

Analysis of the sustainability of productive carbon forests in Garut, West Java, Indonesia

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Abstract. Putra SA, Nurrochmat DR, Purwawangsa H, Nurrochmat NA, Qanitha M, Mutaqin F. 2025. Analysis of the sustainability of productive carbon forests in Garut, West Java, Indonesia. *Biodiversitas* 26: 3218-3226. This study discusses the sustainability of the Productive Carbon Forest (PCF) program in Garut District, West Java, Indonesia. The purpose of this study is to analyze the sustainability index of the PCF program. The data used in this study are primary data (expert interviews, field surveys) and secondary data (library, agency reports). This study uses Multidimensional Scaling (MDS) techniques to analyze the dimensions of sustainability, with a scale of 0 (lowest) to 2 (highest), along with Rapid Appraisal for Private Forests (RAP-PFOREST) support, to assess the level of similarity and dissimilarity for each dimension. The results showed that Halimun community forestry is in the very sustainable category with a sustainability score of 80.35%, and produces 12 sensitive attributes, while Giriawas social forestry is in the moderately sustainable category with a sustainability score of 63.94% and produces 12 sensitive attributes that affect the management of the PCF program. Based on the results of the study at the two locations of the PCF program implementation, this study concluded that there were differences in the sustainability index values at the two locations of the program implementation, meaning that at the Giri Purnama Alam social forestry location, there is a need to improve technical assistance for adaptive management and monitoring. We recommend involving various stakeholders to encourage them to become a strategic reference in formulating sustainable forestry policies in the future.

Keywords: Agroforestry, climate change, Indonesia, productive carbon forests, sustainability

INTRODUCTION

Indonesia is one of the countries with the highest biodiversity in the world (Indrajaya et al. 2022; Nugroho et al. 2022; Sun et al. 2024), with a forest area comprising approximately 63% of its land area (Ministry of Environment and Forestry 2023). According to data from the Ministry of Environment and Forestry (2023), the total area of forest land reaches 125 million hectares. Indonesian forests provide oxygen for living creatures that can absorb carbon dioxide, a harmful substance, and produce oxygen gas, which humans need for survival (Richy et al. 2024; Weber et al. 2024). The protection and management of Indonesia's forests are crucial not only for maintaining biodiversity but also for supporting the lives and welfare of local communities, which are highly dependent on forest resources (Nurrochmat et al. 2023b, et al. 2024a; Rozak et al. 2023).

Sustainable forest management is a comprehensive and holistic concept that maintains the sustainability of forest resources (Muigua 2022; Mattsson et al. 2024; Yakovenko et al. 2024). It is stated that sustainable development, which integrates ecological, economic, and social aspects, has

been adopted in every country as the basis for development activities, from planning to evaluation (Rahmani et al. 2021; Rossita et al. 2021). The Sustainable Development Goals, often called SDGs, summarize a development pattern that involves three main pillars: social, economic, and environmental development, along with legal and governance aspects (Ruhana et al. 2024). The concept of sustainable development will serve as a crucial foundation for every country in its efforts to maintain the sustainability of natural resources, including sustainable forest management (Nurrochmat et al. 2022; et al. 2024b).

Institut Pertanian Bogor collaborates with Astra International to support Indonesia's achievement of its NDC targets through the Astra Carbon Offsetting program, which introduces the concept of a productive carbon forest. According to Purwawangsa et al. (2022) and Nurrochmat et al. (2024b), Productive Carbon Forest (PCF) is the use of forest and non-forest areas through an agroforestry system that aims to produce environmental value in the form of carbon absorption and economic value through productive yields such as coffee and high-value fruit, as well as building a business ecosystem with the concept integrated from planting to marketing. Despite its growing

implementation, there remains limited empirical evidence assessing the long-term sustainability of PCF practices. This program is an initial initiative designed to serve as a role model for productive forest areas and carbon zones, focusing on the Sustainable Development Goals (SDGs) and carbon offsetting (Nurrochmat et al. 2024a).

The green economic and industrial areas are being expanded by applying the PCF concept to specific areas, particularly in Garut District and, more broadly, in West Java Province, Indonesia. Based on initial observations of the implementation of PCF, 300 hectares of planting have been carried out in the Giriawas social forestry area, Cikajang District, and Halimun community forest, Pakenjeng District, Garut District. However, managing PCF in the Garut District still needs to be optimized. Research is needed to comprehensively understand the condition of PCF management in Garut District, including its sustainability aspects.

