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Land use planning strategies for food versus non-food estate sustainable farming

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ABSTRACT

BACKGROUND AND OBJECTIVES: Food estate initiative is an Indonesian government program designed to achieve food security though the cultivation of strategic commodities on large-scale agricultural land. Despite being controversial due to the scale of land use and budgetary requirements, the viability of the program has been questioned by critics pointing to the failure of a similar initiative in the past. In other words, there is widespread pessimism regarding sustainability of food estate program. Therefore, this study presents a new approach to farming sustainability investigation, assessing seven aspects including economy, society, environment, institutions, technology, market, and culture. The objective was to compare the value and status of sustainability as well as design land use planning strategies.

METHODS: Respondents of the questionnaire were 50 food estate farmers, selected from Pollung sub-district, as well as 50 non-food estate farmers from Dolok Sanggul and Lintong Nihuta Sub-districts. Multiaspect Sustainability Analysis software was used to conduct data analysis with Multidimensional Scaling approach. Primary data was collected through interviews using questionnaires and seven aspects analyzed include economic, social, environmental, institutional, technological, marketing, and cultural, with several factors. In addition, a total of 45 indicators were used to compare sustainability of farms, including 7 economics, 6 social, 9 environmental, 5 institutional, 7 technological, 5 marketing, and 6 cultural.

FINDINGS: The results showed that in Food Eestate farming, sustainability value for economic aspects was 47.57, social 50, environmental 72.22, institutional 50, technological 50, market 53.4, and cultural 33.33. On the other hand, sustainability value of non-Food Eestate farming estate was 33.29 for economic, 47.17 for social, 77.78 for environmental, 56.6 for institutional, 42.86 for technological, 36.6 for market, and 41.67 for cultural aspects. The overall sustainability value of Food Eestate farming was 50.93, which was slightly higher than non-food estate score of 48. Improving all aspects in the third scenario is the most favorable approach for improving farming sustainability. Based on the results, 12 sustainability indicators were found to be relevant for designing land use planning strategies. These indicators had different implications for stakeholders in improving sustainability.

CONCLUSION: Sustainability value of food estate farming exceeded that of non-Food Eestate but both were in the moderate category. Higher sustainability scores were recorded in economic, social, technological, and marketing aspects for Food Eestate farming, while higher scores were found in environmental, organizational, and cultural aspects for non-food estate . This study recommended implementing land use strategies such as multiple cropping for Food Eestate farming, and crop rotation for non-food estate. To implement the strategy for Food Eesrare farming, the government needed to increase fertilizer subsidies, provide agricultural insurance, relevant technology, extension services on land leases, agricultural sustainability, and water management. For non-food estate farming, the recommendations included providing capital loans, extension services on land tenure, agricultural sustainability, land conversion, inorganic fertilizer dosage, and weed management.

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INTRODUCTION

The concept of sustainability is gaining more attention following the officialization of Sustainable Development Goals (SDGs) by world leaders in 2015. The idea has been in existence since 1987 when the Brundtland Report, titled “Our Common Future”, was published. This concept has three pillars, namely economic, social, and environmental (WCED, 1987). In 2001, an attempt was made to expand sustainability concept to include four main pillars, with the addition of the institutional aspect (Stenberg, 2001). All activities related to the production of goods, services, and commodities including farming practices, spanning from land cultivation to harvesting must take into account the effects on the economic, social, and environmental aspects. The material outcome of farming practices is the production of goods to nourish humans in response to the rapidly increasing global population projections, estimated to reach 10 billion by 2050. Failure to meet these demands may lead to a food crisis that would herald severe repercussions across various economic sectors. Indonesia, the fourth most populous country in the world, faces a potential food crisis due to the inability to meet the needs of the population, which relies heavily on rice as a primary food source (Rozi *et al*., 2023). Indonesian government has implemented various programs, including food estate (FE), to address the issue. This program represents one of the National Strategy Projects (PSN) being implemented across multiple regions, including Papua, Central Kalimantan, North Sumatra, and South Sumatra covering 2,038,951.09 hectares (ha), 770,601 ha, 30,000 ha, and 235,351 ha, respectively (Menlhk, 2020). This initiative aims to increase the production rate by applying a large-scale land-use strategy to produce strategic food commodities. The government anticipates a considerable surge in output to adequately meet the dietary requirements of the populace and mitigate the possibility of a food crisis in the foreseeable future. FE program has both advantages and disadvantages, stemming from the strategic use of extensive farmland and a substantial budget. The national food security program, as allocated in the 2021 State Budget (APBN), amounted to 104.2 trillion rupiahs (Kacaribu, 2020), equivalent to approximately $US 6,692,099,120 based on the exchange rate of 15,614.14 Indonesian rupiahs per US dollars. The program has been positively received in terms of food security (Wirapranatha *et al*., 2022), but critics have pointed to the potential for forest and environmental degradation (Alfasa and Arlina, 2023; Maskun *et al*., 2021). Previous programs also failed due to inadequate planning (Rasman *et al*., 2023). A program with a similar approach and concept, known as the Merauke Integrated Food and Energy Estate (MIFEE), was reportedly implemented in Indonesia. Extensive studies have been conducted on sustainability of agriculture, but there is a lack of information regarding integrated agricultural farming systems in Indonesia, with a particular emphasis on FE in North Sumatra. Newly cleared land allocated for FE program farms in North Sumatra includes 11,000 ha of protected, 18,252 ha of production, and 785 ha of limited production forest (Menlhk, 2020). Many environmentalists oppose large-scale land clearing as this may harm the natural environment, including forests and ecosystems (Fajrini, 2022). The advantages and disadvantages of the program should be considered in government policies. Critics have mentioned issues with the first harvest in FE farming, for example, the average shallot yield in 2021 was 130,185 tonnes with a productivity rate of 1.17 tonnes per hectare (ton/ha). This was significantly lower than the national productivity rate for shallot of 12.49 ton/ha, raising doubts about sustainability of FE program. According to Beyer *et al*. (2022), agriculture on newly established cropland is challenging due to the requirement of high-input management, which may increase environmental impacts. Several studies have been carried out on sustainability assessment of agriculture. A recent study focused on sustainability assessment of FE program. Utama (2023) found that FE farming had a positive impact on the economy, but a negative impact on the environment, contributing to the potential loss of carbon storage. Santoso *et al*. (2023) identified four main aspects, namely economic, social, environmental, and technological, while also investigating agricultural sustainability using Multidimensional Scaling (MDS) approach. The results showed that the economic and technological dimensions had a sustainability value of 100 percebt (%) and 74.47% respectively. Meanwhile, the social and environmental dimensions had a value of 92.02%. Widjaja *et al*. (2024) studied the assessment of farming sustainability using MDS and reported values of 90.57%, 88.39%, 83.45%, and 74.29% for the economic, institutional, environmental, and technological aspects, respectively. Several recent studies have also analyzed sustainability by determining the factors affecting the scores. Castillo-Diaz *et al*. (2023) reported production factors as the most important aspect of agricultural sustainability, while Lairez *et al*. (2023) identified income factors. Konefal *et al*. (2023) found that the profit factor accounted for 48 % of economic sustainability. Water availability is a crucial factor affecting sustainability of farming in environmental aspects (Geria *et al*., 2023). Keykhosravi *et al*. (2023) stated that there was a direct relationship between the environmental behavior of farmers and the intention to achieve sustainability. Meanwhile, Konefal *et al*. (2023) suggested social aspects such as job security, property rights, and equity. All of the above studies are related to farming sustainability assessment, but there has been no comprehensive assessment of FE farming sustainability, particularly in the context of land use planning. This is important because FE farming uses new farmland on a large scale, has easy access to production inputs, and receives many government subsidies. On the other hand, non-FE farming is dominated by farmers with small land holdings, restricted access to inputs, and limited subsidies. Land use planning approaches have varying impacts on the environment, for example, FE farming may lead to deforestation due to the use of new land on a large scale. The tillage process requires relatively high levels of fertilization to produce optimal yields. Non-FE farming entails cultivating crops on small plots of land that have been used repeatedly, implying the soil contains sufficient nutrients and requires a relatively small quantity of fertilizers. In general, achieving farming sustainability requires different land use planning strategies. This study used several new approaches in sustainability assessment including 1) comparing two objects, 2) assessing sustainability using seven aspects of economic, social, environmental, institutional, technological, market, and cultural, 3) developing strategies based on several indicators. The objectives were to 1) compare sustainability status of FE and non-FE farming using seven aspects of sustainability, 2) determine the factors sensitive to sustainability of both types of farming, as well as 3) design land use planning strategies to improve sustainability. The design of the strategies used indicators with a low score but have the potential for improvement. The selection of indicators should be based on the relationship with farming land use. This study is crucial to achieve a comprehensive assessment of sustainability in FE farming. The results are expected to contribute to the assessment of FE program by the Indonesian government and serve as a reference for determining sustainability. This study was carried out in Humbang Hasundutan Regency, located in North Sumatra Province in 2023.

