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FROM PARTNERSHIP POLICY TO SUSTAINABILITY OUTCOMES: HOW FPKMS SHAPES THE MULTIDIMENSIONAL SUSTAINABILITY OF OIL PALM SMALLHOLDERS

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ABSTRACT

The Facilitation Program for Surrounding Community Plantation Development (FPKMS), introduced under Indonesia's Ministry of Agriculture Regulation No. 18 of 2021, marks a policy shift from land-based partnership schemes toward farmer empowerment and institutional strengthening. Despite its strategic importance, evidence explaining how FPKMS translates partnership implementation into sustainability outcomes remains limited. This study evaluates FPKMS implementation and examines its influence on the multidimensional sustainability of oil palm smallholders. A comparative survey was conducted among 120 smallholders, comprising 60 FPKMS participants and 60 non-participants, in Langkat Regency, North Sumatra, Indonesia. Program implementation was assessed using the Input–Process–Output framework, while sustainability was measured through the Rap-PalmOil approach based on Multidimensional Scaling across ecological, economic, social, technological, and institutional dimensions. Model robustness was verified through stress statistics, coefficients of determination, Monte Carlo simulation, bootstrap confidence intervals, and Wilcoxon rank-sum tests. Partnered smallholders achieved a substantially higher multidimensional sustainability index than non-partnered farmers (79.5 vs. 27.2). Although program inputs remained limited, effective implementation processes and outputs strengthened social capital, institutional capacity, farmer participation, and organizational performance, thereby improving sustainability outcomes. These findings demonstrate that institutional empowerment, rather than direct financial support, constitutes the principal pathway through which partnership policies foster sustainable oil palm smallholder development. Strengthening program inputs and technological support is therefore essential for sustaining long-term ecological, economic, and technological performance.

***Keywords**: Ecological Sustainability, Farmer Empowerment, FPKMS, Institutional Capacity, Multidimensional Sustainability*

INTRODUCTION

The oil palm plantation sector has become one of the main pillars of Indonesia's agricultural economy, contributing significantly to export earnings, employment generation, and rural livelihoods. More than forty percent of Indonesia's oil palm plantations are managed by smallholders, making them increasingly important actors in sustaining national crude palm oil production. Nevertheless, smallholder productivity and competitiveness remain relatively low due to limited access to agricultural inputs, capital, technology, extension services, market information, and institutional support. These constraints reduce farmers' capacity to adopt sustainable farming practices and weaken the long-term resilience of smallholder plantations (Efron & Tibshirani, 2023; Soedarmanto & Setiawati, 2022).

The increasing global demand for sustainable palm oil has shifted the focus of plantation development from productivity-oriented approaches toward multidimensional sustainability. Sustainability is no longer viewed merely as economic performance but also encompasses ecological conservation, social well-being, technological adaptation, and institutional resilience(Cechura et al., 2017; Efron & Tibshirani, 2023). Consequently, the sustainability of oil palm farming should be understood as an interaction among ecological, economic, social, technological, and institutional dimensions that collectively determine the long-term viability of smallholder plantations (Nurliza et al., 2025; Ostrom, 2020; Yadav & Ramakrishna, 2023).

Numerous studies have evaluated the sustainability of oil palm smallholders, and consistently found considerable disparities in productivity, adoption of good agricultural practices, certification readiness, organizational capacity, and access to institutional support (Fauzi & Oxtavianus, 2014; Pitcher & Preikshot, 2021; Soedarmanto & Setiawati, 2022). These findings indicate that improving sustainability requires not only technological interventions, but also effective institutional arrangements and farmer organizations, social capital, continuous capacity building, and collaborative partnerships among government agencies, plantation companies, and surrounding communities (North, 2023; Watts et al., 2021).

In Indonesia, one of the important partnership policies addressing these challenges is the Facilitation Program for Surrounding Community Plantation Development (FPKMS), established through Ministry of Agriculture Regulation No. 18 of 2021. The regulation requires plantation companies to fulfill their statutory obligation of facilitating community plantation development equivalent to at least twenty percent of their cultivated area. Unlike the conventional nucleus–plasma scheme, which primarily emphasizes land allocation, FPKMS adopts a more flexible empowerment-based approach through agricultural input assistance, farmer training, extension services, technical mentoring, institutional strengthening, productive economic activities, and other facilitation programs with equivalent economic value (Hubatková, 2019; Pasaribu, 2025; Supriatna et al., 2024).

Conceptually, FPKMS represents a transformation of plantation partnership policy from a land-based approach toward a capacity-building approach. According to agribusiness partnership theory, sustainable partnerships should not only transfer economic resources but also strengthen farmers through technology transfer, institutional development, and continuous mentoring (Gatto et al., 2017; Tajima et al., 2022). Likewise, Yusuf et al. (2026) Input–Process–Output (IPO) framework explains that program effectiveness should be evaluated as a logical sequence in which program inputs are transformed through implementation processes to generate measurable outputs. In the context of FPKMS, agricultural assistance, training resources, and institutional support (inputs) are processed through socialization, extension activities, technical assistance, and mentoring (processes), producing outputs such as increased farmer knowledge, improved cultivation practices, stronger farmer organizations, and greater participation. These outputs are expected to become the immediate drivers of long-term sustainability.

This causal mechanism suggests that the success of FPKMS should not be evaluated solely by measuring whether assistance has been distributed but also by examining whether implementation processes successfully transform program resources into outputs that strengthen farmers' adaptive capacity. This perspective also explains why different sustainability dimensions may respond differently to the program. Institutional and social dimensions, which are closely associated with farmer participation, organizational strengthening, and collective action, are expected to respond more rapidly, whereas ecological improvements generally require longer periods because they involve behavioral changes, long-term investments, and higher implementation costs, such as the adoption of organic fertilization, empty fruit bunch application, or legume cover crops (Muchlis et al., 2026; Sowińska-Świerkosz & Soszyński, 2022).

Despite its strategic importance, empirical evidence regarding FPKMS implementation remains limited. Existing studies have primarily focused on conventional partnership schemes, certification, productivity improvement, or household income, while few examined how the implementation process of FPKMS contributes to multidimensional sustainability following the enactment of Ministry of Agriculture Regulation No. 18 of 2021. Moreover, previous sustainability studies generally present sustainability indices without explaining how policy implementation generates those outcomes or why particular sustainability dimensions perform better than others (Kruskal, 2024; Woittiez et al., 2017).

