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CASE STUDY

Economic feasibility, perception of farmers, and environmental sustainability index of sorghum-eucalyptus agroforestry

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ABSTRACT

BACKGROUND AND OBJECTIVES: The Indonesian Government is promoting sorghum as an alternative commodity to substitute wheat. The cultivation of this commodity on dryland is initiated in forestry areas through social programs. This study aimed to analyze the economic feasibility, perception of farmers, and environmental sustainability of sorghum-eucalyptus agroforestry in Majalengka.
METHODS: This study innovatively combined qualitative and quantitative methods to assess economic, social, and environmental aspects across five dimensions, namely business organization, actors, working mechanisms, economic impacts, and sustainability of business and environment. Data were collected through focus group discussions and interviews with questionnaires, containing 5 dimensions and 23 attributes. The data collected were analyzed using the revenue-cost ratio, Likert scale, and scoring formulation, as well as multi-dimensional scale method. The level of environmental sustainability status and leverage attributes were examined using the Rapfish program and Monte Carlo analysis.
FINDINGS: Sorghum-eucalyptus agroforestry was economically feasible with a revenue-cost ratio value higher than one. Farmers' perceptions regarding the five dimensions of sorghum-eucalyptus were positive except for the operational mechanisms, and business and environmental sustainability. A distinfuished area of unfavorable perception was the use of sorghum waste as a substrate for renewable energy. The environmental sustainability index for sorghum-eucalyptus agroforestry was categorized as low except for the economic (61.9) and actor (52.3) which attained the moderately sustainable. The results showed that the sustainability analysis using multi-dimensional scale could be used as a guide in formulating strategies for enhancing and developing sorghum-eucalyptus agroforestry in the future.
CONCLUSION: The problems in this study were related to the institutional governance of agroforestry business. The inclusion of the community, government, and private sector was unequal in carrying out the sustainability function of each dimension. The challenge for the future was proper and sustainable management of development efforts to realize economic sustainability, add value for society, and ensure environmental sustainability in agroforestry areas.

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INTRODUCTION

The Russian-Ukrainian conflict is endangering food security by disrupting wheat production and restricting exports to several developing countries (Mottaleb *et al.,* 2022), such as Indonesia. The demand for wheat is 11.17 million tons, while export restrictions have decreased the contribution from Ukraine between 2.83 million (2021) to 166 thousand tons (2022) (Indonesia of Statistics, 2023). The Indonesian Government has turned to sorghum as a wheat substitute. Given the comparable physical and chemical properties, sorghum flour serves as an effective substitute (Osibanjo *et al.,* 2022). Even though the flour cannot completely replace wheat, its use can be reduced. Biscuits using 30 percent (%) sorghum flour were proven to be acceptable in terms of quality and taste (Al Majzoub *et al.,* 2023) and 10% of the flour could produce bread with similar quality to that of wheat (Sibanda *et al.*, 2015). Using 60% or lower amounts can replace the use of wheat flour and improve the quality of noodles to become cheaper (Akajiaku *et al.,* 2017). Sorghum could also be used as livestock feed and a source of energy (Dube and Maphosa, 2022; Malherbe *et al.,* 2023). Incorporating this commodity into wheat flour mixtures offers a potential reduction in imports for developing nations (Adeyeye, 2016). The Indonesian government has preferentially enhanced the production and distribution of sorghum to increase income and ensure national food security. The 2024 roadmap for the development sets ambitious goals, namely a target cultivation area of 30,000 and 40,000 hectares (ha) with a yield of 115,848 and 154,464 tons by 2023 and 2024, spread across 17 provinces (Kemenkoekonomi, 2022). Sorghum is a drought-tolerant plant capable of adapting to dryland soil with scarce water availability and inferior soil conditions (Abdel-Ghany *et al.,* 202), and this commodity can also thrive in intercropping conditions (Ginwal *et al.,* 2021). Indonesia has the potential for dryland agriculture across 63.4 million hectares (Mha), including open-air grasslands and forested areas, but only 7.36 Mha are used for farming (Indonesia of Statistics, 2019). Assuming that sorghum is planted twice a year with an average yield of 6.75 tonnes per year, the potential for the production is 49.65 million tonnes of grain or the equivalent of 29.79 million tonnes of flour with a rendemen of 60%. The government has initiated the cultivation on dryland within forested areas through social forestry programs to improve land-use (Kemenkoekonomi, 2022). Land resource use must be rational and efficient to ensure both food and environmental sustainability (Ma and Chen, 2022). Implementing a sustainable land use management strategy is important. Agroforestry is a land-use system within forested areas that integrates agricultural and forestry practices. The aim extends beyond enhancing food profitability and sustainability to improve environmental functions, mitigate and adapt to climate change, improve biodiversity, and conserve land and water resources by ensuring sustainable landscape management (Octavia *et al.,* 2022). Agroforestry plays an important role in meeting socio-economic necessities (Sarveswaran *et al.*, 2023), and improving livelihoods of farmers through enhanced access to food, livestock feed, and timber (Akter *et al.*, 2022). It enhances greening, plant regeneration, water retention, and soil fertility (Ahmad *et al.*, 2021) to maintain environmental stability and strengthen resilience against climate change (Duffy *et al.*, 2021). Agroforestry is developed with a focus on ensuring sustained benefits and maintaining environmental integrity (Ahmad *et al.*, 2023), emphasizing diversity, and avoiding unfavorable side effects (Kaushal *et al.,* 2023). The concept is a sustainable land-use approach that enhances harvest yields by integrating crops with trees on the same plot (Divya *et al.,* 2022). This presents a more sustainable alternative to monoculture farming, offering greater benefits to farmers (Ramesh *et al.,* 2023). Ethiopian farmers practicing agroforestry report improved livelihoods compared to the counterparts (Wondimenh, 2023). The concept introduces diversity, increasing income, and employment opportunities in Uttar Pradesh, India (Kaushal *et al.,* 2023). Specific practices in Jaunpur District include block plantations, horticulture, silviculture, and scattered trees, predominantly eucalyptus (Kumar *et al.,* 2023). Eucalyptus-based agroforestry has proven more profitable than teak-based systems, and the plantations offer a broader open ground area (Widiyanto *et al.,* 2022; Samimi, 2024). Sorghum, a staple in Rajaf County-South Sudan, is extensively cultivated in agroforestry systems (Mayele and Bongo, 2022). The intercropping of this commodity in Taungya agroforestry in Sudan significantly increases income and productivity of farmers (Hemida *et al.,* 2023). Sorghum-based agroforestry in Indonesia started in Majalengka

District, West Java, with eucalyptus as the primary tree, on a land area of 30 ha. The initiation of the process was part of the government program and did not include all the community in Majalengka. The implementation yields varied social, economic, and environmental outcomes in and among different areas and countries. Comprehensive data regarding its socio-economic impact and sustainability remains limited. Agroforestry represents a participative process, including stakeholders from government, private sectors, and developmental business, contributing distinct production components and sharing in the profits (Dou *et al.,* 2023). The adoption of these multifunctional systems is dependent on socio-economic, agroecological, and environmental factors. Recognizing the variables that influence the adoption of these systems is crucial for shaping policy frameworks conducive to agroforestry practices (Awazi *et al.,* 2023). Stakeholders, including government and non-government entities, scientists, organizations, and farmers, play an important role in agroforestry advancement, and a united approach to foster its implementation at various administrative tiers (Divya *et al.,* 2022). This study focuses on discussing the economic feasibility, perception of farmers, and the environmental sustainability of sorghum farming using a eucalyptus-based agroforestry system in Majalengka. The hypotheses on the dimension of business organization, actors, and working mechanisms on the social side, are an important factor in achieving economic and environmental sustainability. This contributes to enriching the existing knowledge regarding agroforestry, community-based forest management (CBFM), and the ramifications on socio-economic and environmental sustainability. This current study is a reference for policy architects to analyze the feasibility, farmers' perception, and environmental sustainability index of sorghum-eucalyptus in Majalengka, Indonesia, in 2022.

