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Sustainable Palm Oil (*Elaeis guineensis* Jacq.) Agribusiness Development in Indonesia: An Integrated Model

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ABSTRAK/ABSTRACT

Pengembangan agribisnis kelapa sawit berkelanjutan (*Elaeis guineensis* Jacq.) di Indonesia: Sebuah model terpadu

Keberlanjutan agribisnis kelapa sawit merupakan isu strategis yang menghubungkan aspek ekonomi, sosial, dan lingkungan dalam pengelolaannya. Praktik perkebunan hingga industri kelapa sawit berkontribusi signifikan terhadap pertumbuhan ekonomi nasional dan kesejahteraan petani, namun pada kenyataannya kegiatan ini sering dikaitkan dengan deforestasi, degradasi lahan, serta konflik sosial. Pentingnya mengintegrasikan berbagai aspek keberlanjutan dengan agribisnis sebagai suatu sistem dari persepsi petani menghasilkan unsur prioritas yang perlu diutamakan. Tujuan penelitian ini adalah menganalisis faktor penentu pengembangan agribisnis kelapa sawit berkelanjutan. Penelitian ini didesain menggunakan metode kuantitatif dengan pendekatan survey. Teknik penarikan sampel menggunakan *proportionate stratified random sampling* dengan jumlah responden sebanyak 249 petani kelapa sawit rakyat. Pengolahan data dilakukan dengan pendekatan alat analisis *Partial Least Square* (PLS). Hasil penelitian menunjukkan bahwa evaluasi temuan pemodelan menyoroti terdapat pengaruh yang signifikan dari rasionalitas petani terhadap kinerja sistem agribisnis dan agribisnis kelapa sawit berkelanjutan, begitupula terdapat pengaruh yang signifikan dari kinerja sistem agribisnis kelapa sawit terhadap agribisnis kelapa sawit berkelanjutan. Sementara itu, secara nyata, hasil pengujian menunjukkan karakteristik petani tidak memiliki pengaruh yang signifikan terhadap variabel manapun. Lebih lanjut, tingkat keberlanjutan agribisnis kelapa sawit dipersepsikan petani lebih penting secara berurut mulai dari dimensi sosial, lingkungan, teknologi, dan ekonomi. Perlunya kerjasama dan dukungan dari berbagai pihak untuk mencapai dan meningkatkan keberlanjutan agribisnis kelapa sawit baik dari pemenuhan input, produksi, penanganan hasil, pemasaran, dan dukungan penunjang untuk menjamin keberlanjutannya.

Keywords:
Agribusiness, Palm oil, Rationality, Smallholder, Sustainability

The sustainability of palm oil agribusiness was a strategic issue that connected economic, social, and environmental aspects in its management. Plantation practices and the palm oil industry contributed significantly to national economic growth and farmer welfare, but in reality, this activity was often associated with deforestation, land degradation, and social conflict. The importance of integrating various aspects of sustainability with agribusiness as a system from farmer perceptions produced priority elements that needed to be

prioritized. The purpose of this study was to analyze the determinants of sustainable palm oil agribusiness development. This study was designed using a quantitative method with a survey approach. The sampling technique used proportionate stratified random sampling with a total of 249 smallholder palm oil farmers as respondents. Data processing was carried out using the Partial Least Square (PLS) analysis tool approach. The results of the study showed that the evaluation of modeling findings highlighted a significant influence of farmer rationality on the performance of the agribusiness system and sustainable palm oil agribusiness, as well as a significant influence of the performance of the palm oil agribusiness system on sustainable palm oil agribusiness. Meanwhile, in reality, the test results showed that farmer characteristics did not have a significant influence on any variable. Furthermore, the level of sustainability of palm oil agribusiness was perceived by farmers as more important in order from the social, environmental, technological, and economic dimensions. There was a need for cooperation and support from various parties to achieve and improve the sustainability of palm oil agribusiness, both from the fulfillment of input, production, handling of results, marketing, and supporting services to ensure its sustainability.

INTRODUCTION

The concept of sustainable development is founded on three core principles: improving quality of life in a long-term way, utilizing natural resources prudently, and ensuring sufficient resources are preserved for future generations. This approach allows current needs to be met without compromising the ability of future generations to meet theirs. A key focus of sustainable development lies in the integration of social, environmental, and economic dimensions (Munasinghe & Lutz, 1991; Hajian & Kasani, 2021). Due to its multifaceted nature, sustainability can be analyzed across different spatial and temporal scales, providing diverse opportunities to develop metrics that reflect its various components (Idziak *et al.,* 2015; Luque *et al.,* 2021; Kalachevska *et al.,* 2022). The most comprehensive and up-to-date global interpretation of sustainability is embodied in the Sustainable Development Goals (SDGs), which consist of 17 primary objectives and build upon the earlier Millennium Development Goals (MDGs) (Wisena *et al.,* 2014; Kannengieber, 2023).

The export of items derived from palm oil plantations contributes significantly to the Indonesian economy by increasing foreign exchange earnings and fostering economic growth (Teoh, 2010; Limaho *et al.,* 2023). In Indonesia, there are three types of palm oil plantation land ownership: People's Plantation, Large State Plantation, and Large Private Plantation (Kadir & Syapsan, 2012; Sari, 2022). Of all the palm oil farms in the nation, 55.09% are managed by large private enterprises. Moreover, of the nation's total palm oil cultivation area, 40.62% is planted by smallholder plantations, with massive state-owned plantations making up the remaining 4.29% (Saragih *et al.,* 2020).