In previous research, one method for assessing the sustainability of a natural resource was the Multidimensional Scaling approach (Nurrochmat et al. 2024a, b). This approach has been used to determine the sustainability of community forests in the Bogor district by Sukwika et al. (2016) and Nurrochmat et al. (2023b). Meanwhile, this research analyzes the sustainability of PCF in the Garut District, West Java. PCF, initiated by Institut Pertanian Bogor and Astra International, is an innovative effort to combine forest conservation with agricultural production. Although this program has great potential for mitigating climate change and improving community welfare, there is still limited research on its effectiveness and sustainability. This research aims to fill this gap by analyzing the factors that influence the success of the PCF program in the Garut District and its impact on the community's environmental, social, and economic aspects. It is hoped that the results of this research can provide better policy recommendations for the sustainable development of PCF in the region (Nurrochmat et al. 2024a).

Sustainability analysis is a systematic and holistic approach to evaluating whether an action or project can be sustained over the long term (Coşkun et al. 2023; Senanayake et al. 2023). In the context of PCF, sustainability analysis aims to assess the extent to which the program can sustain environmental, social, economic, and institutional benefits (Lloret 2016; Nurrochmat et al. 2023a). Based on this description, it is essential to conduct this research to determine the sustainability status of the PCF program with an agroforestry system (Wang et al. 2023; Tinoco-Jaramillo 2024).

MATERIALS AND METHODS

Time and place

This study was conducted in the Garut District, West Java Province, Indonesia, from June to October 2024. The research focused on two locations for the implementation of the PCF program, namely: (i) Halimun community forest area covering an area of 29 hectares; (ii) Giri Purnama Alam Social Forestry Area covering an area of 130 hectares. The two research locations showed significantly different ecological and social characteristics.

The Halimun community forest area is 100-150 meters above sea level (m asl) with a dominant production forest. Traditionally, local people use this area to cultivate fast-growing plants, coffee plantations, and community tea. On the other hand, the Giri Purnama Alam social forestry Area is at a higher elevation (1500-2000 m asl), which is a protected forest that functions as an essential water catchment area. The land use pattern at this location applies to an intercropping system that combines horticultural and coffee plants while maintaining the existing natural vegetation. Figure 1 presents a map of the research locations.

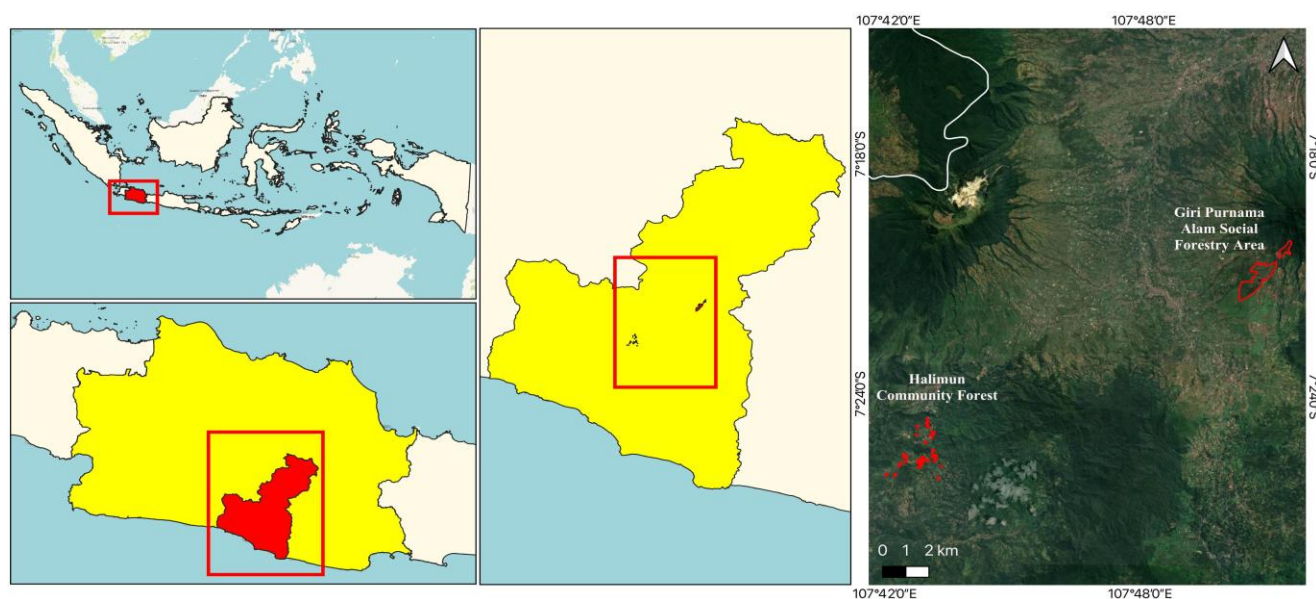


Figure 1. The research location is in the PS Giri Purnama Alam and HR Halimun areas, Garut District, West Java Province, Indonesia

