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Measuring Production Efficiency and Technology Gap Between RSPO-Certified and Non-Certified Smallholders: A Metafrontier - DEA Framework

Khairul Fahmi Purba[1*], Dian Retno Intan[2], Tifany Zia Aznur[3], Azqia Wardani[1], Hendris Syah Putra[4]

[1] Department of Agricultural Socioeconomics, Faculty of Agriculture, Universitas Sriwijaya, Indralaya 30662, Indonesia
[2] Department of Agribusiness, Faculty of Agriculture, Universitas Muhammadiyah Sumatera Utara, Medan 20238, Indonesia
[3] Department of Agribusiness, Faculty of Science and Technology, Institut Teknologi Sawit Indonesia, Medan 20222, Indonesia
[4] Department of Agribusiness, Faculty of Agriculture and Forestry, Universitas Satya Terra Bhinneka, Medan 20128, Indonesia

Corresponding Author Email: khairulfahmipurba@fp.unsri.ac.id

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ABSTRACT

Indonesia is the world's leading palm oil producer. Therefore, it is demanded to comply with sustainability standards through Roundtable on Sustainable Palm Oil (RSPO) certification. Nevertheless, a considerable number of smallholders are still unwilling to pursue certification for their plantations. This phenomenon highlights the underlying constraints and disparities between RSPO-certified and non-certified smallholders across technological, social, economic, and environmental aspects. This study investigates the production efficiency and technology gap between RSPO-certified and non-certified smallholders in Simalungun Regency, Indonesia. A total of 342 smallholders were selected by stratified random sampling. Furthermore, 161 RSPO-certified and 181 non-certified smallholders were interviewed. A Metafrontier - Data Envelopment Analysis (DEA) framework was applied to measure technical, allocative, and economic efficiencies, as well as the technology gap ratio (TGR). The results indicate that RSPO-certified smallholders outperform non-certified smallholders across all kinds of efficiencies. Moreover, RSPO-certified smallholders obtain higher TGR indicating proximity to the best practice frontier compared to non-certified smallholders. These findings highlight the crucial role of RSPO certification in enhancing smallholders' efficiency, competitiveness, and sustainability. Policy implications suggest that expanding certification schemes and strengthening cooperative-based support systems are essential to narrow efficiency gaps and promote sustainable palm oil production in Indonesia.

1. INTRODUCTION

Oil palm is a flagship crop of Indonesia's plantation commodities, positioning Indonesia as the world's first-ranked producer [1]. The oil palm sector holds a strategic position and makes a significant contribution to the national economy, demonstrated by 1.69% share of the gross domestic product (GDP) and export earnings amounting to USD 14.43 billion [2]. As an export commodity, oil palm must adhere to global standards to maintain competitiveness and acceptance in the international market. One of the key standards to be fulfilled is sustainability certification through the Roundtable on Sustainable Palm Oil (RSPO) [3]. This certification aims to ensure that palm oil production is conducted in an environmentally sustainable manner without adverse social and economic impacts at the same time [4, 5].

Moreover, the importance of RSPO certification lies in mitigating deforestation, forest fires, and the loss of wildlife habitats [6-8]. The RSPO framework encourages sustainable palm oil production by limiting illegal land clearance and preventing environmental degradation [9]. Through RSPO certification, Indonesia can effectively demonstrate commitment, image, and reputation regarding the sustainability of oil palm industry to the global [10, 11]. Furthermore, RSPO also protects the rights of workers and smallholders by ensuring fair remuneration, safe working conditions, and the upholding of labour rights. Additionally, smallholders adhering to RSPO standards receive better prices, thereby enhancing their socioeconomic welfare and bargaining power [12-14].

Based on the policy perspective, the RSPO supports the Indonesian government's initiative through the Indonesian Sustainable Palm Oil (ISPO) certification, reinforcing national sustainability efforts. RSPO also positively impacts food security and women's empowerment [15]. Although RSPO and ISPO are distinct schemes, both share the aligned objective to ensure the Indonesian palm oil industry adheres to principles of sustainability, social responsibility, and economic viability [16-18]. Therefore, sustainability certification is crucial for achieving the Sustainable Development Goals (SDGs) and advancing the sustainable palm oil industry in Indonesia, underscoring the importance of conducting research in this domain [19].

One of the leading oil palm-producing provinces in Indonesia is North Sumatra, ranking fourth nationally. Although not being the top producer, North Sumatra is the only province on Sumatra Island with the highest oil palm productivity, amounting to 4,351 kg per hectare [20]. Within this province, Simalungun Regency stands out as a major palm oil producer, ranking among the top five in both production volume and cultivated area. Smallholders' oil palm plantations cover 497,197 hectares, accounting for 36.77% of the total cultivated area in Simalungun, surpassing state-owned plantations in both production and size [21]. This highlights the critical role and substantial contribution of smallholder palm oil cultivation to the regional and national economy. Despite the significant potential of smallholder plantations, various challenges persist including the low adoption rate of RSPO certification among smallholders [22]. This is crucial considering the numerous social, economic, and environmental benefits associated with RSPO certification in the palm oil sector [23, 24].

The RSPO certification process requires smallholders to be members of an organized entity, as individual certification is not permitted. Encouragingly, several smallholder palm oil plantations in Simalungun Regency have obtained RSPO certification by participating in a cooperative, namely Koperasi Bersatu Makmur Jaya (BMJ). This cooperative has facilitated the certification of 656 smallholders. Despite the existence of such rural institution, many smallholders remain reluctant to participate as cooperative members and pursue certification for their plantations. This situation obviously reflects the existing problem and gap between RSPO-certified and non-certified smallholders occurring across technological, social, economic, and environmental aspects.

Measuring production efficiency and technology gaps is essential to quantify the technological and economic disparities between RSPO-certified and non-certified smallholders. Several previous studies have investigated technology gaps in various agricultural commodities such as paddy [25], maize [26], banana [27], cattle [28], etc. A recent study specifically recommends conducting a quantitative assessment of the technology gap between RSPO and non-RSPO-certified smallholders. To date, no studies have applied the metafrontier approach to measure technology gaps in the palm oil sector [29]. Recent research on palm oil in North Sumatra has primarily focused on technical efficiency (TE) and farming income [30]. This study aims to advance beyond prior work by measuring efficiency from three dimensions: technical, allocative, and economic. Therefore, this research objective is to comprehensively assess production efficiency and technology gap between RSPO-certified and non-certified smallholders. The findings are anticipated to provide empirical evidence and policy implications for smallholders, policymakers, and stakeholders towards sustainable oil palm in Indonesia.

2. METHODS

2.1 Data collection

This study was conducted in three villages in Simalungun Regency, namely Sidomulyo (3°01′43″ N, 99°21′40″ E), Marihat Butar (2°59′52″ N, 99°20′53″ E) and Tempel Jaya (3°02′19″ N, 99°20′52″ E). The geographical position of the research location is presented in Figure 1. The site was chosen because it has existing RSPO-certified smallholders and cooperative as rural institution or organisation assisting the oil palm smallholders to obtain RSPO certification. This study employed a quantitative approach. Furthermore, the method used was a survey [31]. The survey was carried out to collect primary data directly from certified RSPO and non-certified smallholders through face-to-face interviews and focus group discussions. This method is a compatible data collection method for comparative study [32].

