Evaluation of the Sustainability of Cash Crop-Based Agroforestry Systems in a Multidimensional Perspective

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Abstract
This study aimed to evaluate the sustainability of commercial crop-based agroforestry systems in Bogorejo Village, Lampung, using a Multidimensional Scaling (MDS) approach. A quantitative approach was used, involving 43 respondents, including farmers and stakeholders. Data were collected through surveys and interviews (October–November 2025) and analyzed using MDS with ordination and leverage techniques across the ecological, economic, social, institutional, and technological dimensions. The ecological dimension was highly sustainable (76.97), while the institutional (70.89), economic (64.84), technological (63.31), and social (56.02) dimensions were moderately sustainable. Sustainability is strongly influenced by deforestation, income trends, mutual cooperation, cooperative involvement, and fertilizer use. The sustainability of agroforestry systems depends on the interaction of ecological, economic, social, institutional, and technological factors, requiring adaptive management strategies focused on sensitive attributes. The study is limited to one village with a small sample size, which restricts generalization. It contributes by providing a multidimensional sustainability assessment and identifying key attributes for policy and sustainable agroforestry management in the region.

Keywords: *Commercial Crops, Forest Management, Multidimensional Analysis, Sustainable Agroforestry*

1. INTRODUCTION

Agroforestry is a land management system that integrates forestry and agricultural crops in a single spatial and temporal environment, providing simultaneous ecological, economic, and social benefits. In recent years, agroforestry has been increasingly recognized as an effective approach to support landscape sustainability, increase community resilience to environmental and economic changes, and maintain a balance between land productivity and natural resource conservation (van Noordwijk, 2021). In Indonesia, agroforestry systems have been widely implemented in forest areas through various government programs, such as the Forest and Land Rehabilitation Movement (GERHAN), Joint Community Forest Management (PHBM), provision of Multi-Purpose Tree Species (MPTS) seedlings, and conservation partnership programs, which encourage community participation in sustainable forest management (Minarningsih, 2022).

The success of agroforestry management is determined not only by the biophysical conditions of the land but also by the involvement of the community as the main actors in forest area management (Bhimasta, Surya, & Pramudita, 2025; S. D. Damanik, Prasetyo, Alie, & Oktaria, 2025). The high intensity of community interaction with forest areas makes community participation a crucial factor in maintaining the sustainability of forest resource management (Wollenberg, Belcher, Sheil, Dewi, & Moeliono, 2004). Forest Farmer Groups (KTH) play a strategic role in forest management because they no longer function solely as extension recipients but also as partners in the planning, implementation, and development of forestry activities. In accordance with the Regulation of the Minister of Environment and Forestry Number P.89/MENLHK/SETJEN/KUM.1/8/2018, KTH are responsible for managing timber and non-timber forest products and environmental services sustainably (Budiastuti, Purnomo, Supriyono, Pujiasmanto, & Setyaningrum, 2020). However, most communities surrounding forest areas still face limited education and economic conditions that affect their capacity to manage agroforestry optimally (Saleh & Ariandi, 2023).

One area that implements an agroforestry system is Bogorejo Village, located in the Wan Abdul Rachman Forest Park (Tahura Wan Abdul Rachman) buffer zone. Communities in this village

develop agroforestry based on commercial crops, such as coffee and other plantation commodities, as the main source of household income while maintaining the ecological functions of the forest area. However, the agroforestry system in Bogorejo Village still faces various challenges, including pressure on ecological conditions due to changes in land use, fluctuations in the income of communities dependent on agricultural commodities, and suboptimal management of social and institutional aspects (Wanderi, Qurniati, & Kaskoyo, 2019). These conditions indicate that increased economic benefits have not been followed by improvements in the sustainability of agroforestry management.

Various studies have shown that agroforestry sustainability is influenced by the interactions among ecological, economic, social, institutional, and technological aspects (Suhartini et al., 2024). Therefore, sustainability evaluations must be conducted multidimensionally to provide a more comprehensive picture of the condition of agroforestry systems. One widely used approach is Multidimensional Scaling (MDS), which can assess sustainability status while identifying the attributes most sensitive to system changes (Akhmad Fauzi & Anna, 2005). However, research on commercial crop-based agroforestry in forest buffer zones that integrates the five dimensions of sustainability and identifies sensitive attributes as a basis for developing management strategies is still limited. Most previous studies have focused on ecological or economic aspects separately, thus failing to fully describe the interrelationships between sustainability dimensions.

Based on these gaps, this study evaluates the sustainability of a commercial crop-based agroforestry system in Bogorejo Village, a buffer zone of the Wan Abdul Rachman Forest Park, by focusing on five dimensions of sustainability: ecological, economic, social, institutional, and technological, using a Multidimensional Scaling (MDS) approach. The novelty of this study lies in the integration of the evaluation of the five dimensions of sustainability with the identification of sensitive attributes that most influence the sustainability of agroforestry systems at the local level. Unlike previous studies that generally only assess sustainability status from an ecological and economic perspective, this study also produces information on priority attributes that can be used as a basis for developing sustainable agroforestry management strategies. Thus, this study contributes to the development of agroforestry sustainability evaluation methods and provides scientific recommendations that can support policy-making and sustainable agroforestry management in forest buffer zones.

