantitative approach, data were collected from 230 respondents through structured surveys and analyzed using Structural Equation Modeling-Partial Least Squares (SEM-PLS). The findings reveal significant positive relationships between all variables, with Technological Innovation showing the strongest influence on the Farming Sector. Farmer Empowerment also emerged as a critical driver, highlighting the importance of capacity-building and participatory decision-making in enhancing agricultural productivity. Economic Sustainability contributes to sectoral growth by stabilizing income and optimizing resource utilization. These results underscore the importance of integrating empowerment, technological advancements, and economic resilience to foster sustainable development in the farming sector. The study provides actionable insights for policymakers and stakeholders aiming to improve the sustainability and competitiveness of oil palm plantations in Kalimantan.

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1. INTRODUCTION

The oil palm plantation sector plays a critical role in the economic development of regions like Kalimantan, contributing significantly to employment, income, and exports. However, its rapid expansion poses sustainability challenges, necessitating a balance between economic growth, environmental conservation, and social equity. The sector significantly contributes to GDP and rural development, as evidenced in Malaysia and Indonesia, where it supports livelihoods and infrastructure development [1], [2]. Despite these benefits, the industry faces challenges such as deforestation, biodiversity loss, and social issues like labor abuses and land conflicts [3], [4]. Empowering farmers through education and certification programs, as seen in West Kalimantan, enhances sustainable practices and aligns with global standards [5]. Smallholder farmers can also improve both economic and ecological outcomes by closing yield gaps through careful intensification [6]. Technological innovations, such as advancements in plantation efficiency and sustainable waste and land management practices, can reduce the environmental footprint of oil palm plantations, although their widespread implementation remains a challenge [5], [6]. Maintaining forest cover and enriching plantations with native trees can enhance biodiversity without compromising productivity [7]. Addressing social equity by resolving labor and land conflicts, ensuring fair practices, and protecting indigenous rights is also crucial for achieving sustainability [8]. Empowering farmers and leveraging technological innovations thus emerge as pivotal strategies for fostering sustainable outcomes in the oil palm plantation sector.

Despite the critical role of these factors, there remains a significant gap in understanding their interconnectedness and collective impact on economic sustainability in the context of oil palm plantations. Previous studies have primarily focused on either the economic or environmental aspects of sustainability, often neglecting the social dimensions and the role of human capital. Additionally, while technological innovation has been widely studied in agricultural contexts, its specific application and effectiveness in the oil palm sector, particularly in Kalimantan, require further exploration.

Understanding the interconnectedness of factors influencing economic sustainability in oil palm plantations is essential but often overlooked. While economic and environmental aspects dominate discussions, social dimensions and human capital are equally critical. Economic sustainability indices, such as the 74.36% reported in West Kalimantan, indicate favorable outcomes [9]. Environmental sustainability, though vital, often overshadows socioeconomic impacts, including rural poverty reduction and ecosystem service loss [10]. Social sustainability, linked to workers' well-being, is enhanced by affective organizational commitment, mediating the relationship between social and environmental sustainability [11]. Smallholder farmers face challenges like market governance and land rights, limiting their ability to improve livelihoods [2]. Technological advancements are crucial for sustainability, yet limited access to technology and agricultural extension services requires stronger institutional support [12]. In Kalimantan, performance assessments highlight the need for improvements in crude palm oil (CPO) quality and water management, offering opportunities for technological intervention [3]. Addressing these intertwined factors is vital for sustainable development in the sector.

This study aims to fill these gaps by investigating the relationship between farmer empowerment, technological innovation, and economic sustainability in the oil palm plantation sector in Kalimantan. Through a quantitative approach, this research seeks to provide empirical evidence on how empowering farmers and fostering innovation can contribute to a more sustainable and resilient agricultural sector.

2. LITERATURE REVIEW

2.1 Farmer Empowerment and Economic Sustainability

Empowerment in oil palm plantations is crucial for promoting sustainable agricultural practices, economic stability, and environmental conservation, particularly in regions like Kalimantan with socio-economic disparities and environmental challenges. Providing farmers access to resources, education, and participatory management practices supports the adoption of sustainable farming techniques. Access to credit and land is especially vital for women, who often face barriers, with empowerment models enhancing their capacity in agriculture [13]. Training programs aligned with Sustainable Development Goals (SDGs) equip farmers with knowledge and tools for sustainable practices, combining intrinsic motivation and innovation to boost adoption rates [14]. Participatory management, as emphasized by Pretty (2008), improves livelihoods by involving farmers in decision-making, ensuring equitable resource use, and enhancing efficiency ([15] Such approaches foster better resource management and support economic and environmental sustainability [16]. Women's empowerment in agricultural value chains is key to boosting productivity and food security, with tools like pro-WEAI offering effective measures for improvement [17]. Addressing gender biases and promoting leadership among women in agriculture is essential for equitable outcomes and sustainable rural development [17].