Another gap of the previous studies is the interpretation of sustainability dimensions themselves. Sustainability assessments frequently identify sensitive attributes through leverage analysis but rarely relate these attributes to the implementation of partnership programs. Consequently, sustainability dimensions are often interpreted independently rather than as outcomes of policy implementation. Integrating implementation analysis with sustainability assessment therefore provides a more comprehensive explanation of how empowerment-oriented interventions contribute to ecological, economic, social, technological, and institutional sustainability.

To address these gaps, this study integrates program implementation analysis and multidimensional sustainability assessment within a single conceptual framework. Two research questions that are expected to be answered through this study. First, how is the implementation of FPKMS in all input, process and output aspects, and (ii) how is the impact of the KPMKS to the smallholdings' sustainability.

RESEARCH METHOD

This study employed a comparative case study design to investigate how the implementation of the Facilitation Program for Surrounding Community Plantation Development

(FPKMS) shapes the multidimensional sustainability of oil palm smallholders. The research was conducted in the operational area of PT Ukindo Blankahan, Kuala District, Langkat Regency, North Sumatra, Indonesia, which was purposively selected because it is among the earliest plantation companies implementing FPKMS and provided an appropriate setting for evaluating its implementation and sustainability outcomes.

The study involved 120 oil palm smallholders, consisting of 60 FPKMS participants and 60 non-participants. The sample of partnered farmers was determined from a population of 153 beneficiaries using the Slovin formula with a 10% margin of error, yielding a minimum sample of 60 respondents. Partnered farmers were subsequently selected through proportionate random sampling based on landholding categories to ensure proportional representation. A comparison group of 60 non-partnered farmers was selected purposively from the same district based on comparable farm characteristics, including plantation age, farm size, production orientation, and farming experience, thereby minimizing structural differences that could influence sustainability performance independently of program participation (Euler et al., 2017; Gatto et al., 2017; Israel, 1992; Schoneveld et al., 2019; Tejada & Punzalan, 2012).

The analytical framework integrates policy implementation evaluation with multidimensional sustainability assessment to examine the pathway through which partnership policies generate sustainability outcomes. Program implementation was evaluated using the Input–Process–Output (IPO) framework (Bushnell, 1990). The input component assessed production support, financing, productive business assistance, and infrastructure; the process component evaluated extension services, technical assistance, institutional facilitation, monitoring, and farmer participation; while the output component measured improvements in farmers' knowledge, technology adoption, utilization of program support, and institutional capacity. All indicators were scored on a three-point ordinal scale and classified into low, moderate, and high implementation categories based on their mean scores.

Sustainability performance was assessed using the Rap-PalmOil approach based on Multidimensional Scaling (MDS), adapted from RAPFISH (Pitcher & Preikshot, 2001). Fifty attributes representing ecological, economic, social, technological, and institutional dimensions were evaluated using ordinal scores to generate sustainability indices ranging from 0 (unsustainable) to 100 (highly sustainable) (Fauzi & Anna, 2005). Model reliability was examined through stress values and coefficients of determination (R^2), while Non-Metric Multidimensional Scaling (NMDS) was employed to visualize sustainability patterns between partnered and non-partnered farmers. Leverage analysis based on the Root Mean Square (RMS) procedure identified the most influential sustainability attributes. The robustness of sustainability estimates was further verified through Monte Carlo simulations and Bootstrap Confidence Intervals. Finally, differences in sustainability performance between the two groups were examined using the Wilcoxon rank-sum test because several variables did not satisfy the assumption of normality. Collectively, these analytical procedures enabled a rigorous evaluation of both the implementation quality of FPKMS and the institutional mechanisms through which the program contributes to multidimensional sustainability among oil palm smallholders.

RESULTS AND DISCUSSION

FPKMS Implementation Performance

Table 1 shows that the three IPO components exhibited different levels of achievement, with the input component obtaining the lowest mean score (0.57), followed by the process component (1.16) and the output component (1.23). The FPKMS implementation resulted a moderate-high output, although the input is low, and the process is just moderate.

Table 1 Implementation of FPKMS Based on the IPO framework

Component	Mean Score	Category	Strongest Indicator (Mean)	Weakest Indicator (Mean)
Input	0.57	Low	Equipment and Technology Assistance (1.52)	Financing Support (0.00)
Process	1.16	Moderate	Training Implementation (1.49)	Monitoring and Evaluation (0.56)
Output	1.23	Moderate–High	The Adoption Of Recommended Cultivation Practices (1.48)	Institutional Strengthening (0.75)

Source: Rap-PalmOil analysis results, 2026

The low input score reflects the limited supports, including financing facilities, productive business assistance, seed provision, and supporting infrastructure. Respondents received high agricultural equipment and technology assistance (1.52), pesticide and herbicide assistance (1.36), and fertilizer support (1.14). However, the availability of inputs alone does not determine program success because program resources must first be transformed through appropriate implementation processes before meaningful outputs can be achieved (Berenschot et al., 2022; Brizuela-Torres et al., 2025; Rowland et al., 2022). The results show the transformation process was moderate. Among all implementation activities, training implementation recorded the highest score (1.49), reflecting the focus of FPKMS on smallholders' capacity building rather than direct financial assistance. This was followed by program socialization, technical assistance, and extension activities, whereas monitoring and evaluation remained relatively weak with the lowest score (0.56), n. In fact, training and technical assistance function as mechanisms for transferring knowledge and encouraging farmers to adopt improved agricultural practices (Padfield et al., 2023; Rincón Barajas et al., 2024; Valbuena et al., 2025). Likewise, Carmenta et al. (2021) and Roessler et al. (2022) argues that successful agribusiness partnerships depend not only on resource transfers but also on continuous mentoring and institutional facilitation that strengthen farmers' capacities.

The highest-performing output indicator was the adoption of recommended cultivation practices (1.48), reflecting smallholders' knowledge improvement through training and technical assistance into practical farm management improvements. Other outputs included increased farmer knowledge, improved utilization of program assistance, and strengthened farmer participation. These findings demonstrate the logical sequence proposed by the IPO framework, whereby available inputs were transformed through training, extension services, and technical mentoring into measurable improvements in farmers' agricultural practices. Rather than emphasizing direct financial transfers, the program focused on strengthening farmers' knowledge, technical skills, and adaptive capacity. Such an approach is consistent with partnership theory (Alencar et al., 2025; Andrianandrasana et al., 2025; Lorimer, 2023), which emphasizes that sustainable partnerships are achieved through technology transfer, institutional strengthening, and farmer empowerment. Consequently, the outputs generated through FPKMS constitute an important foundation for improving multidimensional sustainability.