MATERIALS AND METHODS

Site location

This study was conducted in Humbang Hasundutan Regency, North Sumatra (Fig. 1), with an area of 251,765.92 ha, located at 2°1’ - 2°28’ North (N) latitude and 98°58’ East (E) longitude. The altitude ranges from 330 to 2,075 meters (m) above sea level, while FE sites were located in several highland subdistricts, specializing in cold-air vegetable crops. The sites had average minimum and maximum temperatures of 17.8°C and 29.3°C respectively. Precipitation also varied, with the lowest recorded being 155 millimeters (mm) and the highest being 375 mm, while humidity levels ranged from 82.5% to 91.5%. Furthermore, the area comprised three sub-districts, namely Pollung, Dolok Sanggul, and Lintong Nihuta. In Pollung, FE farmers were from two villages, Ria-Ria and Hutajulu, while non-FE farmers were based in Dolok Sanggul and Lintong Nihuta. These two sub-districts were selected for the study due to the position as the major production centers for shallots and red chilies, along with Pollung. According to 2021 data from (BPS, 2023), Dolok Sanggul produced 996.5 tonnes of shallots and 1,098 tonnes of red chilies. Lintong Nihuta yielded 506 tonnes of shallots and 856.3 tonnes of red chilies. The scope of this study, particularly regarding sustainability analysis was restricted to shallots and red chilies.

Sampling

Respondents, who were red chili and shallot crops farmers, included 50 each practicing both FE and non-FE farming, totaling 100. The comparative analysis was considered fair due to the use of a similar sample size. FE and non-FE farming participants included 25 red chilies and 25 shallot farmers, selected from Pollung, as well as Dolok Sanggul and Lintong Nihuta, respectively.

Data

Primary data was collected through farmer interviews and questionnaires, while a Likert scale was used to identify various aspects of farming

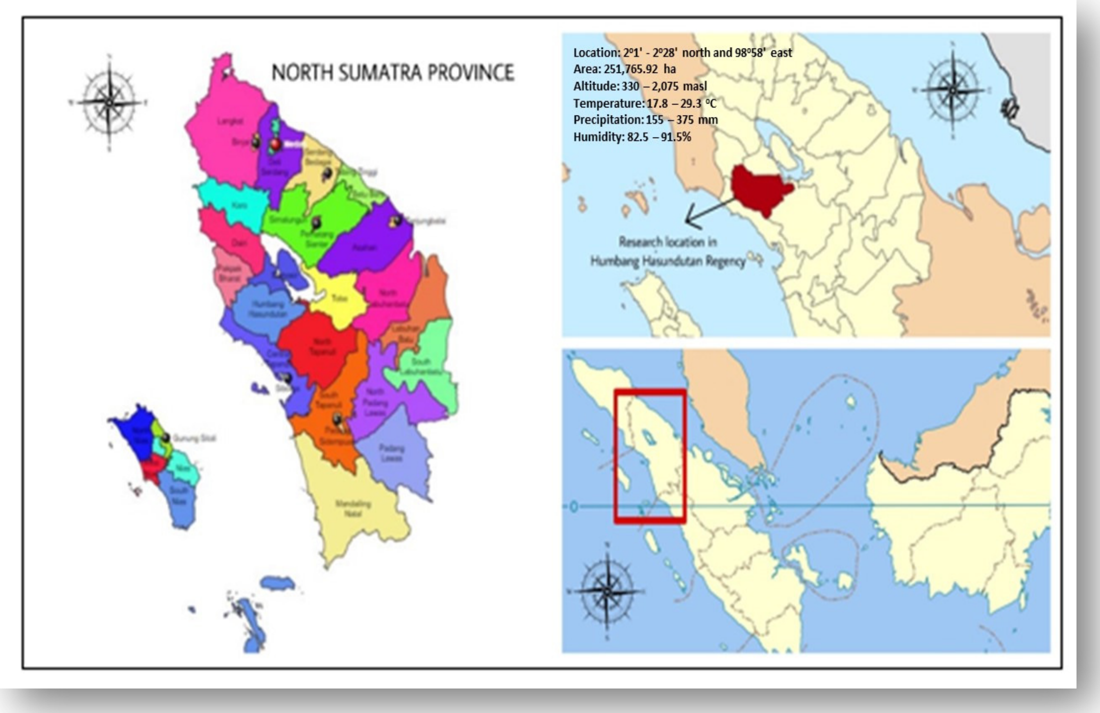

Fig. 1: Geographical location of the study area in Humbang Hasundutan Regency, North Sumatra, Indonesia

sustainability. These aspects included economic, social, environmental, marketing, institutional, technological, and cultural. In addition, a total of 45 indicators were used to compare sustainability of farms namely 7 economical, 6 social, 9 environmental, 5 institutional, 7 technological, 5 marketing, and 6 cultural.

Data Analysis

Sustainability status of FE and non-FE farming was assessed using MDS approach with the licensed Multiaspect sustainability analysis (MSA) software (Firmansyah, 2022). MDS approach was implemented through the ordination process, using a modification of Rapid appraisal for fisheries (RAPFISH) (Kavanagh and Pitcher, 2004; Pitcher *et al.*, 2013). The parameters measured in this approach were on a scale. According to (Pitcher *et al.*, 2013; Pitcher and Preikshot, 2001), MDS is more stable than some other multivariate approaches. The indicators used in each aspect were not specified but were determined from previous studies, which investigated the sensitivity or impact of each factor on sustainability. Strategies to improve sustainability were determined using factors that have the potential to be improved. These factors have a significant influence on farming sustainability, as shown in Table 1.

