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The Efficiency of Smallholder Rubber Plantations and the Factors That Influence It: A Case Study in Indonesia

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ABSTRACT

Rubber has an essential role in supporting the people's economy in Indonesia, but lately, rubber production has continued to decrease. One of the efforts that significantly affected rubber productivity was a more efficient allocation and use of resources. This effort had to be supported by solid empirical knowledge regarding the technical efficiency of production and resource allocation. The efficiency of smallholder rubber plantations helped increase per capita income in rural areas. This study aimed to evaluate the efficiency level of smallholder rubber plantations and suggest several priority areas to increase the efficiency of smallholder rubber production. This study used 318 families of rubber farmers (15% of rubber farmers). Data collection used a questionnaire. This study analyzes the efficiency of smallholder rubber plantations in Indonesia using the Data Envelopment Analysis (DEA) approach. The results show that most smallholder rubber plantations operate in relatively inefficient conditions. The average technical efficiency (TE) and allocative efficiency (AE) of smallholder rubber plantations were 0.791 and 0.473, respectively. This implies an opportunity to increase the TE and AE of smallholder rubber plantations. Increasing the efficiency of smallholder rubber plantations can be done by adopting the best technology available and by increasing the efficiency of resources owned by farmers, such as land, clonal planting materials, and fertilizers. Clonal planting materials, education, agricultural counseling and training, access to credit, market access, experience in rubber farming, and the gender of the plantation manager determine the efficiency of smallholder rubber plantations. Improving the ability of rubber farmers can be done through counseling and training. It is also necessary to develop credit programs that are more accessible to farmers. Future research can be directed to analyze the technology used and the contribution of women to smallholder rubber plantations which are efficient versus inefficient in increasing the productivity of smallholder rubber.

1. INTRODUCTION

The world's natural rubber industry would generate trade flows, providing employment and income for producing countries [1]. In 2021 Indonesia will be known as the second-largest natural rubber producer in the world after Thailand, with a production of approximately 3,037,000 tons per year [2]. Indonesia's rubber production has fluctuated in the last decade. In 2011, total rubber production was 2.99 million tons; it then increased to 3.68 million tons in 2017. Rubber production in Indonesia reached 3,037,000 tons in 2021; this value decreased by 0.26% from the previous year's 3,045,000 tonnes [2].

Rubber plantations are the world's primary source of natural rubber production. Natural rubber is used as a raw material in several manufacturing sectors, such as the tire manufacturing industry. Each rubber plantation has different plant characteristics and latex quality [3], and these factors affect rubber prices. Su et al. [4] state that rubber prices can change in the long and short term. Changes in the price of rubber in a short time are usually influenced by world natural rubber production and changes in world rubber consumption. In contrast, in the long term, prices are generally affected by changes in production, changes in crude rubber stocks, and changes in the consumption rate of a country or region.

Rubber has an essential role in supporting economic development in Indonesia as an export commodity, but lately, rubber production has continued to decline. To overcome these problems, the Government has attempted to increase the productivity of smallholder rubber plantations through smallholder rubber development projects such as the People's Nucleus Plantation Project, the People's Rubber Development Project, Tree Crop Smallholder Development Projects, and Tree Crop Smallholder Sectors. However, the increase in rubber productivity is still slow, so it is necessary to design a strategy that can be implemented to improve smallholder rubber productivity. One effort that significantly affects productivity is a more efficient allocation and use of resources [5, 6]. However, efforts to improve productivity must be supported by solid empirical knowledge of the technical efficiency of production and the allocation of resources.

Rubber farming faced several obstacles related to farmer-level inefficiencies [4]. Agricultural households in Indonesia have relatively low education, low technology adoption rates, and inefficient use of resources [6]. This causes high production costs and a loss of comparative advantage. With increased efficiency, Indonesia can increase its comparative advantage in rubber production and marketing. This increase in efficiency allows rubber farmers not only to meet domestic demand but also to export rubber to other countries.