2. LITERATURE REVIEW

2.1 Agroforestry

Agroforestry is a land management system that integrates forestry plants with agricultural crops in a single spatial and temporal framework to optimize sustainable resource use (Purba et al., 2020). This system has long been implemented in various countries, although scientific research on agroforestry began to develop rapidly in the 1970s (Cessa-Reyes, Ruiz-Rosado, & Alcudia-Armida, 2020). Agroforestry combines woody species with agricultural crops to provide ecological, economic, and social benefits. The implementation of this system aims to increase production diversification, improve soil fertility, optimize nutrient cycling, improve the microclimate, and increase land productivity without compromising sustainability (Fajri, Putra, Irawan, & Latif, 2023). In Indonesia, agroforestry is an important part of the implementation of social forestry policies through various schemes, such as Community Forests (HKm), Community Plantation Forests (HTR), and village forests, which encourage community involvement in forest area management (Widiyanto, Fauziyah, & Suhartono, 2022).

Various studies have shown that agroforestry can reduce pressure on forests by maintaining tree cover while providing economic benefits through food crops, commercial crops, timber, and non-timber forest products (Budiastuti, Purnomo, & Setyaningrum, 2021). Furthermore, the success of agroforestry is influenced by cultivation management, cropping patterns, community participation, and local institutions that support the sustainability of the system (Dako et al., 2025). However, most previous studies have evaluated agroforestry based on specific aspects, such as ecological or economic benefits, thus failing to fully explain the relationships between the sustainability dimensions. Therefore, an approach that integrates ecological, economic, social,

institutional, and technological dimensions is needed to enable a more comprehensive evaluation of agroforestry sustainability in the region.

2.2 Wan Abdul Rachman Grand Forest Park

The Wan Abdul Rachman Large Forest Park (*Tanah Hutan Besar Tahura*), covering an area of approximately 22,244 hectares, is an important conservation area in Lampung Province, strategically maintaining ecosystem balance while supporting the livelihoods of the surrounding community. This area is designated as a large forest park with the main objectives of biodiversity conservation, education, research and sustainable use. In its management, the Tahura Large Forest Park is divided into several blocks, such as protection, utilization, plant and animal collection, rehabilitation, and traditional blocks, each of which has a different role in maintaining the area's ecological and social functions (Herwanti et al., 2022). Ecologically, the Tahura Large Forest Park has a fairly high level of biodiversity, both in terms of flora and fauna. Research shows that this area has a diverse vegetation composition, dominated by Multipurpose Tree Species (MPTS) utilized by the community, such as durian (Durio zibethinus) and candlenut (Aleurites moluccana). Furthermore, the stand structure in this area exhibits relatively complete canopy stratification, reflecting an ecosystem that supports ecological functions such as soil and water protection (Istomo & Ferliana, 2024). However, the WAR Forest Reserve also faces various pressures, primarily due to human activity. Land cover changes in this area are largely driven by community land use for agricultural activities. While this use provides economic benefits to the community, it also has the potential to degrade ecosystem quality if not sustainably managed. Community interaction with forest areas is moderate, encompassing forest utilization, protection, and conservation activities. The level of interaction is influenced by factors such as land area and the income level of the surrounding community (Kristin, Qurniati, & Kaskoyo, 2018).

From a socioeconomic perspective, the Tahura Forest Area (WAR) plays a crucial role in the surrounding community. Most residents rely on forest resources for their livelihoods through agroforestry systems that combine forestry and agricultural crops. This system enables communities to generate income while maintaining their land cover. Research shows that income from the Tahura Area contributes significantly to the total household income, making it a primary source of livelihood (Bella, Abidin, & Widjaya, 2019). Furthermore, community interaction with forest areas is influenced by social and economic factors, such as income levels, land area, and access to forest resources. High levels of interaction without proper management can increase pressure on the area, necessitating a community-based management approach to maintain the sustainability of forest areas (Kristin et al., 2018). In line with developments in forestry policy in Indonesia, the management of the Tahura Forest Area has adopted a social-forestry scheme through conservation partnerships. This scheme allows communities surrounding an area to legally access and manage land while adhering to conservation principles (Mufidah et al., 2024). Agroforestry is a relevant approach to sustainable management in the Tahura Agricultural Area (WAR). Agroforestry systems not only increase land productivity but also maintain the ecological function of forests through the presence of trees in the cultivation system. Thus, agroforestry can be a solution for balancing community economic needs and forest conservation. This aligns with the concept of community-based forest management, which emphasizes active community participation in forest conservation (Syahputra, Mardliyah, & Undadraja, 2025).