MATERIALS AND METHODS

Description of study areas

Data collection was conducted for three months from October to December 2022 in Kertajati Sub-district, Majalengka District, Indonesia. Majalengka covers 1,204.24 square kilometers (km²), making up 3.40% of West Java Province, and is segmented into three geographical zones, namely high, hills, and low plains with elevations between 19 to 857 meters (m) above sea level. This location harbors 20.263 ha of community and state forests and is renowned for producing a variety of agricultural commodities such as paddy, corn, sweet potatoes, cassava, mung beans, peanuts, and soybeans (Majalengka of Statistics, 2023). The land area is 18,177.63 ha (15.10% of Majalengka total administrative area) with the eucalyptus plantation covering 10,600.25 ha (58.32% of Majalengka agroforestry land area) entirely in Kertajati Sub-district (Perhutani, 2022). In the lowlands, Kertajati experiences maximal and minimal rainfall with 646 and 9 millimeters (mm) in November and September at coordinates 6°39'45.0" S and 108°05'29.0" E (Fig. 1) (Kertajati of Statistics, 2022). Sorghum, traditionally known in the locale as 'epoy', has been a staple in Majalengka, and the modern cultivation methods were integrated with innovative agricultural technology in forest areas starting in 2021. This cultivation occurs cooperatively with the State-owned Forestry Company (Perhutani) through a CBFM scheme in designated forest lands. Kertajati has evolved as a pivotal area for the development, using agroforestry systems in the community territories managed by the Forest Management Units (KPH) of Cibenda, Kertajati. Agroforestry, located in areas with flat topography, has developed as the main source of livelihood for the local population. The main crop planted on land is eucalyptus and the agricultural commodities cultivated are rice, corn, and sorghum. The cultivation pattern applied on agroforestry land is rice-sorghum-ratoon sorghum in the alleys between rows of eucalyptus. The cultivation of eucalyptus around sorghum can help prevent wild animals and birds from damaging or eating the plant due to the strong smell. Agroforestry with this commodity can also increase biodiversity as well as control pests and plant diseases. Sorghum is a well-suited companion for cultivation alongside eucalyptus trees within the context of agroforestry. This agricultural approach is adopted by farmers who possess forestry cooperation protection certificates (SK Kulin KK). These certificates symbolize a mutually beneficial and highly productive partnership between Perhutani and the local farming communities. The potential for sorghum and eucalyptus cultivation in Kertajati is 1,300 ha. Farmers with SK Kulin KK have the opportunity to plant sorghum in agroforestry areas, as part of the government program.

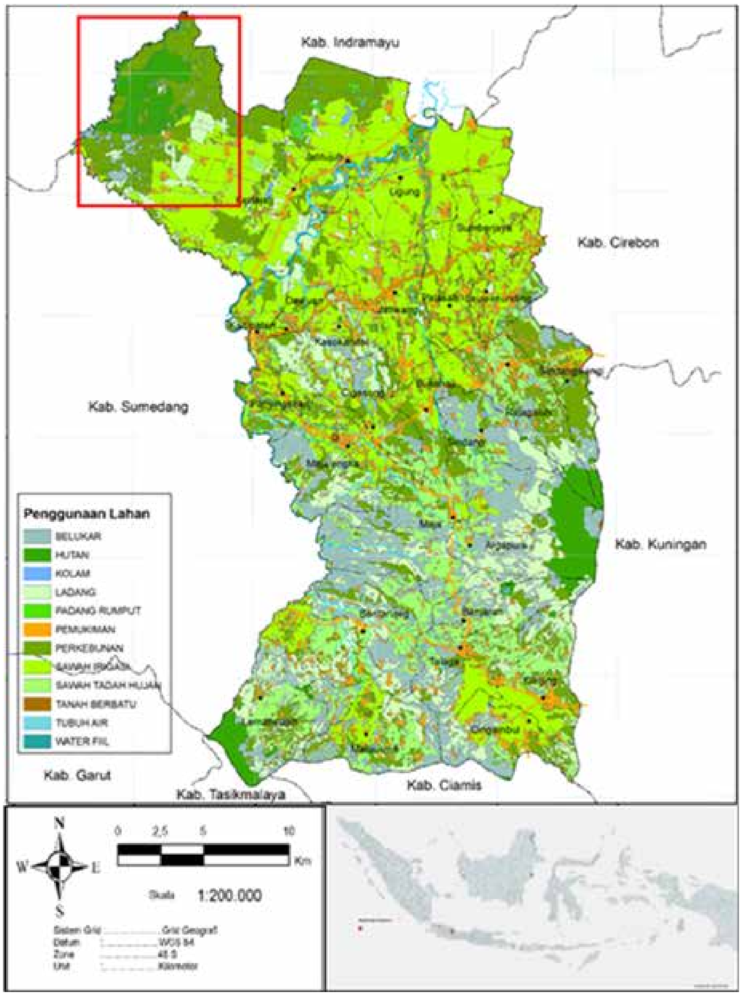

Fig. 1: Geographic location of agroforestry areas shown by red square, in Kertajati, Majalengka, Indonesia

Sampling methods

The study sample area was purposively selected, with Kertajati identified as a development site for sorghum in the eucalyptus agroforestry. They are 100 farmers with experience in cultivating the commodity in this agroforestry area and surroundings. These farmers, representing 100% of the cohort, were included as respondents in the census.

Data collections

Primary data were gathered qualitatively and quantitatively to provide a comprehensive overview and build a deep discussion of the results. Qualitative data produces new insights and theories into social and political actions, while quantitative data scientifically explains these concepts (Kang and Evans, 2020). Quantitative and qualitative data use measurable numerical information to explain and understand a situation (Zhou, 2022). Quantitative data collection was conducted with structured questionnaires and focused on collecting data through observations and census activities. Qualitative data collection was carried out through semi-structured indepth-inteview, and Focus Group Discussions (FGD). Participants in FGD included representatives from government, private sector, community leaders, Forest Village Community Institution (LMDH), Forest Farmer Groups (KTH), sorghum processing unit, and off-takers. The aim of FGD was to extract information concerning sorghum use in the eucalyptus agroforestry area and to verify the previously compiled dimensions and environmental sustainability attributes based on references. The sustainability approach combines social and ecological variables in an activity, process, or human product (Salaz-Zapata and Ortiz-Munoz, 2018). The concept shows social and economic aspects such as social interaction, and the various components (Cirella *et al*., 2020). The correlation between the social and economic aspects is the basis for the elaboration of dimensions and attributes for assessing environmental sustainability. Adopting agroforestry principles and practices will benefit farmers economically as well as society in a positive way (Dwivedi *et al*., 2023). FGD was followed by a census of farmers using a questionnaire directly against 100 respondents. The questions asked include the characteristic of respondents, the input production, output, price of input and output of sorghum farming, and the by-product. Other questions are related to perception of the community towards 5 dimensions and 23 attributes formulated during FGD, namely: i) organizational or institutional dimensions of business (4 attributes about the form, structure, rules and performance of organization), ii) stakeholder engagement (4 attributes related to government, private, public and gender involvement), iii) working mechanism (5 attributes related to capital, production input, technology, market, local wisdom), iv) economic impact (5 attributes related to income, employment absorption, market opportunities, secondary business opportunities, and auxiliary business opportunities), and v) business and environmental sustainability (5 attributes related to upstream-downstream sorghum business, business diversification, waste use for fertilizers, waste use for renewable energy, and forest conservation). The census was followed by semi-structured in-depth interviews and observations conducted to learn more about the development of sorghum in the agroforestry area and clarify some information difficult to retrieve from the questionnaire. In-depth interviews were conducted with key informants from governmental elements (village government, Department of Food Sustainability, Agriculture, and Fisheries District of Majalengka, Field Farmers), foresters, public figures, the head of LMDH, chairman or manager of KTH, farmers, processing group, and traders.

Data analysis

Characteristic of respondents

The characteristic of respondents includes gender, age, education, household size, experience with sorghum cultivation, the scale of the farm in the forest area, and income derived from sorghum farming. The data are represented in a table, showing criteria, ranges, percentages, and ratio values.

Economic feasibility of sorghum-eucalyptus agroforestry

Data on input production and output were calculated resulting in the average used. The costs are derived from the average and price of inputs. The revenue is derived from the cumulative value of the main and the by-product value of grains. The calculations for revenue and income adhere to the model proposed using Eq. 1 (Meena *et al*., 2023).

Gross income (GI) = Value of main product + Value of by-product

$$GI = Q_{mp} \times P_{mp} + Q_{bp} \times P_{bp} \quad (1)$$

Where:

GI = Gross income

Q_{mp} = Quantity of main product

P_{mp} = Price of main product

Q_{bp} = Quantity of by-product

P_{bp} = Price of by-product

The R/C is determined using Eq. 2 (Syuryawati *et al*., 2020).

$$\text{R/C ratio Analysis} = \frac{\sum_{i=1}^{m} Yi.Pyi}{\sum_{i=1} Xi.Pxi} n \quad (2)$$

Where:

$\sum$ = Number from i to m or i to n

Yi = Production (kg/ha)

Pyi = Production price (USD/ha)

Xi = Cost of farming (USD/ha)

Pxi = Price of input (USD/ha)

i ... m = Number of productions obtained

i ... n = Number of inputs used

R/C >1 means that sorghum farming is efficient, because the revenue received is greater than the expenditure, R/C = 1 shows the break-even (income is equal to expenditure), and R/C <1 means sorghum farming is inefficient because revenue is less than expenditure.

Farmer’s perceptions regarding sorghum-eucalyptus agroforestry

Data on farmer's perceptions regarding sorghum development are ordinal and analyzed using a scoring method, according to Parnabhakti and Puspaningtyas (2021). This variable is evaluated using a Likert scale, ranging from 1 to 4, corresponding to the categories of 'very good', 'good', 'bad', and 'very bad'. Subsequently, the data are analyzed using a scoring formulation as Eq. 3 (Parnabhakti and Puspaningtyas, 2021).

$$\text{Score value} = (n_i . s_i)/N_i \quad (3)$$

Where:

n_i = The number of respondents in the i column (i = 1, 2 , 3)

s_i = Statement score in the-i (i = 1, 2, 3)

N_i = The number of respondents in the i row (i = 1, 2, 3)

Farmer's perceptions regarding sorghum development are categorized using a three-grade interval scale of high, medium, and low in Eq. 4 (Ratnawati and Vivianti, 2020).

$$\text{Interval scale} = (\text{maximum value} - \text{minimum value})/(\text{the number of interval scale}) \quad (4)$$

The perception performance of farmers regarding sorghum-eucalyptus agroforestry development is visualized in the form of a histogram.