2.2 Technological Innovation in Agriculture

Technological innovation in agriculture, particularly in oil palm plantations, has significant potential to enhance productivity and sustainability through precision farming, improved seed varieties, and mechanization systems. These technologies, including remote sensing, IoT sensors, AI, and machine learning, optimize farming practices, increase yields, and promote resource efficiency [18]. Digital tools enable real-time crop monitoring and management, reducing waste and enhancing sustainability by improving decisions on water use and fertilizer application [19]. Biotechnology and better seed varieties further improve crop resilience and yield potential, reducing dependence on synthetic inputs [15]. However, barriers such as high initial costs, lack of technical expertise, and infrastructure deficits, including poor internet connectivity, hinder adoption, particularly in developing regions like Kalimantan [18]. An integrated approach combining technological innovation with farmer empowerment is essential for sustainable outcomes. Providing training and resources increases farmers' capacity to adopt new technologies [20], while supportive policies and infrastructure development from governments and institutions are critical to overcoming these barriers [21].

2.3 Farmer Empowerment and Technological Innovation

The interconnection between farmer empowerment and technological innovation is essential in the oil palm plantation sector, where issues like labor shortages and environmental degradation persist. Empowered farmers are more likely to adopt new technologies that enhance productivity and decision-making, especially when participatory approaches involve them in the innovation process. Behavioral factors such as self-efficacy and social influence significantly impact farmers' perceptions of technology usefulness, as seen in Nepal, where training programs and government assistance are vital for adopting Agriculture 5.0 technologies [22]. In Sub-Saharan Africa, mobile phones empower farmers economically by facilitating market participation and providing access to market pricing and production methods [23]. Precision agriculture technologies optimize resource use and productivity but face adoption barriers such as high costs and technical knowledge gaps [24]. Participatory approaches, like a proposed rental app system for agricultural equipment, promote sustainable practices and economic empowerment through stakeholder engagement and data-driven insights [25]. Similarly, ICT integration in Indian agriculture enhances real-time information access and market linkages, promoting sustainable farming and financial inclusion, with government and public-private partnerships playing a crucial role in adoption [26].

2.4 Economic Sustainability in Oil Palm Plantations

Economic sustainability in oil palm plantations involves balancing profitability, resource conservation, and social equity, as emphasized by the Triple Bottom Line framework. Sustainable land management, value chain integration, and certification standards like RSPO play crucial roles in addressing the environmental and socio-economic challenges of oil palm cultivation. Oil palm plantations significantly contribute to national economies, such as Malaysia's, where they account for 2.7% of GDP and provide stable income and job opportunities [27]. However, environmental issues like deforestation and biodiversity loss necessitate the adoption of sustainable practices to mitigate these impacts [28], [29]. Certification standards like RSPO, ISPO, and MSPO are instrumental in aligning practices with international sustainability goals, while measures such as reducing management intensity and enriching plantations with native trees help balance economic and ecological outcomes without compromising productivity [30]. Government initiatives, such as revenue-sharing funds in Indonesia, support infrastructure development and promote sustainability, while strong commitment from governments and stakeholders is essential for addressing socio-economic inequalities [27], [31]. Empowering farmers through education and technological support is critical for closing yield gaps and adopting sustainable practices, while investments in sustainable management and conservation contribute to ecosystem balance and biodiversity [32].

2.5 Theoretical Framework

This study is grounded in the Resource-Based View (RBV) theory, which emphasizes that resources, including human capital and technological capabilities, are critical determinants of competitive advantage and sustainability [33]. Farmer empowerment, as a key human resource, and technological innovation, as a strategic capability, collectively enhance productivity and resilience, forming the basis for exploring their combined impact on economic sustainability in the oil palm plantation sector. While existing literature highlights the importance of both empowerment and innovation in achieving sustainability, empirical studies on their interrelationship and specific impact on economic sustainability in Kalimantan's oil palm sector remain limited. Addressing this gap, the research investigates the dynamic interactions between these variables, contributing to the broader discourse on sustainable agriculture and testing relevant hypotheses.