Figure 1. Location of study

Research instrument used for data collection was a questionnaire. This study collected data encompassing the sociodemographic characteristics of both RSPO-certified and non-RSPO smallholders, including age, year of schooling, farming experience, household size, land tenure, and other pertinent attributes. Furthermore, the data regarding input use and cost covering land area, amount of tree, fertilizer, labour and production outputs were also systematically gathered. The data collection framework follows established methodologies in previous studies [33-36].

The sampling technique utilized in this study was stratified random sampling. Stratified random sampling was chosen to ensure representative subgroups within the population, thereby enhancing the precision and reliability of the study findings [37]. The stratification criteria used was certification status. A total of 342 respondents participated, comprising two distinct groups: 161 RSPO-certified smallholders and 181 non-certified smallholders. The sample size was appropriate, proportional and optimum for this research [38].

2.2 Data analysis

Data analysis to measure technical, allocative, and economic efficiency (EE), as well as technology gaps, was conducted using the Data Envelopment Analysis (DEA) with metafrontier framework [39-43]. DEA is a non-parametric data envelopment technique based on linear programming introduced by Charnes et al. [44] for evaluating efficiency. It has been widely known and applied across various sectors including education [45-48], healthcare [49-51], manufacturing [52-54], banking [55-57], etc. In this study, the input-oriented DEA model under the variable returns to scale (VRS). VRS model considers the relationship between input and output is not always proportional. Increasing input can produce proportionally larger output (increasing returns to scale) or smaller output (decreasing returns to scale). The assumption was utilized to derive TE scores ranging from 0 to 1, along with returns to scale conditions classified as increasing returns to scale (IRS), constant returns to scale (CRS), and decreasing returns to scale (DRS) for each decision-making unit (DMU) [58]. TE was calculated as shown in the below:

$$\text{Minimize } \theta \tag{1}$$

Subject to: $\sum_{j=1}^{n} \lambda_j x_{ij} \leq \theta x_{ij0} \quad i = 1, \dots, m$
$\sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{r0} \quad r = 1, \dots, s$
$\lambda_j \geq 0 \quad j = 1, \dots, n$

where:
θ: vector of input use for the j-th DMU
x_{ij}: input
y_{rj}: output

Subsequently, EE is conceptualized as the integration of both technical and allocative efficiencies. Given that EE is influenced by price variables, it is essential to incorporate a price vector corresponding to the i-th input (w_i) into the analysis. EE is quantitatively assessed using this equation.

$$\text{Minimize } \theta_i w_i \tag{2}$$

Subject to: $\sum_{j=1}^{n} \lambda_j x_{ij} \leq \theta x_i w_{ij0} \quad i = 1, \dots, m$
$\sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{r0} \quad r = 1, \dots, s$
$\lambda_j \geq 0 \quad j = 1, \dots, n$

Upon obtaining the TE and EE scores, the allocative efficiency (AE) can be determined. AE is defined as the ratio of EE to TE [59]. Moreover, AE serves as an indicator of the degree to which farmers are successful in maximizing their profits. It is achieved when the marginal product of each respective production input is equal to its marginal cost, reflecting the capability to employ inputs in optimal proportions. AE was estimated by:

$$AE = \frac{EE}{TE} \tag{3}$$

The metafrontier approach serves as a robust analytical framework for comparing performance across two or more distinct groups by utilizing a unified production frontier. This metafrontier embodies the most efficient production technology achievable by each group, considering their respective resource endowments and technological capabilities. Initially, TE for each group was assessed independently to derive group-specific frontiers (TE_{group}). Subsequently, the complete dataset was analysed collectively to estimate the metafrontier efficiency (TE_{meta}), as depicted in Figure 2.

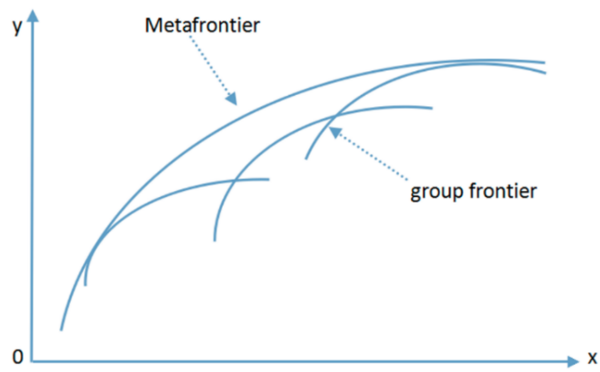

Figure 2. Curve of metafrontier and group frontier [60]

The technology gap ratio (TGR) is employed to predict the maximum output achievable by each DMU based on their input vector. The gap between the group-specific distance function and the metafrontier distance function serves as a measure of how close the group frontier is to the metafrontier, and this is quantified by the TGR. A larger TGR value indicates a smaller technological gap between the group and the metafrontier [61, 62]. The TGR was calculated using formula:

$$TGR = \frac{TE_{group}}{TE_{meta}} \tag{4}$$

3. RESULT AND DISCUSSION

3.1 Sociodemographic characteristics of oil palm smallholders

Table 1 presents information indicating that the majority of oil palm smallholders, both RSPO-certified and non-certified, are male, accounting for 79.5% and 69.1%, respectively. This suggests that oil palm cultivation remains male-dominated;

nevertheless, female participation is still considerable. This finding is consistent with data from the RSPO database, which reports that women's involvement in oil palm farming is approximately 23%. Hence, gender equality in oil palm smallholding can be considered relatively encouraging. Previous studies also highlight that women's participation in agriculture plays an essential role in agricultural production and sustainability [63, 64].

Table 1. Sociodemographic characteristics of oil palm smallholders

Characteristic	Roundtable on Sustainable Palm Oil (RSPO)-certified		Non-certified	
	Frequency	%	Frequency	%
Gender				
Male	128	79.503	125	69.0641
Female	33	20.497	56	30.939
Age (years old)				
21-30	5	3.106	18	9.945
31-40	22	13.665	36	19.890
41-50	34	21.118	39	21.547
51-60	48	29.814	61	33.702
61-70	41	25.466	22	12.155
≥ 71	11	6.832	5	2.762
Education				
Unschooled	16	9.938	12	6.630
Primary school	68	42.236	88	46.619
Secondary school	38	23.602	47	25.967
High School	36	22.360	29	16.022
College	3	1.863	5	2.762
Household size				
1-2	68	42.236	35	19.337
3-4	82	50.932	127	70.166
5-6	9	5.590	19	10.497
≥ 7	2	1.242	0	0.000
Side job				
Without	117	72.671	134	74.033
Livestock	21	13.043	26	14.365
Small retail	12	7.453	12	6.630
Others	11	6.832	9	4.972
Cultivating experience (years)				
5-10	30	18.634	28	15.470
11-20	59	36.646	56	30.939
21-30	67	41.615	88	48.619
≥ 31	5	3.106	9	4.972

Furthermore, most oil palm smallholders are within the productive age group (21–60 years old). Notably, most smallholder in both groups are concentrated in the 51–60 years age range. While the farming population is predominantly older, the most pronounced decline in productivity, around 10%, is observed among farmers over 65 years of age [65]. This finding suggests that age-related physical limitations and reduced working capacity at this stage of life become critical factors influencing agricultural efficiency.