Palm oil plantations, including those established within officially designated forest zones in regions such as Sumatra and Kalimantan, constitute a significant source of foreign exchange earnings for both national and subnational governments (Sitepu *et al.,* 2020). North Sumatra Province, encompassing approximately 5,123 hectares of oil palm plantations, is recognized as one of Indonesia's principal centers of palm oil production (Firdaus *et al.,* 2020). Nevertheless, productivity performance in this province has not progressed proportionally with the ongoing expansion of plantation areas (Chalil & Barus, 2021). Moreover, among the three prevailing land tenure arrangements in the palm oil sector, smallholder-managed plantations in North Sumatra demonstrate the lowest productivity relative to state-owned and privately operated estates.

Within the palm oil agribusiness system, smallholder farmers function as pivotal actors at the upstream stage of production (Nurjanah *et al*., 2024). Owing to their independent mode of operation and the absence of contractual obligations with specific firms or processing companies, smallholder oil palm growers are eligible beneficiaries of various government support programs (Pramudya *et al.,*

2018). Labuhanbatu District in North Sumatra Province represents a prominent palm oil production area, encompassing approximately 35,160 hectares of plantations managed by 21,513 smallholders and generating an annual production volume of about 503,100 tons (Sylvia *et al*., 2022).

The productivity of smallholder palm oil plantations in Labuhanbatu Regency has fluctuated over time, with the lowest yield recorded in 2023 at 14.3 tons per hectare. This highlights the need for a structured palm oil agribusiness system to stabilize production levels within the community (Hermundsdottir & Aspelund, 2021). As development goals shift from merely maximizing profits to promoting environmentally sustainable practices, several challenges have emerged alongside the expansion of palm oil farming in Labuhanbatu. Creating a sustainable agribusiness model tailored for smallholder palm oil farmers is essential for ensuring long-term plantation sustainability. Such a model can serve as a guide for farmers to manage their plantations more effectively, allowing them to focus on key components and performance indicators that support sustainable development.

Farmers can lower production costs by treating smallholder palm oil farmers poorly and using insufficient agribusiness subsystems (Mirajiani, 2022). A type of farmer rationality is what farmers do. Naturally, the performance of the palm oil agribusiness will be influenced by the rationality of the farmers. By placing a higher value on reason, farmers will be better able to think through their judgments before engaging in palm oil production. When making decisions to adopt palm oil farming, farmers must take into account not only the economic benefits of their operation but also the social and cultural aspects of their decision-making process (Nugraha *et al*., 2022; Rahayu & Waluyati, 2023).

Sustainable agribusiness development is built upon five key pillars: institutional, technological, social, environmental, and economic aspects (Zhen & Routray, 2003; Ioris, 2018; Migunov *et al.,* 2023). Economically, it aims to enhance income generation; socially, it incorporates local knowledge and encourages behavioral change; environmentally, it emphasizes the conservation of natural resources; technologically, it promotes the adoption of eco-friendly innovations; and institutionally, it ensures support systems and affordability are accessible (Nasution *et al.,* 2021).

The sustainability of palm oil agribusiness is influenced by how effectively the system operates, particularly when considering farmers' decision-making processes. Integrating these components leads to the development of a comprehensive and sustainable model for advancing the palm oil industry.

In recent years, the significant advancement in human resource quality has led many researchers to shift focus away from smallholders in detailed studies on the development of the palm oil industry. Grounded in the principles of sustainable agricultural development and the process of palm oil agribusiness transformation, this study seeks to offer a strong theoretical basis for future research on the sustainable development of smallholder-based palm oil agribusiness.

Most studies on sustainable agricultural development focus on its three main components, offering a broad overview of sustainability levels (Kunene & Chung, 2020; Falgenti *et al.,* 2021; Tiasmalomo *et al.,* 2021). Although research on the sustainability of palm oil-based biodiesel has addressed this topic, it has yet to thoroughly explore the significance of discussing the environmental, social, and economic dimensions of sustainability, or to clearly define what constitutes the overall sustainability of palm oil-based biodiesel (Sukiyono *et al.,* 2022).

This study seeks to identify the factors that drive the development of sustainable palm oil agribusiness by examining both external factors (agribusiness system performance) and internal factors (farmer characteristics and decision-making logic). The findings provide concrete references to support the advancement of environmentally sustainable palm oil production. The study has several practical implications: (a) For business stakeholders: it is expected to enhance understanding of smallholder palm oil agribusiness and serve as a basis for implementing best practices in cultivation; (b) For other relevant parties: the insights may help increase production, productivity, and quality, thereby benefiting farmers, improving community welfare, and contributing to industry sustainability; (c) For policymakers: the research is expected to inform sustainable palm oil agribusiness policies by highlighting farmer profiles, agroecosystem diversity, and offering model frameworks to support the development of smallholder-based palm oil farming.

MATERIALS AND METHODS

Sustainable Development

The notion of sustainability has become increasingly integral to agricultural development, driven by rising awareness of the adverse environmental and socio-economic consequences associated with intensive farming systems (Bai *et al.,* 2020). As articulated by Velten *et al.* (2015) and Ayompe *et al.* (2021), sustainable agriculture entails the management and utilization of agricultural ecosystems in a manner that maintains their productivity, ecological integrity, regenerative capacity, biodiversity, and overall functional resilience. Such an approach seeks to fulfill the economic and social needs of present and future generations at local, national, and global scales, while avoiding detrimental effects on other ecosystems. Intergenerational equity constitutes a fundamental dimension of sustainability within this framework. Although multiple strategic pathways are available to promote economic growth in the agricultural sector, the sustainable development of agribusiness represents a strategy that most comprehensively aligns with these principles (Xu *et al.,* 2021).