The IPO analysis provide a logical explanation for the sustainability results presented in the following section. Improvements in cultivation practices, farmer knowledge, and institutional participation are expected to contribute directly to technological, social, and institutional sustainability dimensions, while ecological improvements may emerge more gradually because they require long-term investment, behavioral change, and continuous implementation of environmentally friendly cultivation practices. Thus, the IPO analysis explains not only how FPKMS was implemented but also why different sustainability dimensions exhibit different levels of performance.

The impact of FPKMS to smallholders' sustainability was estimated with Rap-PalmOil Model. With stress values ranged from 0.078 to 0.205, and R^2 values ranged from 0.795 to 0.985 across all sustainability dimensions (Table 2), it can be concluded that the Rap-PalmOil model achieved satisfactory goodness-of-fit and exhibiting the strongest performance, thus can be considered statistically reliable, stable, valid and suitable for interpreting the sustainability status of oil palm smallholders (Andreucci et al., 2023; Ro et al., 2023; Sardar & Samadder, 2021).

Table 2 Goodness-of-Fit Statistics of the Rap-PalmOil Model

Dimension	**Stress**	**R^2**	**Model Interpretation**
Ecological	0.115	0.885	Good
Economic	0.162	0.838	Good
Social	0.095	0.903	Very Good
Technological	0.205	0.795	Fairly Good
Institutional	0.078	0.922	Very Good
Multidimensional	0.123	0.985	Very Good

Source: Rap-PalmOil analysis results, 2026

Monte Carlo simulation results in Table 3 indicate that the sustainability model is statistically robust with mean values ranging from 49.97 to 50.93. Therefore, the resulting sustainability indices can be interpreted with confidence (Córdoba et al., 2022; Dialga & Ouoba, 2022; Martinez-Alier, 2021).

Table 3 Monte Carlo Simulation Results for Sustainability Indices

Dimension	**Mean**	**SD**	**Minimum**	**Maximum**	**Interpretation**
Ecological	50.93	4.361	41.08	60.03	Stable
Economic	50.55	9.621	36.11	63.33	Moderately Stable
Social	50.47	3.697	43.46	57.69	Stable
Technological	49.99	4.841	41.30	59.05	Stable
Institutional	50.43	3.474	43.09	58.14	Highly Stable
Multidimensional	49.97	4.539	42.97	57.89	Stable

Source: Monte Carlo simulation results, 2026

The economic dimension showed the largest variation (SD = 9.621), suggesting greater heterogeneity among farmers with respect to productivity, production costs, household income, and access to economic resources. The greater variability in the economic dimension is understandable because economic performance is inherently influenced by external factors beyond the scope of FPKMS program, including fluctuations in fresh fruit bunch (FFB) prices, production costs, weather conditions, labor availability, and differences in farm productivity. Consequently, economic sustainability tends to exhibit greater variation among smallholders even when they participate in the same partnership program. Similar observations have been reported by Elliot Noe et al. (2026) and Honlah et al. (2024), who found that household economic performance among oil palm smallholders remains strongly affected by market dynamics despite receiving institutional and technical support. Nevertheless, the variability remained within an acceptable range and did not substantially alter the sustainability classification.

Table 4 Bootstrap Confidence Interval Results of Sustainability Indices

Dimension	**Mean**	**95% Confidence Interval**	**SD**	**Minimum**	**Maximum**	**Interpretation**
Ecological	50.93	41.73–58.89	4.361	41.08	60.03	Stable
Economic	50.55	37.77–63.09	9.621	36.11	63.33	Variable
Social	50.47	45.40–57.00	3.697	43.46	57.69	Stable
Technological	49.99	41.40–58.28	4.841	41.30	59.05	Stable
Institutional	50.43	44.41–57.30	3.474	43.09	58.14	Highly Stable
Multidimensional	49.97	43.15–57.16	4.539	42.97	57.89	Stable

Source: Monte Carlo simulation results, 2026

Similarly, the Bootstrap Confidence Interval (BCI) results also show the stability of sustainability indices (Artiga-Purcell, 2026; Borras et al., 2022; A. A. Yusuf, 2021). Across all dimensions, mean sustainability scores ranged from 49.97 to 50.93, accompanied by relatively narrow 95% confidence intervals.

The institutional dimension displayed the most consistent results, with a mean score of 50.43, a standard deviation of 3.474, and a confidence interval of 44.41–57.30, while the economic dimension showed a wider interval (37.77–63.09) and a higher standard deviation (9.621), indicating greater variation in economic conditions among respondents. Overall the multidimensional assessment, the average sustainability score reached 49.97 with a 95% confidence interval ranging from 43.15 to 57.16. The differences in simulation stability among sustainability dimensions might reflect the characteristics of the underlying sustainability attributes. The institutional and social dimensions exhibited the most stable estimates because many of their attributes—such as farmer group organization, institutional legality, participation, cooperation, and social trust—represent relatively established organizational conditions that are less sensitive to short-term fluctuations. According to Parra-Paitan et al. (2024) and Reich & Musshoff (2025), institutional arrangements create stability by reducing uncertainty and providing predictable rules for collective action. Likewise, De Haro (2025) and Irengbam & Sneddon (2025) argues that strong local institutions enhance the resilience of collective resource management, thereby contributing to greater consistency in sustainability performance.

Viewed together with the Monte Carlo results, the bootstrap estimates provide additional evidence that the sustainability classification generated by the Rap-PalmOil model is statistically reliable and not overly sensitive to sampling fluctuations. Narrow confidence of intervals and consistent resampling results strengthen confidence in sustainability assessments and improve the credibility of policy recommendations derived from multidimensional analytical approaches (Hendrawan & Musshoff, 2024; Oliphant & Simon, 2022; Warburton, 2024).