Data collection

This research used primary and secondary data. Snowball sampling is employed in this research to conduct in-depth interviews with key individuals associated with these agroforestry programs (Cruz-López et al. 2023). Snowball sampling relies on initial subjects to identify and recruit additional participants, creating a chain of referrals (Kennedy-Shaffer et al. 2021). This method is particularly effective for accessing populations that are difficult to reach through traditional sampling methods (Kirchherr and Charles 2018). Primary data were collected directly through field observations, while structured interviews were conducted using questionnaires with key information to assess several ecological, economic, social, and institutional parameters (Nurrochmat et al. 2023b; et al. 2024b). The key informants in this research were representatives from the Institut Pertanian Bogor campus as program facilitators, the head of the CKL consultant (Cedar Karyatama Lestarindo), the BRIN (National Innovation Research Agency) researcher, the head of the Al-Bayyinah cooperative, and the head of the Giri Purnama Alam social forestry group. The key informant category in this research comprises individuals who possess and have access to various basic information required for the research. Five key pieces of information were used in this study. Secondary data were collected through desk studies, literature reviews of various documents, and previous research proceedings (Lina 2024; Willis 2024).

Data analysis

The Rapid Appraisal for Fisheries (RAPFISH), a novel multidisciplinary quick evaluation technique, was created at the University of British Columbia in Canada and is used to assess the sustainability of fisheries. RAPFISH depends on the Multidimensional Scaling (MDS) ordination of scored qualities aggregated in many evaluation fields. Multidimensional Scaling (MDS) is a powerful statistical technique for reducing dimensionality and visualizing data (Saeed et al. 2018). The Multidimensional Scaling (MDS) analysis used in this Productive Carbon Forest (PCF) research is a non-metric type; it aims to represent high-dimensional data in a lower-dimensional space while preserving the relationships between data points as much as possible (Groenen and Velden 2016). This process utilizes an analysis tool called Rapid Appraisal for Private Forests (RAP-PFOREST), a modification of the Rapid Appraisal for Fisheries (RAPFISH) method. The analyzer uses the RAPFISH feature that is added in Ms. Excel (Reza et al. 2021).

Adiga et al. (2015) explained that the RAPFISH method is used to assess the sustainability of fisheries resources. This method also validates indicator-based evaluation tools from various scientific disciplines based on assessments by resource owners, users, and experts (Narendra et al. 2019). On the other hand, RAP-PFOREST is a modified version of RAPFISH, specifically adapted to the conditions and characteristics of forests (Kang et al. 2020).

This PCF sustainability assessment aims to bring closer the concept of evaluating forest management performance from various scientific disciplines and sectoral actors. This

approach considers essential aspects such as ecology, economics, social, and institutional, thereby providing a holistic assessment of the sustainability of resource management. Fauzi (2019) stated that scoring in RAPFISH typically originates from three primary sources due to RAPFISH's nature as a rapid appraisal tool. These sources are as follows: peer-review scoring, which is a score based on a review of scientific documentation with threshold determination; gray literature, which is a score based on the results of previous analysis, both published and unpublished; and expert judgment, namely the determination of scores carried out through expert agreement, as well as other methods such as the Delphi technique.

The stages of RAP-PFOREST analysis using the Multidimensional Scaling (MDS) method with the RAP-PFOREST application are: (i) Evaluating and determining attributes from the four dimensions (attribute review); (ii) Providing an assessment of each attribute that has been compiled from each dimension on an ordinal scale; (iii) Carrying out leverage factor analysis and uncertainty simulation; (iv) Calculate index values and assess sustainability status; (v) Determine the leverage factor; (xi) Monte Carlo analysis to calculate uncertainty. In summary, the stages of the sustainability analysis and multidimensional scaling of RAP-PFOREST are presented in Figure 2.

Figure 2 explains the RAP-PFOREST flow analysis that we conducted systematically, starting from: (i) selection and evaluation of attributes from four dimensions of desirability (ecology, economy, social, institutional) through literature studies and field observations, where attributes that have strong correlations are combined; (ii) ordinal scoring (0-2) for each attribute based on expert assessment of actual conditions compared to ideal standards; (iii) leverage factor analysis to identify the most influential attributes using Root Mean Square (RMS) values, as well as measurement simulations using the Monte Carlo method to anticipate assessment variations and data errors; (iv) fluctuations in the desirability index (0-100%) which are categorized into four levels (unsustainable to highly sustainable); e) determination of critical factors (RMS values (>8%) as the basis for improvement recommendations; (v) final validation through Monte Carlo analysis which ensures results with an error, if the difference between these two analyses is >5%, the MDS analysis is not adequate for estimating the sustainability index value, and if the difference between these two analyses is <5%, the MDS analysis is adequate for estimating the sustainability index value of PCF.