Another important sociodemographic characteristic is education level. The education level of oil palm smallholders remains relatively low, with the majority having only completed primary school, both among RSPO-certified smallholders (42.2%) and non-certified smallholders (46.6%). Several studies have also demonstrated a significant relationship between education level and both productivity and efficiency [66, 67]. Moreover, limited formal education can hinder smallholders' ability to understand complex certification standards. Education positively influences farmers' capacity to adopt sustainability standards and certification such as RSPO [68]. Low educational attainment also poses a challenge for effective farm management practices, as literacy and numeracy are essential for decision-making [69].

Most certified smallholders live in households with 3–4 dependents, a pattern also observed among non-certified smallholders' households. While larger households may provide greater availability of family labour, they also increase the economic burden. The larger households often rely heavily on family labour for traditional farming [70]. Another noteworthy finding is that the majority of smallholders, both RSPO-certified and non-certified smallholders, do not have secondary occupations (approximately 73%). However, livelihood diversification appears slightly higher among RSPO-certified smallholders, for instance, through livestock or small-scale retail. Income diversification has been shown to be an important strategy for mitigating commodity price risks as well as a livelihood strategy for rural households [71]. RSPO-certified smallholders may be more resilient to market fluctuations than non-certified smallholders.

3.2 Production and agricultural input use

Table 2 presents a comparison between RSPO-certified and non-certified oil palm smallholders in terms of production and agricultural input use. The analysis reveals significant differences that may indicate the impact of certification on productivity and resource-use efficiency. The average production of RSPO-certified smallholders is higher (949.5 kg) compared to non-certified smallholders (610.2 kg). This suggests that certification is associated with improved productivity. Previous studies support this finding, showing that sustainability certification encourages the adoption of better agronomic practices, more intensive farm management, and access to more favourable markets [72, 73].

Table 2. Production and agricultural input use between Roundtable on Sustainable Palm Oil (RSPO)-certified and non-certified smallholders

Item	RSPO-certified		Non-certified	
	Mean	Std. Deviation	Mean	Std. Deviation
Production (kg)	949.476	616.460	610.222	475.153
Land size (ha)	1.141	0.770	0.921	0.657
Planting density (tree/ha)	129.762	79.334	106.133	69.878
Fertilizer (kg)	165.839	86.759	170.972	90.860
Labour (hour)	34.427	17.7933	16.889	9.646

The average cultivated land area of certified smallholders is also larger (1.14 ha) compared to non-certified smallholders (0.92 ha). Although the difference appears relatively small, it has implications for production capacity and farm scale. Larger landholdings provide more opportunities for implementing management practices that comply with certification standards. Furthermore, certification schemes are often more accessible to farmers operating on relatively larger scales [74]. RSPO-certified smallholders also maintain higher planting density (129 trees/ha) compared to non-certified smallholders (106 trees/ha). Optimizing planting density can contribute to higher yields, provided that key agronomic factors such as maintenance, fertilization, and harvesting are properly managed. Planting density management is a critical factor for improving the productivity of smallholder oil palm plantations [75].

Interestingly, fertilizer use tends to be slightly higher among non-certified smallholders (171 kg) compared to RSPO-certified smallholders (166 kg). However, the findings of this study indicate that higher productivity among certified farmers does not primarily result from fertilizer inputs, but rather from a combination of factors such as improved agronomic practices, better farm management, and greater access to information. Fertilizer use among smallholder oil palm farmers is often inefficient, and that yield improvements rely more heavily on sound farm governance than on the sheer quantity of inputs applied [76].

A striking difference is observed in labour allocation. RSPO-certified smallholders dedicate an average of 34.4 working hours, more than double that of non-certified smallholders (16.9 hours). It demonstrates that sustainability certification promotes more intensive farm maintenance, for instance through timely fertilization, effective weed control, and more cultivation practices. The certification schemes encourage greater management intensity, albeit with the implication of higher labour requirements [77].

3.3 Technical efficiency

Figure 3 illustrates the distribution of TE among RSPO-certified smallholders and non-certified smallholders. The results reveal a distinct difference in efficiency distribution; whereby certified farmers tend to exhibit higher levels of TE with a distribution concentrated around medium to high efficiency scores. In contrast, non-certified smallholders display a more dispersed distribution, with a significant proportion falling within the lower efficiency range.

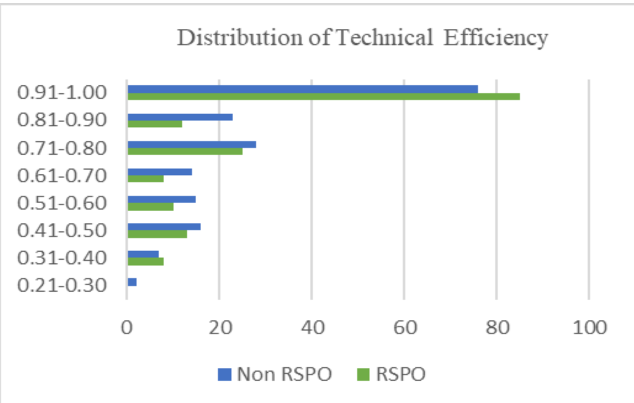

Figure 3. Distribution of technical efficiency (TE) between RSPO-certified and non-certified smallholders

RSPO-certified farmers exhibit a more stable distribution of efficiency, indicating consistency in the implementation of cultivation practices in accordance with RSPO standards. RSPO-certified smallholders obtain good agricultural practices (GAP) training. On the other hand, non-certified smallholders do not have access to such training and extension. The sustainability certification can enhance farmers' technical skills and assist the farmers reduce inefficient cultivation practices [78]. In contrast, the wider efficiency distribution among non-certified smallholders reflects heterogeneity in farm management practices, with some farmers already technically efficient while many others remain considerably behind.

The higher level of TE among certified farmers, despite their fertilizer use being relatively similar to that of non-certified smallholders, suggests that productivity gains stem from improved input allocation rather than increased input intensity. One of the key modules delivered through GAP training is the optimal use of fertilizers. This underscores the fact that certification not only facilitates better market access but also plays a crucial role in enhancing input-use efficiency. Sustainability certification helps reduce productivity gaps by promoting farmer training and the adoption of sustainable agronomic practices [79].