The Rap-PalmOil assessment revealed substantial differences in sustainability performance between partner and non-partner farmers across all five sustainability dimensions (Figures 1). Partner farmers achieved sustainability indices of 81.2 for the ecological dimension, 81.4 for the economic dimension, 80.2 for the social dimension, 73.3 for the technological dimension, and 81.3 for the institutional dimension, resulting in an overall multidimensional sustainability index of 79.5, which falls within the highly sustainable category. In contrast, non-partner farmers recorded a multidimensional sustainability index of only 27.2, indicating a less sustainable condition. These findings demonstrate that participation in the FPKMS program is associated with substantially better sustainability performance across all dimensions of oil palm farming.

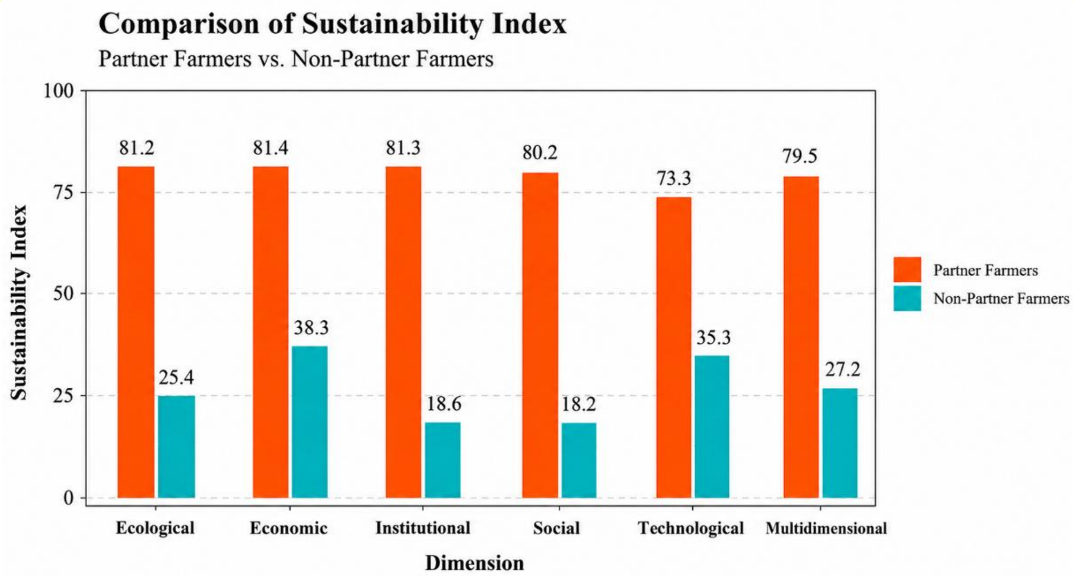

Figure 1 Sustainability Index of Partner and Non-Partner Farmers
Source: Monte Carlo simulation results, 2026

Further evidence is provided by the Non-Metric Multidimensional Scaling (NMDS) ordination (Figure 2), which reveals a clear spatial separation between partner and non-partner farmers. Most partner farmers are concentrated within a distinct ordination cluster, whereas non-partner farmers occupy a different region of the multidimensional space with only limited overlap. According to Prabawani et al. (2024), observations located close together in an NMDS ordination possess similar multivariate characteristics, whereas observations located farther apart indicate greater dissimilarity. Accordingly, the clear separation between the two groups demonstrates that partner and non-partner farmers possess fundamentally different sustainability profiles.

The distinct clustering has important implications for understanding the effectiveness of FPKMS. Rather than improving only one aspect of farming, the program appears to have shifted the overall sustainability profile of participating farmers. This indicates that FPKMS generated cumulative improvements across multiple sustainability dimensions simultaneously. The clear separation suggests that partner farmers have developed a more integrated sustainability system in which institutional capacity, technological adoption, ecological management, economic performance, and social participation reinforce one another. In contrast, the more dispersed distribution of non-partner farmers reflects greater heterogeneity and weaker integration among these sustainability dimensions.

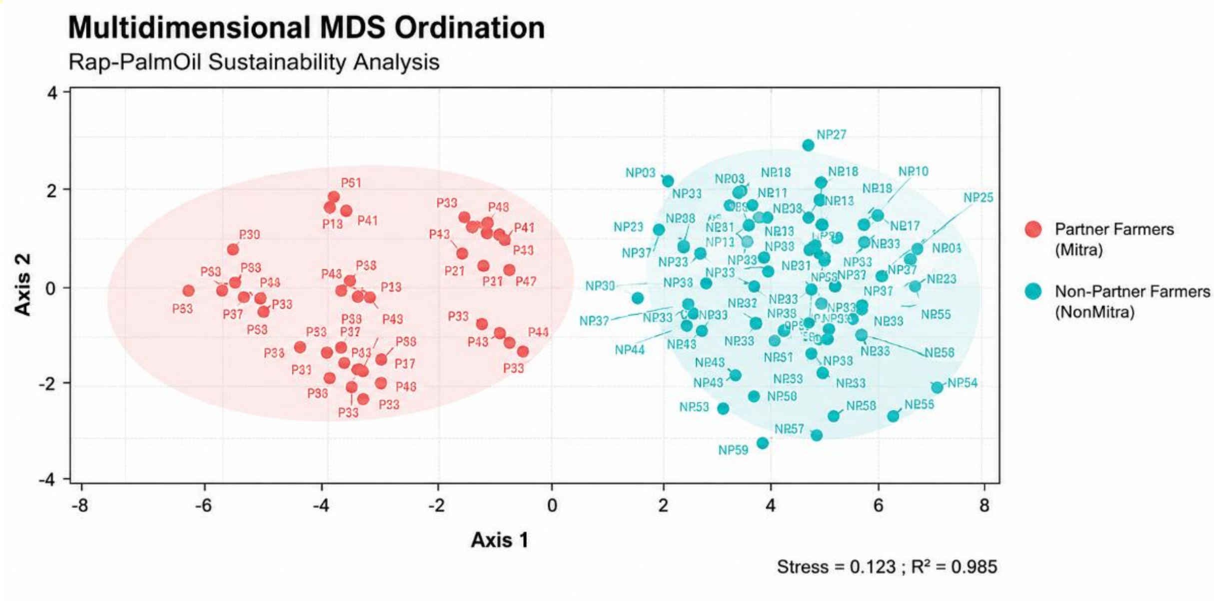

Figure 2 NMDS Ordination Plot
Source: Rap-PalmOil analysis results, 2026

From a program evaluation perspective, the NMDS configuration also confirms the implementation pathway identified through the IPO analysis. Earlier findings demonstrated that FPKMS emphasized extension services, technical assistance, farmer participation, and institutional facilitation rather than direct material assistance. These implementation processes generated outputs in the form of improved farmer knowledge, wider adoption of recommended cultivation practices, stronger farmer organizations, and increased participation. The distinct NMDS clustering indicates that these outputs collectively altered the sustainability configuration of partner farmers, shifting them toward higher ecological, economic, social, technological, and institutional sustainability.