Indonesia has agroecological and climatic conditions suitable for rubber plantations. Therefore, this offers a rare opportunity for Indonesian farmers to produce higher-quality rubber. However, to increase their comparative advantage, Indonesian rubber farmers must achieve higher farming productivity and efficiency. Several reports indicate that inadequate use of fertilizers and pesticides and poor access to credit and markets limited the productivity of rubber farmers [4, 7, 8]. However, the statement does not provide specific policies for rubber-producing countries. Therefore, an empirical study was needed to analyze the relationship between inputs, socio-economic factors, and efficiency in smallholder rubber plantations. This study aimed to evaluate the efficiency level of smallholder rubber plantations, identify the factors that affect it, and suggest several priority areas to increase the efficiency of smallholder rubber production.

2. MATERIALS AND METHODS

2.1 Study areas and sampling methods

The research area is Riau Province, and this region was selected based on the central production area (the third largest after South Sumatra and North Sumatra). This region had a rubber production of 308,021 tons in 2019 [9]. Three hundred eighteen households of rubber farmers were randomly selected, and this number is 15% of the rubber farmers in the area [10]. Data collection uses a questionnaire; the data collected is production inputs, production input prices, output quantities, rubber prices at the farmer level, and information on the characteristics of rubber farming households. For qualitative data, before the questionnaire was used, it was tested for the validity and reliability of the items using 20 samples. The validity test uses the Corrected Item to Total Correlation, and the reliability test uses the Cronbach Alpha method with SPSS 24 (Table 1).

Table 1. Validity and reliability test of the instrument

Item-Total Statistics				
Variables	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Adoption of planting material	1.9906	2.319	0.654	0.776
Education	1.9528	2.386	0.597	0.793
Access to credit	1.8208	2.431	0.590	0.795
Access to market	1.9308	2.380	0.602	0.791
Gender of a plantation manager	2.0786	2.382	0.635	0.782

The test results show that the R table value at DF=18 and a probability of 0.05 is 0.468 because the Corrected Item-Total Correlation value>R table=0.468, all items are valid. In addition, the value of Croncbach's Alpha if Item Deleted>R table=0.468 means that all items are reliable. After all the things are valid and reliable, the questionnaire is feasible to use.

2.2 Efficiency analysis with DEA approach

Several studies have been conducted to analyze farming efficiency using Data Envelopment Analysis (DEA) including Tang et al. [11], Le et al. [12], Horvat et al. [13], Chien and Chi [14], Wysokiński et al. [15], Ibrahim et al. [16], and Aziz and Chowdhury [17], but these use time series data. This study uses cross-sectional data with the CRS (constant returns to scale), and VRS (variable returns to scale) approaches to the DEA model. This approach assumes constant returns to scale (CRS)-for example, there are no decision units (DMU)-in this case, rubber farming produces one type of output using different inputs (m). Here, y_i is the production output; xi is the input vector (m×1); Y is the (1×n) output vector, and X is the (m×n) input matrix of the DMU. Then the problem can be stated as follows:

$$\begin{gathered} \text{Min}_{Z_i,\lambda}\ Z_i \\ Z_i\ \lambda,\ \text{subject to:} -y_i+Y\lambda \geq 0, \\ Z_i\ x_i - X\lambda \geq 0, \\ \lambda \geq 0. \end{gathered} \tag{1}$$

where,

Z_i is the ith technical efficiency score of the DMU under CRS conditions, and λ is the (n×1) vector. If Z=1, the DMU is at the boundary and achieves technical efficiency assuming CRS; if Z<1, the DMU lies below the limit and does not achieve technical efficiency. Technically, the cost-efficient production i of the DMU is given by $W_i.Z_i.X_i$ for the CRS model.