3.4 Allocative efficiency

Figure 4 presents the distribution of AE scores for two groups of smallholders, namely RSPO-certified and non-certified smallholders. In summary, the emerging pattern shows that RSPO-certified smallholders display a more concentrated distribution of AE scores that tends to shift toward higher values. It indicates that farmers in this group are more likely to use an input mix (labour, fertilizer, land area, etc.) that is closer to the cost-minimizing combination for producing the observed output. In contrast, non-certified smallholders exhibit a more dispersed distribution with a larger proportion at lower AE scores. This suggests substantial heterogeneity in input allocation strategies and the presence of potential cost inefficiencies among some smallholders.

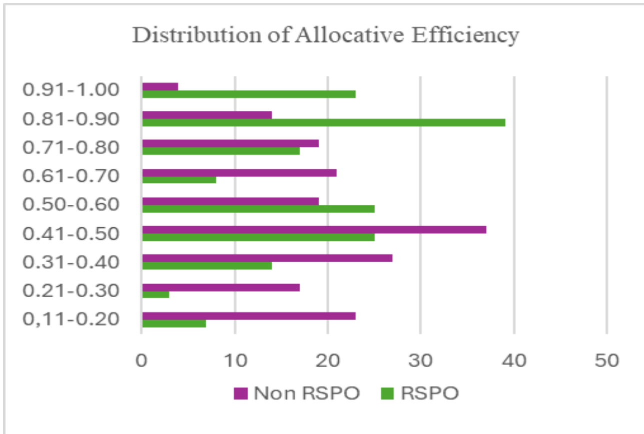

Figure 4. Distribution of allocative efficiency (AE) between RSPO-certified and non-certified smallholders

AE reflects the extent to which inputs are used in optimal proportions given their prices and marginal productivity. Higher AE implies that smallholders are more likely to select an input mix that maximizes the value of output relative to production costs. Higher AE among RSPO-certified smallholders can be explained by several mechanisms. One of the mechanisms is incentive [80]. RSPO-certified smallholders receive a price incentive of IDR 30 per kg of production, meaning that they obtain higher prices than non-certified smallholders. This incentive is accumulated over the year and later converted into fertilizer support and subsidy for the smallholders. The price differential between RSPO-certified and non-certified smallholders directly contributes to differences in AE. These finding highlights that financial support schemes, such as price incentives, can play an important role in improving the performance of low-efficiency smallholders [81].

In addition, the formation of farmer groups or cooperatives can improve access to price information and facilitate collective input purchases, thereby enhancing AE. In this context, Koperasi Bersatu Makmur Jaya (BMJ) plays a pivotal institutional role in strengthening certified farmers' access to both information and markets [82]. Such collective action mechanisms have been shown to reduce transaction costs, improve bargaining power, and enhance the adoption of efficient input-use practices among smallholders [83, 84]. Unfortunately, this cooperative has not provided microfinance and credit service for smallholders. Consequently, the smallholders are not ready to conduct replanting the plantation. In fact, the crop's age is no longer productive [85].

3.5 Economic efficiency

Figure 5 displays the distribution pattern of EE across the two groups: RSPO-certified smallholders tend to cluster around medium-to-high EE scores, whereas non-certified smallholders display a more dispersed distribution with a larger proportion at lower EE levels. Conceptually, EE combines both technical aspects (producing maximum output from given inputs) and allocative aspects (choosing an input mix that optimizes costs relative to revenues). Thus, the pattern observed in Figure 5 indicates that certification is associated with a more favourable combination of technical practices and cost-management decisions. The phenomenon that certification is linked to improved managerial performance and cultivation practices has also been documented in field studies on smallholders and oil palm certification schemes.

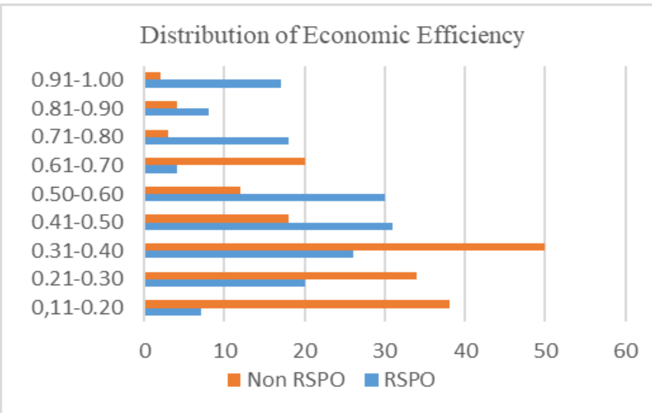

Figure 5. Distribution of economic efficiency (EE) between RSPO-certified and non-certified smallholders

These results suggest that RSPO certification strengthens smallholders' ability to combine TE with cost-minimizing input choices, thereby enhancing their overall economic competitiveness. RSPO-certified smallholders obtain benefit not only from training in GAP but also from institutional support that improves access to markets and input supply chains. The certification can reduce productivity and efficiency gaps by promoting improved agronomic practices and managerial capacities among smallholders [86]. Furthermore, yield gaps in oil palm are primarily driven by management practices rather than the quantity of inputs applied [87] which is consistent with the findings of this study.

At the same time, the broader distribution of EE among non-certified smallholders reflect high heterogeneity in farm performance, with some farmers operating efficiently but many others lagging behind. This heterogeneity often arises from differences in access to capital, information, and institutional support. Without targeted interventions, these disparities may persist and widen. Previous studies argue that certification schemes can serve as a pathway to address such heterogeneity by standardizing practices, offering price incentives, and facilitating access to collective action mechanisms such as cooperatives [88].

From a policy perspective, the findings underscore the importance of expanding certification programs alongside complementary institutional support. Financial incentives, cooperative-based marketing, and training programs can help improve both technical and AE among uncertified farmers, thereby narrowing the EE gap between groups. In this regard, certification functions not only as a market-based instrument but also as a capacity-building mechanism that enables smallholders to improve resource use, increase productivity, and enhance resilience to market fluctuations.

3.6 Technology gap

Table 3 highlights substantial differences in technical performance between RSPO-certified and non-certified smallholders. The average TE score for RSPO-certified smallholders is 0.910, compared to 0.766 for non-certified smallholders, while the metafrontier (combined) value is recorded at 0.842. The difference in mean TE was also statistically tested (t = 5.736, p = 0.002), indicating that the performance gap between the two groups is statistically significant at conventional levels. This suggests that RSPO-certified farmers consistently operate closer to the TE frontier compared to the non-certified smallholders.