Economic, social, and environmental sustainability are the minimum requirements for agribusiness development. In order to measure sustainability in the face of changing times, it is imperative to have both an institutional and technological dimension, supported by a number of influencing elements. Accordingly, developing an agribusiness serves both long-term and short-term goals (Dharmawan *et al.,* 2020).

The sustainable palm oil agribusiness development model presented in this study is grounded in multiple theoretical frameworks and prior research, particularly those that emphasize sustainability indicators across five critical dimensions: institutional, technological, social, environmental, and economic aspects. These dimensions serve as a comprehensive lens to evaluate and guide the sustainable development of palm oil agribusiness. According to studies by Hosseini *et al.* (2017) and Hariyanti *et al.* (2022), the overall performance of the agribusiness is assessed through various subsystems including input, production, product handling, marketing, and support systems. Each of these subsystems plays a crucial role in determining the sustainability of the palm oil sector by affecting efficiency, quality, and environmental impact throughout the value chain. Furthermore, these external factors do not operate in isolation but are significantly influenced by farmer characteristics such as their knowledge, skills, and behaviors, as well as their decision-making processes that consider economic viability, social dynamics, environmental stewardship, and technical expertise. This integrated approach highlights that achieving sustainability in palm oil agribusiness requires addressing both structural components and the rationality of farmers, making the model both comprehensive and grounded in existing scholarly work.

Study areas and Research Data

This study employed a quantitative analytical approach, with surveys as one of the primary research methods. Data were obtained from both primary and secondary sources. Primary data were collected through field surveys using structured questionnaires, structured interviews, and in-depth observations. Secondary data were gathered through a comprehensive review of relevant literature. The research was conducted between December 2023 and February 2024. North Sumatra Province was selected as the study area because it is one of the nine key palm oil–producing provinces in Indonesia. Field data were collected in Labuhanbatu Regency as the central research area, as well as in two additional locations, namely Pangkatan District and Rantau Utara District. A proportional stratified random sampling technique was applied to select 249 smallholder palm oil farmers as respondents.

The sample size of 249 respondents was considered adequate for Partial Least Squares–Structural Equation Modeling (PLS-SEM) analysis, as it exceeded the minimum sample size required for this method. PLS-SEM is a variance-based approach that is relatively undemanding in terms of sample size; accordingly, the *10 times rule* suggests that the minimum required sample size is ten times the largest number of indicators or structural paths pointing to an endogenous construct. With 249 respondents, this study not only satisfies the minimum requirement but also falls within the sample size range recommended in the literature to ensure stable and reliable parameter estimation, as well as sufficient statistical power for testing the relationships among latent constructs.

Variable Selection

The selected variables are presented in Table 1. Table 1 provides a detailed description of the factors examined in this study from each dimension.

Table 1. Research variables

Variables	Indicators	Scale
Farmer characteristics (X1)	Age (X1.1)	Ratio
	Land area (X1.2)	
	Education (X1.3)	
	Farming Experience (X1.4)	
	Family dependents (X1.5)	
Farmer rationality (X2)	Economic rationality (X2.1)	Ordinal
	Social rationality (X2.2)	
	Environmental rationality (X2.3)	
	Technological rationality (X2.4)	
Agribusiness system performance (Y1)	Input subsystem (Y1.1)	Ordinal
	Production subsystem (Y1.2)	
	Result handling subsystem (Y1.3)	
	Marketing subsystem (Y1.4)	
	Supporting subsystem (Y1.5)	
Sustainable palm oil agribusiness (Y2)	Economic dimension (Y2.1)	Ordinal
	Social dimenion (Y2.2)	
	Environmental dimension (Y2.3)	
	Technology dimension (Y2.4)	
	Institutional dimension (Y2.5)	

Description: Ordinal (1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree).

Partial Least Square

Partial Least Square is applicable to all data scales, requires few assumptions, and does not require a big sample size, it is a strong analytical tool. PLS can be utilized for proposition testing, connection building for which there is no theoretical foundation, and validation of theory. Moreover, structural modeling using reflective or formative indicators can be done with PLS (Chin, 1998). In this study, inferential statistical analysis is conducted using Smart PLS (Partial Least Square) version 3.0 software, following the proposed hypotheses. The analysis process starts with evaluating the measurement model (outer model), followed by the structural model (inner model), and concludes with hypothesis testing.

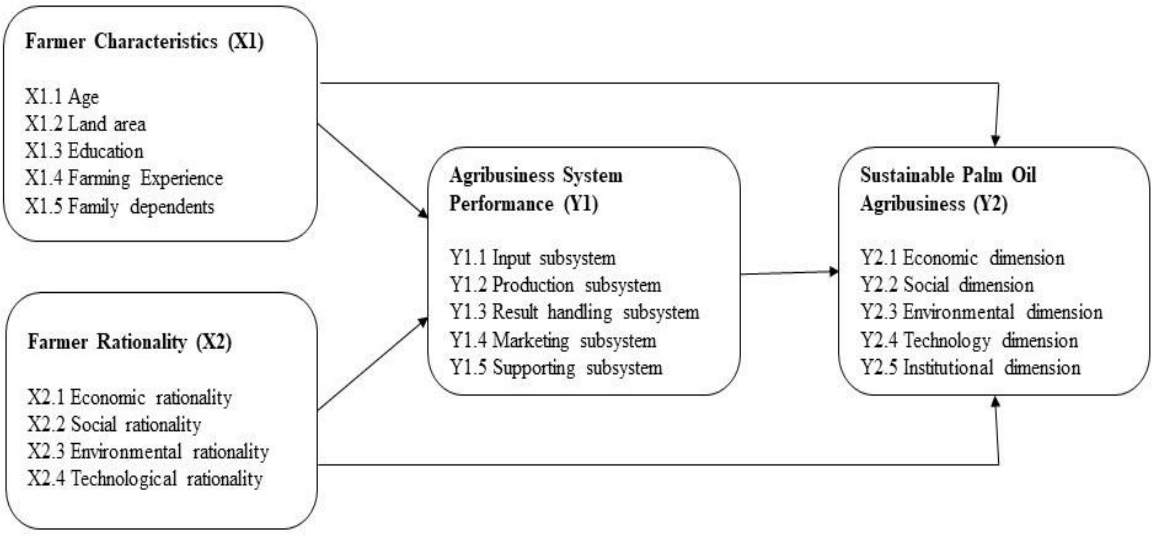

Figure 1. Conceptual model of sustainable palm oil agribusiness development.