Environmental sustainability index of sorghum-eucalyptus agroforestry

The environmental sustainability of sorghum-eucalyptus agroforestry development is evaluated using Multi-dimensional Scaling (MDS) method. Assessments from FGD participants concerning the sustainable development serve as the foundation for establishing the dimensions and attributes of each dimension. The confirmations are thoroughly analyzed and assessed in MDS analysis stages to identify the attributes in each dimension impacting the sustainability of business (Kavanagh and Pitcher, 2004). MDS uses the Rapfish (Rapid Appraisal of Fisheries) software, emphasizing multi-criteria analysis (MCA) principle and relying on the algorithm (Fauzi and Anna, 2022). The stages of sustainability include: i) Definition of attributes: attributes associated with the development of sorghum agroforestry are determined and adjusted based on field observations and literature studies. These are formulated during FGD and in-depth interviews with key informants, previous study references, as well as the adaptation to the situational context and conditions of the site. ii) Attribute scoring: each attribute in each dimension is assigned an ordinal score ranging from 0–10. This is based on scientific judgment, representing a spectrum from the lowest (0) to the highest (10) rating. A score of 0 and 10 signify poor and optimal contribution to sustainability. The higher value contributes to the sustainability of business. iii) Multi-dimensional analysis of scores: the score values are subjected to multi-dimensional analysis using the Rapfish program to ascertain sustainability status. Indices and sustainability statuses are categorized according to Kavanagh and Pitcher (2004), as outlined in Table 1.

iv) The evaluation of sustainability level: sustainability level of business is assessed by evaluating the index and status of each dimension, including the calculation of the value and visualizing the concept in a spider web diagram. MDS values are derived by averaging sustainability of each dimension. This evaluation shows the extent of the environmental sustainability of sorghum agroforestry business and analyzes areas in need of enhancement. v) Leverage analysis: this is used to analyze sensitive attributes identified based on priority sequences from the analysis results, examining the root mean square (RMS) ordination changes on the x-axis. A higher RMS value change signifies a substantial role or sensitivity

Table 1: The category of index and sustainability status

Index Value	Category
0.00 – 24.99	Unsustainable
25.00 – 49.99	Less sustainable
50.00 – 74.99	Moderately sustainable
75.00 – 100.00	Highly sustainable

of the attribute in improving continuity status to enable observation or amendment. vi) Monte Carlo Analysis: This analysis evaluates the error level in attribute score creation, variation, and the ordination process due to value differences, stability of MDS analysis process repetitions, data input errors or loss, and high-stress values of MDS analytics (Kavanagh and Pitcher, 2004). vii) Model validation: this includes examining the stress value, square correlation (SQR), and the disparity between the Monte Carlo value as well as the analysis results against the actual data. A stress value below 25% is deemed good, and SQR close to 100 shows optimal model performance. The discrepancy between the Monte Carlo value and the analysis results should not exceed 5% (Kavanagh and Pitcher, 2004). This validation determines the model adequacy in representing the acquired data.

RESULTS AND DISCUSSION

Characteristic of respondents

The survey respondents comprised 77% men and 23% women among the practitioners. The median age was 46.8 years, and 59% were categorized in the 41–60 age bracket, while 28% were under 40. A total of 77% had completed 6 years of schooling, 12% experienced between 7 to 9 years of education, and the remaining had more than 10 years. Farmers usually had families of 2–7 members, with 83% supporting 3–5 people. Sorghum was predominantly cultivated in and outside forest areas. A minor 2% of farmers had been growing this commodity for 2.1–3.0 years, and 98% had less than 2 years of experience. The land harvested in forest areas was 1.3 ha, where 71% and 12% cultivated sorghum on 0.50–1.00 ha and 1.51–2.00 ha. Incomes from farming varied, with an average of USD 493.08 per growing season. A total of 35% earned above USD 514.30, and 23% earned less than USD 385.72. Table 2 shows the characteristic of respondents at the study location.

Sorghum-eucalyptus agroforestry farming in Majalengka predominantly includes men and women, constituting 77.00% and 23.00%. This gender dichotomy implicates a larger socio-cultural context where traditional roles designate men as primary cultivators and decision-makers, affirming the findings of Ibrahim and Nabage (2023). The predominance

Table 2: The characteristic of respondents (Bank Indonesia, 2023)

Description	Criteria	Amount (%)	Average
Gender	Men	77 (77.00)	-
	Women	23 (23.00)	
Age (years)	<30	7 (7.00)	46.8
	31–40	21 (21.00)	
	41–50	38 (38.00)	
	51–60	21 (21.00)	
	>60	13 (13.00)	
Education (years)	<6	77 (77.00)	7.1
	7–9	12 (12.00)	
	10–12	8 (8.00)	
	>13	3 (3.00)	
The number of family dependents (person)	≤2	13 (13.00)	3.4
	3–5	83 (83.00)	
	>6	4 (4.00)	
Sorghum farming experiences (years)	≤1	25 (25.00)	1.7
	1.1–2	73 (73.00)	
	2.1–3	2 (2.00)	
Size of land cultivation (ha)	<0.50	3 (3.00)	1.3
	0.50 –1.00	71 (71.00)	
	1.10–1.50	8 (8.00)	
	1.51–2.00	12 (12.00)	
	>2.00	6 (6.00)	
Sorghum farming incomes (USD/season)	≤385.71	23 (23.00)	493.08
	392.15–450.01	19 (19.00)	
	456.44–514.30	23 (23.00)	
	>514.30	35 (35.00)	

Noted: Primary data, 2022 (processed): 1 USD = 15.555 exchange rate October 2022 allows men greater access to resources and a decisive role in the adoption of new technology (Aduwo *et al.,* 2017), reflecting the extent of socio-cultural norms and values (Ndubi *et al.,* 2023). The agricultural sector has experienced intensified gender campaigns since the 1990s (Chete, 2019), stating the equitable distribution of resources (Quisumbing *et al.,* 2014) and recognizing the substantial contributions of women in various agricultural activities (Chakma and Rubu, 2021). Gender differences in sorghum-eucalyptus agroforestry still exist despite the increasing inclusion of women in agribusiness organizations and management. The demographics of farmers are composed of individuals of productive age, including the millennial generation, a factor that has a positive implication for sorghum farming. Age and educational attainment significantly influence the receptivity to agroforestry technology (Wijayanto *et al.,* 2022). Farming experiences and farm size are also determining factors that influence the adoption of technology (Awe *et al.,* 2021). Young people seem more willing and interested in agriculture. This interest is seen as a hopeful sign for the future of agriculture (Hasan *et al*., 2022). A significant proportion of these farmers have limited educational backgrounds, impacting the understanding and adoption of innovative technology and modern agricultural method (Ghosh *et al.,* 2023). Education is important, influencing management levels and output (Ninh, 2021) as well as individuals' capability to make informed decisions as a catalyst for community empowerment and sustainable ecosystem preservation (Aziza *et al.,* 2023). The size of the household is an important factor affecting the implementation of agroforestry (Ibrahim and Nabage 2023), and influencing family income and welfare (Sulasni and Suwendra, 2021). This variable drives farmers to obtain diversified income sources, such as sorghum-eucalyptus agroforestry business to enhance livelihoods and fulfill family responsibilities. A significant correlation exists between farming experience, land area, and the adoption of agroforestry practices (Ngango *et al*., 2023). Most farmers in the area have relatively limited experience in sorghum business, impacting crop management and yield (Cock *et al.,* 2023). The land in forest areas is cultivated ranging from 0.5–2.0 ha for sorghum. The extent of cultivated land positively correlates with income (Akbar and Fawwaz, 2022), and necessitates higher farming costs related to production inputs and labor. Success in farming is not exclusively limited to the extent of land cultivated but depends on production efficiency (Lai *et al.,* 2018). The income derived from sorghum-eucalyptus agroforestry business in one cultivation season varies, ranging between USD 385.72 and USD 514.30. Farmers need to manage land efficiently and improve knowledge and skills in sustainable agricultural practices, as well as sorghum cultivation to raise income. Successful implementation of agroforestry to increase agricultural productivity and income depends on a better understanding of benefits, sufficient technical support, and use of agricultural land (Kamal *et al.,* 2023).