Table 3. Result of technical gap analysis between RSPO-certified and non-certified smallholders

Item	RSPO	Non-certified	Metafrontier
Mean of TE	0.910	0.766	0.842
TGR	0.951	0.707	0.822
Slack output	23.727	46.938	34.794
Slack input			
Land size	0.137	0.412	0.227
Planting density	18.384	27.734	23.300
Fertilizer	20.500	39.280	33.600
Labour	0.159	0.427	0.362
t-test		8.365 (p = 0.000)	
Mann-Whitney U		6.890 (p = 0.000)	

Note: TE = technical efficiency, TGR = technology gap ratio, RSPO = Roundtable on Sustainable Palm Oil

Conceptually, the technical gap (0.951 for RSPO-certified smallholders vs. 0.707 for non-certified smallholders, with a metafrontier of 0.822) reflects the distance between the group frontier and the metafrontier (regional or overall "best practice" frontier). A higher technical gap ratio for RSPO-certified farmers indicates that their group frontier is almost aligned with the metafrontier in other words, RSPO-certified smallholders are closer to the overall technical "best practice" among the sample. Conversely, the score of 0.707 for non-certified smallholders suggests a larger deviation from best practice, implying greater biological and managerial potential to improve TE [89]. The greater variation observed among non-certified smallholders also reflects higher socio-economic heterogeneity, such as differences in education levels, farming experience, and household size (see Table 1). A wider distribution of TE scores typically signals constraints in access to technology, information, and institutions [90]. Furthermore, smallholders' oil palm plantations in Indonesia show significant land inefficiency, which supports the notion that slack in land input is a common issue among non-certified or resource-constrained farmers [91].

Slack analysis provides a quantitative perspective on the scope for operational improvements. The average output slack for RSPO-certified smallholders is 23,727 compared to 46,938 for non-certified smallholders (metafrontier: 34,794), suggesting that the non-certified group has greater potential output gains if inefficiencies are eliminated. For input slack, all categories (land size, planting density, fertilizer, labour) exhibit higher values among non-certified smallholders (e.g., land size 0.412 vs. 0.137; fertilizer 39,280 vs. 20,500; labour 0.427 vs. 0.159). It indicated that the agricultural input and resources use was not optimum. This aligns with findings by Irawan et al. [92] who documented that RSPO-certified smallholders often achieve cost reductions and reduce input redundancies compared to non-certified smallholders, particularly in fertilizer use and labour allocation. The economic interpretation is that there is substantial room to reduce input waste and/or increase output among non-certified smallholders through improved agronomic management and input allocation strategies [93].

4. CONCLUSIONS

This study concluded that RSPO certification contributes to improve production efficiency of smallholders and reduce technology gap. Explicitly, the sustainability certification supports sustainable palm oil production in Indonesia. Therefore, the non-certified smallholders should be encouraged to pursue the certification to obtain the benefits impacting to the economic welfare and performance. The government and relevant stakeholders should formulate policies concerning empowerment and enforcement of rural institution such as farmer group, cooperative, etc. to expand this certification inclusively for the smallholders.

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REFERENCES

[1] Khatiwada, D., Palmén, C., Silveira, S. (2021). Evaluating the palm oil demand in Indonesia: Production trends, yields, and emerging issues. Biofuels, 12(2): 135-147. https://doi.org/10.1080/17597269.2018.1461520

[2] Purnomo, H., Okarda, B., Dermawan, A., Ilham, Q.P., Pacheco, P., Nurfatriani, F., Suhendang, E. (2020). Reconciling oil palm economic development and environmental conservation in Indonesia: A value chain dynamic approach. Forest Policy and Economics, 111: 102089. https://doi.org/10.1016/j.forpol.2020.102089

[3] Brandi, C., Cabani, T., Hosang, C., Schirmbeck, S., Westermann, L., Wiese, H. (2015). Sustainability standards for palm oil: Challenges for smallholder certification under the RSPO. Journal of Environment and Development, 24(3): 292-314. https://doi.org/10.1177/1070496515593775

[4] Apriani, E., Kim, Y.S., Fisher, L.A., Baral, H. (2020). Non-state certification of smallholders for sustainable palm oil in Sumatra, Indonesia. Land Use Policy, 99: 105112. https://doi.org/10.1016/j.landusepol.2020.105112

[5] Renner, S., Ruml, A., Lakemann, T., Nuryartono, N., Tjoa, A., Corre, M.D., Lay, J. (2024). Smallholder RSPO certification, economic benefits and agrochemical use. Environmental Research Letters, 19(11): 114093. https://doi.org/10.1088/1748-9326/ad8367

[6] Cattau, M.E., Marlier, M.E., DeFries, R. (2016). Effectiveness of roundtable on sustainable palm oil (RSPO) for reducing fires on oil palm concessions in Indonesia from 2012 to 2015. Environmental Research Letters, 11(10): 105007. https://doi.org/10.1088/1748-9326/11/10/105007

[7] Carlson, K.M., Heilmayr, R., Gibbs, H.K., Noojipady, P., Burns, D.N., Morton, D.C., Walker, N.F., Paoli, G.D., Kremen, C. (2018). Effect of oil palm sustainability certification on deforestation and fire in Indonesia. Proceedings of the National Academy of Sciences of the United States of America, 115(1): 121-126. https://doi.org/10.1073/pnas.1704728114

[8] Purnomo, H., Okarda, B., Dewayani, A.A., Ali, M., Achdiawan, R., Kartodihardjo, H., Pacheco, P., Juniwaty, K.S. (2018). Reducing forest and land fires through good palm oil value chain governance. Forest Policy and Economics, 91: 94-106. https://doi.org/10.1016/j.forpol.2017.12.014

[9] Oliphant, E., Simon, A.C. (2022). The cost of sustainable palm oil: Should an Indonesian smallholder pursue RSPO-certification? World Development Perspectives, 26: 100432. https://doi.org/10.1016/j.wdp.2022.100432

[10] McCarthy, J., Zen, Z. (2009). Regulating the oil palm boom: Assessing the effectiveness of environmental governance approaches to agro-industrial pollution in Indonesia. Law and Policy, 32(1): 153-179. https://doi.org/10.1111/j.1467-9930.2009.00312.x

[11] Nusli, H., Muhamad, M.Z., Mustafa, M.M., Vaiapuri, S., Fatah, F.A., Syahlan, S. (2024). Sustainable certification in the oil palm industry: A comparative analysis of MSPO, RSPO, ISPO and ISCC schemes. In International Conference on Agritechnology & Biprocessing Innovation 2024: Fostering Sustainability through Emerging Trends in Agriculture Technology and Bioprocessing, Universiti Teknologi Maysia.

[12] De Vos, R.E., Suwarno, A., Slingerland, M., Van Der Meer, P.J., Lucey, J.M. (2021). Independent oil palm smallholder management practices and yields: Can RSPO certification make a difference? Environmental Research Letters, 16(6): 065015. https://doi.org/10.1088/1748-9326/ac018d

[13] Furumo, P.R., Rueda, X., Rodríguez, J.S., Parés Ramos,

I.K. (2020). Field evidence for positive certification outcomes on oil palm smallholder management practices in Colombia. Journal of Cleaner Production, 245: 118891. https://doi.org/10.1016/j.jclepro.2019.118891

[14] Hutabarat, S., Slingerland, M., Rietberg, P., Dries, L. (2018). Costs and benefits of certification of independent oil palm smallholders in Indonesia. International Food and Agribusiness Management Review, 21(6): 681-700. https://doi.org/10.22434/IFAMR2016.0162

[15] Oosterveer, P., Adjei, B.E., Vellema, S., Slingerland, M. (2014). Global sustainability standards and food security: Exploring unintended effects of voluntary certification in palm oil. Global Food Security, 3(3-4): 220-226. https://doi.org/10.1016/j.gfs.2014.09.006