From a biophysical perspective, Tahura WAR Natural Park has diverse topography, ranging from lowlands to hills with varying slopes, ranging from gentle (<8%) to very steep (>40%). This condition influences the distribution of vegetation and the land use patterns in the region. Areas with steep slopes are generally still dominated by forest vegetation, whereas areas with gentler slopes are widely used by the community for agroforestry activities. This topographic variation also affects the level of vulnerability to erosion and landslides; therefore, land management in this area must consider aspects of soil and water conservation (Minarningsih, 2022). Overall, Tahura Wan Abdul Rachman Natural Park is an area with interconnected ecological, social, and economic functions. Despite its high biodiversity potential, this area faces challenges in terms of land-use pressure. Therefore, an integrated and sustainable management strategy is needed, one of which is through the

implementation of community-based agroforestry to ensure the sustainability of the area while improving the welfare of the surrounding community.

2.3 Commercial Crops

Cash crops are agricultural commodities cultivated primarily for sale and income generation. In the context of agroforestry, cash crops are often a key component in determining the economic sustainability of the system, as they contribute directly to farmers' household income. According to Bakri, Apriliani, Kaskoyo, and Wulandari (2024), agroforestry systems in Indonesia, particularly in Lampung, rely heavily on cash crops such as coffee and cocoa as their primary source of income. These cash crops serve not only as an economic resource but also as part of communities' adaptation strategies to land limitations and economic pressures in forested areas in the region. This study explains that coffee, as a cash crop in agroforestry systems, plays a crucial role in increasing farmers' incomes. However, cash crop productivity is strongly influenced by physical capital factors (land and production facilities) and social capital (networks and institutions). Furthermore, other studies related to the income of agroforestry communities show that the contribution of cash crops to household income is significant, but is still influenced by external factors such as infrastructure, market access, and off-farm activities. In other words, the success of cash crops does not stand alone but is influenced by the broader socio-economic system (A. K. Damanik, Bakri, & Wulandari, 2021).

Commercial crops in agroforestry also play a role in encourage economic diversification. For example, commodities such as cocoa not only produce beans as the primary product but can also be combined with other products, such as fruits and non-timber forest products. This diversification has been shown to increase farmers' total income and strengthen household economic resilience (Middendorp, Vanacker, & Lambin, 2018). Furthermore, another study by Wulandari (2009) explains that on marginal land in North Lampung, various agroforestry patterns exist based on combinations of tree crops and commercial crops, such as coffee, cocoa, and fruit, mixed rubber, and even a combination of timber and food crops. This variation in patterns indicates that the choice of commercial crops is strongly influenced by farmer preferences and land biophysical conditions. Community crop combination selection patterns are influenced by local ecological knowledge in agroforestry.

Communities surrounding forests possess local wisdom in selecting crop types, including commercial crops, that are appropriate for land conditions and economic needs. This knowledge is crucial for maintaining the sustainability of agroforestry systems (Pamungkas, Wulandari, Iswandaru, & Hilmanto, 2022). Furthermore, in the context of food security, agroforestry contributes to providing food sources and income. Wulandari et al. (2019) stated that agroforestry systems can improve household food security due to product diversification, both in the form of commercial crops and food crops. However, previous studies generally position commercial crops as an economic factor without linking them to ecological, social, institutional, and technological aspects in an integrated manner. In fact, a production orientation that is not balanced with sustainable management can increase the pressure on forest resources. Therefore, this study views commercial crops as an integral part of agroforestry systems that need to be evaluated using a multidimensional approach so that the relationship between economic benefits and environmental sustainability can be analyzed more comprehensively.

3. METHODOLOGY

3.1 Time and Location

This study was conducted between October and November 2025. The research location was Bogorejo Village, Gedong Tataan District, within Wan Abdul Rachman Grand Forest Park (Tahura Wan). Bogorejo Village has one farmer group called Gapoktan Wanakarya, with eight Forest Farmer Groups (KTH). The work map of Gapoktan Wanakarya in Bogorejo Village, Gedong Tataan District is shown in Figure 1.