The radar profile (Figure 3) further illustrates that partner farmers exhibit a balanced sustainability structure, whereas non-partner farmers consistently perform poorly across nearly all dimensions. This finding supports the multidimensional sustainability concept proposed by the World Commission on Environment and Development (Abman & Lundberg, 2024; He et al., 2023; West et al., 2021) and further operationalized in the FAO Sustainability Assessment of Food and Agriculture Systems (SAFA), which emphasizes that agricultural sustainability emerges from the interaction of ecological, economic, social, technological, and institutional dimensions rather than from improvements in a single aspect (Chrisendo et al., 2022; Suarez & Cardona-Arenas, 2026). Consequently, the sustainability advantage observed among partner farmers reflects a comprehensive improvement in the farming system rather than isolated gains in productivity or income.

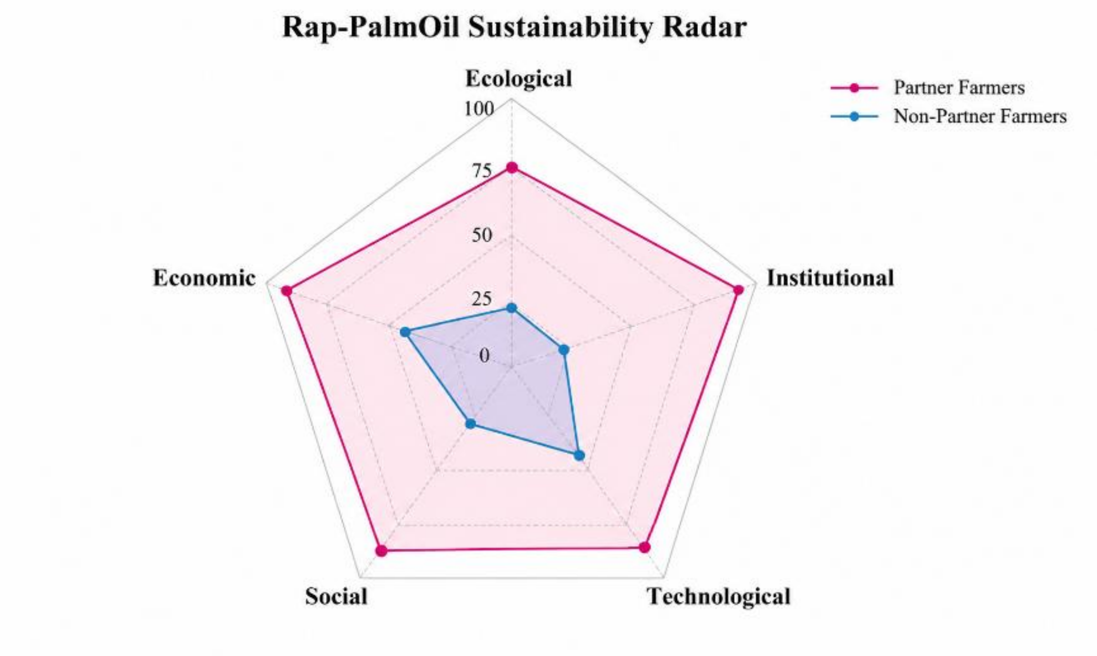

Figure 3 Radar Sustainability of Partner and Non-Partner Farmers
Source: Rap-PalmOil analysis results, 2026

Among all dimensions, the institutional dimension achieved one of the highest sustainability indices (81.3). This strong performance can be explained by the consistently high scores obtained for institutional attributes, including farmer group organizational structure, institutional legality, cooperation among members, participation in collective activities, and organizational problem-solving capacity. These attributes correspond closely with the implementation processes of FPKMS, particularly institutional facilitation, farmer group strengthening, technical mentoring, and continuous farmer participation identified in the IPO analysis. According to Balogh (2022) and Ruml et al. (2022), institutions reduce uncertainty by establishing rules and coordination mechanisms that facilitate cooperation and collective action, while Ostrom (1990) argues that effective local institutions strengthen adaptive capacity through trust, participation, and shared resource management. Therefore, improvements in institutional attributes explain why institutional sustainability emerged as one of the strongest dimensions among partner farmers. Similar findings were reported by Delina (2021) and Russo Lopes et al. (2021), who identified institutional capacity as one of the principal determinants of sustainable oil palm smallholder development.

The economic (81.4) and social (80.2) dimensions also demonstrated high sustainability performance. These improvements were primarily associated with enhanced managerial capacity, increased access to technical information, stronger farmer cooperation, and more active participation in training and extension programs. Unlike conventional partnership models that mainly provide financial support, FPKMS emphasizes farmer empowerment through continuous learning and institutional development. Lo et al. (2024) and Tabe-Ojong et al. (2023) explains that repeated communication, technical guidance, and knowledge exchange accelerate the adoption of improved farming practices and managerial innovations. Consequently, partner farmers were better able to improve farm management, increase production efficiency, strengthen social networks, and enhance household resilience. Similar conclusions were reported by Ferreira (2026) and Huff (2024), who found that partnership programs improve farmer welfare by strengthening both human capital and institutional support.

Although partner farmers also achieved a high ecological sustainability index (81.2), ecological sustainability develops through a different mechanism than institutional or social sustainability. Most ecological attributes—including the application of organic fertilizers, utilization of empty fruit bunches (EFB), establishment of legume cover crops (LCC), soil and water conservation, and integrated pest management—require substantial financial investment, continuous implementation, and long-term behavioral change before measurable environmental benefits become evident. Levy et al. (2024) and Trájer (2022) emphasizes that environmentally sustainable agriculture is achieved through gradual improvements in resource management rather than immediate technological interventions. Therefore, ecological sustainability generally responds more slowly to empowerment programs than institutional or social sustainability, despite continuous technical assistance provided through FPKMS.