The PLS testing process involves several key steps. First, the structural model is designed based on the research problem or hypothesis, outlining the relationships between latent variables. Next, the measurement model, also called the outer model, is carefully developed to identify whether each indicator is formative or reflective, which is essential for accurate analysis. Following this, a path diagram is created and converted into a system of equations representing the inner model, outer model, and weight relationships. The model is then estimated, and the Goodness of Fit (GOF) is assessed to evaluate its suitability. Finally, hypothesis testing is conducted to validate the proposed relationships. The study utilized this conceptual model framework, which is explained in detail in Fig. 1. The study puts forth the following hypotheses: 1) Farmer characteristics and farmer rationality affect the performance of the palm oil agribusiness system, 2) Farmer characteristics and farmer rationality influence sustainable palm oil agribusiness, and 3) The performance of the palm oil agribusiness system affects sustainable palm oil agribusiness.

RESULTS AND DISCUSSION

The sustainable palm oil agribusiness development model was created based on the analysis results obtained from processing data using Partial Least Square (PLS). This model is systemic so that the correlations and influences are displayed as a whole, both positive and negative, both significant and insignificant. However, the focus of analysis is emphasized on the value of significant influence, both partially and simultaneously.

Evaluation of the Measurement Model (Inner Model)

The assessment of the indicator measurement model entails the evaluation of several key criteria, namely average variance extracted (AVE), discriminant validity, internal consistency or composite reliability, and the reliability of individual indicators. Convergent validity is examined through three primary tests: indicator reliability, which reflects the validity of each observed measure; composite reliability; and the AVE. Convergent validity refers to the extent to which a set of indicators effectively represents and explains the underlying latent construct. Accordingly, higher levels of convergent validity indicate a stronger capacity of the indicators to capture and operationalize the latent variable.

a. Reliability Item

The standardized loading factor of an item reflects its reliability in the assessment of indicator validity. This coefficient denotes the magnitude of the relationship between each observed indicator and its corresponding latent construct (Fig. 2). An indicator is generally considered a valid measure of the construct when its loading factor exceeds 0.70; however, indicators with standardized loading values above 0.50 may still be deemed acceptable. In contrast, indicators exhibiting standardized loading factors below 0.50 should be excluded from the measurement model (Geladi & Kowalski, 1986).

Figure 2 shows that the standardized loading factor is nearly fully more than 0.5; nevertheless, indications X1.4 and X1.5 must be put away because their loading factor values are less than 0.5. One by one, the variables are eliminated until the measurement model evaluation size for every variable is satisfied. It is required to set aside other indicators with the smallest value, specifically X1.1 (age), because the results of setting aside both indicators X1.4 and X1.5 one at a time still leave a little AVE value for variable X1 (farmer qualities). Thus, only X1.2 (land area) and X1.3 (education) are used to measure X1 (farmer attributes). These are the enhanced model's findings following the addition of indicators X1.1, X1.4, and X1.5.

Land area, or X1.2, is the indicator in the farmer characteristics variable (X1) with the highest loading factor value (Fig. 3). One of the most important metrics in palm oil plantation production is land area. There are 120–130 palm oil trees in one region of the plantation (Oloukoi, 2022). Therefore, the number of palm oil trees that will yield a higher production will increase with the amount of land owned by farmers. This is consistent with studies (Simangunsong *et al.,* 2019) that showed the production of land area has a major impact on farmers' perceptions. The impact of land area on income and productivity is highly influential, with a 99% R^2 value.