Land use planning strategies for FE and non-FE farming were designed using three scenarios to enhance sustainability. The scenarios were created using the features available in MSA software, allowing users to form a maximum of three scenarios and indicators for each aspect. The indicator score was increased for the aspect with the lowest sustainability score. The three scenarios included simulating improvements in 1) aspect with the lowest score, 2) aspect with the second-lowest score, and 3) all aspects of sustainability. The scenarios differed in terms of determining land use planning strategies because FE and non-FE farming varied in different aspects with lower scores.

Statistical analysis

Data was collected by conducting interviews with

Table 1: Aspects, factors, and indicators of sustainability for farming

Aspects		Factors	Indicators	Sources
Economy	1.	Financial farming	Frequency of financial loans for farming (EC1)	Yusuf *et al*., 2022
	2.	Profit	Farm profit level for daily needs (EC2)	Fauzi, *et al*., 2017; Nandini *et al*., 2017; Saida *et al*., 2011, 2016; Yusuf *et al*. 2022
	3.	Income farming for education	Spending of farm income on children's education (EC3)	Saida *et al*., 2011
	4.	Income farming ratio	Percentage of farm income to overall household income (EC4)	(Pawiengla *et al*., 2020; Saida *et al*., 2011
	5.	Availability of Agricultural Industry	Degree of availability in the agricultural industry (EC5)	Allaily *et al*., 2024; Mujio *et al*., 2023
	6.	Subsidy	Degree of availability in input subsidy (EC6)	Nuraini and Mutolib, 2023; Rastagari *et al*., 2023
	7.	Agricultural insurance	Level of agricultural insurance use (EC7)	Nuraini and Mutolib, 2023
Social	8.	Education level	Level of completed education (SC1)	Mujio *et al*., 2023; Nandini *et al*., 2017
	9.	Knowledge of land tenure	Knowledge level of land tenure (SC2)	Ningsih *et al*., 2022
	10.	Land lease	Level of knowledge on land lease standards (SC3)	Yusuf *et al*., 2022
	11.	Knowledge of agricultural sustainability	Knowledge level of sustainable agriculture (SC4)	Saida *et al*., 2016
	12.	Transportation access	Transport access to the field (SC5)	Pawiengla *et al*., 2020
	13.	Farming share mechanism	Percentage share of farm income (SC6)	Yusuf *et al*., 2022
Environment	14.	Land use suitability assessment	Frequency of land use suitability assessments (EV1)	Fauzi *et al*., 2017; Pawiengla *et al*., 2020
	15.	Burning practice of agricultural waste	Frequency of burning crop residue (EV2)	Pawiengla *et al*., 2020
	16.	Organic fertilizer	Organic fertilizer application rate as recommended (EV3)	Saida *et al*., 2016
	17.	Inorganic fertilizer	Organic fertilizer application rate as recommended (EV4)	Fauzi, *et al*., 2017; Saida *et al*., 2011, 2016
	18.	Crop rotation	Crop rotation rates (EV5)	Pawiengla *et al*., 2020
	19.	Weed management	Weed management rates (EV6)	Fauzi *et al*., 2017
	20.	Pesticide	Pesticide application rate as recommended (EV7)	Fauzi *et al*., 2017; Nuraini and Mutolib, 2023; Pawiengla *et al*., 2020; Saida *et al*., 2016
	21.	Water availability	Knowledge levels for water availability (EV8)	Mujio *et al*., 2023; Ningsih *et al*., 2022; Yusuf *et al*., 2022
	22.	Water management	Level of knowledge to supply the accurate volume of wáter (EV9)	Ningsih *et al*., 2022
Institution	23.	Availability of financial institution	The availability level of financial institutions (IS1)	Yusuf *et al*., 2022
	24.	Extension frequency	Frequency of extension activities (IS2)	Nuraini and Mutolib, 2023; Saida *et al*., 2011, 2016; Yusuf *et al*., 2022
	25.	Farmer group	Existence and activity level of farmer groups (IS3)	Nandini *et al*., 2017; Saida *et al*., 2011, 2016; Yusuf *et al*., 2022
	26.	Land conversion	Level of extension for land conversión (IS4)	Saida *et al*., 2011
	27.	Conflict of farmer group	Frequency of conflicts in farmer groups (IS5)	Fauzi *et al*., 2017

Continued Table 1: Aspects, factors, and indicators of sustainability for farming

Aspects		Factors	Indicators	Sources
Technology	28.	Internet access for information on digital agricultural technology	Frequency of accessing the internet for agricultural technology information (TC1)	Maharani *et al.*, 2023; Zhong *et al.*, 2023
	29.	Using for price information	Level of awareness of the use of digital technology for price information (TC2)	Maharani *et al.*, 2023
	30.	Adoption of new technology	Adoption level of new technology (TC3)	Ningsih *et al.*, 2022
	31.	Relevance of agricultural technology	The relevancy level of agricultural technology to farmers' habits (TC4)	Yusuf *et al.*, 2022
	32.	Farmers' response to new technology	The level of response to new technology by farmers (TC5)	Ningsih *et al.*, 2022
	33.	Suitability of new technology for farmer skill	The level of compatibility of new technologies with farmers' capabilities (TC6)	Takagi *et al.*, 2021; Yusuf *et al.*, 2022
	34.	Availability of new agricultural technology	Level of availability of appropriate agricultural technology (TC7)	Yusuf *et al.*, 2022
Marketing	35.	Availability of market institutional	Number of marketing institutions buying the harvest (MR1)	Mujio *et al.*, 2023; Nandini *et al.*, 2017; Nuraini and Mutolib., 2023; Paweingla *et al.*, 2020; Yusuf *et al.*, 2022
	36.	Promotion activity	Promotional activities to sell the harvest (MR2)	Djuwendah *et al.*, 2023; Saida *et al.*, 2016
	37.	Price information of harvest	Level of knowledge about the importance of having a reasonable selling Price (MR3)	Fauzi *et al.*, 2017; Saida *et al.*, 2011, 2016; Yusuf *et al.*, 2022
	38.	Farmer-consumer relationship	The presence of a buyer-seller linkage (MR4)	Mujo *et al.*, 2023
	39.	Knowledge of harvest selling	Knowledge level of selling crops to intermediate agents (MR5)	Mujio *et al.*, 2023; Ningsih *et al.*, 2022; Prihawantoro *et al.*, 2019
Culture	40.	Communal work	Level of communal work activity (CL1)	Saida *et al.*, 2011, 2016
	41.	Tradition of environmental behavior	Level of knowledge that traditions are valuable for environmental conservation (CL2)	Fauzi *et al.*, 2017
	42.	Knowledge of agricultural sustainability tradition	Level of knowledge regarding the significance of tradition in contributing to sustainable agriculture (CL3)	Fauzi *et al.*, 2017
	43.	Local wisdom	Level of knowledge on the importance of keeping local wisdom to support sustainable agriculture (CL4)	Fauzi *et al.*, 2017
	44.	Farming motivation	The farming knowledge level is oriented towards social solidarity (CL5)	Fauzi *et al.*, 2017; Pawiengla *et al.*, 2020
	45.	Knowledge of local culture	Knowledge level of local agricultural culture (CL6)	Nandini *et al.*, 2017

50 farmers each practicing FE and non-FE farming as samples. The survey approach was used to determine the sample, while interviews were conducted through a structured questionnaire model using multiple response options with a Likert scale. The classification of the indicators in each aspect was based on the concept of 'good' and 'poor' (Fisher, 2002). Indicators in good condition were assigned a score of 3 or 2, depending on the range defined for each attribute, while the worst were given a score of 0, in the range of 0 to 3 (or 2). The mode value, considered a definitive score, was analyzed to determine the relative position of sustainability to the 'good' and 'poor' scores, using multidimensional statistical organization approaches.