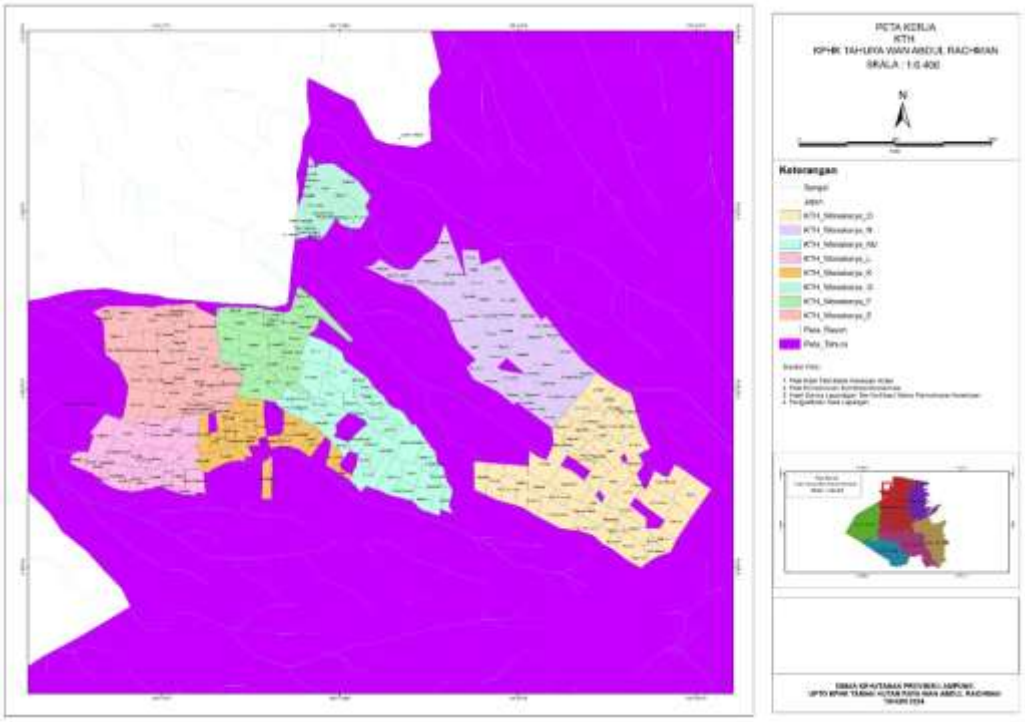

Figure 1. Work map of the Wanakarya Farmers Group in Bogorejo Village, Gedong Tataan District.

The research location was chosen because the area directly borders the Wan Abdul Rachman Forest Reserve area and the community's high dependence on forest land use through agroforestry systems. The people of Bogorejo Village are known to have intensive interactions with forest areas to meet their living needs, which are accommodated in forest farmer groups such as Gapoktan Wanakarya (Safira, Wulandari, & Kaskoyo, 2017). The population of Bogorejo Village in the Gedong Tataan District is 5,551 people, with a total of 1,505 families. Based on the results of interviews with stakeholders, the Head of Gapoktan Wanakarya, it is known that Gapoktan Wanakarya Bogorejo Village has 277 members divided into eight forest farmer groups.

3.2 Respondent Determination Method

The sample in this study consisted of residents of Bogorejo Village who were members of the Wana Karya Farmers Group (Gapoktan Wana Karya) and stakeholders as special respondents or key informants. The sampling technique used in Bogorejo Village was random sampling. The sampling method used the Slovin formula with a 15% margin of error (MOE). The sample size was calculated using Slovin's formula as follows:

$$n = \frac{\mathrm{N}}{\mathrm{N}(\mathrm{e}^2) + 1} \quad (1)$$

The sample size was determined using the Slovin formula with a precision of 15% (0.15). The total population of the Wana Karya Farmers Group in Bogorejo Village comprised 277 members. Based on the Slovin formula, the calculated sample size was 39 respondents, which was considered sufficient to represent the population. Stakeholders and respondents in this study were the Head of UPTD Tahura WAR Lampung, the Head of Bogorejo Village, the Head of Gapoktan Wanakarya, and the Extension Team of Tahura WAR Lampung assigned to Bogorejo Village. The number of respondents in this study was 43, consisting of 39 members of Gapoktan Wanakarya and four stakeholders. Data were obtained through structured interviews and questionnaires completed by the respondents.

3.3 Data Analysis

The analysis of agroforestry management sustainability was conducted using the Multidimensional Scaling (MDS) approach with the Rapid Appraisal of the Status of Forestry (Rap-forest) analysis tool. The MDS approach was chosen because it can comprehensively evaluate the sustainability status through a simultaneous analysis of various dimensions and identify the most sensitive attributes influencing the level of sustainability of a system. This approach is in accordance with the research objectives because the sustainability of agroforestry management is influenced by the interrelationships between ecological, economic, social, institutional, and technological dimensions, which cannot be evaluated partially. The attributes used in each dimension were selected based on the characteristics of the resources studied and the availability of relevant information, referring to the method developed by Pitcher and Preikshot (2001) as a guide.

3.3.1 Sustainability Index Analysis

The compilation of index values and sustainability status of agroforestry management based on each dimension and attribute follows the concept developed by Pitcher and Preikshot (2001) as follows: sustainability index value categories consist of four assessments, as listed in Table 1.

Table 1. Sustainability status categories of agroforestry management

Index Value	Category
≤25	Not sustainable
26-50	Less sustainable
51-75	Quite sustainable
76-100	Highly Sustainable

3.3.2 Leverage Analysis

Leverage analysis was used to identify the most sensitive attributes influencing sustainability values in each dimension. The attribute with the highest Root Mean Square (RMS) change is considered to have the greatest influence on the system.

3.3.3 Monte Carlo Analysis

The accuracy of the MDS model in this study was evaluated using the stress values and the coefficient of determination (R^2). A low stress value indicates that the model has a good level of fit in representing data.

4. RESULTS AND DISCUSSIONS

4.1 Results of the 5-Dimensional Sustainability Status Index

A radar diagram depicts the sustainability status in an integrated manner across multiple dimensions. The closer the analysis results are to zero, the lower the sustainability (Rusdi, Setyobudiandi, & Damar, 2020). The sustainability status of Bogorejo Village agroforestry management measures five dimensions: ecological, economic, social, institutional, and technological. The sustainability status of Bogorejo Village agroforestry management can be illustrated using a kite diagram, as shown in Figure 2.