Compared with the other dimensions, technological sustainability recorded the lowest sustainability index among partner farmers (73.3), although it remained within the sustainable category. This relatively lower performance reflects the characteristics of the underlying technological attributes, including the adoption of modern cultivation equipment, utilization of recommended technologies, access to agricultural innovation, and investment in improved production practices. While the IPO analysis demonstrated that FPKMS successfully enhanced farmers' technical knowledge through training and extension services, the adoption of technology-intensive practices depends not only on knowledge but also on farmers' financial capacity, access to equipment, and perceived economic benefits. Braunstein & Chuchko (2025) and Rayo et al. (2024) argues that technology adoption is influenced by its relative advantage, compatibility with existing farming systems, complexity, trialability, and observability. Consequently, technological sustainability tends to improve more gradually than institutional or social sustainability because farmers require additional investment before adopting advanced technologies at the farm level.

The variation observed among sustainability dimensions indicates that FPKMS does not influence every aspect of sustainability equally. Institutional and social dimensions responded more rapidly because the program directly targeted farmer organizations, participation, technical mentoring, and collective learning through its implementation processes. In contrast, ecological and technological improvements depend on longer implementation periods, behavioral adaptation, and additional financial investment. This finding demonstrates that different sustainability dimensions respond according to the characteristics of their underlying attributes rather than uniformly across the farming system.

Importantly, these multidimensional sustainability outcomes represent the logical consequences of the Input–Process–Output (IPO) implementation pathway identified in the previous section. The relatively limited material inputs provided by FPKMS were transformed through intensive implementation processes—including socialization, extension services, technical assistance, institutional facilitation, and continuous mentoring—into outputs consisting of improved farmer knowledge, wider adoption of recommended cultivation practices, stronger farmer organizations, and increased participation. These outputs correspond directly to the institutional, social, economic, technological, and ecological attributes evaluated in the Rap-PalmOil assessment. Therefore, the higher sustainability performance observed among partner farmers confirms that the effectiveness of FPKMS lies primarily in strengthening farmers' capacities, organizational resilience, and institutional quality rather than merely increasing the amount of material assistance distributed. Accordingly, the MDS results reinforce the IPO findings by demonstrating that empowerment-oriented partnership programs contribute to long-term sustainability through improvements in human capital, social capital, and institutional capacity.

These findings demonstrate that the contribution of FPKMS is not limited to improving individual sustainability attributes but extends to transforming the overall sustainability structure of participating smallholders. Strengthening institutional capacity and farmer empowerment through FPKMS creates positive spillover effects across other sustainability dimensions (Cechura et al., 2017; Debonne et al., 2021).

Similarly, the Leverage analysis in Figure 4 shows that the most influential attributes were predominantly concentrated within the institutional and social dimensions. The highest RMS values were recorded for farmer group organizational structure (0.887), fairness of program benefit distribution (0.877), legality of farmer institutions (0.872), cooperation among farmers (0.850), and social conflict management (0.831). Additional influential attributes included community acceptance of FPKMS, environmentally friendly pesticide use, participation in community activities, mutual trust among farmers, and organizational problem-solving capacity.

The dominance of institutional and social attributes indicates that sustainability among oil palm smallholders is determined not only by biophysical or economic conditions but also by the quality of farmer organizations and collective action. According to Efron & Tibshirani (2023) and Yadav & Ramakrishna (2023), institutions reduce uncertainty by establishing rules, facilitating coordination, and lowering transaction costs among economic actors. Likewise, Nurliza et al. (2025) and Ostrom (2020) argues that effective local organizations improve collective resource management through cooperation, trust, shared norms, and participatory decision-making. Consequently, stronger farmer organizations enhance farmers' capacity to exchange knowledge, coordinate farming activities, solve common problems, and adapt to changing environmental and market conditions.

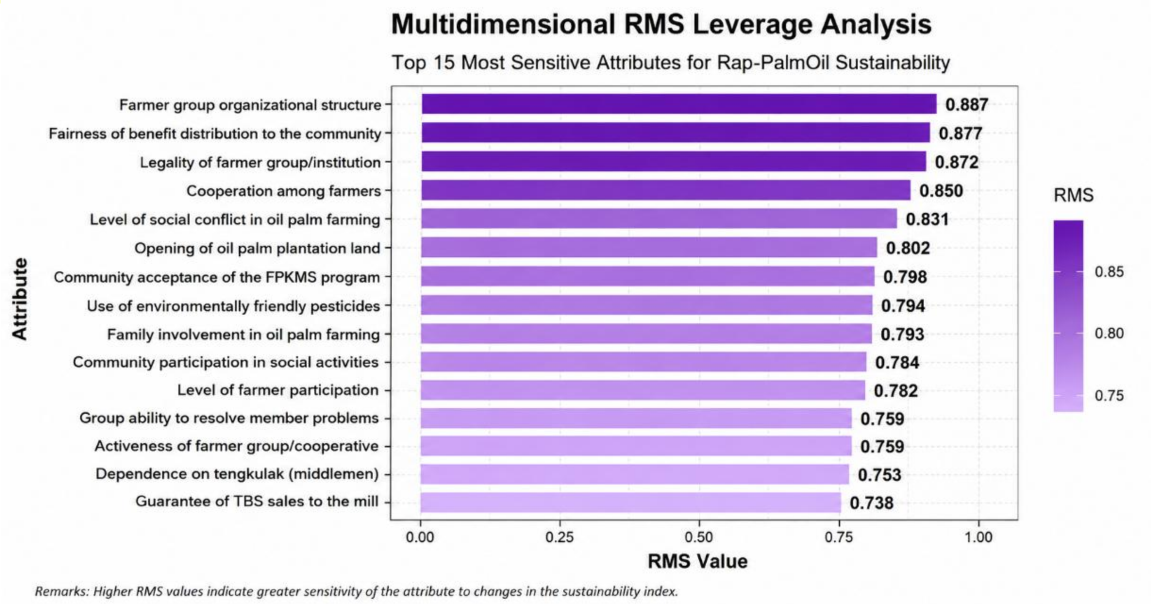

Figure 4 Leverage Analysis of sustainability Attributes
Source: Monte Carlo simulation results, 2026

These findings are also consistent with agribusiness partnership theory proposed by Pitcher & Preikshot (2021) and Soedarmanto & Setiawati (2022), which emphasizes that successful partnership programs should prioritize institutional strengthening, technology transfer, and farmer empowerment rather than relying solely on direct material assistance. In the context of FPKMS, activities such as farmer group facilitation, training, extension services, and continuous technical mentoring strengthen organizational capacity and encourage greater participation among beneficiaries. These institutional improvements subsequently become important drivers of long-term sustainability.