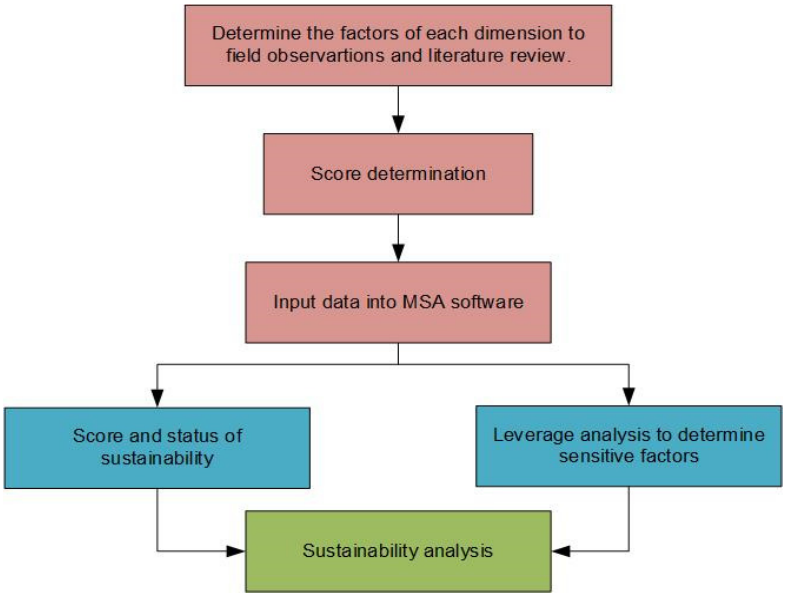

Fig. 2: The process and approach of analyzing farming sustainability using MSA software

A total of 45 questions corresponded to the defined indicators and the collected data were processed using MSA software. Farming sustainability scores were classified into three categories based on data interpretation (Gunduz *et al*., 2011). These included low, moderate, and high sustainability, comprising index scores between 0 – 0.4, 0.41 – 0.67, and ≥ 0.68, respectively. Furthermore, sensitivity analysis was conducted to determine the attributes most sensitive to sustainability index on each dimension. The sensitive attributes were obtained by changing the Root Mean Square (RMS) ordination on the X-axis or sustainability scale. The greater the change in RMS due to the loss of a particular attribute, the greater the sensitivity to sustainability. Attributes with middle or larger values must be considered for policy formulation. The goodness of fit in MDS analysis was determined by the S-stress value and coefficient of determination (R^2). These values can also be used to determine whether the existing indicators have accurately described each aspect analyzed in relation to the actual situation or the need for additional indicators. A low S-stress value indicates a good fit, while a high S-stress value denotes a poor fit. When the analysis produces an S-stress value of less than 0.25 ($S < 0.25$) and R^2 close to 1 (100%), the model is considered good (Pitcher *et al*., 2013). After the determination of sustainability value through MDS analysis using MSA software, the next step entailed identifying the sensitive factors in each aspect based on the maximum and sensitivity values. This inquiry aimed to ascertain two critical points in every sustainability aspect by totaling the utmost and maximum sensitivity. Several considerations for the identification of sensitive factors and the improvement of sustainability can be derived from the results of MSA software, which shows a graph of sensitivity and features the maximum value.

- The maximum value is represented by a green graph, while sensitivity is indicated by yellow.
- Factors with the highest sensitivity and green graph alone are considered to already be in an ideal state, requiring no further changes.
- When more than one factor has the same highest sensitivity value with both a green and a yellow graph, then these factors are considered sensitive and changes will be needed based on the results of the Random Interactions generated by the software.
- Sensitive factors and changes need to be made for “Random Iteration”, namely factors that do not have a gap between “status value per variable” and “random simulation per variable” or on the Random Iteration graph at the same point.

RESULTS AND DISCUSSION

Table 2 shows that sustainability status of FE and non-FE farming was moderately sustainable. FE farming had a higher overall sustainability score in four aspects, while non-FE farming scores were better in three aspects. Among the seven aspects analyzed, FE farming achieved high sustainability in one (environment), while a moderate level was found in five aspects, namely economic, social, institutional, technological, and market. Non-FE farming had a high level of sustainability in one aspect (environmental), and a moderate level in four aspects, including social, institutional, technological, and cultural. Meanwhile, a low level was found in economic and market aspects. The results showed that both FE and non-FE farming received the highest scores in the environmental aspect. Komalawati *et al.* (2024) reported that the environment had the lowest sustainability score of only 19.8% out of the five aspects analyzed. Agricultural sustainability assessment by Prabowo *et al.* (2024) also found that the environment had the lowest score of 75.15% out of the three aspects studied. The disparity in results can be attributed to differences in the number of aspects and indicators used.

Cultural and economic aspects had the lowest scores in FE farming, while economic and market aspects in non-FE farming had the lowest scores. The two aspects with the lowest scores were considered in determining the three scenarios used to design land use planning strategies. For FE farming, three scenarios were prepared based on the two lowest-scoring aspects. The first, second, and third scenarios aimed to improve cultural, economic, and all aspects respectively. For non-FE farming, the three scenarios improved economic, market, and all aspects respectively.

Economic aspect

The economic sustainability score was significantly higher for farms with FE program, at 47.57% compared to only 33.29% for those without. However, FE farming generally had a moderate level of economic sustainability, while non-FE farming remained at the lower end of the scale. The greater economic sustainability of FE farming was because farmers were provided with subsidized inputs, including seeds, fertilizers, pesticides, and agricultural equipment, with the potential to increase production, income, and farm profits (Tang *et al*., 2023). Shallot yields an average of 1,558 kilograms (kg) in FE and 1,898 kg in non-FE in one season. To increase yields, FE farming land use planning requires additional production input subsidies in the form of fertilizer. Intensive fertilizer use can increase soil nutrients on new land. In conditions where nutrient conditions are not optimal for shallot commodities, the government can provide several alternative crop choices. As reported by Lark *et al*. (2020), the yields of newly established cropland are relatively lower than existing ones due to the lower quality of the land, underscoring the need for extensive land clearing and fertilization. According to Li *et al*. (2023), the organic content of newly established cropland, including soil, particulate, and mineral-associated organic carbon, decreased overtime following land

Table 2: Value and level of sustainability status of FE and non-FE Farming

No.	Aspect	Sustainability value	
		FE farming	Non-FE farming
1.	Economy	47.57	33.29
2.	Social	50	47.17
3.	Environment	72.22	77.78
4.	Institution	50	56.6
5.	Technology	50	42.86
6.	Market	53.4	36.6
7.	Culture	33.33	41.67
Total average		50.93	48
Sustainability status		Moderate sustainability	Moderate sustainability