H1: Farmer empowerment has a positive and significant effect on technological innovation in the oil palm plantation sector.

H2: Farmer empowerment has a positive and significant effect on economic sustainability in the oil palm plantation sector.

H3: Technological innovation has a positive and significant effect on economic sustainability in the oil palm plantation sector.

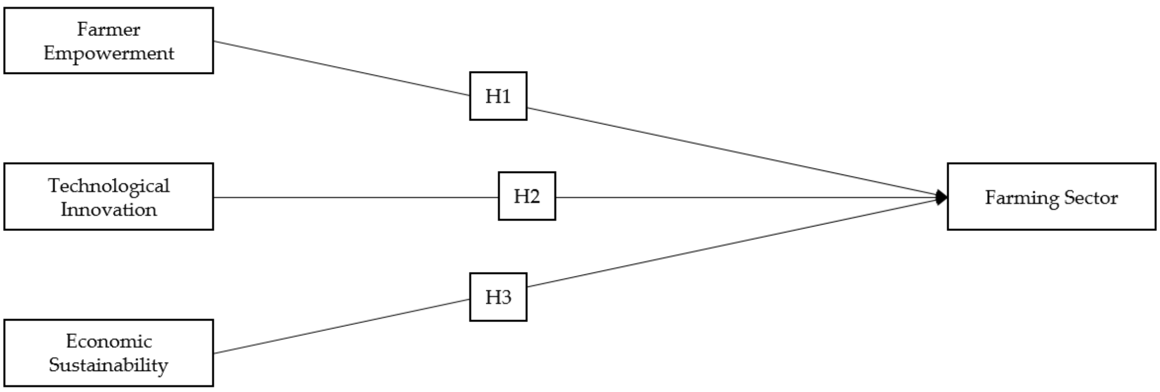

Figure 1. Theoretical Framework

3. METHODS

3.1 Research Design

This study employs a quantitative research design to examine the relationship between farmer empowerment, technological innovation, and economic sustainability in the oil palm plantation sector in Kalimantan. The research is explanatory in nature, seeking to establish causal relationships among the variables. A structured survey was used as the primary data collection tool, and the data were analyzed using Structural Equation Modeling-Partial Least Squares (SEM-PLS 3), which is well-suited for examining complex relationships in social sciences.

3.2 Population and Sample

The population for this study comprises farmers engaged in the oil palm plantation sector in Kalimantan. A purposive sampling technique was employed to select respondents who are directly involved in plantation activities and have experience with technological innovations and empowerment programs. The sample size consists of 230 respondents, which is considered sufficient for robust statistical analysis using SEM-PLS.

3.3 Data Collection

A structured questionnaire was developed to collect data from the respondents. The questionnaire was designed based on validated scales from prior studies and adapted to the context of oil palm plantations. A Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree) was used to measure the responses.

Data collection was carried out through face-to-face interviews and online surveys. The face-to-face interviews were conducted with the assistance of local facilitators who are familiar with the farming community and plantation activities in Kalimantan. The online surveys targeted respondents with access to digital communication tools, ensuring broader geographic coverage. Ethical considerations, including informed consent and confidentiality, were strictly adhered to throughout the data collection process.

3.4 Data Analysis

The data were analyzed using SEM-PLS 3, a statistical technique that integrates factor analysis and path analysis to evaluate both measurement and structural models. The analysis began with descriptive statistics to summarize the demographic profile of respondents and key variables. Next, the measurement model was evaluated to assess construct reliability and validity using composite reliability, Cronbach's alpha, average variance extracted (AVE), and factor loadings. This was followed by structural model evaluation, where the hypothesized relationships between farmer empowerment, technological innovation, and economic sustainability were tested through path coefficients, t-values, and p-values to determine their significance. Finally, model fit indices were analyzed to evaluate the robustness and goodness-of-fit of the SEM-PLS model.