The sustainability index value for each dimension can be visualized as a kite diagram and analyzed multidimensionally to determine the point or position of sustainability for PCF management. Considering that the sustainability index value in the RAP-PFOREST method ranges from 0 (not sustainable) to 100 (very sustainable), the index values are grouped as shown in Table 1 to determine the sustainability status.

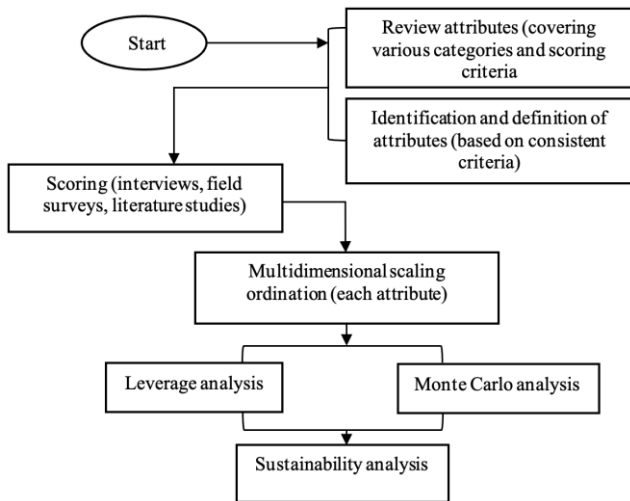


Figure 2. Stages of RAP-PFOREST analysis

Table 1. Productive carbon forest sustainability status index

Number	Index value	Category
1	0.00-24.99	Not sustainable
2	25.00-49.99	Less sustainable
3	50.00-74.99	Moderately sustainable
4	75.00-100.00	Very sustainable

Source: Fauzi (2019)

RESULTS AND DISCUSSION

Sustainability analysis

Ecological dimension

The sustainability status of PCF in the Halimun community forest, as measured in the ecological dimension, is 92.60% on a scale of 0-100% (Figure 3). This

index indicates that the ecological dimension falls within the "sustainable" category. Based on the results of the leverage analysis, three attributes are considered sensitive: vegetated land cover (RMS value of 7.40%), natural disasters (RMS value of 2.25%), and protection of flora and fauna species (RMS value of 2.02%). Meanwhile, the sustainability status of PCF in the Giri Purnama Alam social forestry, as measured in the ecological dimension, is 88.70% on a scale of 0-100% (Figure 3). This index indicates that the ecological dimension falls into the "very sustainable" category. Based on the results of the leverage analysis, three attributes are considered sensitive: the availability of water sources (RMS value of 11.30%), the protection of flora and fauna species (RMS value of 2.24%), and the percentage of plant growth (RMS value of 2.21%).

Economic dimension

The economic sustainability status of PCF (productive carbon forest) in the Halimun community forest is 81.17% on a scale of 0-100% (Figure 4). This index indicates that the economic dimension falls into "sustainable". Based on the results of the leverage analysis, three attributes are considered sensitive: land ownership area (RMS value of 12.83%), labor absorption (RMS value of 3.20%), and community income level (RMS value of 3.09%). Meanwhile, the sustainability status of PCF in the Giri Purnama Alam social forestry, as measured in the economic dimension, shows a value of 52.02% on a scale of 0-100% (Figure 4). This index indicates that the economic dimension falls into the "fairly sustainable" category. Based on the results of the leverage analysis, three attributes are considered sensitive: land ownership area (RMS value of 8.55%), market certainty (RMS value of 6.82%), and business feasibility/financial analysis (RMS value of 4.14%).