CRS can be modified to VRS by adding the convexity constraint: N1'λ=1 in Eq. (1):

$$\begin{gathered} min_{\theta,\lambda}\ \theta^{VRS}, \\ \text{Subject to: } y_i \leq Y\lambda, \\ \theta_{X_i} \geq X\lambda, \\ N1\lambda' = 1 \\ \lambda \geq 0, \end{gathered} \tag{2}$$

where,

N1=N x 1 vector of ones.

The overall economic efficiency (EE) can be solved with a cost-minimizing DEA model (Eq. (3)) assuming CR.

$$\begin{gathered} min_{\lambda,X_i^*}\ W_i' X_i^* \\ \text{Subject to: } y_i \leq Y\lambda, \\ X_i^* \geq X\lambda, \\ \lambda \geq 0, \end{gathered} \tag{3}$$

X_i^*=cost-minimizing input vector (economically efficient for the i^{th} DMU);

W_i'=input price vector;

y_i=output.

Overall, the economic efficiency level of DMU for i^{th} farms is calculated as the ratio of minimum costs to observed costs [18] and is proportional to the level of economic efficiency (EE) (Eq. (4)); if EE=1, it is called economically efficient, and if EE<1 then it does not achieve economic efficiency.

$$EE = \frac{w_i^{'} x_i^{*}}{w_i^{'} x_i} \quad (4)$$

The allocative efficiency index is calculated by Equation (Eq. (5)).

$$AE = \frac{EE}{TE} \quad (5)$$

If AE=1 this indicates that farming has reached price efficiency, AE<1 shows that agriculture is inefficient from a price point of view, so costs must be minimized, and AE>1 indicates farming is not yet efficient. For the three measurements (TE, AE, and EE), TE and EE can take values ranging from 0 to 1, while AE can be 0-1 and>1, where 1 indicates total efficiency.

The output of DEA can be used as the dependent variable in further analysis between socioeconomic variables and units of efficiency [19-22]. Regression analysis of the Tobin model with the ML approach [23] was used to analyze the factors that influence the efficiency of rubber farming (farming variables related to technology and socioeconomic characteristics). This analysis is used because the efficiency value is limited to between zero and one.

$$EE_i^{*} = \alpha_0 + \sum_{j=1}^{k} \alpha_j K_{ij} + \mu_i \cdots\cdots \mu_i \sim \text{ind}\left(0, \sigma^2\right) \quad (6)$$

EE_i^{*} is the dependent variable representing the economic efficiency score i for the DMU estimated from the EEi DEA model, α_0 and α_j are the estimated parameters; K_{ij} is the independent variable related to rubber farming such as planting material, education, etc; and μ_i is a normally distributed error term with zero mean and constant variance (0, σ^2).

2.3 Variable data and specifications

The rubber production function in this study is:

$$Y = f\,(X1, X2, X3, X4, X5, X6) \quad (7)$$

where,

Y=rubber production;
X1=land;
X2=chemical fertilizer;
X3=labor;
X4=cost of pesticides;
X5=plantation sanitation costs.

The determinants of rubber farming efficiency are:

$$EE_i^{*} = f\,(K1, K2, K3, K4, K5, K6, K7) \quad (8)$$

where,

EE_i^{*}=the Ith efficiency of the DEA model DMU;
K_1=adoption of planting material (Dummy)
0=non-clonal
1=clonal;
K_2=education (Dummy)
0=elementary school
1=For others;
K_3=extension and training (number);
K_4=credit access (Dummy)
0=For non-banks
1=For banks;
K_5=market access (Dummy)
0=For those without market access
1=For those who have market access;
K_6=rubber farming experience (number);
K_7=gender of a plantation manager (Dummy)
0=For male
1=For female.

3. RESULTS AND DISCUSSION

3.1 Description of research variables

Descriptions of the variables used in this study are presented in Table 2.