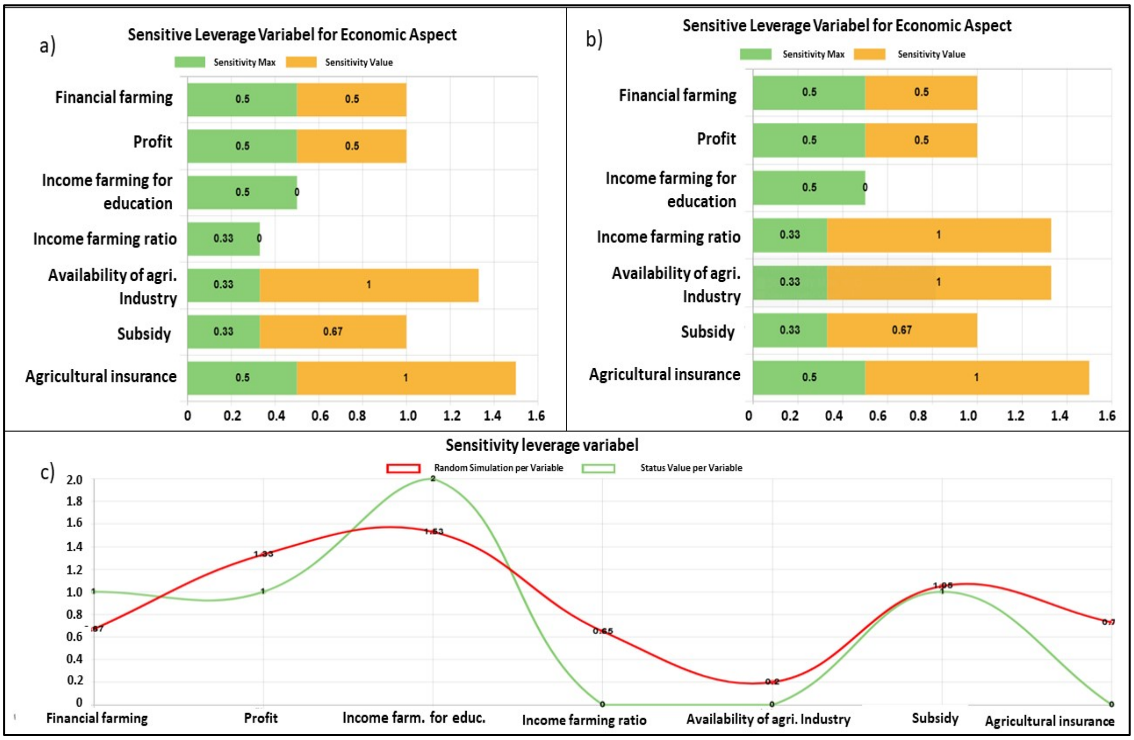

Fig. 3: Sensitivity values for economic factors in (a) FE farming, (b) non-FE farming, (c) Gap analysis of the sensitivity values of economic factors in non-FE farming

conversion. FE farming land was relatively in an optimized condition, resulting in higher crop yields compared to non-FE farming. Planning for non-FE farming requires business capital loans to increase yields in cases of limited land. Farmers can use capital loans to expand land and increase the scale of farming activities (Tesyfay, 2021). In FE farming, the availability of agricultural industry and insurance were the economic factors with the most sensitive and maximum sensitivity values (Fig. 3a). Similar results were also found for non-FE farming, with two factors showing identical sensitivity values, namely the availability of the agricultural industry and the income farming ratio (Fig. 3b). Fig. 3c shows a smaller gap during random iteration, attributed to the availability of the agricultural industry factor.

Based on the sensitive economic values of the two objects, two factors were found to be common, namely the availability of agricultural industry and the impact of competition in processing on maintaining commodity prices (Muflikh *et al.*, 2021). The availability of the agricultural industry can lead to an increase in value-added products, and consequently higher prices. The results suggest that the government can support the agricultural processing industry by adopting two strategies, namely cooperation with private sector industries, or providing basic training and technology to farmers. These strategies will facilitate the creation of value-added products with small and medium enterprises (SMEs) that can be managed independently through farmer groups. According to (Iyabano *et al.*, 2022; Zhou *et al.*, 2023), farmers who join groups are more likely to adopt technology. Another critical factor that played a significant role in enhancing sustainability of FE farming was agricultural insurance. This factor has the potential to increase the profits of farmers, banks, and industrial companies (Li *et al.*, 2023). Considering most of the farming activities in FE program are carried out on newly cleared land, production results may not be optimal in the first harvest season. Despite the significantly lower productivity of shallots compared to the national average, introducing agricultural insurance can potentially reduce the risk of crop failure for farmers. Mihai *et al*. (2023) showed that knowledge had a substantial impact on the use of agricultural insurance. Therefore, it is important to address the lack of awareness and understanding of this factor among farmers. Agricultural insurance had minimal impact on non-FE farming, while the ratio of farm income to total household income was important for farming sustainability. This suggests that a relatively small proportion of income is generated by farming, as farmers typically work with only 0.26 ha of land on average.

Social aspect

Social sustainability score of FE farming was 50%, compared to 47.17% for non-FE farming, placing both at a moderate level. Similar to the economic aspect, social sustainability score of FE farming was higher than non-FE farming, primarily due to differing educational levels. Farmers in FE farming had 12 years of education while non-FE farmers had 11 years. Social interaction for sustainable knowledge acquisition was also better for farmers in FE farming due to the support received in implementing agricultural practices on land. Regular support from extension workers increases the pace of technology adoption by providing relevant information and knowledge. Farmers with higher education are more likely to adopt technology, which is essential for efficiency in large-scale land cultivation. Rocha *et al.* (2019) suggested that agricultural mechanization has the capacity to increase land productivity in large-scale land cultivation. For non-FE farmers with low education levels, other strategies are needed, particularly those that do not rely on technology or agricultural mechanization. To reduce cost, land use planning requires an increase in the intensity of farmer group activities in land management. Ochieng *et al.* (2018) also underscored the importance of farmer groups in land management. Social factors with the potential to enhance sustainability in FE farming include land leasing and farming share mechanisms (Fig. 4a), while in non-FE farming, the factors are knowledge of land tenure and agricultural sustainability (Fig. 5b). In the economic aspects, the sensitive social differences between FE and non-FE farming show that social issues are site-specific.