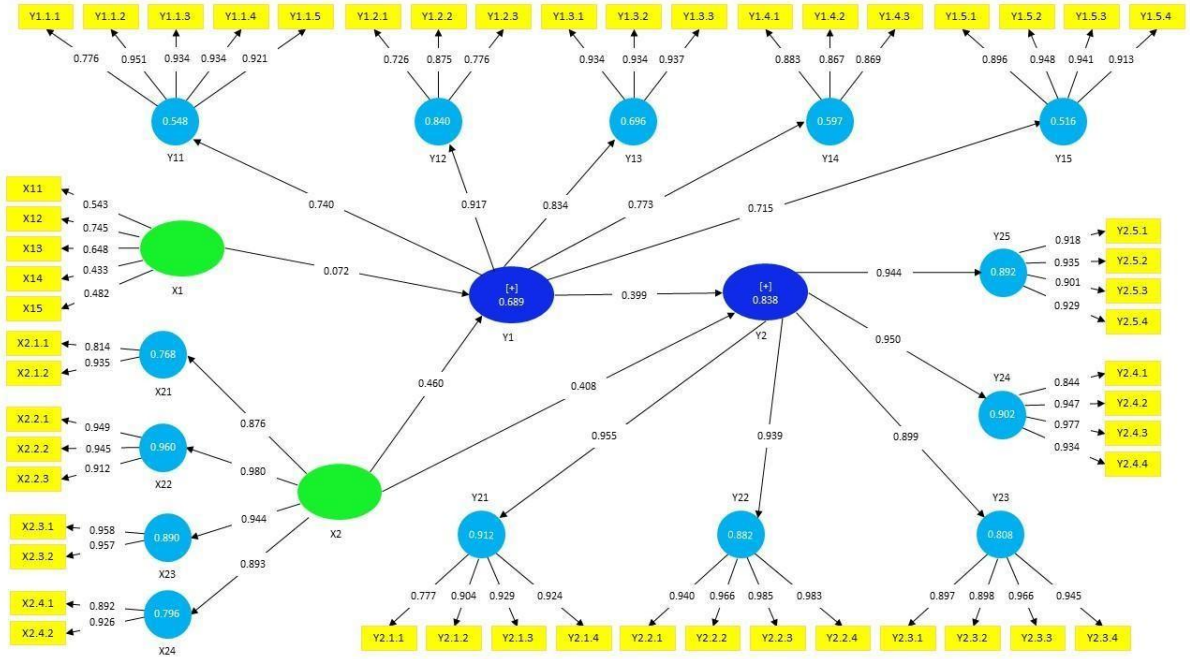

Figure 2. Standardized loading factor inner and outer model initial.

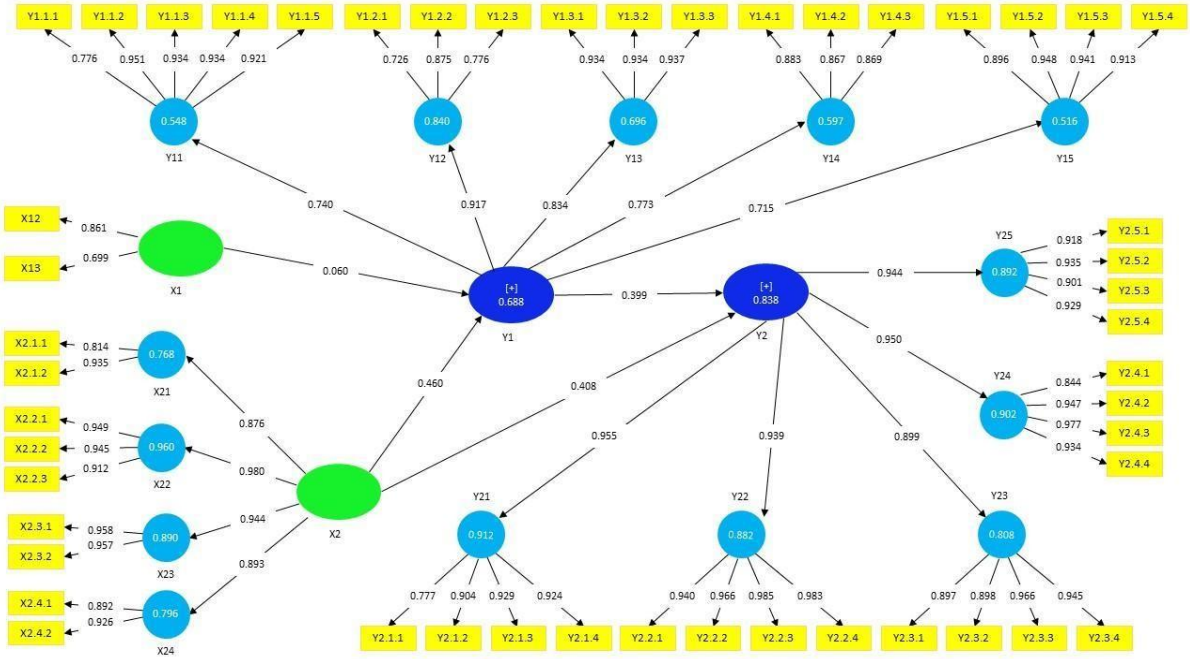

Figure 3. Standardized loading factor inner and outer model improvements.

On the variable rationality of farmers seen from economic rationality (X2.1), social rationality (X2.2), environmental rationality (X2.3), and technological rationality (X2.4), it was found that social rationality (X2.2) has the highest contribution to the overall rationality of farmers. This is seen based on the loading factor value of social rationality of 0.980 reflects the rationality of farmers. The palm oil agribusiness performance variable (Y1) is measured by the input subsystem (Y1.1), production/agribusiness subsystem (Y1.2), product handling subsystem (Y1.3), marketing subsystem (Y1.4), and supporting subsystem (Y1.5). Based on the five agribusiness subsystems in the palm oil agribusiness performance variable (Y1), the production subsystem (Y1.2) has the largest loading factor value among all subsystems so it can be said that the production subsystem (Y1.2) is able to reflect the greatest palm oil agribusiness performance. The economic (Y2.1), social (Y2.2), environmental (Y2.3),

technological (Y2.4), and institutional (Y2.5) components are the five that characterize the sustainable palm oil agribusiness variable (Y2). The economic dimension (Y2.1) can represent the most sustainable palm oil agribusiness since it has the greatest loading factor value among the five dimensions in the sustainable palm oil agribusiness variable (Y2).

b. Composite Reliability

Cronbach's alpha and D.G. rho are employed to assess composite reliability, commonly referred to as construct reliability within the principal component analysis (PCA) framework. A measurement instrument is considered to exhibit a high level of reliability when the values of Cronbach's alpha and D.G. rho (PCA) exceed 0.70 (Table 2). As noted by Ghozali and Latan (2015), values of 0.70 or higher indicate good reliability, whereas coefficients above 0.80 and 0.90 reflect very strong or excellent reliability. As presented in Table 2, all constructs demonstrate satisfactory reliability as measurement instruments, given that the composite reliability values for all latent variables surpass the recommended threshold of 0.70.