[16] Bissonnette, J.F. (2016). Is oil palm agribusiness a sustainable development option for Indonesia? A review of issues and options. Canadian Journal of Development Studies, 37(4): 446-465. https://doi.org/10.1080/02255189.2016.1202101

[17] Teapon, R.R.H., Evalia, N.A., Purba, K.F., Rumkel, N., Hayati, P.K.D. (2023). A modeling for sustainable oil palm development in South Halmahera, Indonesia: An evidence from local community. Journal of Sustainability Science and Management, 18(5): 16-32. https://doi.org/10.46754/jssm.2023.05.002

[18] Evalia, N.A., Teapon, R.R.H., Purba, K.F., Rumkel, N., Hayati, P.K.D. (2024). The synergy between SDGs and Indonesian sustainable palm oil in realising sustainable oil palm development in South Halmahera, Indonesia. Environmental Research, Engineering and Management, 80(2): 88-99. https://doi.org/10.5755/j01.erem.80.2.34761

[19] Abubakar, A., Ishak, M.Y. (2024). Exploring the intersection of digitalization and sustainability in oil palm production: Challenges, opportunities, and future research agenda. Environmental Science and Pollution Research, 31: 50036-50055. https://doi.org/10.1007/s11356-024-34535-9

[20] Statistics Indonesia. (2024). Indonesian Oil Palm Statistics 2023. Jakarta: BPS RI. https://www.bps.go.id/en/publication/2024/11/29/d5dcb42ab730df1be4339c34/indonesian-oil-palm-statistics-2023.html.

[21] Statistics Indonesia. (2024). Sumatera Utara Province in Infographics 2024. Medan: BPS Sumut. https://sumut.bps.go.id/en/publication/2024/06/05/2a6d2b7038b0313e85a9c98f/sumatera-utara-province-in-infographics-2024.html.

[22] Qaim, M., Sibhatu, K.T., Siregar, H., Grass, I. (2020). Environmental, economic, and social consequences of the oil palm boom. Annual Review of Resource Economics, 12: 321-344. https://doi.org/10.1146/annurev-resource-110119-024922

[23] Aziz, N.F., Chamhuri, N., Batt, P.J. (2021). Barriers and benefits arising from the adoption of sustainable certification for smallholder oil palm producers in Malaysia: A systematic review of literature. Sustainability, 13(18): 10009. https://doi.org/10.3390/su131810009

[24] Watts, J.D., Pasaribu, K., Irawan, S., Tacconi, L., Martanila, H., Wiratama, C.G.W., Musthofa, F.K., Sugiarto, B.S., Manvi, U.P. (2021). Challenges faced by smallholders in achieving sustainable palm oil certification in Indonesia. World Development, 146: 105565. https://doi.org/10.1016/j.worlddev.2021.105565

[25] Haryanto, T., Talib, B.A., Salleh, N.H.M. (2016). Technical efficiency and technology gap in Indonesian rice farming. Agris On-Line Papers in Economics and Informatics, 8(3): 29-38. https://doi.org/10.7160/aol.2016.080303

[26] Pourzand, F., Bakhshoodeh, M. (2014). Technical efficiency and agricultural sustainability-technology gap of maize producers in Fars province of Iran. Environment, Development and Sustainability, 16: 671-688. https://doi.org/10.1007/s10668-013-9501-x

[27] Sarmiento, J.M., Rola-Rubzen, M.F., Fogarty, J., Digal, L.N. (2024). Smallholder inclusion through cooperative contract farming of Cavendish banana farmers in Davao del Norte, Philippines: A meta-frontier analysis. Agribusiness. https://doi.org/10.1002/agr.22002

[28] Alem, H., Lien, G., Hardaker, J.B., Guttormsen, A. (2019). Regional differences in technical efficiency and technological gap of Norwegian dairy farms: A stochastic meta-frontier model. Applied Economics, 51(4): 409-421. https://doi.org/10.1080/00036846.2018.1502867

[29] Hutabarat, S., Slingerland, M., Dries, L. (2019). Explaining the "Certification Gap" for different types of oil palm smallholders in Riau Province, Indonesia. Journal of Environment & Development, 28(3): 253-281. https://doi.org/10.1177/1070496519854505

[30] Chalil, D., Barus, R., Hasnah, Utami, A.D., Krisnamurthi, B. (2023). Technical efficiency, household income, and deforestation mitigation among oil palm smallholder in South Tapanuli, Indonesia. International Journal of Applied Agricultural Sciences, 29(2): 1-12.

[31] Gürbüz, S. (2017). Survey as quantitative research method. In Research Methods and Techniques in Public Relations and Advertising, pp. 141-161.

[32] Billiet, J. (2013). Quantitative methods with survey data in comparative research. In A Handbook of Comparative Social Policy, Second Edition, pp. 264-300. https://doi.org/10.4337/9781782546535.00024

[33] Alulu, J., Jakinda Otieno, D., Oluoch-Kosura, W., Ochieng, J. (2021). Comparison of technical efficiency and technology gaps between contracted and non-contracted vegetable farmers in Western Kenya. Cogent Food & Agriculture, 7(1): 1910156. https://doi.org/10.1080/23311932.2021.1910156

[34] Chemak, F., Mazhoud, H., Rached, Z., Gara, A., Rahmeni, R., Ghannem, H. (2022). Measuring technical efficiency for closuring yield gap and improving water productivity of the irrigated durum wheat in Tunisia. Water, 14(14): 2270. https://doi.org/10.3390/w14142270

[35] Geffersa, A.G., Agbola, F.W. (2025). Technical efficiency and technology gaps among smallholder maize farmers in Ethiopia. Sustainable Futures, 9: 100620. https://doi.org/10.1016/j.sftr.2025.100620

[36] Ngo, M.H., Kim, M.K., Takagi, C. (2025). Assessing technical efficiency and farmer adoption of organic rice in the Red River Delta of Vietnam: An application of metafrontier DEA and Probit Models. Organic Agriculture, 15: 107-123. https://doi.org/10.1007/s13165-025-00486-9

[37] Latpate, R., Kshirsagar, J., Gupta, V.K., Chandra, G.

(2021). Advanced Sampling Methods. Springer Singapore. https://doi.org/10.1007/978-981-16-0622-9

[38] Barnabas, A.F., Sunday, A.O. (2014). Comparison of allocation procedures in a stratified random sampling of skewed populations under different distributions and sample sizes. International Journal of Innovative Science, Engineering & Technology, 1(8): 218-225. https://www.ijiset.com/v1s8/IJISET_V1_I8_30.pdf.