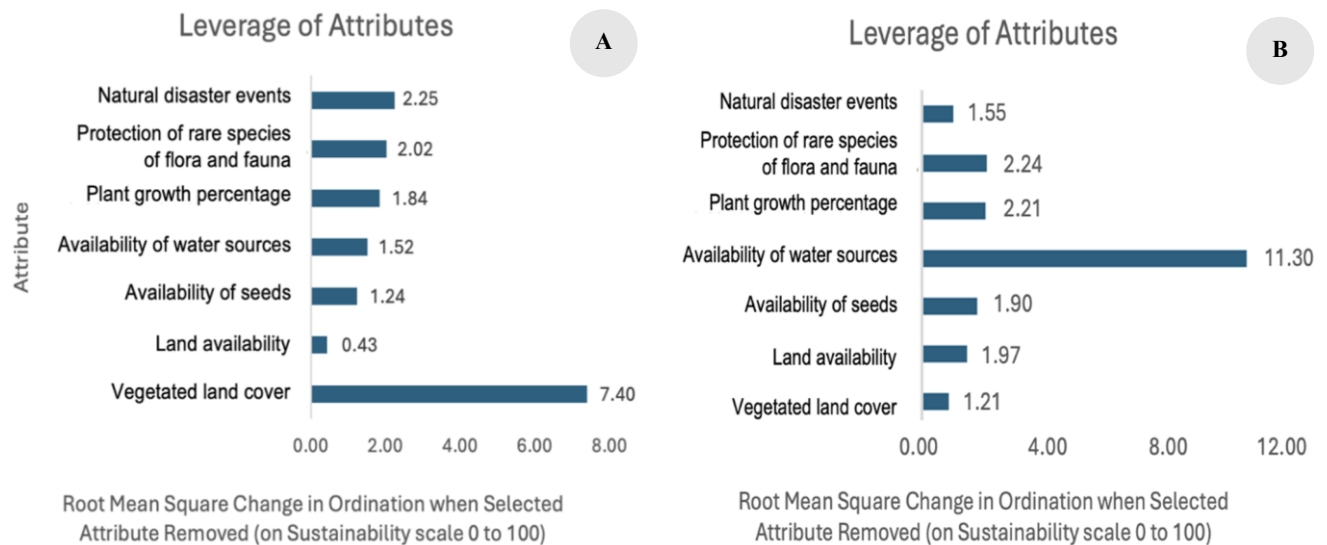


Figure 3. Leverage analysis of the ecological dimensions in Garut, West Java, Indonesia. A. Halimun community forestry, B. Giriawas social forestry

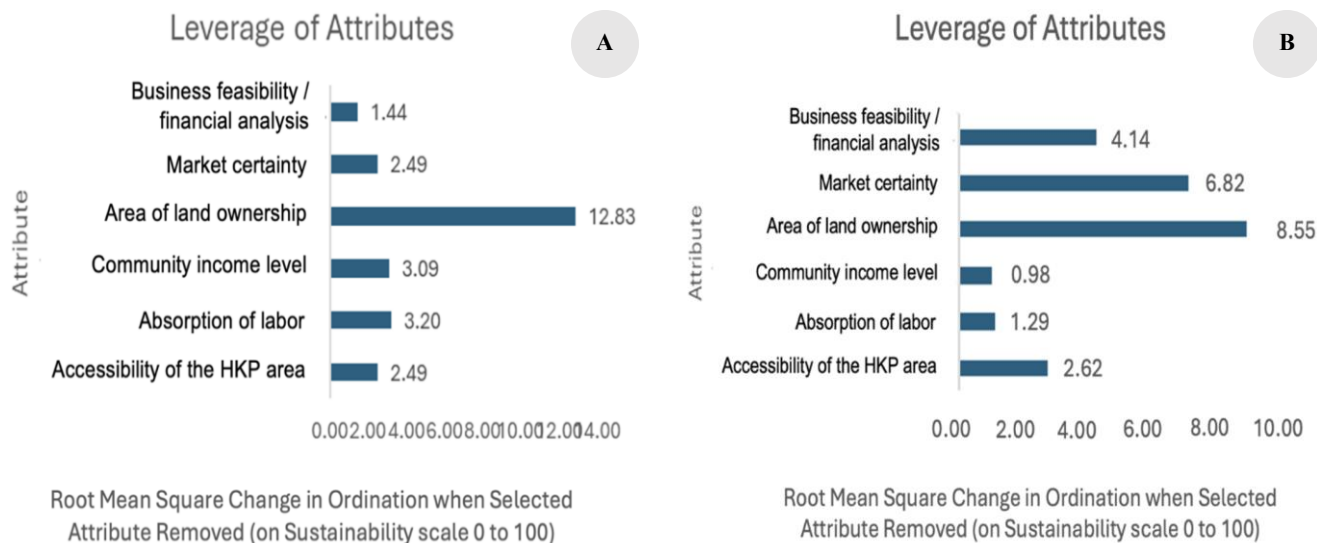


Figure 4. Leverage analysis of the economic dimensions in Garut, West Java, Indonesia. A. Halimun community forestry, B. Giriawas social forestry

Social dimension

The social dimension sustainability status of PCF (productive carbon forest) in the Halimun community forest is 75.57% on a scale of 0-100% (Figure 5). This index indicates that the social dimension is "sustainable." Based on the results of the leverage analysis, three attributes are considered sensitive: local wisdom (RMS value of 9.75%), community education level (RMS value of 8.39%), and resource conflict (RMS value of 5.63%). Meanwhile, the sustainability status of PCF (productive carbon forest) in the Giri Purnama Alam social forestry, as measured in the social dimension, is 58.95% on a scale of 0-100% (Figure 5). This index indicates that the social dimension falls into the "fairly sustainable" category. Based on the results of the leverage analysis, three attributes are considered sensitive: local wisdom (RMS value of 6.17%), frequency of community meetings (RMS value of 4.10%), and community education level (RMS value of 3.79%).