Table 2. Composite reliability results

Code	Laten variables	Composite reliability
X1	Farmer characteristics	0.760
X2	Farmer rationality	0.961
X2.1	Economic rationality	0.868
X2.2	Social rationality	0.955
X2.3	Environmental rationality	0.957
X2.4	Technological rationality	0.905
Y1	Agribusiness system performance	0.933
Y1.1	Input subsystem	0.958
Y1.2	Production subsystem	0.837
Y1.3	Result handling subsystem	0.954
Y1.4	Marketing subsystem	0.906
Y1.5	Supporting subsystem	0.951
Y2	Sustainable palm oil agribusiness	0.967
Y2.1	Economic dimension	0.935
Y2.2	Social dimenion	0.984
Y2.3	Environmental dimension	0.961
Y2.4	Technology dimension	0.961
Y2.5	Institutional dimension	0.957

Source: Data processing results.

c. Average Variance Extracted (AVE)

Average variance extracted (AVE) represents the proportion of variance captured by a construct through its indicators relative to the variance attributable to measurement error. A construct is considered to exhibit adequate convergent validity when its AVE value exceeds 0.50, signifying that, on average, the latent variable explains more than half of the variance observed in its associated indicators.

Table 3. Average variance extracted (AVE) results

Code	Laten variables	AVE
X1	Farmer characteristics	0.615
X2	Farmer rationality	0.734
X2.1	Economic rationality	0.768
X2.2	Social rationality	0.875
X2.3	Environmental rationality	0.918
X2.4	Technological rationality	0.826
Y1	Agribusiness system performance	0.500
Y1.1	Input subsystem	0.820
Y1.2	Production subsystem	0.632
Y1.3	Result handling subsystem	0.874
Y1.4	Marketing subsystem	0.762
Y1.5	Supporting subsystem	0.829
Y2	Sustainable palm oil agribusiness	0.712
Y2.1	Economic dimension	0.784
Y2.2	Social dimenion	0.938
Y2.3	Environmental dimension	0.859
Y2.4	Technology dimension	0.859
Y2.5	Institutional dimension	0.848

Source: Data processing results.

Table 3 indicates that all latent variables exhibit AVE values exceeding 0.70, reflecting a high degree of reliability of the measurement instruments for each construct. Furthermore, the AVE values for all latent variables are above the 0.50 threshold, demonstrating strong convergent validity. This finding implies that, on average, each latent construct accounts for more than half of the variance observed in its respective indicators.

Structural Model Evaluation (Outer Model)

Determining the significance of the relationships between the constructs is the first stage in evaluating the structural model. The path coefficient, which indicates how strongly the constructions are related to one another, illustrates this.

a. Path Coefficient

The bootstrapping approach (resampling method) yields the t test (critical ratio), which can be used to assess the path coefficient's significance. The route coefficient's sign needs to line up with the suggested theory. Figure 4 displays the inner and outer models' t test findings, which are as follows.

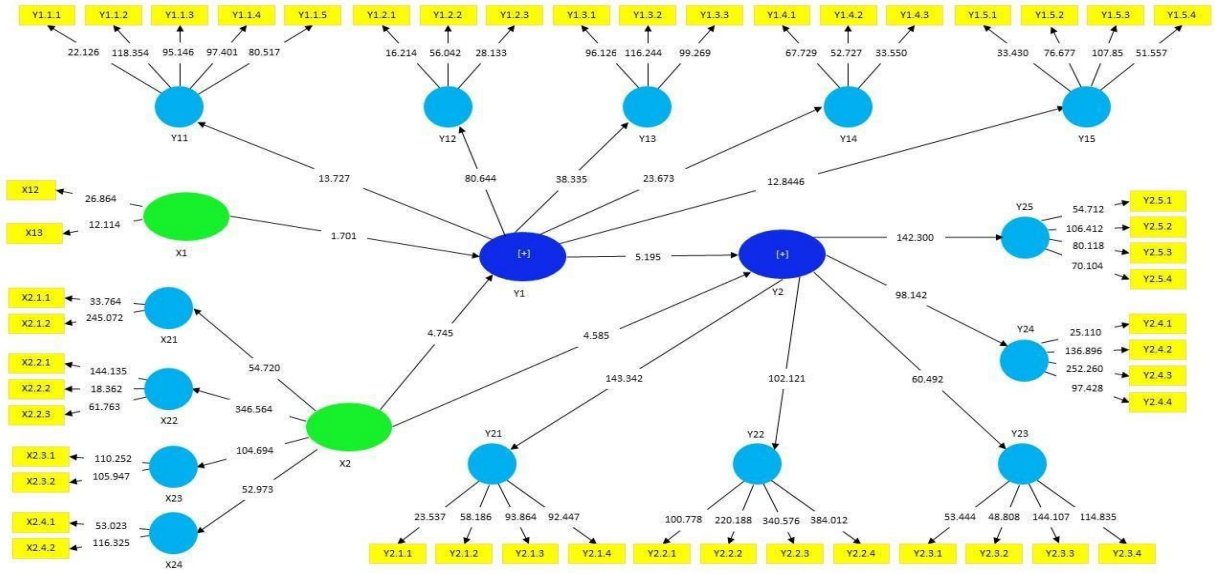

Figure 4. T-value of inner and outer model. Source: Data processing results.