4. RESULTS AND DISCUSSION

4.1 Descriptive Statistics

The demographic profile of the 230 respondents reveals that the majority are male (68%), aged between 31-50 years (55%), and have over 10 years of experience in oil palm farming (62%). Educational attainment varies, with most respondents having completed secondary education (47%), while 35% hold tertiary qualifications. Key constructs were measured with the following means and standard deviations: Farmer Empowerment (Mean = 3.85, SD = 0.72), Technological Innovation (Mean = 3.76, SD = 0.80), and Economic Sustainability (Mean = 4.02, SD = 0.68). These results indicate a generally positive perception of empowerment and technological innovation among farmers, alongside strong agreement on the importance of economic sustainability.

4.2 Measurement Model Discussion

The measurement model evaluates the reliability, convergent validity, and discriminant validity of the constructs.

Table 1. Validity and Reliability

Variable	Code	Loading Factor	CA	CR	AVE
Farmer Empowerment	FE.1	0.768	0.909	0.928	0.648
	FE.2	0.862			
	FE.3	0.869			

	FE.4	0.798			
	FE.5	0.769			
	FE.6	0.800			
	FE.7	0.762			
Technological Innovation	TI.1	0.584	0.884	0.914	0.641
	TI.2	0.870			
	TI.3	0.870			
	TI.4	0.845			
	TI.5	0.807			
	TI.6	0.792			
Economic Sustainability	ES.1	0.837	0.893	0.918	0.651
	ES.2	0.822			
	ES.3	0.837			
	ES.4	0.749			
	ES.5	0.813			
	ES.6	0.781			
Farming Sector	FS.1	0.608	0.833	0.891	0.676
	FS.2	0.886			
	FS.3	0.891			
	FS.4	0.870			

Reliability, convergent validity, and factor loadings confirmed the robustness of the constructs. Cronbach's Alpha (CA) and Composite Reliability (CR) indicated high internal consistency (CA: 0.833–0.909, CR: 0.891–0.928), exceeding the 0.7 threshold. Convergent validity, assessed through Average Variance Extracted (AVE), showed values above 0.5 for all constructs (e.g., Farmer Empowerment = 0.648, Economic Sustainability = 0.651), ensuring adequate variance capture. Factor loadings were mostly above 0.7, with minor exceptions like TI.1 (0.584) and FS.1 (0.608), which remained acceptable for exploratory analysis. Overall, the constructs demonstrated strong reliability, validity, and item representation.

Discriminant validity ensures that a construct is distinct and measures what it is intended to, without overlap with other constructs. In this study, discriminant validity was assessed using the Fornell-Larcker criterion, which compares the square root of the Average Variance Extracted (AVE) for each construct with its correlations with other constructs. For adequate discriminant validity, the square root of the AVE (diagonal values) should be greater than the inter-construct correlations (off-diagonal values).

Table 2. Discriminant Validity

	Economic Sustainability	Farmer Empowerment	Farming Sector	Technological Innovation
Economic Sustainability	0.807			
Farmer Empowerment	0.752	0.805		

Farming Sector	0.791	0.777	0.822	
Technological Innovation	0.825	0.793	0.575	0.801

The discriminant validity analysis shows that the square root of the AVE for each construct exceeds its correlations with other constructs, confirming overall good validity. Economic Sustainability (ES) has an AVE square root of 0.807, higher than its correlations with Farmer Empowerment (0.752), Farming Sector (0.791), and Technological Innovation (0.825), though the high correlation with Technological Innovation suggests potential overlap. Farmer Empowerment (FE) with an AVE square root of 0.805 also exceeds its correlations, including a moderately high correlation with Technological Innovation (0.793). Farming Sector (FS) and Technological Innovation (TI), with AVE square roots of 0.822 and 0.801 respectively, similarly show strong validity, though TI's high correlation with ES (0.825) indicates some construct overlap.