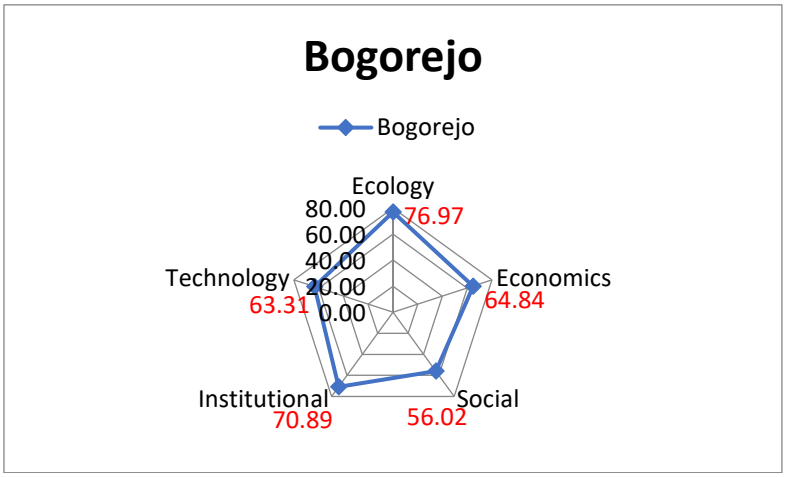

Figure 2. 5-dimensional sustainable flight diagram.

The kite diagram shows that the ecological dimension is in the highly sustainable category, while the economic, social, institutional, and technological dimensions are still in the moderately sustainable category. The ecological dimension's sustainability ordination value was 76.97, which is included in the highly sustainable category because it is in the index range of 75.01–100. These results indicate that the ecological conditions in the agroforestry system provide excellent support for sustainable area management. These conditions indicate that the implemented agroforestry practices can maintain ecological functions, such as maintaining vegetation cover, reducing pressure on forest areas, and supporting soil and water conservation. Therefore, management efforts must focus on maintaining environmental quality by preventing deforestation, preserving vegetation diversity, implementing environmentally friendly cultivation practices, and strengthening the monitoring of land use changes to maintain the achieved ecological conditions. This finding is in line with the research by Suhartini et al. (2024), which shows that the ecological dimension is in the highly sustainable category and emphasizes the importance of maintaining environmental quality as a basis for sustainable agroforestry management.

The economic dimension obtained an ordination value of 64.84, thus it is included in the category of moderately sustainable because it is in the index range of 50.01–75.00. This result indicates that the economic aspect has provided sufficient support for the sustainability of agroforestry management but still requires improvement efforts to achieve a highly sustainable category. This indicates that the income stability of communities dependent on agroforestry still needs to be strengthened through diversification of commercial crops, increased land productivity, development of value-added products, and expansion of market access. This strategy is expected to increase the economic resilience of farming households while reducing their dependence on a single commodity that is vulnerable to price fluctuations. This finding is in line with the research of Jayadi, Hariyanto, Apriyanto, Saputra, and Putra (2025), which states that improving the welfare of rural communities needs to be realized through economic development oriented towards sustainable growth to improve community welfare while supporting the sustainability of natural resource management.

The sustainability ordination score for the social dimension was 56.02, categorizing it as moderately sustainable, as it fell within the index range of 50.01–75.00. These results indicate that social aspects have supported the sustainability of agroforestry management, but their effectiveness still needs to be improved to achieve a highly sustainable category. This indicates that community participation, cooperation among farmers, and involvement in farmer group activities and joint management still require strengthening. Therefore, improving the social dimension can be achieved by increasing community capacity through extension and training, strengthening the role of farmer groups in decision-making, and developing more intensive partnerships between the community, government, and other stakeholders. These efforts are expected to increase community participation, strengthen social capital, and encourage collaborative and sustainable agroforestry management.

These findings align with those of Reed et al. (2020), who stated that multistakeholder collaboration contributes to the success of natural resource management by improving community welfare, strengthening local institutions, and fostering social resilience.

The institutional dimension plays a crucial role in determining the sustainability of agroforestry management because it serves as the basis for coordination, decision-making, and implementation of integrated resource management. The ordination score for the institutional dimension was 70.89, placing it in the moderately sustainable category, which is acceptable. These results indicate that existing institutions are capable of supporting agroforestry management, but their effectiveness needs to be improved to achieve a highly sustainable category. This improvement can be achieved by strengthening the institutional capacity of farmer groups, enhancing coordination between stakeholders, optimizing the role of forestry extension workers, and strengthening access to government programs and ongoing mentoring. These efforts are expected to increase institutional effectiveness in supporting adaptive and sustainable agroforestry management practices. This finding aligns with that of Irianto et al. (2023), who indicated that the institutional dimension is in the moderately sustainable category and requires institutional strengthening as a key factor in enhancing the sustainability of forest resource management.