The t-test results used in this study were derived from the bootstrap calculations. The p-values from the t-tests, shown in Figure 4, are compared to the significance level to evaluate the hypotheses. According to the testing criteria, a hypothesis is considered supported if the p-value is less than the 5% significance level (0.05). If the p-value is greater than 0.05, the results are deemed not significant. The following section presents the findings from the data analysis for each hypothesis tested. Moreover, the outcomes of the hypothesis testing demonstrate that:

1. The influence of farmer characteristics and farmer rationality on the performance of the palm oil agribusiness system

The success of the palm oil agribusiness is impacted by farmer traits, with a p-value of 0.093. When compared to the 5% significant level, the p-value (0.093) is higher than the significant threshold (0.05), indicating that the test results are not significant. Accordingly, farmer characteristics do not exhibit a statistically significant effect on the performance of the palm oil agribusiness. In contrast, the influence of farmer rationality on agribusiness performance is statistically significant, as indicated by a p-value of 0.000, which falls well below the conventional significance level of 0.05. These results confirm that farmer rationality exerts a meaningful and positive effect on the performance of the palm oil agribusiness sector. Only factors pertaining to education and land area can adequately explain the characteristics of palm oil growers when compared to the loading factor value over 0.5, which denotes item reliability. A farmer's variable qualities include age, education, land acreage, agricultural experience, and the number of dependents in the household. Better farmer attributes are linked to higher land ownership and educational attainment, which in turn affects the expansion of farmer-run palm oil agribusiness, as evidenced by the positive values of the land area and education indicators.

The features or characteristics that palm oil farmers possess can be examined through patterns of behavior toward the environment, attitudes toward the environment, and cognitive patterns. Farmers have a variety of innate qualities or elements that make them who they are (Hutami *et al.,* 2023; Rini & Aswin, 2023). According to Pinem (2021), the degree of education can be understood as a stage of learning that is dependent on an individual's capacity to both assimilate and apply knowledge in daily life.

The formal education that palm oil growers have finished is the education that is discussed in this study. A high degree of education among the farmers can boost the palm oil agribusiness's productivity. According to a study by Simatupang and Cantona

(2025), education level has an effect on the performance of palm oil farming. However, field data indicates that most palm oil farmers have relatively low levels of formal education, emphasizing the importance of non-formal education—such as counseling, training, and support from both public and private sectors to enhance their knowledge. Sulandari (2015) states that non-formal education is essential in improving farmers' intellectual capacity and can produce results that are comparable to those of formal education.

Table 4. Results of the t-test of the effect of farmer characteristics and farmer rationality on palm oil agribusiness performance

Relationship between variables	Original sample (O)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
Farmer characteristics → Agribusiness performance	0,060	0,036	1,687	0,093*
Farmer rationality → Agribusiness performance	0,466	0,085	5,473	0,000**

Notes: **) significant at 5% level, *) significant at 10% level. Source: Data processing results.

Additionally, when it comes to planning, smallholder palm oil plantation growers give more weight to land acreage and plant number than accessibility. A key component of farming operations that affects productivity levels is land area. The performance of the palm oil agribusiness will improve if the farmer's land area increases. The data from the field indicates that palm oil growers in the study region had a comparatively limited amount of cultivated land. The available land can be optimized through effort. A narrow land area can be maximized, according to Wan Shahidan and Nadzri (2020) and Ministry of Agriculture (2011), if palm oil growers follow guidelines for using production inputs.

The performance of the palm oil agribusiness is positively and significantly impacted by farmer rationality characteristics. Thus, the various levels of farmer rationality may be explained by each of the four indicators of farmer rationality: economic, social, environmental, and technological. The more economically, socially, environmentally, and technologically rational farmers are, the more their rationality influences the palm oil agribusiness's performance (Vanclay & Lawrence, 1994; Chandra *et al.,* 2023). According to theory, farmer rationality is the process, strategy, and action of rationally improving in order to minimize expenses and maximize profits. A number of research show that farmer rationality is a tactic to increase community wellbeing. In order to maximize profit, growers operate their palm oil farms rationally by minimizing production expenses as much as feasible. The subsystems that make up the palm oil agribusiness performance variable input, production, product handling, marketing, and supporting provide assistance for this. Put another way, sound farmer reasoning supports effective agribusiness performance.

2. The influence of farmer rationality on sustainable palm oil agribusiness

The p-value for farmers' rationale in supporting sustainable palm oil agribusiness is 0.000. Since this value is below the 5% significance level (0.05), the test results are considered statistically significant. Therefore, it can be concluded that farmers' rational thinking has a meaningful influence on the success of sustainable palm oil agribusiness. Furthermore, the positive path coefficient indicates that the more rational the farmers are, the better the performance of agribusiness efforts aimed at sustainable palm oil production. Based on the results of the analytical test, farmers' individual characteristics do not have a significant influence on the performance of the palm oil agribusiness or on the industry's sustainability. This aligns with the findings of some researches, which indicate that farmer attributes have minimal impact on the sustainability of the palm oil sector. The primary reason for this is the generally small landholdings of farmers, which fall short of the recommended minimum of two hectares for sustainable palm oil cultivation. However, in practice, collaboration through cooperative farming can help overcome this limitation and support progress.

The sustainability of the palm oil industry is strongly and directly influenced by the rational decision-making of farmers. Their rationality viewed through economic, social, environmental, and technological lenses affects the overall sustainability of palm oil agribusiness, which is measured across economic, social, environmental, technological, and

institutional dimensions. There is a positive correlation between farmers' rational thinking and the long-term sustainability of their palm oil plantations (Adrian *et al.,* 2023; Rodthong *et al.,* 2023). Bolis *et al.* (2017) also emphasizes that rationality research has significant implications for sustainability outcomes. Field data from the study area show that the level of farmer rationality is relatively high, and their assumptions play a crucial role in shaping sound and logical decisions.