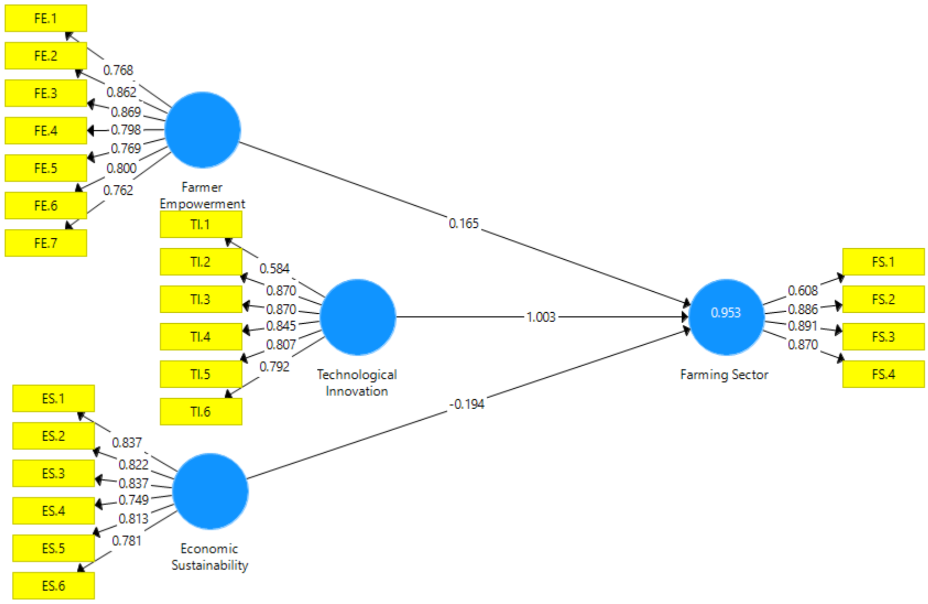

Figure 2. Internal Model

4.3 Model Fit

Evaluating the model fit ensures that the data align well with the proposed model and adequately represent the relationships among variables. In this study, the Standardized Root Mean Square Residual (SRMR) was computed as 0.048, well below the threshold of 0.08, indicating an excellent fit between the proposed model and the observed data. The Normed Fit Index (NFI) was 0.917, exceeding the commonly accepted threshold of 0.90, which demonstrates a strong model fit and supports the validity of the proposed relationships.

The R-squared (R^2) values further illustrate the model's explanatory power. For Economic Sustainability, R^2 was 0.62, indicating that Farmer Empowerment and Technological Innovation together explain 62% of its variance. Similarly, the R^2 value for Technological Innovation was 0.54, showing that 54% of its variance is explained by Farmer Empowerment. These results suggest moderate to strong explanatory power, affirming the model's robustness in capturing the key relationships.

4.4 Hypothesis Testing Discussion

Hypothesis testing in this study evaluates the strength and significance of relationships among the constructs using path coefficients, T-statistics, and P-values derived from SEM-PLS analysis.

Table 3. Hypothesis Test

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
Economic Sustainability -> Farming Sector	0.394	0.389	0.078	2.497	0.003
Farmer Empowerment -> Farming Sector	0.465	0.460	0.061	5.694	0.000
Technological Innovation -> Farming Sector	0.763	0.764	0.031	12.271	0.000

The analysis reveals significant relationships between Economic Sustainability, Farmer Empowerment, Technological Innovation, and the Farming Sector. Economic Sustainability shows a moderately strong positive influence on the Farming Sector (Path Coefficient = 0.394, T-Statistic = 2.497, P-Value = 0.003), indicating that improvements in stable income, resource optimization, and long-term viability significantly benefit the sector. Farmer Empowerment demonstrates a strong positive relationship with the Farming Sector (Path Coefficient = 0.465, T-Statistic = 5.694, P-Value = 0.000), emphasizing the importance of empowering farmers through resource access, decision-making authority, and value chain participation, which drive productivity and sustainable practices. Technological Innovation exhibits the strongest positive impact on the Farming Sector (Path Coefficient = 0.763, T-Statistic = 12.271, P-Value = 0.000), highlighting the transformative role of advancements such as precision agriculture, mechanization, and digital tools in enhancing productivity, efficiency, and sustainability within the sector.

4.5 Discussion

Economic Sustainability and Farming Sector

The study identified a moderately strong positive relationship between Economic Sustainability and the Farming Sector (Path coefficient = 0.394, T-statistic = 2.497, P-value = 0.003), demonstrating that improvements in economic sustainability—such as stable income, efficient resource use, and long-term profitability—significantly enhance the performance and resilience of the farming sector. Economic sustainability serves as a foundation for financial security, enabling farmers to invest in modern practices and infrastructure, thereby boosting productivity and profitability. This finding aligns with [34] Triple Bottom Line framework, which underscores the interconnectedness of economic, social, and environmental dimensions in achieving sustainability. Policymakers and industry stakeholders are encouraged to focus on initiatives like fair trade practices, price stabilization, and affordable financing to strengthen farmers' economic stability, thereby fostering regional development and sectoral growth.