Institutional dimension

The sustainability status of PCF (productive carbon forest) in the Halimun community forest, as measured in the institutional dimension, is 66.06% on a scale of 0-100% (Figure 6). This index indicates that the institutional dimension falls into the "fairly sustainable" category. Based on the results of the leverage analysis, three attributes are considered sensitive: the capacity of administrators to manage PCF, with an RMS value of 6.99%; the legality of the PCF area, with an RMS value of 6.55%; and law enforcement, with an RMS value of 6.14%. Meanwhile, the sustainability status of PCF (productive carbon forest) in the Giri Purnama Alam social forestry, as measured in the institutional dimension, is 56.08% on a scale of 0-100% (Figure 6). This index indicates that the institutional dimension falls into the "fairly sustainable" category. Based on the results of the leverage analysis, three attributes are considered sensitive: law enforcement,

with an RMS value of 7.16%; research and community service programs, with an RMS value of 6.15%; and the availability of management regulations, with an RMS value of 5.36%.

The overall results of the leverage analysis for the four dimensions produce 12 attributes that substantially impact PCF management (Table 2). These values are selected based on the RMS (root mean square) value. These leverage factors are essential for developing a sustainable PCF management policy model. The overall results of the leverage analysis for the four dimensions produce 12 attributes that substantially impact PCF management in the Giri Purnama Alam social forestry (Table 4). These values are selected based on the RMS (root mean square) value. These leverage factors are essential for developing a sustainable management policy model for the PCF program.

Validity test

Monte Carlo validity shows that the difference in the average value of the two analyses is 0.60%. This means that the MDS analysis model is adequate to estimate the value of the PCF sustainability index.

Discussion

Different results were found in the four analyzed dimensions based on the analysis of the sustainability index in two locations implementing the PCF program, specifically Halimun community forestry and Giri Purnama Alam social forestry in Garut District. At the Halimun community forest location, the kite diagram results (Figure 7) indicate that the ecological dimension reached 92.60%, the economic dimension 87.17%, and the social dimension 75.57%, all classified as "very sustainable". Meanwhile, the institutional dimension has an index of 66.06%, which falls into the "moderately sustainable" category. Overall, the sustainability index at this location obtained a multidimensional scaling value of 80.35%, which is also

classified as "sustainable". On the other hand, at the Giri Purnama Alam social forestry location, the kite diagram shows that the ecological dimension reached 88.70% and was declared "very sustainable", while the economic dimensions (52.02%), social (58.95%), and institutions

(56.08%) are at "moderately sustainable" status. The overall sustainability index for this location reached a multidimensional scaling value of 63.94%, also categorized as "moderately sustainable".

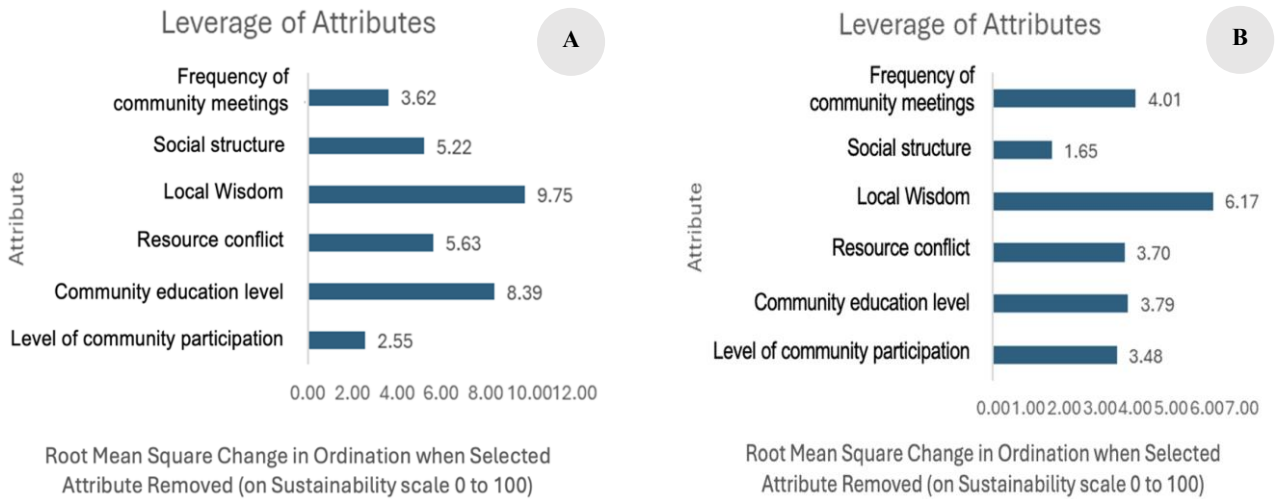


Figure 5. Leverage analysis of the social dimensions in Garut, West Java, Indonesia. A. Halimun community forestry, B. Giriawas social forestry