Table 2 shows the average area of smallholder rubber plantations is 1.75 ha per farm with a production of 7,524 kg. The main costs in a rubber plantation are chemical fertilizers, labor, pesticides, and sanitation. Farmers use clonal planting material 45%. Most farmers have primary education (51%), and the average number of extension and training sessions attended by rubber farmers is less than 5 times. 62% of rubber farmers access bank facilities for credit and consist of 51% of the rubber market. The average experience of farmers in rubber farming is 18 years, and 36% of rubber plantations are managed by women; this shows that the role of women in rubber farming is significant.

Table 2. Description of research variables

Variable	Units	Min.	Max.	Mean	Std. Deviation
Output	kg/farm	2,250	16,300	7,524.80	3,167.27
Land	ha/farm	1	3	1.75	0.60
Chemical fertilizer	kg/farm	100	1,100	435.78	234.70
Labor	man-days/farm	78	487	211.38	87.17
Pesticides costs	IDR/farm	231,222	1,156,110	530,000.50	190,671.53
Plantation sanitation costs	IDR/farm	100,000	5,000,000	1,135,465.41	983,929.36
Adoption of planting material	dummy	0	1	0.45	0.50
Education	dummy	0	1	0.49	0.50
Extension and training	number	0	9	4.32	1.63
Credit access	dummy	0	1	0.62	0.49
Market access	dummy	0	1	0.51	0.50
Rubber farming experience	number	9	29	18.39	2.91
Gender of a plantation manager	dummy	0	1	0.36	0.48

Source: Own calculations

3.2 The efficiency of smallholder rubber plantations

Statistical analysis of ordinary least squares (OLS) is used to identify the actual condition of farmers in rubber production. The OLS estimation results from this study are reported in Table 3.

Table 3. Parameter estimation using the OLS method for smallholder rubber plantations

Model	Coefficients	Std. error	rank
Intercept	0.88	0.26	
lnLand	0.31**	0.07	4
lnLabor	0.40***	0.05	3
lnChemical fertilizer	0.88***	0.04	1
lnPesticides costs	0.74***	0.05	2
lnPlantation sanitation costs	0.18***	0.02	5
Adjusted R Square	0.922		

*** significant at α 1%,** significant at α 5%
Source: Own calculations

Table 3 shows that all independent variables in the model were significant in influencing rubber yields. Chemical fertilizers play a major role in the production of rubber, and then pesticides. This indicates that pests and diseases often attack rubber plantations in Indonesia.

The DEAP 2.1 program [24] was used to analyze the efficiency of rubber plantations. The level of technical, allocative, and economic efficiency of smallholder rubber plantations using the CRS and VRS approaches is presented in Table 4.

Table 4 shows smallholder rubber farmers using several different and mostly inefficient technologies. The TE, AE, and EE levels in the CRS and VRS approaches are different. To increase efficiency, smallholder rubber farmers must use production inputs by recommendation and improve plantation management through counseling and training. The average TE, AE, and EE levels in the VRS approach are higher than in CRS; this result is consistent with the findings of Ullah and Perret [25] and Karimov [26].

Table 4. Level of technical, allocative, and economic efficiency of smallholder plantations

Efficiency level	TE		AE		EE	
	CRS	VRS	CRS	VRS	CRS	VRS
	%		%		%	
<4.0	5.03	0.00	33.33	37.12	50.00	42.45
4.0-0.49	4.72	0.00	19.81	17.61	17.30	18.24
0.5-0.59	7.23	5.98	16.35	15.41	13.21	14.78
0.6-0.69	12.58	5.03	13.52	13.21	8.49	9.12
0.7-0.79	27.04	19.18	8.81	9.12	6.60	7.23
0.8-0.89	17.61	15.41	5.98	4.72	2.83	4.72
≥0.9	25.79	54.40	2.20	2.83	1.57	3.46
Mean Efficiency	0.791	0.819	0.473	0.524	0.395	0.423

TE=technical efficiency, AE=allocative efficiency, EE=economic efficiency.
Source: Own calculations