The leverage results closely correspond with the findings of the IPO analysis presented earlier. Although the program provided relatively limited direct inputs in the form of financial assistance and physical infrastructure, FPKMS emphasized implementation processes such as socialization, technical training, extension activities, mentoring, and institutional facilitation. These implementation processes generated outputs including improved farmer participation, wider adoption of recommended cultivation practices, stronger farmer organizations, and increased institutional legitimacy. Notably, these outputs correspond directly to the attributes identified as the most sensitive in the leverage analysis, indicating that the effectiveness of FPKMS is primarily achieved through strengthening human and institutional capacities rather than through direct economic assistance.

The leverage analysis also explains why the institutional and social dimensions achieved among the highest sustainability indices in the MDS assessment. Because the most sensitive sustainability attributes are concentrated within these dimensions, improvements in organizational structure, institutional legality, cooperation, trust, and benefit distribution have a disproportionately large influence on overall sustainability performance. In contrast, ecological and technological dimensions contain several attributes that require longer implementation periods and greater financial investment, such as environmentally friendly farming practices and technology adoption, resulting in comparatively slower improvements despite continuous program support.

The Wilcoxon analysis in Table 5 revealed statistically significant differences across all sustainability dimensions ($p < 0.001$) between partnered and non-partner smallholders. Preliminary normality testing using the Shapiro–Wilk test indicated that several sustainability variables were not normally distributed. Consequently, differences in sustainability performance between partner and non-partner smallholders were analyzed using the Wilcoxon rank-sum test (Field, 2018). Beyond statistical significance, the calculated effect sizes ranged from medium ($r = 0.380$) to very large ($r = 0.863$), indicating that the observed differences are not only statistically reliable but also practically meaningful. The strongest difference was observed in the multidimensional sustainability index ($r = 0.863$), followed by the technological ($r = 0.710$), economic ($r = 0.620$), ecological ($r = 0.540$), institutional ($r = 0.490$), and social dimensions ($r = 0.380$).

Table 5 Wilcoxon Test Results for Sustainability Differences Between Partner and Non-Partner Smallholders

Dimension	**Wilcoxon W**	**p-value**	**Effect Size (r)**	**Effect Category**	**Conclusion**
Ecological	13.5	<0.001	0.540	Large	Significant Difference
Economic	66.0	<0.001	0.620	Large	Significant Difference
Social	0.0	<0.001	0.380	Medium	Significant Difference
Technological	236.0	<0.001	0.710	Large	Significant Difference
Institutional	0.0	<0.001	0.490	Medium–Large	Significant Difference
Multidimensional	0.0	<0.001	0.863	Very Large	Significant Difference

Source: Wilcoxon Test Results, 2026

The very large effect size observed for multidimensional sustainability indicates that participation in the FPKMS program is associated with substantial improvements across the overall sustainability system rather than within a single sustainability dimension. The relatively large effects observed in the technological and economic dimensions are closely associated with the implementation mechanism identified through the IPO analysis. Previous sections demonstrated that FPKMS primarily emphasized farmer training, extension services, technical assistance, and continuous mentoring rather than direct financial assistance. Continuous communication, knowledge transfer, and technical guidance could accelerate the adoption of improved agricultural technologies (Pitcher & Preikshot, 2021). Consequently, partner farmers were more likely to adopt recommended cultivation practices, improve farm management, and utilize production resources more efficiently, resulting in higher technological and economic sustainability.

The significant differences observed in the institutional and social dimensions can be explained by the FPKMS focus on institutional strengthening and smallholder participation. Partnerships could strengthen organizational capacity, collective learning, and smallholders' empowerment than merely providing material support (Parra-Paitan et al., 2024). Stronger smallholder organizations could reduce uncertainty, facilitate cooperation, improve access to information, and increase collective capacity for solving production and marketing problems. These institutional improvements correspond directly with the leverage analysis, which identified organizational structure, institutional legality, cooperation, and benefit distribution as the most influential sustainability attributes.

Although the social dimension produced the smallest effect size (r = 0.380), the difference remained statistically significant. Social sustainability generally develops more gradually because it depends on the accumulation of social capital, trust, participation, and collective experience over time rather than immediate program interventions. According to A. A. Yusuf (2021), social capital is strengthened through repeated interaction, cooperation, and shared institutional experiences. Therefore, improvements in social sustainability often require longer implementation periods than improvements in technical knowledge or agricultural practices.

The Wilcoxon results confirm the causal sequence established throughout this study. The IPO analysis demonstrated that FPKMS transformed available program inputs into implementation processes emphasizing training, extension services, technical assistance, and institutional facilitation. These processes generated outputs including improved farmer knowledge, wider adoption of recommended cultivation practices, stronger farmer organizations, and increased participation. The leverage analysis further identified these institutional and social outputs as the most influential determinants of sustainability. Finally, the Wilcoxon test confirms that these cumulative improvements resulted in statistically significant differences between partner and non-partner farmers across all sustainability dimensions.

Pitcher & Preikshot (2021) and Soedarmanto & Setiawati (2022) demonstrated that partnership schemes improve productivity, household welfare, and farmers' adaptive capacity through better access to technology and institutional support. Pitcher & Preikshot (2021) and Soedarmanto & Setiawati (2022) similarly reported that integrated partnership programs strengthen economic resilience while improving farmers' managerial capabilities. More recent studies by (Dialga & Ouoba, 2022) further emphasize that sustainable transformation among oil palm smallholders depends on continuous capacity building, institutional strengthening, and effective collaboration between plantation companies and surrounding communities. The present study extends these findings by demonstrating that FPKMS achieves these improvements through a measurable implementation pathway captured by the Input–Process–Output framework and reflected in multidimensional sustainability outcomes.

The findings of this study demonstrate that the implementation of the Facilitation Program for Surrounding Community Plantation Development (FPKMS) and the multidimensional sustainability of oil palm smallholders are closely interconnected rather than representing two independent outcomes. The Input–Process–Output (IPO) framework provides a logical explanation of how program implementation contributes to sustainability improvements. Program effectiveness should be interpreted as a sequential process in which available inputs are transformed through implementation activities into measurable outputs that subsequently generate broader development impacts. The present findings confirm this implementation pathway within the context of FPKMS.