The sustainability ordination result for the technology dimension was 63.31, which was categorized as moderately sustainable. Based on the sustainability ordination results for the technology dimension, improvements are needed to achieve a high-sustainability category. Efforts to improve the technology dimension can be made through the application of more appropriate cultivation technologies, increasing farmers' access to information and extension services, and utilizing technologies that support efficient land management and crop productivity. The application of appropriate technology in agroforestry systems has been shown to increase land productivity, resource management efficiency, and support the sustainability of community-based agricultural systems (Sinclair & Coe, 2019).

4.2 Results of 5-Dimensional Leverage Analysis

In this section, we describe the results of the influence analysis across all dimensions: ecological, economic, social, institutional, and technological. The results of the influence analysis, which illustrate the most sensitive attributes affecting the sustainability index value of the ecological dimension, are shown in Figure 3.

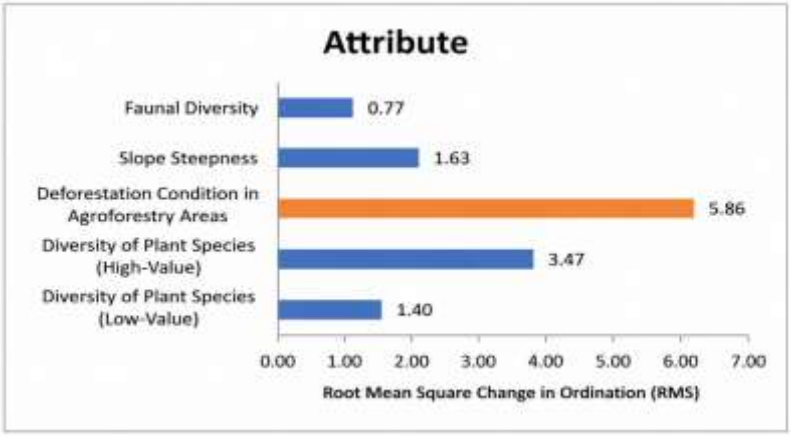

Figure 3. It takes advantage of its ecological dimension.

In Figure 3, agroforestry deforestation is the attribute with the greatest influence on the ecological dimension of sustainability ordination. This is evident from the sensitivity value of the agroforestry deforestation attribute, which was 5.86%. This value indicates the percentage difference in the ordination position if this attribute is removed. This means that if the agroforestry deforestation attribute is removed, the difference in sustainability ordination position will change by 5.86. The level of agroforestry deforestation in Bogorejo Village is categorized as high. This result indicates a

significant increase in land conversion pressure in the Tahura area. Based on various studies, the Wan Abdul Rachman Large Forest Park area has experienced dynamic land-cover changes over time. These changes are influenced by community activities in land use and regional management policy factors, which result in forest land degradation and conversion (Auliya Fikri et al., 2022). This means that this attribute must be removed, and at least the level of deforestation must be reduced to support the sustainability of agroforestry land in Bogorejo Village. The results of the influence analysis, which describe the most sensitive attributes that influence the value of the economic dimension sustainability index, are shown in Figure 4.

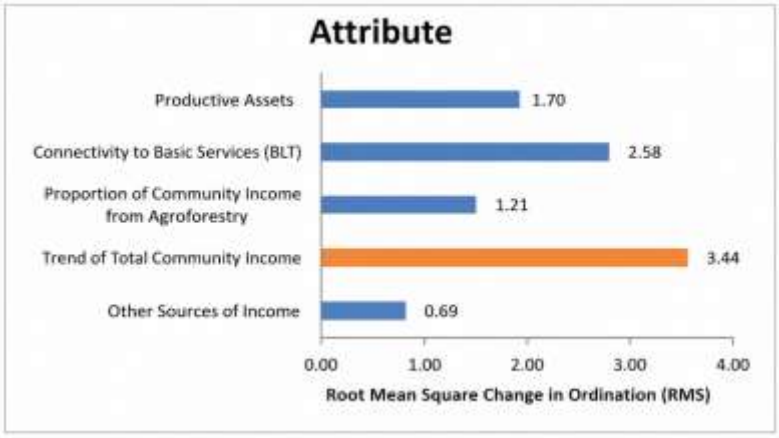

Figure 4. This takes advantage of the economic dimension.

Of the five attributes, the trend in total community income is the most influential in coordinating the sustainability of the economic dimension. This is evident from the sensitivity value of the total community income trend attribute, which was 3.44%. The trend in the total community income in Bogorejo Village is relatively low. Low income impacts the sustainability of the economic dimension. Changes in income trends are influenced by various factors, such as economic activity, natural resource utilization, and production systems implemented by the community. Furthermore, other research shows that increases or decreases in community income are not always linear, but can fluctuate depending on commodity prices, land area, and land management intensity (Bagas Putra, Darmawan, Dewi, Fitriana, & Febryano, 2022). The results of the influence analysis, which describe the most sensitive attributes that influence the social dimension sustainability index value, are shown in Figure 5.