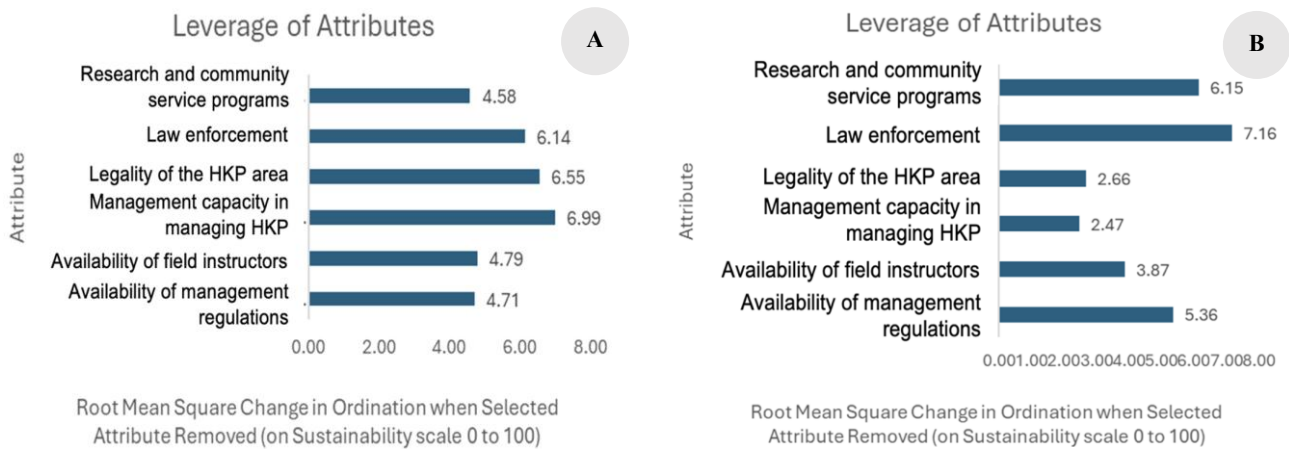


Figure 6. Leverage analysis of the institutional dimensions in Garut, West Java, Indonesia. A. Halimun community forestry, B. Giriawas social forestry



Figure 7. Kite diagram sustainability index in Garut, West Java, Indonesia. A. Halimun community forestry, B. Giriawas social forestry

Table 2. Sustainability-sensitive attributes

Dimension	Halimun community forestry		Giri Purnama Alam social forestry	
	Atribut	RMS	Atribut	RMS
Ecology	Vegetated land cover	7.40	Availability of water sources	11.30
	Natural disaster events	2.25	Protection of rare species of flora and fauna	2.24
	Protection of rare species of flora and fauna	2.02	Plant growth percentage	2.21
Economy	Area of land ownership	12.83	Area of land ownership	8.55
	Absorption of labor	3.20	The market certainly	6.82
Social	Community income level	3.09	Business feasibility/financial analysis	4.14
	Local wisdom	9.75	Local wisdom	6.17
	Community education level	8.39	Frequency of community meetings	4.01
Instutional	Resource conflict	5.63	Community education level	3.79
	Management capacity in managing PCF	6.99	Law enforcement	7.16
	Regional legality	6.55	Research and community service programs	6.15
	Law enforcement	6.14	Availability of management regulations	5.36

Table 3. Differences in RAP-PFOREST sustainability index values for Halimun community forests, Garut, West Java, Indonesia

Dimension	Sustainability Index (%)	Monte Carlo (%)	Difference (%)	Stress Value	R ²	Iteration
Ecology	92.60	89.07	3.53	0.1400	0.9476	2
Economy	87.17	83.18	3.99	0.1429	0.9391	3
Social	75.57	72.49	3.08	0.1441	0.9396	2
Institution	66.06	64.63	1.43	0.1489	0.9398	2
Multidimensional	80.35	77.34	3.01	0.1440	0.9415	

Table 4. Differences in RAP-PFOREST sustainability index values for Giri Purnama Alam social forestry, in Garut, West Java, Indonesia

Dimension	Sustainability Index (%)	Monte Carlo (%)	Difference (%)	Stress Value	R ²	Iteration
Ecology	88.70	84.96	3.74	0.1388	0.9431	2
Economy	52.02	51.25	0.77	0.1477	0.9381	2
Social	58.95	57.84	1.11	0.1556	0.9389	2
Institution	56.08	55.43	0.65	0.1497	0.9424	2
Multidimensional	63.94	62.37	1.57	0.1479	0.9406	