The results showed insufficient knowledge regarding land lease and farming share mechanisms among farmers practicing FE farming. Farmers rarely rent land, preferring the unused type and request consent of the owner, without payment of land rent. The land is plentiful, but labor is in short supply, hence, a significant proportion is unproductive and depreciating. The lack of a defined standard for the benefit-sharing mechanism results from the lack of land rent. The relatively low education level of 11 years showed the limited knowledge of land tenure rights and sustainable farming practices among non-FE farmers. According to Belay *et al.* (2022), many farmers lack active participation, reducing knowledge base and affecting the adoption of advanced farming technology. Increased agricultural knowledge leads

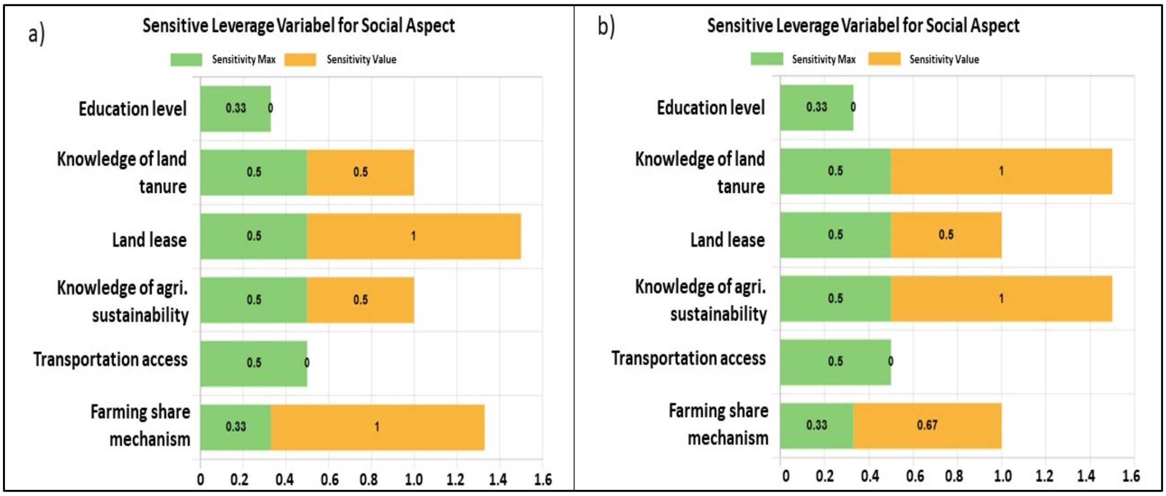

Fig. 4: Sensitivity values for social factors in (a) FE farming, (b) non-FE farming

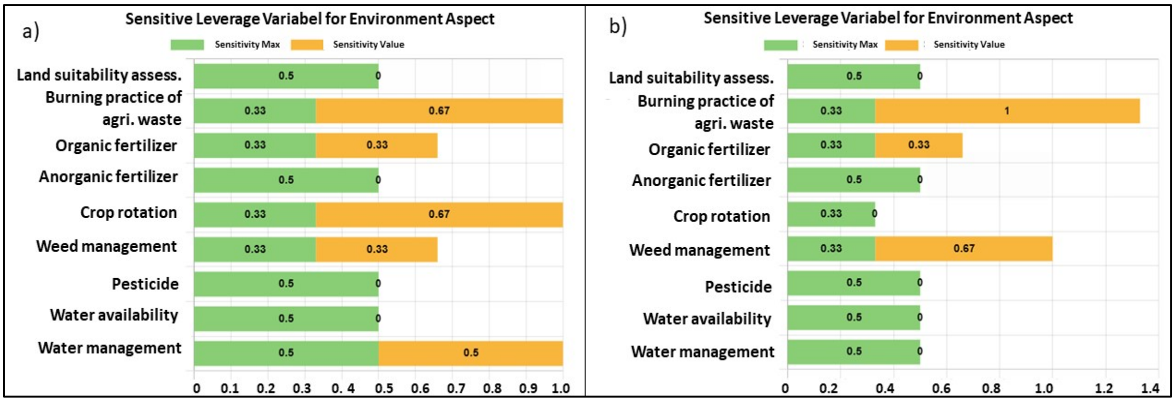

Fig. 5: Sensitivity values for environmental factors in (a) FE farming, (b) non-FE farming

to heightened production (Ule *et al*., 2023) and the adoption of sustainable practices (Ha *et al*., 2023; Slijper *et al*., 2023). Meanwhile, increased adoption of sustainable agricultural practices can improve environmental qualities such as climate change (Akrong *et al*., 2023).

Environmental aspect

Environmental sustainability score of non-FE farming surpassed FE, with values of 77.78% and 72.22%, respectively. Although both were categorized as high levels, environmental sustainability score of non-FE farming was higher due to longer farming experience. Farmers practicing non-FE farming had 15.4 years of experience, while those in FE farming only had 11.3 years. Farming experience has an impact on activities related to the protection of the environment, as older farmers tend to adopt a higher level of environmentally friendly practices (Drescher *et al*., 2024). On the other hand, farmers with low experience may be less concerned about the environment. Land use planning for FE farming should include extension to increase awareness of farmers regarding environmentally responsible land management. According to Aregay *et al.* (2018), this factor is influenced by farmer characteristics and knowledge of the environment. Farmers practicing non-FE farming had more awareness of land management due to longer experience. To improve sustainability in small-scale cultivation, a potential strategy could be to increase the intensity of extension services on the use of inorganic fertilizers. Farmers in non-FE farming often only receive information on fertilizer application dosage from sellers. Emeane *et al.* (2019) stated that agricultural extension officers provided information to make farmers cultivate land in an environmentally sustainable manner. Sensitive environmental factors, which can improve sustainability in farming with a focus on food ethics, include the disposal of agricultural waste through burning and crop rotation (Fig. 5a). In non-FE farming, subsidized agricultural waste burning and weed management played a significant role (Fig. 5b).

Burning agricultural waste was found to be a sensitive factor in both study areas as farmers used similar practices to manage crop wastes due to the practicality and cost-effectiveness. According to a previous report, burning crop residues returns essential nutrients, including calcium, potassium, and phosphorus, back to the soil (Odzijewicz *et al*., 2022). This process enhances soil fertility and improves the structure. However, several significant negative impacts are associated with biomass burning, such as the release of smoke, particulate matter, carbon monoxide, and other pollutants into the atmosphere contributing to greenhouse gas emissions, loss of valuable organic matter, depletion of natural resources, and influence on biodiversity (Bhuvaneshwari *et al*., 2019). The use of crop residues can provide an alternative material through the isolation of nanofibers and processing for biogas production (Bascon-Villeges *et al*., 2020, Frankowski and Czeskala, 2023). Furthermore, crop rotation is a sensitive factor for environmental sustainability in FE farming. The government has pre-selected the commodities, including shallots, garlic, and red chilies, to be grown under FE program, limiting the opportunities for crop rotation. The aim was to focus on strategic commodities that could supply domestic demand. This strategy is unlikely to succeed as land suitability must be planned for in FE program (Hasbullah *et al*., 2023). Crop rotation has the potential to enhance yield (Niether *et al*., 2023) and increase land productivity (Liu *et al*., 2023). This practice exerts minimal impact on the environment and helps farmers manage risks associated with weather variability of market demands (Lago-olveira *et al*., 2023; Tsai and Lee, 2023). Farmers in non-FE farming rotate crops as deemed appropriate but there was a sensitive weed management factor. This was a consequence of limited time and labor availability, significantly affecting crop maintenance. In reality, weed growth poses a threat to crop production (Choudhary *et al*., 2022; Daba *et al*., 2023) and also has the potential to reduce the income of farmers (Dentzman, 2018). According to Daramola *et al*. (2021), conventional weed management, hand weeding, does not give high yields, underscoring the need for integrated management. It is also important to consider the economic, cultural, physical, and biological aspects of using pesticides (Francis, 2019).