Farmer Empowerment and Farming Sector

The relationship between Farmer Empowerment and the Farming Sector was found to be strong and significant (Path coefficient = 0.465, T-statistic = 5.694, P-value = 0.000), indicating that empowered farmers, with greater access to resources, decision-making authority, and participatory roles in value chains, contribute to higher productivity and resilience in the sector. Farmer empowerment is a critical driver of success, enabling the adoption of sustainable practices, improved resource management, and effective stakeholder collaboration. This aligns with [15] findings on the transformative impact of empowerment on community development. In regions like Kalimantan, where socio-economic disparities persist, empowerment can catalyze equitable growth and sustainability. To achieve this, government and non-governmental organizations should prioritize capacity-building programs, including training, credit access, and participatory platforms, while integrating farmers into decision-making processes to strengthen the farming sector.

Technological Innovation and Farming Sector

The relationship between Technological Innovation and the Farming Sector was found to be the strongest among the variables analyzed (Path coefficient = 0.763, T-statistic = 12.271, P-value = 0.000), highlighting technology's transformative role in enhancing efficiency, productivity, and sustainability in agriculture. Technological innovations such as precision agriculture, improved seed varieties, mechanized harvesting, and digital farming tools significantly improve resource utilization and reduce environmental impacts, aligning with [35] findings on the critical role of technology in sustainable agriculture. In Kalimantan's oil palm plantations, technology adoption not only boosts yield but also addresses challenges like labor shortages and environmental degradation. To fully harness these benefits, investments in infrastructure, training, and knowledge dissemination are crucial. Collaborative efforts among government, private sector, and research institutions can ensure technology is accessible, affordable, and tailored to the specific needs of Kalimantan's farmers.

Integration of Economic Sustainability, Farmer Empowerment, and Technological Innovation

The interplay between Farmer Empowerment, Technological Innovation, and Economic Sustainability reveals a synergistic relationship where empowerment and innovation drive sustainability, which in turn strengthens the Farming Sector. This aligns with the Resource-Based View (RBV) theory [33], highlighting the critical role of human and technological resources in achieving competitive advantage and sustainability. Empowered farmers are better positioned to adopt and implement technological innovations, enhancing productivity and fostering sustainability, while economic stability enables further investments in modern practices, creating a virtuous cycle of growth. This integrated approach underscores the need for holistic strategies addressing multiple development dimensions. A coordinated effort involving farmer training, technological support, and financial incentives, alongside policies to reduce barriers such as credit and infrastructure deficits, is essential for promoting sustainable growth in the farming sector.

Comparison with Previous Studies

The findings of this study are consistent with prior research on the importance of empowerment, innovation, and sustainability in agriculture. However, the context-specific insights provided for the oil palm plantation sector in Kalimantan add unique value to the literature. The study highlights the need for tailored solutions that consider the socio-economic and environmental challenges unique to the region.

Limitations and Future Directions

While the study provides robust evidence for the hypothesized relationships, several limitations must be acknowledged. The cross-sectional design captures relationships at a single point in time, limiting causal inferences; future studies could use longitudinal designs to explore these dynamics over time. Additionally, the reliance on self-reported data may introduce response bias, which could be mitigated by combining survey responses with objective performance metrics. Furthermore, the findings are specific to the oil palm sector in Kalimantan and may not be generalizable to other contexts. Future research could examine the role of environmental sustainability alongside economic sustainability and explore how external factors, such as policy changes and market dynamics, influence these relationships.

5. CONCLUSION

This study underscores the interconnected roles of Economic Sustainability, Farmer Empowerment, and Technological Innovation in enhancing the

Farming Sector within Kalimantan's oil palm plantation industry. Key findings reveal that Economic Sustainability fosters stable income, resource optimization, and long-term viability; Farmer Empowerment drives sectoral growth by enabling sustainable practices and boosting productivity; and Technological Innovation, the most significant factor, addresses efficiency and sustainability challenges. These results highlight the importance of an integrated approach that combines policy support, capacity-building programs, and technological investment. By overcoming systemic barriers such as limited infrastructure and credit access, stakeholders can create a more resilient and sustainable agricultural sector. This study contributes to the growing discourse on sustainable agriculture and provides a basis for future research to investigate dynamic interactions and external influences over time.

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