Economic feasibility of sorghum-eucalyptus agroforestry

Sorghum farming in eucalyptus agroforestry areas is economically viable with an R/C value of >1. Components of production cost, including fixed and variable cost, are analyzed to assess the economic feasibility. Fixed cost, comprising of the annual land rental value converted per cultivation season, amounts to USD 40.18/season as sorghum farming occurs in two distinct seasons, namely main cultivation and ratoon maintenance. Variable cost differs between the main plant and maintenance (ratoon), standing at USD 541.31 for the former and USD 300.55 for the latter, including production inputs and labor costs. The cost for the main crops consists of expenses for seeds, fertilizers, pesticides, and labor for various farm activities, from cultivation to harvesting and transport. The cost of ratoon maintenance covers fertilizers, pesticides, and labor for treatments, pest control, and harvesting. Sorghum yield includes grains and plant waste (stems and leaves), with the main crop yielding lower than ratoon, namely 3,000 kg/ha compared to 3,750 kg/ha, which is a 25% increase. The waste also experienced a 33.34% increase from the main crop to the ratoon. The price for both was USD 0.19/kg, and the total income from sorghum-eucalyptus agroforestry farming was USD 1,574.95, where 47.86% was derived from plant waste. Table 3 shows a comprehensive analysis of sorghum-eucalyptus agroforestry farming.

Farmers have the opportunity to carry out farming in the eucalyptus agroforestry area in groups through collaboration with Perhutani. Socio-economic benefits are obtained from land ownership permits for the

Table 3: Analysis of sorghum-eucalyptus agroforestry farming in Kertajati, Majalengka, Indonesia in 2022 (Bank Indonesia, 2023)

Description	Sorghum production	
	Main crops	Ratoon 1
Production cost		
Fixed cost	40.18	40.18
Variable costs	541.31	300.55
a. Production inputs (USD)	149.15	94.82
b. Labors (USD)	392.16	205.72
Total cost	581.49	340.73
Production		
Grain (kg)	3,000	3,750
Sorghum plant waste (kg)	22,767	30,357
Price (/kg)		
Grain	0.19	0.19
Sorghum plant waste	0.02	0.02
Revenue	1,090.87	1,406.30
Grain production	578.59	723.24
Sorghum plant waste	512.28	683.06
Income	509.38	1,065.57
R/C	1.9	4.1

Noted: Primary data, 2022 (processed): 1 USD = 15,555 exchange rate October 2022

production of seasonal crops. Incomes are earned from farming sorghum and other annual crops, but are required to analyze eucalyptus. Integration of the commodity with eucalyptus plantation is considered economically feasible based on input-output analysis for two harvest times, namely the main crop and ratoon maintenance. The income is obtained from the sale of grains and sorghum plants as food and animal feed. The proportion of labor costs incurred is greater than the production inputs. The cost incurred on the main plant is 72.45% and 68.45% of total production and ratoon maintenance. These are higher than the costs of sweet sorghum farming in Wuyuan, China and India at 63% (Liu *et al.,* 2015) and 40–54% of total production costs (Gautam *et al.,* 2021). High labor costs of sorghum-eucalyptus agroforestry farming in Majalengka economically have a positive impact on the absorption of agricultural labor. The average absorption is 80 men/day/season, with wages of USD 4.50 for 6–7 hours of work/day. The use of labor is comparable to agricultural production in India with an average of 84.64 men day/ha/season (Kumar *et al.,* 2017). The potential area for cultivation in Kertajati is 1300 ha with labor costs of USD 597.88/ha/year, resulting in the economic value from employment opportunities at USD 777,244/year. The income derived from the primary crop amounts to USD 1,090.87, with 53.04% and 46.96% attributed to grains and sorghum waste. The income generated from the ratoon is at USD 1,406.30, comprising 51.43% and 48.57% from grains and sorghum plant waste. Income obtained by farmers in Maros, South Sulawesi, from sorghum plant waste is between USD 446.03–603.72/ha (Syuryawati *et al.,* 2020). Sorghum-eucalyptus agroforestry in the main crop has an R/C value of 1.9 and 4.1 in ratoon maintenance. This shows the economic feasibility of the commodity through the main cropping pattern and ratoon maintenance. Agroforestry system in Sudan has been recognized to yield higher economic returns compared to monocropping (Fahmi *et al*., 2018). The farming of the commodity with ratoon maintenance enhances profitability by managing the costs of production inputs and labor (Sari *et al*., 2022). The production from ratoon, including grains and waste, surpasses the main crops, and offers better quality (Zhou *et al.,* 2022). Sorghum waste, used directly or through fermentation as animal feed, serves as a raw material for producing sugar, ethanol, wax, fiber, paper, and building materials (McCuistion *et al*., 2019). There is a substantial opportunity to increase the added value of sorghum through product diversification from both grains and waste.

Perception of farmers regarding sorghum-eucalyptus agroforestry

Perception of farmers regarding the prevailing business organization, such as LMDH, is positive, with scores ranging between 3.14–3.57, reflecting good to very good results for the future. Perception of stakeholder support and inclusion in sorghum-eucalyptus agroforestry efforts are also high, with scores falling between 3.27–3.88, indicating very good. Perception of farmers on the working mechanisms of LMDH are more varied between 1.29–3.14, showing a spectrum of views from challenging to easy to implement. Perception of the economic impact of sorghum-eucalyptus agroforestry business is favorable, with values between 2.43–3.27. Public views on business and environmental sustainability are diverse, spanning from poor to good. An area of unfavorable perception is the use of sorghum waste as a substrate for renewable energy. Fig. 2 shows the varied perception of farmers on sorghum-eucalyptus agroforestry.

Sorghum-eucalyptus agroforestry farming in Majalengka is a business considered new. The community perceptions regarding the development tend to express a future orientation in the present realities and the existing business organization, LMDH. This organization has evolved into an important entity, capable of providing farming input needs and alternative market options as well as establishing connections among the community, government, and capital providers. LMDH has not worked as expected, requiring comprehensive technical and institutional support to meet the community expectations. Most farmers in the low hills of Himachal Pradesh have a positive perception of agroforestry and can be promoted to practice the concept through improved extension services, cooperative groups, and distribution of quality cultivation materials and products (Pathania *et al.*,

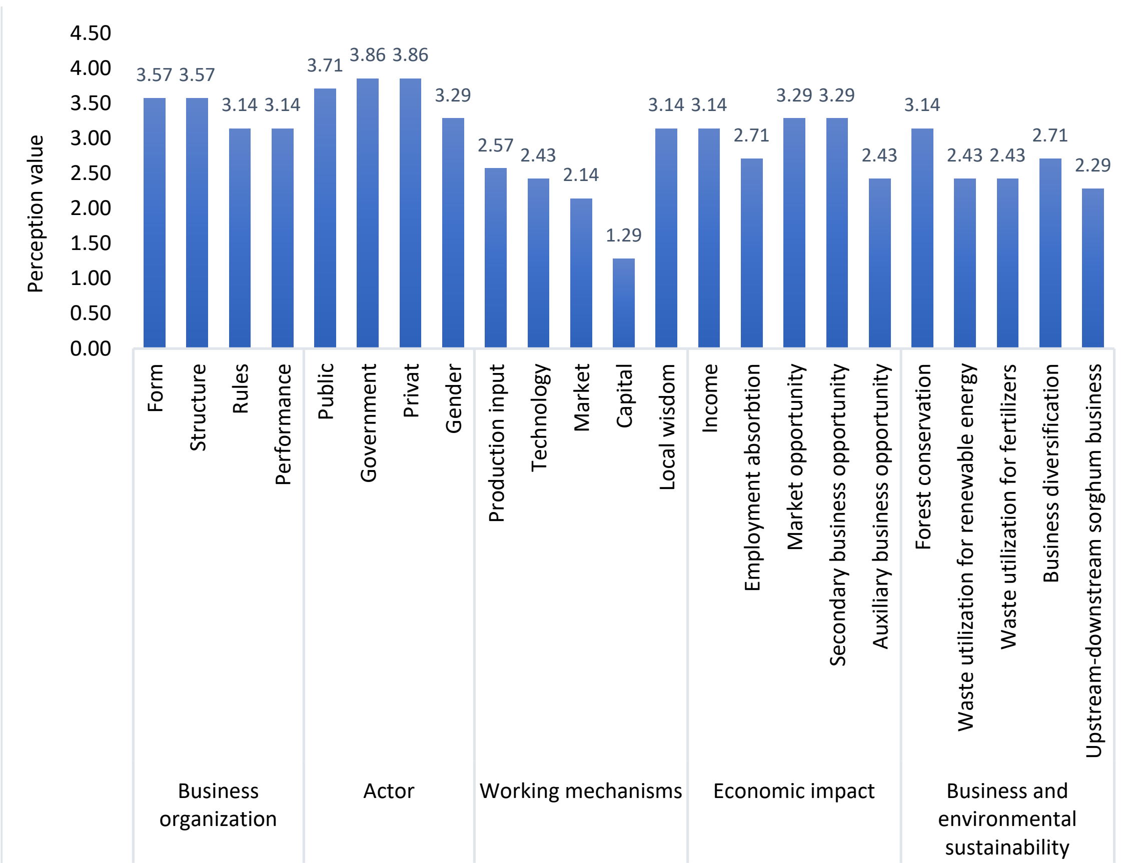

Fig. 2: Perception of farmers on the development of sorghum-eucalyptus agroforestry business in Kertajati, Majalengka, Indonesia, 2022