Table 5. Results of the t-test of the direct effect of farmer rationality on sustainable palm oil agribusiness

Relationship between variables	Original sample (O)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
Farmer rationality → Sustainable palm oil agribusiness	0,408	0,091	4,497	0,000**

Notes: **) significant at 5% level, *) significant at 10% level. Source: Data processing results.

3. Effect of palm oil agribusiness performance on sustainable palm oil agribusiness

The relationship between palm oil agribusiness performance and sustainability outcomes yields a p-value of 0.000, which is below the 5% significance level (0.05), indicating statistical significance. This finding demonstrates that the effectiveness of agribusiness operations exerts a substantial influence on the sustainability of the palm oil sector. Moreover, the positive path coefficient implies that higher levels of agribusiness performance are associated with an increased likelihood of achieving sustainable palm oil practices.

The performance of the palm oil agribusiness—evaluated across the input, production, post-harvest handling, marketing, and support subsystems—exerts a direct and statistically significant effect on the sustainability of palm oil farming. This result corroborates the proposed research hypothesis and is consistent with prior empirical findings (Wahyuni *et al.,* 2022; Adwiyah *et al.,* 2023). Each subsystem plays an integral role, with its effectiveness contributing cumulatively to overall sustainability outcomes. Consequently, improvements in the functioning of individual subsystems enhance the sector's capacity to support the long-term sustainability of the palm oil industry (Hermanto & Wahyuni, 2021). Some studies show that agribusiness performance has an impact on agribusiness sustainability. This description is consistent with their findings. The performance of business actors, such as the provision of inputs for farming activities, infrastructure and facilities that can increase production, efficient result handling, effective marketing channels, and the role of supporting institutions (formal financial institutions, extension institutions, research institutions, and government), must be reviewed if the sustainability of the palm oil agribusiness increases.

Table 6. Results of the t-test of the direct effect of palm oil agribusiness performance on sustainable palm oil agribusiness

Relationship between variables	Original sample (O)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
Agribusiness performance → Sustainable palm oil agribusiness	0,399	0,069	5,766	0,000**

Source: Data processing results.

b. Evaluation R^2

The variables that impact the performance of palm oil agribusiness, namely farmer traits and farmer rationality, together or simultaneously, have an effect of 0.688 (68.8%), according to the R^2 (Table 7). Other constructions influence the remaining 31.2% of the performance. Then, 0.838 (83.8%) is the impact of palm oil agribusiness performance on sustainable palm oil agribusiness, with other structures influencing the remaining 16.2%.

Tabel 7. R^2 results

Variable	R^2
Y_1	0,688
Y_2	0,838

Source: Data processing results.

c. Goodness of Fit

To assess the overall validity of the model, the Goodness of Fit (GoF) approach proposed by Tenenhaus *et al.* (2004). The GoF index serves as a unified metric to evaluate the combined adequacy of both the measurement model and the structural model. This value is derived by multiplying the average of the communalities index by the model's R^2 value. The results of the GoF calculation are presented in Table 8. A communality's average result is 0.722. After that, this value is rooted and multiplied by R2 (0.763). The strong category includes the requirements for an R2 value of 0.67, the moderate group includes 0.33, and the weak category includes 0.19. The computed GoF value in this study is 0.742, which is higher than 0.67 and classified as a substantial GoF with a strong value, indicating that the proposed model is consistent with empirical data.

Table 8. Goodness of fit (GoF) results

Variables	R Square	Average variance extracted (AVE)
X1	-	0,615
X2	-	0,952
Y1	0,688	0,500
Y2	0,838	0,712
Average	0,763	0,722
GoF		**0,742**

Source: Data processing results.

Based on the overall results of the structural model evaluation, it can be concluded that the proposed conceptual framework demonstrates strong explanatory power and empirical consistency. The findings indicate that farmer rationality serves as a key factor that significantly influences both the performance and sustainability of the palm oil agribusiness, whereas individual farmer characteristics do not exhibit a significant direct effect. Agribusiness performance is also confirmed to be a critical determinant in promoting the sustainability of the palm oil agribusiness. The high coefficient of determination (R^2) values, together with a strong Goodness of Fit (GoF) index, suggest that the model adequately captures and represents the interrelationships among the examined variables in a comprehensive and meaningful manner. Accordingly, this study not only reinforces the theoretical foundations concerning the role of farmer rationality and agribusiness performance in sustainable agribusiness development, but also offers practical implications for policy formulation and strategic interventions aimed at enhancing farmers' rational decision-making capacities and strengthening the overall performance of the palm oil agribusiness system.

CONCLUSION

The sustainable palm oil agribusiness development model indicates that farmer characteristics do not have a significant effect on either the performance of the palm oil agribusiness system or the sustainability of the palm oil agribusiness. However, farmers' rationality has a significant influence on both the performance of the agribusiness system and the sustainability of palm oil agribusiness. Additionally, the performance of the agribusiness system significantly affects the sustainability of the palm oil sector. The first evaluation of farmer characteristics is demonstrated by the modeling findings, which also highlight the importance of managed land and non-formal education. The degree of palm oil sustainability can be ascertained by farmers based on their rationale, primarily in the following order: social, environmental, technological, and economic. The significance of cooperation and backing for the function of auxiliary establishments in accomplishing and enhancing the agricultural system about the production, marketing, product handling, and input subsystems.

RECOMMENDATION

Based on the study's findings, it is recommended to strengthen the role of farmer-level organizations in palm oil processing and marketing. This can empower farmers by improving their bargaining power, building their capacities, and encouraging stronger cooperation among them. Furthermore, the government ought to consistently engage in socialization and collaborate with farmers in order to formulate policies concerning the trajectory of palm oil sustainability and its potential as a superior product.

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