Institutional aspect

FE farming had an institutional sustainability score of 50%, while non-FE farming scored 56.6%. This indicates that non-FE farming has higher institutional sustainability than FE, although both were categorized at a moderate level. Top-down policies of the government, which determine the commodities grown and the formation of farmers groups, lower the institutional sustainability score for FE farming. The land area for each commodity is also determined by the government based on the target to be achieved. According to Niedzialkowski and Chmielewski, (2023), top-down policies create the potential for social conflict in the community. In such situations, the relationship between farmers group members is weakened and activities are carried out only with government support. Farmers are free to plant crops on land depending on climate, weather, and market demand in non-FE farming. Two institutional factors were equally sensitive for FE and non-FE farming, namely the frequency of extension and farmer group conflict (Fig. 6a and Fig. 6b). However, as shown in Fig. 6c and Fig. 6d, the farmer group conflict factor has a low variance. The issue of land conversion was a sensitive one in both cases. This activity has a potential risk of threatening sustainability of farming practices.

Land conversion may lead to agricultural areas being converted to industrial or residential use. Policy failures and lack of capacity, as well as climate change population growth and urban sprawl, have all contributed to the conversion of agricultural land

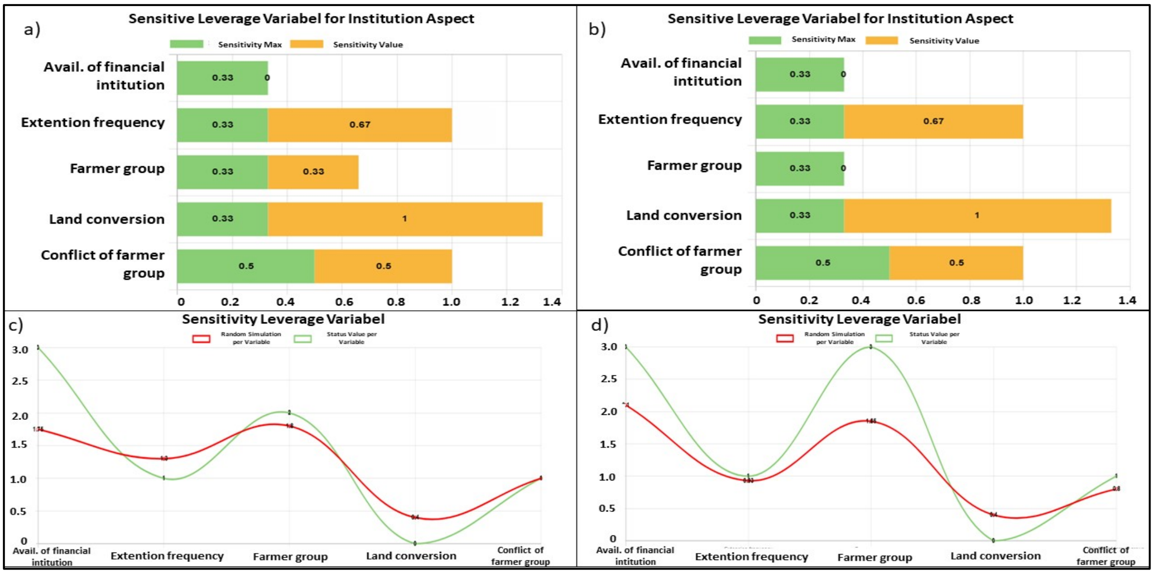

Fig. 6: Sensitivity values for institution factors in (a) FE farming, (b) non-FE farming, (c) Gap analysis of the sensitivity values of institution factors in FE farming, (d) Gap analysis of the sensitivity values of institution factors in non-FE farming

(Ortiz-Oliveros *et al*., 2022; Virtriana *et al*., 2023). To ensure that farms continue to exist and to supply food, governments need to set rules to regulate the conversion of agricultural land. According to Kangah and Atampugre (2022), extension services play a key role in providing information about the conversion of agricultural land to non-agricultural uses. Governments need to provide incentives to those who select to stay in agriculture to discourage the conversion of land (Zeng *et al*., 2020). Another important factor in ensuring institutional sustainability is the occurrence of conflicts in farmer groups. Conflict is a natural part of group dynamics, and enhances socio-ecological sustainability in farming when balanced with cooperation (Rasheki *et al*., 2023). However, frequent conflicts tend to make group members uncomfortable and unproductive. Differences in access to agricultural inputs can be a source of conflict in farmer groups (Bukari, 2023; Spiric, 2022).

Technology aspect

Sustainability score for technology in FE farming was 50, compared to 42.86 for non-FE, but both types were at a moderate level. FE farming is more sustainable, because the implementation of cultivation activities benefits from significant government intervention such as drip irrigation systems, while non-FE farming tends to use conventional technology to maintain water availability. Efficient land use planning for farming in FE requires the application of technology and agricultural mechanization due to the large scale. However, the use of agricultural mechanization for large-scale agriculture has a negative impact on the environment by increasing carbon emissions (Guan *et al*., 2023). Non-FE farming, which averages only 6,817 meters square (m^2), is inefficient in using modern technology to manage agricultural land. As stated by Ochieng *et al*. (2018), farmer groups can achieve efficient cultivation with agricultural mechanization for small land farms, while integrated irrigation has the potential to meet 50% of water needs (Taye *et al*., 2022). Similar to the institutional sustainability aspect, FE and non-FE farming share the same factors for adopting new technology and acknowledging the relevance (Fig. 7a and 7b). This implies that farmers face similar problems when adopting technology. Character (Bukchin and Kerret, 2020), land ownership (Ngango *et al*., 2023), education level (Nhundu *et al*., 2023), institutional support (Smidt and Jokonya, 2022), and access to extension services (Metouole *et al*., 2018; Oyetunde-Usman *et al*., 2021) play a crucial role in the problem of technology adoption in agriculture. As stated by Coromaldi *et al*. (2015), technology adoption can improve welfare and food security.

The adoption of new technology is a sensitive factor in both objects compared in this study, suggesting that farmers share similar approaches in terms of accepting modern technology in farming practices. The slow process of adopting new technology is attributed to farming experience (Malila *et al*., 2023). Due to the many years of experience, farmers tend to stick to traditional ways of farming. Motivating