These four dimensions are calculated from expert opinion scores and combined into the sustainability dimension. Three sensitivity (leverage) attributes exist in the ecological dimension in both locations. The first is the Halimun community forest location, one of which is the attribute of vegetated land cover (RMS value of 7.40). At the same time, the social forestry of Giri Purnama Alam is characterized by its attribute of water source availability, with an RMS value of 11.30. Attributes that show a high level of importance (sensitivity) based on the results of this analysis are considered leverage factors. If improvements are made to these attributes, significant changes will occur, which can increase the value of the sustainability index. The differences in sensitivity (leverage) attributes between Halimun community forest and Giri Purnama Alam social forestry are caused by various factors influencing environmental conditions and management practices in each location. In the Halimun community forest, the dominant leverage attribute is vegetated land cover with an RMS value of 7.40. In contrast, in the Giri Purnama Alam social forestry, the main attribute is the availability of water

sources with an RMS value of 11.30. This difference highlights how environmental factors and management practices impact sustainability outcomes in the two locations (Martinho and Ferreira 2020; Latifah et al. 2025).

In the economic dimension in the two locations where PCF is implemented, Halimun community forest and Giri Purnama Alam social forestry, the sensitivity (leverage) attribute of these two locations is the attribute of land ownership area with RMS value of 12.83% in Halimun community forest and RMS value of 8.55% social forestry; this shows that land ownership is an attribute that influences economic sustainability. The larger land ownership area in the Halimun community forest allows the community to manage forest resources more effectively, increasing their productivity and income. Previous research by Rahmandani et al. (2023) also emphasizes the importance of clear and defined land ownership in community forest management. By having clear ownership, communities can plan and implement sustainable management practices that utilize forest resources responsibly and sustainably. On the other hand,

in the Giri Purnama Alam social forestry, the RMS value is lower, indicating that limited land ownership can limit farmers' ability to increase production and income. Therefore, strengthening land rights and expanding the area of land ownership are important strategies to enhance the sustainability of forestry management in these two locations.

The social dimensions in the two locations where PCF is implemented, in the Halimun community forest and Giri Purnama Alam social forestry, possess the sensitivity (leverage) attribute of local wisdom, with values of RMS of 9.75% for the Halimun community forest and 6.17% for social forestry. Local wisdom contributes to sustainability analysis by guiding communities in the sustainable management of forest resources. Practices rooted in local wisdom often include the wise use of forest resources, preserving traditions, and social arrangements supporting environmental conservation. Overall, local wisdom attributes are essential in supporting sustainability at both PCF locations by providing a framework for communities to manage forest resources effectively and sustainably.

Meanwhile, in the institutional dimension of the PCF program in the Halimun community forest, the institutional dimension is based on the results of leverage analysis, the attribute that is considered sensitive, namely the capacity of administrators in managing PCF with an RMS value of 6.99%, while in the Giri social forestry location Purnama Alam in the institutional dimension, based on the results of leverage analysis, namely law enforcement with an RMS value of 7.16%. This difference highlights that in the Halimun community forest, the success of the PCF program is highly dependent on administrators' ability to manage resources effectively. Effective management capacity can enhance community participation and ensure forest management practices adhere to sustainability principles. On the other hand, law enforcement in the Giri Purnama Alam social forestry program demonstrates that legality and compliance with regulations are key factors in its success. Vigorous law enforcement can prevent illicit practices, such as illegal logging and the unsustainable exploitation of natural resources.

Based on the analysis of the sustainability index at two locations implementing the PCF (program, namely, Halimun community forestry and Giri Purnama Alam social forestry), significant differences were found in the four dimensions analyzed: ecological, economic, social, and institutional. Halimun community forest showed better results with a multidimensional scaling index of 80.35%, classified as "very sustainable", while Giri Purnama Alam social forestry had an index of 63.94%, categorized as "moderately sustainable". Both locations demonstrate good (sustainable) performance in the ecological dimension; however, the Halimun community forest exhibits more favorable sensitivity attributes regarding vegetated land cover. On the economic side, the area of land ownership in the Halimun community forest contributes positively to community productivity and income. At the same time, the Giri Purnama Alam social forestry faces limitations that hamper this potential. Local wisdom also plays a crucial role in both locations, guiding communities in the prudent

management of forest resources. In the institutional dimension, the management capacity in the Halimun community forest is a key factor in the program's success. At the same time, law enforcement in the Giri Purnama Alam social forestry is crucial to prevent illegal practices. These findings indicate that the PCF approach not only has the potential to strengthen ecological resilience but also opens sustainable economic opportunities for local communities, so that it can be encouraged to become a strategic reference in formulating sustainable forestry policies in the future.

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