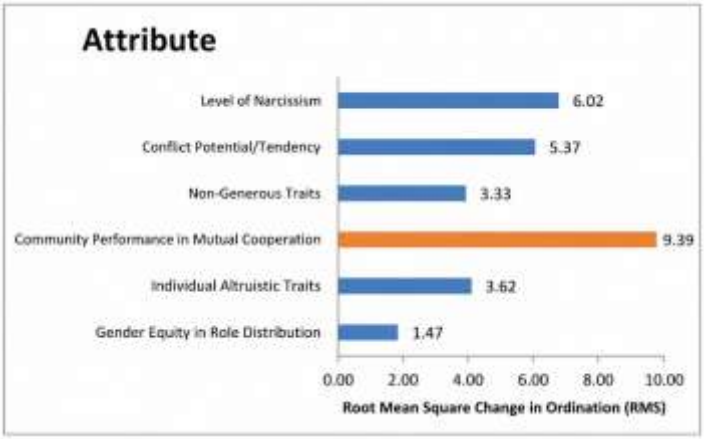

Figure 5. Take advantage of social dimensions.

Of the six attributes, community performance in reciprocal cooperation among neighbors is the attribute that most influences the arrangement of the social sustainability dimensions. This is evident

from the sensitivity value of the community performance attribute in reciprocal cooperation among neighbors, which is 9.39%. This indicates that the level of togetherness and cooperation among communities plays a crucial role in supporting social sustainability in a region. The value of reciprocal cooperation reflects the existence of strong social capital within the community, which can increase participation, trust, and cooperation in the management of natural resources. Strong social capital will facilitate communities to address various environmental problems and encourage the creation of more sustainable resource management (Bennett, Blythe, Cisneros-Montemayor, Singh, & Sumaila, 2019).

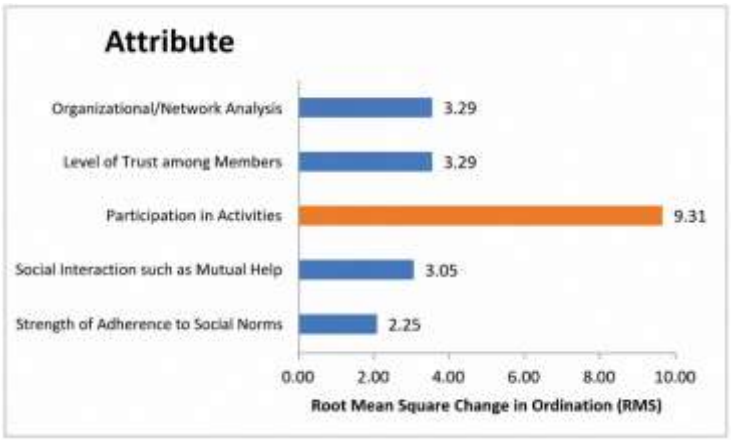

Figure 6. Leveraging institutional dimensions.

Figure 6 shows the results of the influence of the institutional dimension. Of the five attributes, participation in cooperative/arisan activities had the greatest influence on institutional sustainability. This is evident from the sensitivity value of the attribute of participation in cooperative/arisan activities of 9.31%. Currently, there are no cooperatives among KTH members in Bogorejo Village; they used to exist but are now defunct. Arisan activities are held in every sub-district, but community participation in cooperative/arisan activities remains low, with only a few people actively participating. This attribute plays a crucial role in the sustainability of the institutional dimension. This indicates that community economic institutions, such as cooperatives and group activities, play a crucial role in strengthening cooperation, increasing access to capital, and encouraging community participation in resource management activities. Active local institutions can increase community capacity for collective resource management and support sustainable development at the local level (Zhang, Mi, & Liu, 2024).

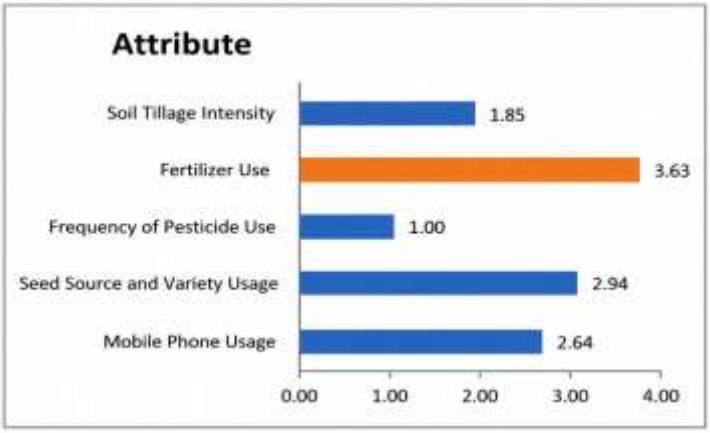

Figure 7. Take advantage of The technological dimension should be leveraged.