[39] O'Donnell, C.J., Rao, D.S.P., Battese, G.E. (2008). Metafrontier frameworks for the study of firm-level efficiencies and technology ratios. Empirical Economics, 34: 231-255. https://doi.org/10.1007/s00181-007-0119-4

[40] Sengupta, J., Sahoo, B. (2006). Productivity and efficiency analysis. In Efficiency Models in Data Envelopment Analysis, pp. 1-35. https://doi.org/10.1057/9780230598171_1

[41] Yu, M.M., Chen, L.H. (2020). A meta-frontier network data envelopment analysis approach for the measurement of technological bias with network production structure. Annals of Operations Research, 287: 495-514. https://doi.org/10.1007/s10479-019-03436-3

[42] Chen, L., Huang, Y., Li, M.J., Wang, Y.M. (2020). Meta-frontier analysis using cross-efficiency method for performance evaluation. European Journal of Operational Research, 280(1): 219-229. https://doi.org/10.1016/j.ejor.2019.06.053

[43] Walheer, B. (2024). Meta-frontier: Literature review and toolkit. Operational Research, 24: 20. https://doi.org/10.1007/s12351-024-00830-z

[44] Charnes, A., Cooper, W.W., Rhodes, E. (1978). Measuring the efficiency of decision-making units. European Journal of Operational Research, 2(6): 429-444. https://doi.org/10.1016/0377-2217(78)90138-8

[45] Andersson, C., Antelius, J., Månsson, J., Sund, K. (2017). Technical efficiency and productivity for higher education institutions in Sweden. Scandinavian Journal of Educational Research, 61(2): 205-223. https://doi.org/10.1080/00313831.2015.1120230

[46] Andersson, C., Sund, K. (2022). Technical efficiency and productivity of higher education institutions in the Nordic Countries. International Journal of Public Administration, 45(2): 107-120. https://doi.org/10.1080/01900692.2020.1868508

[47] Halkiotis, D., Konteles, I., Brinia, V. (2018). The technical efficiency of high schools: The case of a Greek prefecture. Education Sciences, 8(2): 84. https://doi.org/10.3390/educsci8020084

[48] Salas-Velasco, M. (2020). The technical efficiency performance of the higher education systems based on data envelopment analysis with an illustration for the Spanish case. Educational Research for Policy and Practice, 19: 159-180. https://doi.org/10.1007/s10671-019-09254-5

[49] Gandhi, A.V., Sharma, D. (2018). Technical efficiency of private sector hospitals in India using data envelopment analysis. Benchmarking: An International Journal, 25(9): 3570-3591. https://doi.org/10.1108/BIJ-06-2017-0135

[50] Ali, M., Debela, M., Bamud, T. (2017). Technical efficiency of selected hospitals in Eastern Ethiopia. Health Economics Review, 7: 24. https://doi.org/10.1186/s13561-017-0161-7

[51] Jing, R., Xu, T.T., Lai, X.Z., Mahmoudi, E., Fang, H. (2020). Technical efficiency of public and private hospitals in Beijing, China: A comparative study. International Journal of Environmental Research and Public Health, 17(1): 82. https://doi.org/10.3390/ijerph17010082

[52] Erena, O.T., Kalko, M.M., Debele, S.A. (2021). Technical efficiency, technological progress and productivity growth of large and medium manufacturing industries in Ethiopia: A data envelopment analysis. Cogent Economics & Finance, 9(1): 1997160. https://doi.org/10.1080/23322039.2021.1997160

[53] Cheruiyot, K.J. (2017). Determinants of technical efficiency in Kenyan manufacturing sector. African Development Review, 29(1): 44-55. https://doi.org/10.1111/1467-8268.12237

[54] Rezitis, A.N., Kalantzi, M.A. (2015). Investigating technical efficiency and its determinants by data envelopment analysis: An application in the Greek food and beverages manufacturing industry. Agribusiness, 32(2): 254-271. https://doi.org/10.1002/agr.21432

[55] Yannick, G.Z.S., Zhao, H.Z., Thierry, B. (2016). Technical efficiency assessment using data envelopment analysis: An application to the banking sector of Côte D'Ivoire. Procedia - Social and Behavioral Sciences, 235: 198-207. https://doi.org/10.1016/j.sbspro.2016.11.015

[56] Horvatova, E. (2018). Technical efficiency of banks in Central and Eastern Europe. International Journal of Financial Studies, 6(3): 66. https://doi.org/10.3390/ijfs6030066

[57] Jelassi, M.M., Delhoumi, E. (2021). What explains the technical efficiency of banks in Tunisia? Evidence from a two-stage data envelopment analysis. Financial Innovation, 7: 64. https://doi.org/10.1186/s40854-021-00282-w

[58] Zarrin, M., Brunner, J.O. (2023). Analyzing the accuracy of variable returns to scale data envelopment analysis models. Europeran Journal of Operational Research, 308(3): 1286-1301. https://doi.org/10.1016/j.ejor.2022.12.015

[59] Camanho, A.S., Silva, M.C., Piran, F.S., Lacerda, D.P. (2024). A literature review of economic efficiency assessments using Data Envelopment Analysis. European Journal of Operational Research, 315(1): 1-18. https://doi.org/10.1016/j.ejor.2023.07.027

[60] Mei, G.P., Gan, J.Y., Zhang, N. (2015). Metafrontier environmental efficiency for China's regions: A slack-based efficiency measure. Sustainability, 7(4): 4004-4021. https://doi.org/10.3390/su7044004

[61] Battese, G.E., Prasada Rao, D.S. (2002). Technology gap, efficiency, and a stochastic metafrontier function. International Journal of Business and Economics, 1(2): 87-93.

[62] Battese, G.E., Prasada Rao, D.S., O'Donnell, C.J. (2004). A metafrontier production function for estimation of technical efficiencies and technology gaps for firms operating under different technologies. Journal of Productivity Analysis, 21: 91-103. https://doi.org/10.1023/B:PROD.0000012454.06094.29

[63] Mulema, A.A., Jogo, W., Damtew, E., Mekonnen, K., Thorne, P. (2019). Women farmers' participation in the agricultural research process: Implications for agricultural sustainability in Ethiopia. International Journal of Agricultural Sustainability, 17(2): 127-145. https://doi.org/10.1080/14735903.2019.1569578

[64] Satyavathi, C.T., Bharadwaj, C., Brahmanand, P.S. (2010). Role of farm women in agriculture: Lessons learned. Gender, Technology and Development, 14(3): 441-449. https://doi.org/10.1177/097185241001400308

[65] Fried, H.O., Tauer, L.W. (2016). The aging U.S. Farmer: Should we worry? In Advances in Efficiency and Productivity. International Series in Operations Research & Management Science, pp. 391-407. https://doi.org/10.1007/978-3-319-48461-7_16

[66] Asadullah, M.N., Rahman, S. (2009). Farm productivity and efficiency in rural Bangladesh: The role of education revisited. Applied Economics, 41(1): 17-33. https://doi.org/10.1080/00036840601019125

[67] Reimers, M., Klasen, S. (2013). Revisiting the role of education for agricultural productivity. American Journal of Agricultural Economics, 95(1): 131-152. https://doi.org/10.1093/ajae/aas118