2020). The community stresses the indispensability of government and private sector, such as Perhutani support for sustaining the business and achieving successful land management in forest areas. The absence of support decreased the development of sorghum-eucalyptus agroforestry business. Farmers, constrained by limited resources, access to markets, and connectivity with external entities, heavily rely on support to overcome the limitations. The proactive inclusion of the government and corresponding entities is important in enabling small farmers to implement agroforestry for community livelihood sustainability in forest areas (McGunnigle *et al.,* 2023). Perception of farmers on agroforestry and decisions to implement are influenced by factors including social relationships, historical memory, practical abilities, and the existence of formal and informal institutions (Wienhold and Goulao, 2023). The government and other responsible entities must support and assist small in the implementation of agroforestry for the sustainability of community livelihoods in forest areas (Tega and Bojago, 2023). This is because agroforestry is a catalytic factor adopted through targeted programs, policies, and practices by the government and related agencies (Islam *et al.,* 2021). The community finds the operational mechanisms of the sorghum-eucalyptus agroforestry business ranging from manageable to challenging, with business capital being the most elusive aspect. There is also a collective desire for governmental intervention to facilitate access to business capital. Sorghum production technology is perceived as integrative with local wisdom, offering lucrative market opportunities due to the economic value of the plant and the by-products. Limited market access may affect government intervention to expand opportunities for sorghum and increase the diversity of the products. Poor market accessibility, lack of subsidies, and credit facilities are major problems faced in the low hills of Himachal Pradesh (Pathania *et al*.,2020) and the Indus River Basin, Pakistan (Mahmood and Zubair, 2020). The perceived economic ramifications of sorghum-eucalyptus agroforestry are positive, attributed to its potential to elevate income, generate employment, and create new business ventures. The community perceives the production as a catalyst for the creation of supportive business opportunities managed by the organization related to sorghum seeds, fertilizers, and other inputs. Sorghum production has the potential to increase income compared to other cereal crops (Chavula and Turyasingura, 2023). Preferences of farmers for design and commodity selection can increase the motivation to implement agroforestry system in the long term (San *et al*., 2023). The practices in Faridpur District of Bangladesh are considered to increase agricultural productivity and household income, as well as an effort to achieve food security (Saha *et al.,* 2018). The community expects that sorghum business can create other opportunities for the organization (LMDH) including the provision of farming inputs, sorghum seeds, and fertilizer. The community perception of sustainability is in the moderate sustainable category, such as in the attribute of land conservation activities. Sorghum-eucalyptus cultivation pattern does not have a negative impact on forest conservation efforts. This is because eucalyptus is planted in an alley system with a distance between rows of around 5–7 m, and the crown is small, allowing annual plants to grow optimally without interfering with each other. This is necessary to provide understanding among farmers regarding eucalyptus allelopathy (Ramesh *et al.,* 2023). The community has an unfavorable perception regarding the aspect of using sorghum plant waste as raw material for renewable energy, organic fertilizer, and diversification of food processing. This is understandable since the location is far from technological sources and there is minimal assistance from the government. Tokede *et al.,* (2020) recommend extension workers and other stakeholders to deliver knowledge about the practices and benefits of agroforestry to farmers in the simplest form for easy understanding. Positive perception of farmers on the five dimensions studied show that the business is quite promising because of the high economic value. Comprehensive support from the government and private sectors is very important, particularly for LMDH. The support should not be fragmentary but holistic, addressing the current deficiencies of the community in managing sorghum-eucalyptus agroforestry business. This facilitates access to technology, farming inputs, alternative markets, and capital. The benefits can be realized by creating supportive legislation, improving extension services, using the results of study and innovation (Shukla *et al.,* 2021), and increasing awareness regarding the enduring benefits of the system (Wondimenh, 2023).

Environmental sustainability indexes of sorghum-eucalyptus agroforestry

The analysis results show that the environmental sustainability index for sorghum-eucalyptus agroforestry business is low since the highest achieved values attain the 'moderately sustainable' category in the economic (61.9) and actor (52.3) dimensions. The index values for work mechanism (41.7) and business organization (42.8) fall into the 'less sustainable' category, and the business and environmental sustainability dimension is marked at 19.8 in the 'unsustainable' category. These results show the presence of numerous aspects and conditions in sorghum-eucalyptus agroforestry business. Fig. 3 shows a detailed representation of the environmental sustainability index across the five dimensions in sorghum-eucalyptus agroforestry business.

Dimensions of business organization

The index value in the organizational dimension shows that sustainability is relatively low. The organizational activities consistent with the memorandum of association/articles of association (AD/ART) are scored poorly. Attributes such as the establishment of a legal entity, the community inclusion in the structure, and adherence to AD/ART have received reasonably good scores (Fig. 4). In-depth interviews report that these scores accurately reflect the prevailing conditions in the field. The establishment of LMDH in Kertajati is supervised by a community representative and managed by the members. Since LMDH abides by AD/ART, the concept is recognized as a legal organization. The role has predominantly been as a mediator between Perhutani and KTH, coordinating the cultivation, maintaining, and harvesting of eucalyptus plants owned by Perhutani. LMDH as an enabling institution for CBFM, particularly those related to sorghum, remains unclear. The establishment formalizes the eucalyptus plant maintenance activities between Perhutani and the community.

Actor dimensions

The assessment of the actor dimension shows a relatively sustainable status, with an index value of 52.3. This moderate level of sustainability in the actor dimension can be attributed to less-than-optimal attributes in the level of community and private sector support as shown in Fig. 5. This observation is consistent with in-depth interviews, indicating the prevalent influence and leadership of Perhutani in determining community inclusion and support in land management in forest areas. The existing relationship is restricted to land ownership and tenancy, serving as labor for Perhutani and being compensated for

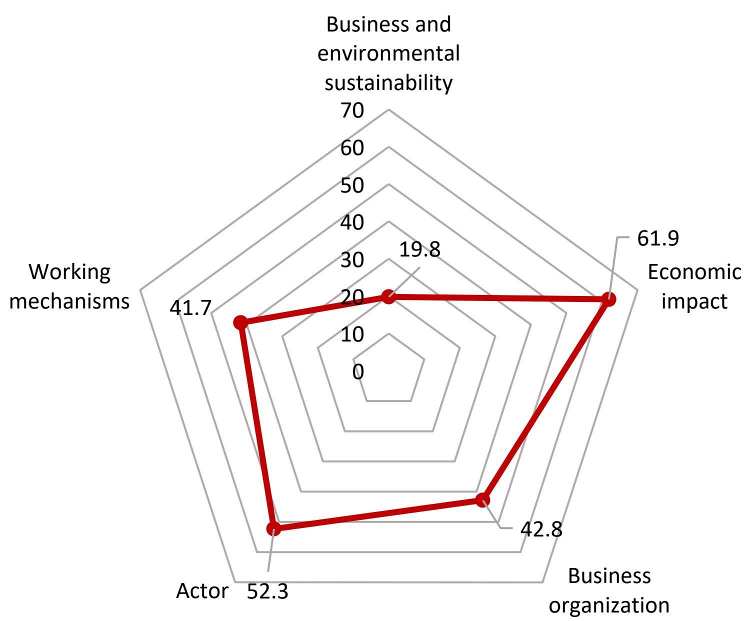

Fig. 3: Sorghum-eucalyptus agroforestry business environmental sustainability index