The average TE levels assuming CRS and VRS are 0.791 and 0.819. Smallholder rubber plantations with TE levels of more than 0.90, assuming CRS and VRS, are 25.79% and 54.40%. Most smallholder rubber plantations have TE levels between 0.70–1.00 with these two assumptions. The average AE levels in smallholder rubber plantations, assuming CRS and VRS, are 0.473 and 0.524. Rubber plantations with AE levels>0.90, assuming CRS and VRS, are 2.20% and 2.83%. Most smallholder rubber plantations have an AE level of less than 0.70. The average EE of smallholder rubber plantations, assuming CRS and VRS, is 0.395 and 0.423. This indicates that smallholder rubber plantations are not economically efficient. The EE and AE levels that have been described indicate that cost reduction can be achieved by shifting the production of smallholder rubber plantations to the border isoquant through the efficient use of rubber production inputs (TE) and input reallocation (AE).

3.3 Determinants of the efficiency of smallholder rubber plantations

The results of the Tobit regression analysis of the determinants of TE, AE, and EE of smallholder rubber plantations are presented in Table 5.

Table 5. The determinants of TE, AE, and EE in smallholder rubber plantations

Model	TE		AE		EE	
	Estimate	Std. error	Estimate	Std. error	Estimate	Std. error
Intercept	0.78	0.01	0.56	0.01	0.39	0.01
Adoption of planting material	0.01***	0.01	0.07***	0.01	0.05***	0.01
Education	0.05***	0.01	0.18***	0.01	0.17***	0.02
Extension and training	0.04***	0.02	0.03***	0.01	0.02***	0.01
Credit access	0.08***	0.01	0.05***	0.02	0.07***	0.01
Market access	0.08***	0.02	0.001^{ns}	0.02	0.05***	0.01
Rubber farming experience	0.03***	0.01	0.001^{ns}	0.01	0.04***	0.01
Gender of plantation managers	0.03***	0.01	0.041***	0.01	0.04***	0.01
Sigma	0.096***	0.01	0.13***	0.01	0.09***	0.02
Log likelihood	342.24		276.13		397.97	

*** significant at α 1%,** significant at α 5%
Source: Own calculations

Table 5 implies a positive and significant relationship between the independent variables and technical efficiency, allocative efficiency, and economic efficiency in smallholder rubber plantations. This shows that the inefficiencies in smallholder rubber plantations are largely determined by the variables in Table 5. The planting materials used by rubber farmers are positively and significantly related to TE, AE, and EE, implying that clonal planting materials can reduce inefficiencies in smallholder rubber plantations. Clonal planting materials can increase technical efficiency so that the productivity of smallholder rubber plantations can correspondingly increase. The results of this study differ from Syarifa's [27] findings, which stated that clonal planting materials do not play a role in increasing the efficiency of the rubber plant. Instead, clonal planting materials (superior materials) play an important role in smallholder rubber cultivation and are potentially more technically efficient through higher productivity. This means that clonal planting material has the potential to increase the productivity of smallholder rubber plantations so that the income of rubber farmers also increases. Fuwa et al. [28] and da Silva Dias [29] stated that clonal planting materials play a role in increasing the income of rural communities. Education has a significant and positive effect on TE, AE, and EE, and this shows that education can increase TE, AE, and EE in smallholder rubber plantations. This research is supported by the study of Giroh and Adebayo [30] and Poungchompu and Chantanop [31], which concluded that the level of education plays a role in reducing the inefficiency of smallholder rubber plantations. However, this study differs from the findings of Giroh and Adebayo [32], which stated that the education level of farmers does not affect the inefficiency of smallholder rubber plantations. Higher levels of education can influence farmers to adopt new technologies [33-35].