[68] Reich, C., Musshoff, O. (2025). Oil palm smallholders and the road to certification: Insights from Indonesia. Journal of Environmental Management, 375: 124303. https://doi.org/10.1016/j.jenvman.2025.124303

[69] Kilpatrick, S. (2000). Education and training: Impacts on farm management practice. The Journal of Agricultural Education and Extension, 7(2): 105-116. https://doi.org/10.1080/13892240008438811

[70] Ayaz, M., Mughal, M. (2024). Farm size and productivity: The role of family labor. Economic Development and Cultural Change, 72(2): 959-995. https://doi.org/10.1086/721837

[71] Bojnec, Š., Knific, K. (2021). Farm household income diversification as a survival strategy. Sustainability, 13(11): 6341. https://doi.org/10.3390/su13116341

[72] Apriyanti, I., Ramadhani, J. (2019). Palm oil marketing model through performance analysis approach in Simalungun Regency. IOP Conference Series: Materials Science and Engineering, 697(1): 012004. https://doi.org/10.1088/1757-899X/697/1/012004

[73] Krumbiegel, K., Tillie, P. (2024). Sustainable practices in ocoa production. The role of certification schemes and farmer cooperatives. Ecological Economics, 222: 108211. https://doi.org/10.1016/j.ecolecon.2024.108211

[74] Hidayat, K.N., Glasbergen, P., Offerrmans, A. (2015). Sustainability certification and palm oil smallholders' livelihood: A comparison between scheme smallholders and independent smallholders in Indonesia. International Food and Agribusiness Management Review, 18(3): 1-24. https://doi.org/10.22004/ag.econ.208400

[75] Herdiansyah, H., Negoro, H.A., Rusdayanti, N., Shara, S. (2020). Palm oil plantation and cultivation: Prosperity and productivity of smallholders. Open Agriculture, 5(1): 617-630. https://doi.org/10.1515/opag-2020-0063

[76] Euler, M., Schwarze, S., Siregar, H., Qaim, M. (2016). Oil palm expansion among smallholder farmers in Sumatra, Indonesia. Journal of Agricultural Economics, 67(3): 658-676. https://doi.org/10.1111/1477-9552.12163

[77] Oya, C., Schaefer, F., Skalidou, D., McCosker, C., Langer, L. (2017). Effects of certification schemes for agricultural production on socio‐economic outcomes in low- and middle-income countries: A systematic review. Campbell Systematic Reviews, 13(1): 1-346. https://doi.org/10.4073/csr.2017.3

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

[79] Schoneveld, G.C., van der Haar, S., Ekowati, D., Andrianto, A., Komarudin, H., Okarda, B., Jelsma, I., Pacheco, P. (2019). Certification, good agricultural practice and smallholder heterogeneity: Differentiated pathways for resolving compliance gaps in the Indonesian oil palm sector. Global Environmental Change, 57: 101933. https://doi.org/10.1016/j.gloenvcha.2019.101933

[80] Piñeiro, V., Arias, J., Dürr, J., Elverdin, P., et al. (2020). A scoping review on incentives for adoption of sustainable agricultural practices and their outcomes. Nature Sustainability, 3: 809-820. https://doi.org/10.1038/s41893-020-00617-y

[81] Veriasa, T.O., Nurrunisa, M., Fadhli, N. (2024). Revisiting the implications of RSPO smallholder certification relative to farm productivity in Riau, Indonesia. Forest and Society, 8(1): 123-139. https://doi.org/10.24259/fs.v8i1.26964

[82] Raharja, S., Marimin, Machfud, Papilo, P., Safriyana, Massijaya, M.Y., Asrol, M., Darmawan, M.A. (2020). Institutional strengthening model of oil palm independent smallholder in Riau and Jambi Provinces, Indonesia. Heliyon, 6(5): e03875. https://doi.org/10.1016/j.heliyon.2020.e03875

[83] Jelsma, I., Slingerland, M., Giller, K.E., Bijman, J. (2017). Collective action in a smallholder oil palm production system in Indonesia: The key to sustainable and inclusive smallholder palm oil? Journal of Rural Studies, 54: 198-210. https://doi.org/10.1016/j.jrurstud.2017.06.005

[84] Markelova, H., Meinzen-Dick, R., Hellin, J., Dohrn, S. (2009). Collective action for smallholder market access. Food Policy, 34(1): 1-7. https://doi.org/10.1016/j.foodpol.2008.10.001

[85] Siregar, G., Harahap, M., Novita, D. (2018). Readiness of oil palm smallholders in facing oil palm replanting in North Sumatra. IOP Conference Series: Earth and Environmental Science, 205: 012003. https://doi.org/10.1088/1755-1315/205/1/012003

[86] Rahutomo, A.B., Karuniasa, M., Frimawaty, E. (2025). Enhancing farmers' land productivity through sustainable palm oil certification: Strategies for promoting environmental and economic benefits in agricultural practices. Journal of Agrosociology and Sustainability, 2(2): 97-112. https://doi.org/10.61511/jassu.v2i2.2025.1131

[87] Woittiez, L.S., van Wijk, M.T., Slingerland, M., van Noordwijk, M., Giller, K.E. (2017). Yield gaps in oil palm: A quantitative review of contributing factors. European Journal of Agronomy, 83: 57-77. https://doi.org/10.1016/j.eja.2016.11.002

[88] Zakaria, Z., Abdul Rahim, A.R., Aman, Z. (2019). Integration of sustainability-oriented practices in the oil palm cooperatives performance: Proposal of a conceptual model. Asian Journal of Research in Business and Management, 1(2): 1-18.

[89] Varina, F., Hartoyo, S., Kusnadi, N., Rifin, A. (2020). Efficiency of oil palm smallholders in Indonesia: A meta-frontier approach. Jurnal Manajemen Dan Agribisnis, 17(3): 217-226. https://doi.org/10.17358/jma.17.3.217

[90] Coelli, T.J., Prasada Rao, D.S., O'Donnell, C.J., Battese, G.E. (2005). An Introduction to Efficiency and Productivity Analysis. Springer New York, NY. https://doi.org/10.1007/b136381

[91] Abdul, I., Wulan Sari, D., Haryanto, T., Win, T. (2022). Analysis of factors affecting the technical inefficiency on Indonesian palm oil plantation. Scientific Reports, 12: 3381. https://doi.org/10.1038/s41598-022-07113-7

[92] Irawan, S., Pasaribu, K., Busch, J., Dwiyastuti, A., Martanila, H., Retnani, D., Fajri, D.M., Hukom, V. (2024). Cost reduction for upscaling voluntary sustainability standards: The case of independent oil palm smallholders in Central Kalimantan, Indonesia. Frontiers in Forests and Global Change, 7: 1418782. https://doi.org/10.3389/ffgc.2024.1418782

[93] Tey, Y.S., Brindal, M., Djama, M., Hadi, A.H.I.A., Darham, S. (2021). A review of the financial costs and benefits of the roundtable on sustainable palm oil certification: Implications for future research. Sustainable Production and Consumption, 26: 824-837. https://doi.org/10.1016/j.spc.2020.12.040