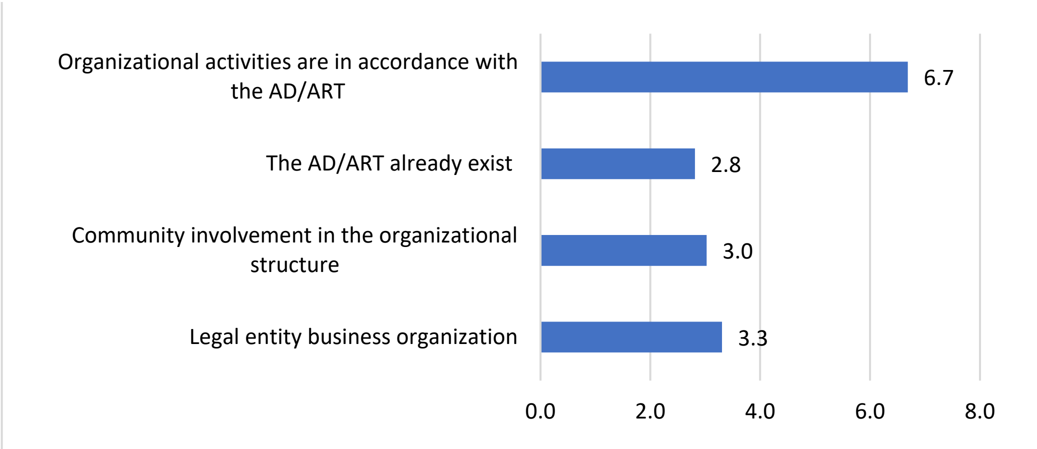

Fig. 4: Leverage of attributes in business organization dimensions

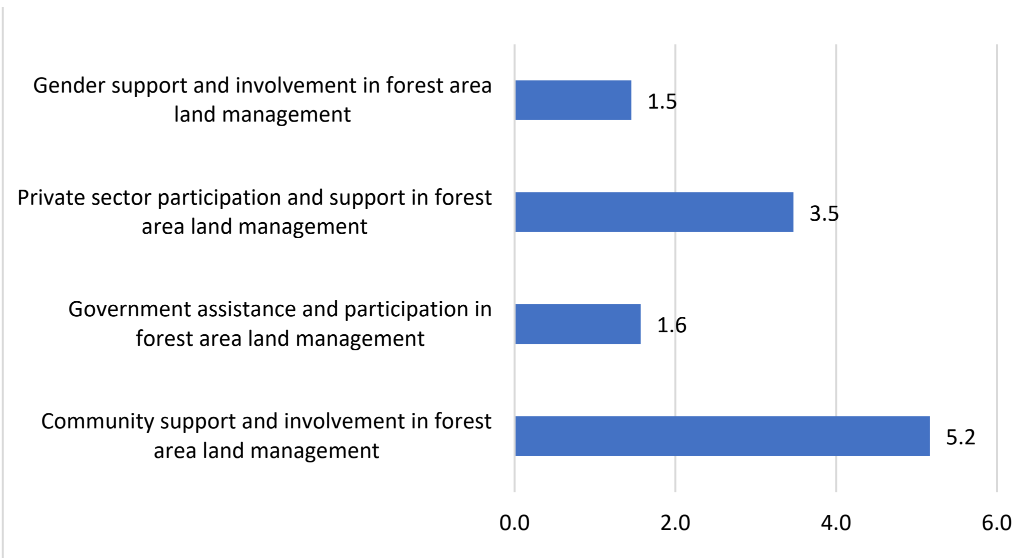

Fig. 5: Leverage attributes in the actor dimension

each related activity including eucalyptus. Therefore, the community essentially functions as an object for Perhutani's agenda. Furthermore, no additional private entities have shown any form of support or engagement in sorghum business. The community expects the inclusion of the private sector in providing farming inputs and acting as off-takers for sorghum, to ensure sustainability in the established commodities. Even though government support and inclusion are viewed positively and act as a propellant for the sustainability of the agroforestry venture, a deeper analysis shows a unilateral, top-down approach to governmental support. The government has not implemented a collaborative strategy in the planning stages with the community predominantly positioned as the recipient of the program.

Dimensions of working mechanisms

The evaluation of the working mechanism dimensions indicates a less sustainable. Three attributes positively contribute to the working mechanism dimensions of sorghum-eucalyptus agroforestry operation. The first factor is the production process which is streamlined seamlessly with existing local wisdom, eliminating potential conflicts. The efficient marketing and beneficial pricing of sorghum, as the second factor, are facilitated by lead farmers or local intermediaries. This is enhanced by the high sale prices driven by the current scarcity of sorghum during the rising demand. The challenge of securing business capital adversely affects the sustainability index of the working mechanism dimension as the third factor. Farmers benefited from the support in 2021 in the form of seeds, fertilizers, and pesticides to cultivate sorghum as a local agricultural service forestry area development program. The community encountered obstacles in the subsequent season because of sparse availability and elevated prices of high-quality sorghum seeds in the market, restricting the plantation of sorghum except for farmers with ample capital. Access to government-subsidized fertilizers is not universal due to quota limitations, leaving the majority struggling to acquire capital for the business without government assistance. This less sustainability in working mechanisms is connected to the actor dimension. The government treats the community as passive recipients rather than active and empowered contributors in sorghum business. Fig. 6 shows the leverage attributes in the working mechanism dimension.

Dimensions of economic impact

The results in the economic impact dimension show a state of moderate sustainability, achieving a value of 61.7. Interviews with farmers showed that the integration of sorghum and eucalyptus in agroforestry practices has the potential to enhance employment opportunities, broaden market access, and elevate income levels. Sorghum farming is considered unsuccessful in generating businesses that support production, such as those focused on producing sorghum seed or supplying farming inputs. The farming has not provided new business opportunities in the agroforestry areas, and the commodity only serves as an alternative source of income. There is an absence of businesses transforming sorghum into processed food items to potentially elevate the value-addition prospects. Fig. 7 shows the leverage attributes associated with economic impact.

Dimensions of business and environmental sustainability

The assessment results for the business and environmental sustainability dimensions fall into the 'unsustainable' category, representing the least

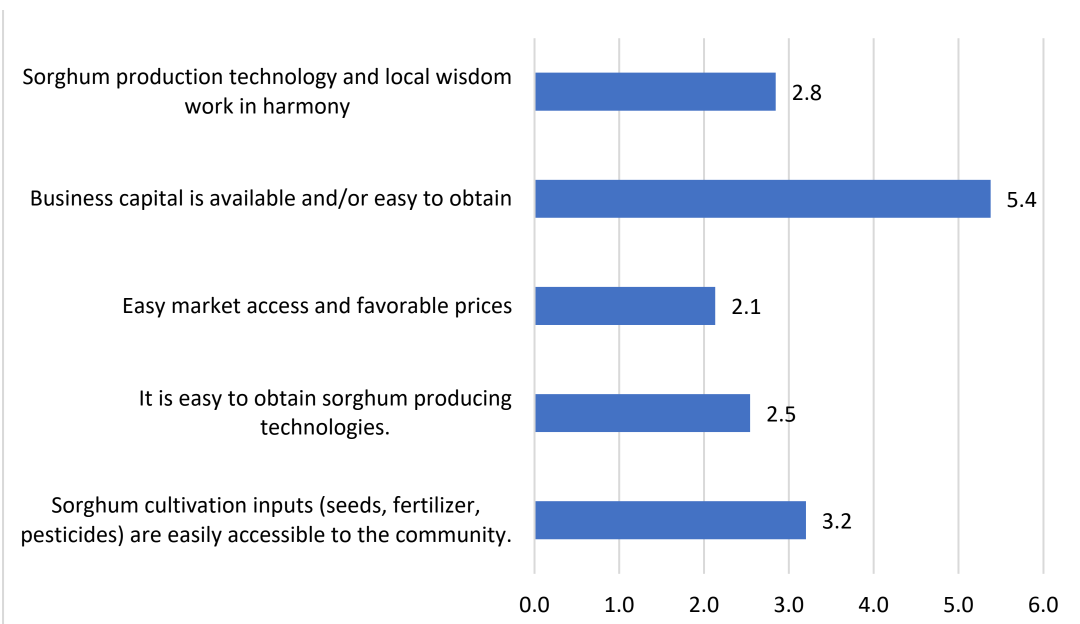

Fig. 6: Leverage attributes in the work mechanism dimension

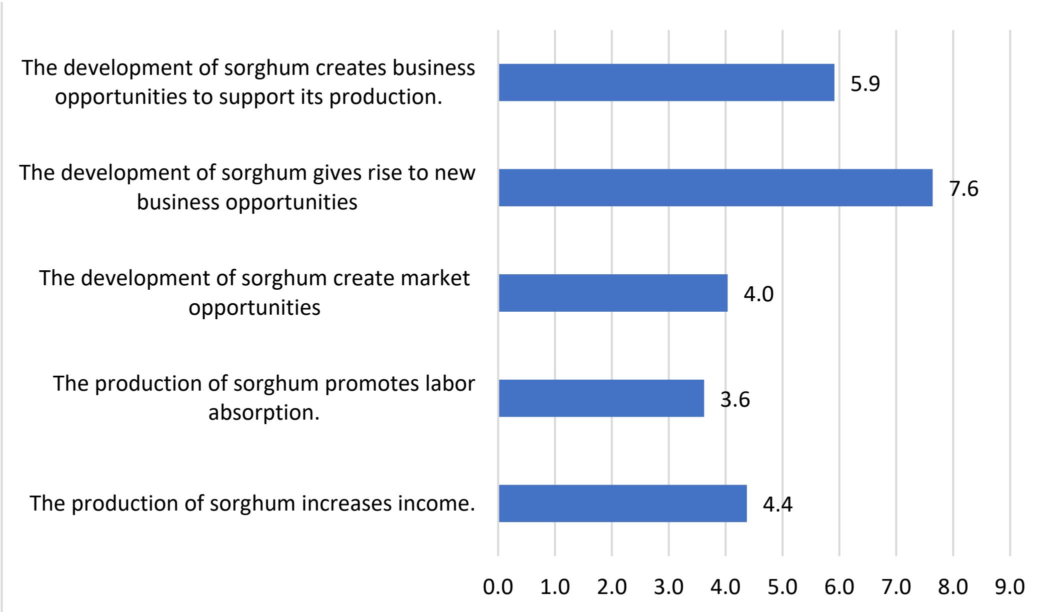

Fig. 7: Leverage attributes in the economic impact dimension

favorable outcomes compared to other dimensions. Three important attributes need attention to improve the dimension in sorghum-eucalyptus agroforestry practices. These include i) the absence of initiatives to leverage sorghum waste for organic fertilizer, ii) a lack of structured management for the development of products, from upstream to downstream, in the agroforestry landscape, and iii) the non-initiation of using sorghum waste for renewable energy. The efforts to convert sorghum waste into organic fertilizer are in an experimental phase, conducted by a limited number of farmers. Insights from in-depth interviews show that farmers have not been adequately informed concerning the potential economic value of processing sorghum waste into organic fertilizer and renewable energy sources. This waste is sold directly for animal feed, as a beneficial by-product of sorghum-eucalyptus agroforestry system. The situation correlates with the results from the business organization dimension, showing that the consistency of activities with AD/ART remains suboptimal. This is because LMDH activities are predominantly confined to mediating interactions between Perhutani and tenant farmers. Fig. 8 shows the leverage attributes within the business and environmental sustainability dimensions.