Figure 7 shows that fertilizer use is the most influential attribute in coordinating the sustainability of the technology dimension. This is evident from the sensitivity value of the fertilizer-use attribute, which was 3.63%. Fertilizer use in Bogorejo Village is categorized as medium-high, as the community uses fertilizer to improve soil fertility and plant productivity in the agroforestry systems. Farmers frequently use organic and inorganic fertilizers to maintain soil nutrient availability, thereby optimizing plant growth and increasing yields. Proper fertilizer management is crucial for increasing land productivity while maintaining the sustainability of agricultural and agroforestry systems (Agegnehu et al., 2021). However, fertilizer use in conservation forest areas such as Tahura (Tahura) should be limited because of the potential to alter soil properties and affect the balance of the natural ecosystem. Land management in conservation areas is generally recommended to use environmentally friendly approaches, such as utilizing natural organic matter or managing vegetation that naturally maintains soil fertility (van Noordwijk, 2021).

4.3 Monte Carlo Analysis Results

Achmad Fauzi (2019) explain that Monte-Carlo analysis is used to detect sources of error in data diversity. Error source detection was performed by comparing the MDS index value with the Monte Carlo value. Table 2 shows a comparison of the sustainability index results from the MDS and Monte Carlo simulations.

Table 2. Difference in index values between MDS and Monte Carlo

Size	MDS Value (%)	Monte Carlo (%)	Difference (%)
Ecology	76.97	75.52	1.45
Economy	64.84	63.69	1.15
Social	56.02	55.08	0.94
Institutional	70.89	69.42	1.47
Technology	63.31	61.69	1.62

Based on the Monte Carlo analysis results, the difference in index values between the Rapfish MDS results and the Monte Carlo simulation for each dimension was relatively small, at less than 5%. This indicates that the agroforestry sustainability assessment results across the five dimensions analyzed–ecological, economic, social, institutional, and technological–have a low level of uncertainty. This small difference indicates that the assessment process by respondents is quite consistent, the variance between attributes is not too large, and the analysis procedure remains stable. Therefore, the sustainability index results obtained can be considered to have good reliability and can serve as a strong basis for interpreting the sustainability status of agroforestry in Bogorejo Village. Therefore, it can be concluded that the sustainability evaluation of commercial crop-based agroforestry in the Wanakarya Farmers' Group (Gapoktan Wanakarya) in Bogorejo Village, Pesawaran Regency, Lampung, has a high level of reliability, making it suitable for use as a basis for formulating strategies to develop sustainable agroforestry management.

5. CONCLUSIONS

5.1 Conclusion

This study shows that commercial crop-based agroforestry management in Bogorejo Village, a buffer zone of Wan Abdul Rachman Forest Park, is generally categorized as fairly sustainable. The ecological dimension obtained the highest sustainability score (76.97) and was included in the highly sustainable category, while the economic (64.84), social (56.02), institutional (70.89), and technological (63.31) dimensions were still in the fairly sustainable category. These results indicate that the sustainability of agroforestry in the research location has been supported by good ecological conditions but still requires strengthening in the economic, social, institutional, and technological aspects to achieve more optimal management.

Leverage analysis identified that agroforestry deforestation conditions, community income trends, reciprocal cooperation, participation in cooperatives or social activities, and fertilizer use were the most sensitive attributes influencing the sustainability of the system. These findings confirm

that agroforestry sustainability is determined not only by environmental quality but also by the ability to integrate economic, social, institutional, and technological aspects in a balanced way. Therefore, agroforestry management must be directed towards an adaptive strategy that prioritizes improvements in these sensitive attributes to enhance the overall sustainability of the system.

5.2 Research Limitations

This study had several limitations. First, the study was conducted in only one location, Bogorejo Village, within the Wan Abdul Rachman Forest Park buffer zone. Therefore, the results cannot be generalized to other agroforestry areas with different social, economic, and biophysical characteristics or to other countries. Second, sustainability evaluation using the Multidimensional Scaling (MDS) approach depends on the selected attributes and the conditions at the time of data collection; therefore, future changes in conditions could potentially influence the sustainability evaluation results.

5.3 Suggestions and Directions for Future Research

Based on the research findings, area managers and policymakers need to focus on improving community income stability through the diversification of commercial crops, strengthening community participation in local institutions, increasing the capacity of farmer groups, and developing and adopting more efficient and environmentally friendly cultivation technologies. These steps are expected to improve the economic, social, institutional, and technological dimensions without compromising the achieved ecological sustainability.

For future research, it is recommended to evaluate agroforestry sustainability in a broader range of locations with different ecosystem characteristics and to integrate a multidisciplinary approach to more deeply examine the relationship between income stability, strengthening social capital, technological innovation, and environmental sustainability. Future research should explore the application of technologies and management models that can enhance economic sustainability while maintaining the long-term ecological function of agroforestry systems.

AUTHOR CONTRIBUTION

AA was responsible for the conceptualization, methodology, investigation, data curation, formal analysis, writing of the original draft, visualization, and reviewing and editing of the manuscript. CW contributed to the methodology, validation, supervision, manuscript review, and editing. SB contributed to the formal analysis, validation, and manuscript review and editing. DAI contributed to the investigation, data curation, resources, manuscript review, and editing. PB contributed to the investigation, validation, resources, and manuscript review and editing of the study. HK was responsible for supervision, project administration, manuscript review, and editing.

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