Extension and training attended by smallholder rubber farmers have a positive and significant relationship to TE, AE, and EE, indicating that extension and training can reduce inefficiencies in smallholder rubber plantations. This finding differs from the study by Aliyu et al. [36], which stated that access to extension services does not affect the efficiency level of smallholder rubber plantations. However, Giroh and Adebayo [30] support the results of this study by concluding that training plays a significant role in increasing the efficiency of smallholder plantations. Extension and training have the potential to increase technical efficiency so that the productivity of smallholder rubber plantations can increase. Extension and training can assist farmers in making decisions, especially with regards to using clonal planting materials, cultivation, and marketing [37]. Extension and training can improve agricultural management skills to increase agricultural efficiency [38-40].

Access to credit has a significant and positive effect on TE, AE, and EE of smallholder rubber plantations. This implies that access to credit can reduce inefficiencies in smallholder rubber plantations. Relevant to the research of Poungchompu and Chantanop [31], which concluded that capital has a positive effect on the production of smallholder rubber plantations. Access to credit allows farmers to obtain the necessary inputs for efficient rubber plantations [41, 42]. Market access has a positive and significant relationship to TE and EE but is not significant to AE, but the direction is positive. This result shows that market access can reduce inefficiency in smallholder rubber plantations. Su et al. [4] revealed that access to the rubber market allows farmers to know the stability of natural rubber prices to sell their products reasonably. In developing countries, farmers are often limited by market access due to a lack of information systems, so the marketing chain becomes ineffective [6]. This condition causes farmers' income to decrease, resulting in decreased availability of inputs, thereby reducing agricultural efficiency.

Rubber farming experience has a significant and positive effect on TE and EE; this implies that rubber farming experience can improve technical and economic efficiency in smallholder rubber plantations. This finding differs from the research by Giroh and Adebayo [30] and Harshani and Shantha [43], which concluded that experience in rubber farming does not affect the inefficiency of smallholder rubber plantations. However, this research is supported by the findings of Aliyu et al. [36] and Syarifa [27], which stated that the rubber farming experience plays an important role in reducing the inefficiency of rubber plantations. Furthermore, rubber farming experience can help farmers decide, especially in choosing the right technology and efficient marketing activities. Furthermore, the gender of plantation managers has a significant and positive effect on TE, AE, and EE of smallholder rubber plantations; this shows that women managers also play a role in smallholder rubber plantations. This differs from the research results by Aliyu et al. [36], which stated that gender does not affect the inefficiency of smallholder rubber plantations. Giroh and Adebayo [30, 32], Harshani and Shantha [43], and Poungchompu and Chantanop [31] argued differently; they concluded that gender plays an important role in increasing the efficiency of smallholder rubber plantations. The same thing was stated by Gbigbi [41] that women managers also play a role in the agricultural sector. Women's participation in smallholder rubber plantations includes work with sanitation, harvesting, post-harvesting, and marketing.

4. CONCLUSIONS

Indonesia is the second largest natural rubber producer in the world after Thailand, but in the last decade, Indonesia's rubber production has fluctuated. To analyze this condition, we estimated the efficiency level of smallholder rubber plantations with DEA analysis and the factors that affected it using Tobit analysis. Most smallholder rubber plantations can increase their income because the average farmer operates relatively inefficiently (Average TE=0.791 and AE=0.473). There is potential to improve the technical and allocative efficiency of smallholder rubber plantations, and this can be done by streamlining the resources owned by farmers. Clonal planting material, education, frequency of attending counseling and training, access to credit, access to markets, rubber farming experience, and the gender of rubber plantation managers are determinants of the technical, allocative, and economic efficiency in smallholder rubber plantations. This implies that these variables are important to increase the output and income of smallholder rubber plantations. These variables need to be considered by policymakers. There is need to promote women's ability in smallholder rubber plantations (such as women's farmer groups). Counseling and training need to be increased in frequency, content, and quality so that the productivity and income of smallholder rubber plantations can increase. People's credit programs need to be considered, and programs that make production credit more accessible to farmers should be developed. We suggest future research to determine the technology used and the contribution of women against efficient versus inefficient smallholder rubber plantations. The study would complement the contribution of our research. In addition, our research would lead to policies that would increase the income of smallholder rubber farmers.

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