Validity of environmental sustainability index data analysis

The sustainability index for each dimension is presented in Table 4. The model used is considered appropriate with stress values ranging from 0.13 to 0.15, and an R^2 value of 0.95, showing appropriateness. The resulting environmental sustainability index has an average of 43.7 or less sustainable, but the data has been studied using a robust model, credible and accountable.

The environmental sustainability of sorghum-eucalyptus agroforestry business in Majalengka remains low, mainly due to the lack of support and collaborative partnership amongst local government, private sector entities such as Perhutani, and the community. Previous studies showed that community forests in Bogor, Indonesia, had moderate sustainability and required improvement through comprehensive stakeholder engagement (Sukwika *et al.*, 2016). Achieving higher indices necessitates more inclusive approaches from the government and private sectors, beyond top-down initiatives or strategies perceiving the community as beneficiaries. Future policies should state the environmental awareness of farmers, show the balance between ecological conservation and

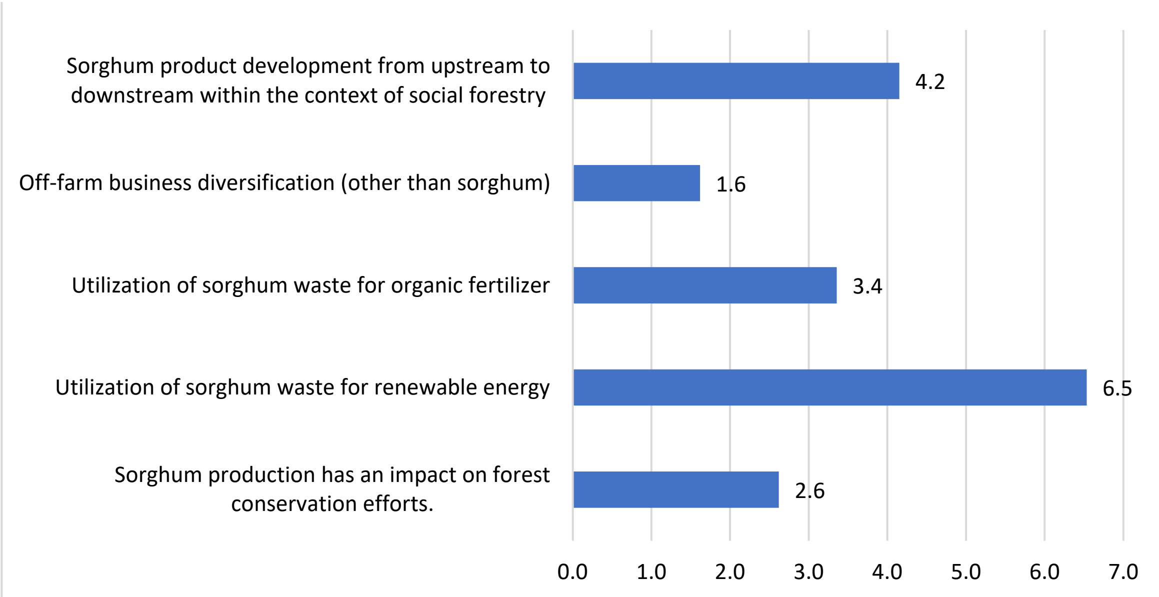

Fig. 8: Leverage attributes in the dimensions of business and environmental sustainability

Table 4: The sustainability index of five dimensions, and data quality indices

Dimensions	Index	Stress	R^2 (SQR)	Status
Business organization	42.8	0.1449	0.9559	Less sustainable
Actor	52.3	0.1504	0.9542	Moderately sustainable
Work mechanism	41.7	0.1305	0.9574	Less sustainable
Economy	61.9	0.1353	0.9500	Moderately sustainable
Continuity	19.8	0.1497	0.9525	Unsustainable
Average	43.7			Less sustainable

economic progression, as well as strengthen and sharpen farmers' way of thinking (Lei *et al.,* 2023). Success in sorghum-eucalyptus agroforestry depends on community participation across planning, rule establishment, and continuous program implementation. Collaborations with non-governmental entities and external bodies are important for the advancement of LMDH (Ramadhan *et al.,* 2022). Several attributes significantly influence the low environmental sustainability values in the dimensions, with distinct interrelations leading to decreased scores across different dimensions. The incongruence of business activities with the organization AD/ART contributes to the low value. The community expects that LMDH will become a business institution helping in sorghum cultivation activities, providing production facilities such as seeds and fertilizer, becoming a local off-taker, and finding buyers from outside the area to facilitate the marketing process. The community seeks the assistance of LMDH in facilitating the establishment of business capital institutions in proximity to forested areas due to the constraints posed by limited access to capital resources. The actor dimension's less sustainability is attributed to inadequate support and engagement from the government, the private sector, and the community in forest land management. Collaboration between actors and communities plays a role in ensuring the sustainable management of forests (Aisharyaa *et al.,* 2020). These two dimensions show no relationship between Perhutani and the community, as the landowner and tenants. Effective CBFM, reliant on community support, is crucial for enduring sustainability (Hajjar *et al*., 2021). The inclusion in agroforestry program needs to be supported by the government and other entities (Tega and Bojago, 2023). The concept is a catalytic factor accepted through targeted programs, policies, and practices by the government and related agencies from the positive perceptions and attitudes of farmers (Islam *et al.,* 2021). The existing legal entity, LMDH, has not been able to serve as a collaborative forum between Perhutani and the community for managing forest land or developing sorghum-eucalyptus agroforestry business. This is because the community observes a lack of diverse activities in LMDH. LMDH only facilitates the coordination between farmers and KTH for land leasing in forest areas owned by routine eucalyptus maintenance activities assigned by Perhutani. Community inclusion is limited to individuals used and compensated by Perhutani. This situation is greatly influenced by the existing working mechanisms, such as the barriers to accessing capital, thereby reducing the environmental sustainability value of sorghum-eucalyptus agroforestry business. Perhutani and the government are not adequately in line with the community interests. This shows the urgent necessity to acknowledge the community as equal partners, thereby promoting the active inclusion in sustaining business and preserving the environment. Haldane *et al*. (2019) stated that private and community partnerships were an important process in learning how to collaborate, describing initiative and active participation to encourage inclusion. A collaborative approach between farmers, government, private sector, scientists, and policymakers plays an important role in promoting agroforestry system in Uttar Pradesh (Divya *et al.,* 2022). To improve independence, the government must facilitate training and institutional development, promote proactive community inclusion in production and marketing processes, and cease the propagation of top-down programs. This shifts the role from passive recipients to active contributors in the development of sorghum-eucalyptus agroforestry business. Enhanced extension services and consistent support, through training and the formation of cooperatives for credit access, are crucial (Oladele *et al.,* 2020). The community acknowledges the potential of sorghum-eucalyptus agroforestry business in enhancing market opportunities, income, and employment. Sorghum, as an important crop, yields the highest net returns compared to others (Ramesh *et al.,* 2023). This commodity can be enhanced for animal feed during dry seasons (Hemida *et al*., 2023). The economic value of sorghum is not only from grain but plant waste processed as animal feed to reduce livestock maintenance costs. The conversion of sorghum plant leaf waste into organic fertilizer and its reintroduction into the land as an ameliorant not only enhances the carrying capacity of forest land but also reduces the reliance on chemical inputs. The development of sorghum production and its related products has been impeded by the lack of consistent guidance and support from both the government and the private sector. Government initiatives, particularly through the Agricultural Office of Majalengka, have focused on providing input for production, without addressing the community's needs in terms of technological and institutional support. The implementation of a sorghum-eucalyptus agroforestry approach has the potential to significantly improve economic, social, and environmental aspects. This requires a synergistic and equitable partnership between the community and the government. Comprehensive guidance and support from the government, spanning from upstream to downstream, including sustainable technologies across economic, social, and environmental dimensions, is essential. The absence of a well-defined business potential indicates that the sustainability assessment in the economic dimension remains low. This economic assessment can serve as an indicator to maintain the sustainability of the business and its environmental dimensions, emphasizing the need for development and support. The concept is closely related to the lack of values in the previous dimensions. Addressing the attributes leading to diminished values invariably improves sustainability and enhances the index in the business and environmental dimensions. Advancements in the attributes of the economic dimension inherently elevate the added value of product development from upstream to downstream. Environmental and business sustainability have the smallest value because the public does not understand the relationship between the dimensions. The economic value of sorghum-eucalyptus business is affected when society is only concerned with gaining economic profits without paying attention to sustainability. The absence of consistent guidance and support from the government and the private sector is one of the causes of the lack of awareness regarding efforts to preserve the forest environment and the use of waste to support conservation. One of the leading factors contributing to the low score is the absence of business activities aimed at using plant waste. The use of agricultural waste provides valuable added value to social, economic, and technological development system (Santoso *et al.*, 2023; Samimi *et al.,* 2023). The cultivation pattern in the eucalyptus agroforestry area is rice-sorghum-sorghum ratoon. Rice husks can be used as material for making biochar applied to agroforestry land. The use of biochar reduces herbicide residues in the soil and environmental pollution (Yavari *et al*., 2022). The management of sorghum product development from upstream to downstream in sorghum-eucalyptus agroforestry area has not been established. Sorghum grains can be processed into various products, including gluten-free flour which is healthier than wheat (Curti *et al*., 2023), raw material for noodles (Akajiaku *et al*., 2017), and wheat substitute flour for making cakes (Bataruic *et al*., 2023). The use of sorghum waste for renewable energy has not been initiated. This commodity is a raw material for bioethanol and is a renewable energy source from biomass (Frankowski *et al*., 2022). In sorghum-eucalyptus agroforestry area, there is potential to develop sorghum-based bioethanol production. The government needs to empower the community in forest areas, through guidance and training related to (a) biochar and organic fertilizer from rice and sorghum waste, (b) development of sorghum-based food processing, and (c) biomass-based renewable energy. The community also gains added value from upstream and downstream processing to increase income and the forest area is maintained. The government and private sector guide the community in collaboration with LMDH for upstream and downstream use of sorghum with the production facilities and marketing of the harvest. The challenges encountered in the implementation share similarities with the issues faced in CBFM. This necessitates the establishment of efficient governance in agroforestry business. The Community-Government and Private Partnership (CGPP) business institutional governance model, as formulated by Komalawati *et al*., (2023), can be applied to address these challenges. The model positions cooperatives as central institutions, regulating organizational and business governance, human resource development, as well as business and environmental sustainability. Cooperatives are placed as central institutions given the community-based formation. Internal and external coordination with stakeholders, including the community, government, and private sector, can improve beneficial partnerships to ensure the preservation and sustainability of forest areas (Komalawati *et al*., 2023). Implementing CGPP under the orchestration of cooperatives, through equal partnerships, can ensure the environmentally sustainable development of sorghum-eucalyptus agroforestry business. This study introduces innovative approaches in assessing the environmental sustainability of the business, using qualitative and quantitative methods across economic, social, and environmental aspects. There are limitations regarding the depth of analysis in each dimension and the specificity of the geographical location of the study, restricting the generalization of results to other contexts. More comprehensive studies are essential to explore other influential variables and broader areas for a holistic understanding of agroforestry environmental sustainability. Future analysis should also benefit from additional data collected through field surveys or in-depth interviews. This study is expected to contribute to the literature on agroforestry and its business governance as well as to inform policy recommendations for the environmentally sustainable development of sorghum-eucalyptus agroforestry and other similar ventures.