Although the input component recorded the lowest performance, this result does not necessarily indicate weak program implementation. Rather, it reflects the design of FPKMS, which emphasizes farmer empowerment instead of direct material assistance. Agricultural inputs such as fertilizer support, pesticides, agricultural equipment, and institutional assistance functioned as initial resources that were subsequently transformed through implementation processes consisting of farmer training, extension services, technical assistance, demonstration activities, institutional facilitation, and continuous mentoring. These implementation processes generated measurable outputs, including improved farmer knowledge, wider adoption of recommended cultivation practices, stronger farmer organizations, and greater participation in collective activities. Thus, the effectiveness of FPKMS was determined not by the quantity of resources distributed but by the program's ability to transform available inputs into farmers' capacities and institutional development.

This implementation pathway is clearly reflected in the sustainability assessment. For example, fertilizer assistance was accompanied by training on fertilizer application and field supervision, resulting in more appropriate nutrient management practices that contributed to higher ecological sustainability. Likewise, the provision of agricultural equipment was followed by technical guidance and practical demonstrations, enabling farmers to improve operational efficiency and supporting technological sustainability. Institutional facilitation was implemented through farmer group formation, organizational mentoring, regular meetings, and participatory decision-making, which strengthened organizational structure, institutional legitimacy, cooperation, and farmer participation. These institutional outputs subsequently contributed to the high sustainability performance observed in the institutional and social dimensions. Similarly, continuous extension services and farm management training enhanced farmers' managerial capacity and production efficiency, thereby supporting improvements in economic sustainability. These findings demonstrate that each sustainability dimension developed through specific implementation processes rather than as a direct consequence of material assistance alone.

The multidimensional sustainability assessment confirms this implementation mechanism. Partner farmers consistently achieved substantially higher sustainability indices than non-partner farmers across ecological, economic, social, technological, and institutional dimensions. However, the magnitude of improvement differed among dimensions because each dimension responded according to the characteristics of its underlying attributes. Institutional and social sustainability exhibited the strongest performance because their principal attributes—including organizational structure, institutional legality, cooperation, participation, and collective action—were directly strengthened through the implementation processes of FPKMS.

By contrast, technological and ecological sustainability developed more gradually because many of their underlying attributes require longer implementation periods and additional financial investment. Technological sustainability depends on farmers' adoption of improved equipment, modern cultivation practices, and agricultural innovations, all of which require capital investment beyond the knowledge acquired through training. Pitcher & Preikshot (2021) and Soedarmanto & Setiawati (2022) explains that innovation adoption is influenced not only by information availability but also by perceived economic benefits, compatibility with existing farming systems, complexity, and farmers' capacity to invest. Similarly, ecological sustainability depends on the continuous application of environmentally friendly practices such as organic fertilization, utilization of empty fruit bunches (EFB), establishment of legume cover crops (LCC), soil conservation, and integrated pest management. These practices require gradual behavioral change and sustained investment before their environmental benefits become fully apparent (Andrianandrasana et al., 2025; Roessler et al., 2022). Therefore, although FPKMS successfully improved farmers' knowledge through capacity-building activities, ecological and technological dimensions responded more slowly than institutional and social dimensions.

The leverage analysis further strengthens this interpretation by identifying farmer group organizational structure, institutional legality, cooperation, fairness of benefit distribution, and conflict management as the most influential sustainability attributes. Importantly, these attributes correspond directly to the outputs generated through the IPO implementation process. Rather than identifying isolated indicators, the leverage analysis demonstrates that institutional and social capacities developed through training, mentoring, farmer participation, and organizational facilitation constitute the primary drivers of multidimensional sustainability.

The robustness analyses—including goodness-of-fit statistics, NMDS ordination, Monte Carlo simulation, Bootstrap Confidence Intervals, and the Wilcoxon rank-sum test—consistently reinforce this implementation pathway. The goodness-of-fit evaluation confirmed that the Rap-PalmOil model accurately represented the sustainability structure, while the NMDS ordination clearly separated partner and non-partner farmers into distinct sustainability clusters. Monte Carlo simulation and Bootstrap Confidence Intervals demonstrated that the sustainability estimates remained stable under repeated simulations, and the Wilcoxon test confirmed statistically significant differences across all sustainability dimensions. Collectively, these analyses indicate that the sustainability improvements observed among partner farmers represent genuine program outcomes rather than statistical artifacts or random variation.

CONCLUSION

This study demonstrates that the implementation of the Facilitation Program for Surrounding Community Plantation Development (FPKMS) contributes to the multidimensional sustainability of oil palm smallholders by strengthening institutional capacity, farmer participation, and social capital rather than relying primarily on direct production support or financial assistance. The evaluation confirms that while program inputs remain relatively limited, effective implementation processes and outputs have generated measurable improvements across ecological, economic, social, technological, and institutional sustainability dimensions among participating farmers. These findings indicate that the sustainability outcomes of FPKMS are shaped not only by the provision of resources but also by the quality of implementation that enhances farmers' knowledge, organizational capacity, and collaborative networks. By integrating the Input–Process–Output framework with multidimensional sustainability assessment, this study provides empirical evidence of the implementation pathway linking partnership policy to sustainability outcomes, thereby extending current understanding of empowerment-based partnership models in the oil palm sector. Accordingly, strengthening institutional facilitation, continuous capacity building, and technology-oriented support should become central priorities for improving the long-term effectiveness of FPKMS and promoting more sustainable smallholder oil palm development.

ETHICAL STATEMENT AND DISCLOSURE

This study was conducted in accordance with accepted ethical principles for social and agricultural research. Participation was voluntary, informed consent was obtained from all respondents, and the confidentiality of personal information was maintained throughout the study. The research involved adult oil palm smallholders, and no vulnerable populations were included. This research received no specific funding from public, commercial, or non-profit organizations. The authors declare that there are no financial or personal conflicts of interest related to this study. Data were collected through structured questionnaires, field observations, interviews, and document reviews, and were analyzed using appropriate statistical and sustainability assessment methods. Artificial intelligence (AI) tools were used solely to improve language quality, grammar, and manuscript organization. All methodological decisions, data analyses, interpretations, and conclusions remain the sole responsibility of the authors. The authors gratefully acknowledge the participating farmers, PT Ukindo Blankahan for facilitating field access, and the anonymous reviewers for their constructive comments that improved this manuscript.

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