CONCLUSION

In conclusion, the novelty of this study was the use of five dimensions, namely business organization, actors, work mechanisms, economic impacts, and environmental sustainability, to evaluate and assess sorghum-eucalyptus agroforestry in a comprehensive and interrelated manner. These five dimensions influenced each other to achieve high sustainability values. The results obtained were: 1) the development of sorghum-eucalyptus agroforestry was economically feasible as shown by the R/C value higher than 1, and 2) the economic profits obtained did not guarantee the sustainability of the business. This was proven by the low sustainability index value in aspects of the role of organization, actors, and working mechanisms, as well as environmental aspects, impacting business sustainability. The challenge for the future was to develop an economically sustainable sorghum-eucalyptus agroforestry business, providing added value to society and having a positive impact on the environment. An unexpected benefit was the added value of upstream-downstream diversification of sorghum. Horizontal diversification of sorghum included processing plant waste into animal feed, organic fertilizer, and renewable energy. Vertical diversification took the form of processing sorghum grain into different processed food products. The problems were related to the institutional governance of sorghum-eucalyptus agroforestry businesses. The establishment of efficient governance with multi-stakeholder partnerships was one of the solutions similar to the issues faced in the CBFM. The inclusion of the community, government, and private sector was not equal in carrying out the sustainability function of each dimension. Further analyses should be directed at appropriate and sustainable institutional governance to realize business and environmental sustainability in agroforestry areas. This study contributed valuable recommendations and insights for policy-making and implementation, showing the urgent need for enhanced cooperative initiatives and institutional reforms to realize the full potential and ensure the environmental sustainability of sorghum-eucalyptus agroforestry business.

AUTHOR CONTRIBUTIONS

Komalawati, the corresponding author, conducted the conception, methodology, proper analysis, examination, writing the initial draft of the manuscript, reviewing and revising manuscripts, featuring. S. Hidayat conducted the conception, methodology, proper analysis, examination, writing the initial draft of the manuscript, reviewing and revising manuscripts. R.H. Praptana conducted the conception, methodology, proper analysis, examination, writing the initial draft of the manuscript, reviewing and revising manuscripts, featuring. M.D. Pertiwi conducted the conception, methodology, proper analysis, examination, writing the initial draft of the manuscript, reviewing and revising manuscripts, featuring. A.S. Romdon conducted the conception, methodology, proper analysis, examination, writing the initial draft of the manuscript, reviewing and revising manuscripts, featuring. Y. Hidayat conducted the conception, methodology, proper analysis, examination, writing the initial draft of the manuscript, reviewing and revising manuscripts, featuring. R.P. Ramadhan conducted the conception, methodology, examination, writing the initial draft of the manuscript, reviewing and revising manuscripts. D. Yuniati conducted the conception, methodology, proper analysis, examination, writing the initial draft of the manuscript, reviewing and revising manuscripts. Saptana conducted the conception, methodology, proper analysis, examination, reviewing, and revising manuscripts. Syahyuti conducted the conception, methodology, proper analysis, examination, reviewing, and revising manuscripts. N. Khaririyatun conducted the examination, wrote the initial draft of the manuscript, reviewing and revised manuscripts, and featured. S. Ika conducted the conception, methodology, examination, reviewing, and revising of manuscripts, featuring. R.K. Jatuningtiyas conducted the examination, wrote the initial draft of the manuscript, and reviewed and revised manuscripts, featuring. Subiharta conducted the conception, methodology, examination, writing the initial draft of the manuscript, reviewing and revising manuscripts. R.N. Hayati conducted the examination, wrote the initial draft of the manuscript, reviewing and revised manuscripts, and featured. Sudarto conducted the conception, methodology, proper analysis, examination, reviewing, and revising manuscripts. M.P. Yufdy conducted the conception, methodology, examination, writing the initial draft of the manuscript, reviewing and revising manuscripts. B. Nuryanto conducted the conception, methodology, examination, reviewing, and revising of manuscripts, featuring. A. Prasetyo conducted the conception, methodology, examination, writing the initial draft of the manuscript, reviewing and revising manuscripts.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript. Ethical issues, including plagiarism, informed consent, misconduct, data fabrication and falsification, double publication and/or submission, and redundancy, were observed.

OPEN ACCESS

PUBLISHER'S NOTE

ABBREVIATIONS

%	: Percent
AD/ART	: Memorandum of Association/ Articles of Association
CBFM	: Community-Based Forest Management
CGPP	: Community-Government and Private Partnership
Day/Season	: Per day per season
Day/ha/ season	: Day per hectare per season
FGD	: Focus group discussions
GI	: Gross income
ha	: Hectare
ha/year	: Per hectare per year
IDR	: Indonesian Rupiahs
kg	: Kilogram
kg/ha	: Kilogram per hectare
/kg	: Per kilogram
KPH	: Kuasa Pemangku Hutan (Forest Management Units)
KTH	: Forest farmer groups
LMDH	: Forest Village Community Institution
MCA	: Multi-criteria analysis
MDS	: Multi-dimensional scaling
Men/day	: Men per day
Men/day/ha/ season	: Man day per hectare per season
Mha	: Million hectares
mm	: Millimeter
Perhutani	: State-owned Forestry Company in Indonesia
P_{bp}	: Price of by-product
P_{mp}	: Price of main product
Q_{bp}	: Quantity of by-product
Q_{mp}	: Quantity of main product
R^2	: R Square is used to identify the influence of independent variables on dependent variable
Rapfish	: Rapid Appraisal of Fisheries
R/C	: Revenue per cost
RMS	: Root mean square
SK Kulin KK	: Surat Keterangan Pengakuan dan Perlindungan Kemitraan Kehutanan (Forestry partnership recognition and protection decree)
SQR	: Square correlation
USD	: United States of America's Dollar
/years	: Per year

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