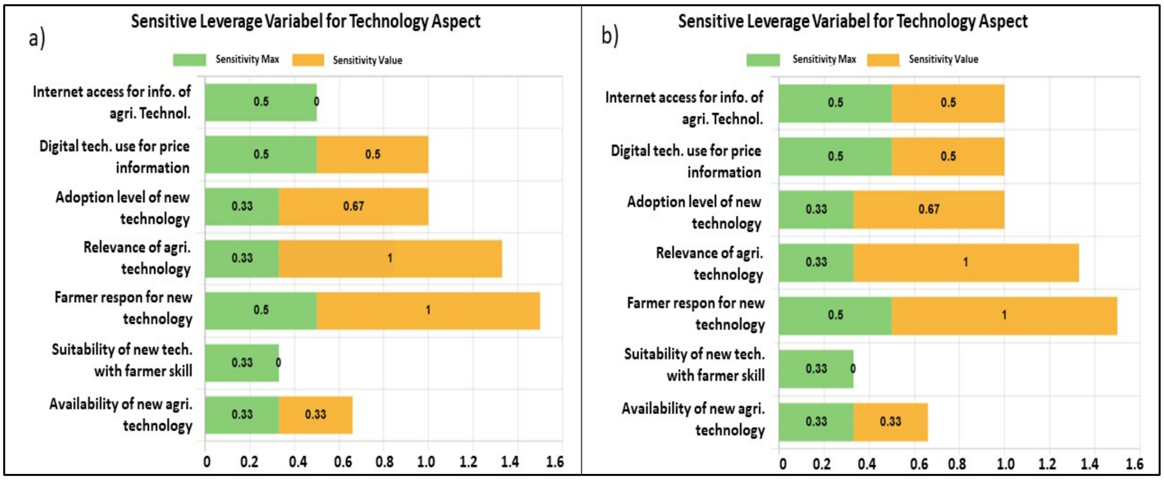

Fig. 7: Sensitivity values for technology factors in (a) FE farming, (b) non-FE farming

farmers to adopt new technology is essential to improve efficiency but this requires government intervention (Wang *et al*., 2023). Despite the present challenges, extension workers must speed up responses of farmers to new technology. The farmer-to-farmer extension approach offered by Martini *et al*. (2023) can be used to increase the adoption of new sustainable technology, with mobile phones playing a crucial role in disseminating information (Kiptot and Frazel, 2015). According to Namyenya *et al*., (2022) and Oluronfemi *et al*., (2020), the government needs to improve the performance and knowledge of extension workers to increase the rate of technology adoption by farmers. The sensitivity towards the relevance of agricultural technology is significant and is driven by top-down policy rather than the needs of farmers. Technology that does not match the needs of farmers will not be used. Bukchin and Kerret, (2020) and Tulu *et al*., (2020) stated that farmers' personalities could be altered through education, enabling the effective use and operation of new technology.

Market aspect

Marketing sustainability score for FE farming exceeded non-FE farming, with scores of 53.4% and 36.6%, respectively. Non-FE farming was at a low sustainability level, while FE farming was categorized as moderate. Several factors contribute to the higher value of marketing sustainability for FE farming. The higher marketing sustainability value was attributed to the availability of several crop-selling options for farmers. The marketing aspect is less directly related to land use planning. The government facilitates the planning and design of FE program (Kementan, 2020) by providing several companies to purchase crops, thereby reducing dependence on middlemen. When the government sets up companies to buy the crops of FE farming, farmers must meet up with demand accordingly, and this requires proper land use planning. Effective land use planning needs accurate estimation of both harvest and demand from the company. The government must regulate planting areas and times to ensure the sustainable use of resources. Non-FE farmers, on the other hand, often experience losses during the harvest season due to the planting of commodities without considering demand. To address this issue, an effective land use planning strategy for non-FE farms with small areas, namely crop rotation should be adopted to correctly predict the demand for commodities. It is also important to consider the land conditions when selecting specific commodities to plant. Two equally significant sensitive factors were found in FE farming namely, the pricing information of the harvest and farmer-consumer relationship (Fig. 8a). In addition, a random iteration based on Fig. 8c indicates these two factors also share the same gap. The results showed three crucial sensitive factors in FE farming, namely promotion activity, pricing information of the harvest, and the relationship between the farmer and consumer. Non-FE farming had similar three sensitive factors, namely crop price information, farmer-consumer relationship, and crop sales knowledge (Fig. 8b). Based on Fig. 8c and Fig. 8d, random iteration showed that the relationship with consumers had a smaller gap. Non-FE farming had two additional sensitive factors, namely promotional activities and the farmer-consumer relationship.

A total of two sensitive factors were similar for FE and non-FE farming, namely promotional activity and farmer-consumer relationship. Promotion activity has a crucial role in selling produce but farmers' promotional approaches differ from creating billboards in various media, as these activities can be achieved through personal selling in the neighborhood. Promotion activity can also be achieved through social media, which serves as a platform to market crops to potential customers. As suggested by Kurdi and Alshurideh (2023), social media is a more effective means of promoting products, potentially enhancing farmer-consumer relationships (Chen and Tan, 2019). The use in rural markets faces various challenges, including regulatory issues, infrastructure, and operational factors (Son and Niehm, 2021). The farmer-consumer relationship is also a sensitive factor for FE and non-FE farming. In general, farmers have intermediaries and end consumers who buy harvested crops. Strong consumer relations ensure a stable market and increase the confidence of farmers in selling crops. Additionally, the availability of market has a profound impact on the income of farmers through relationships with buyers, which, in turn, limits access to food (Miller and Malacarne, 2023).

Cultural aspect

Cultural sustainability score for non-FE farming

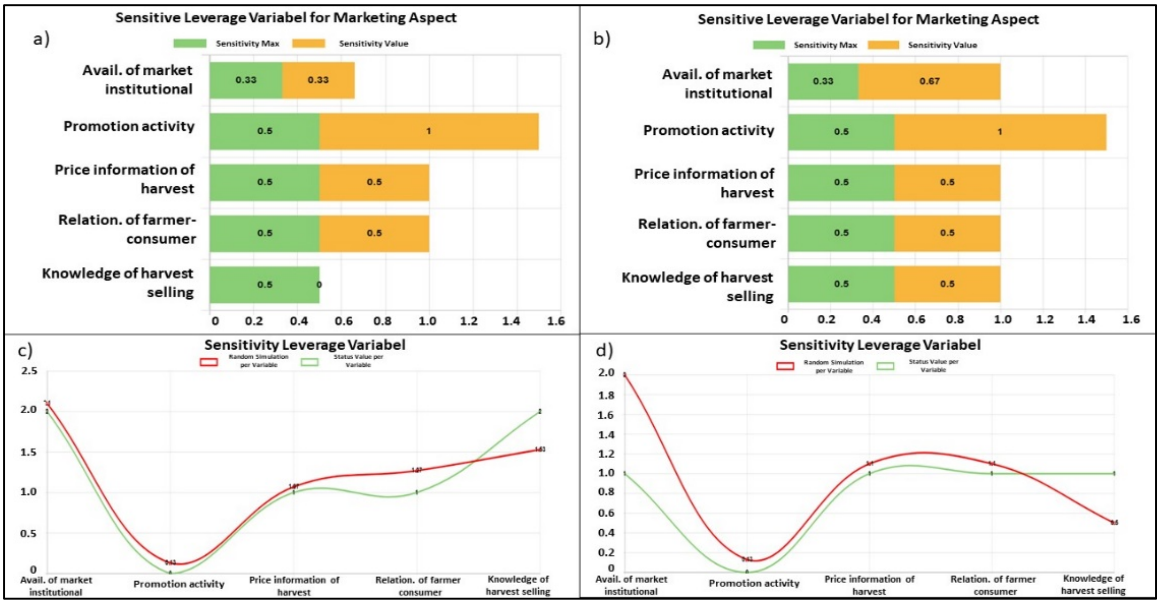

Fig. 8: Sensitivity values for market factors in (a) FE Farming, (b) non-FE farming, (c) Gap analysis of the sensitivity values of market factors in FE farming, (d) Gap analysis of the sensitivity values of market factors in non-FE farming

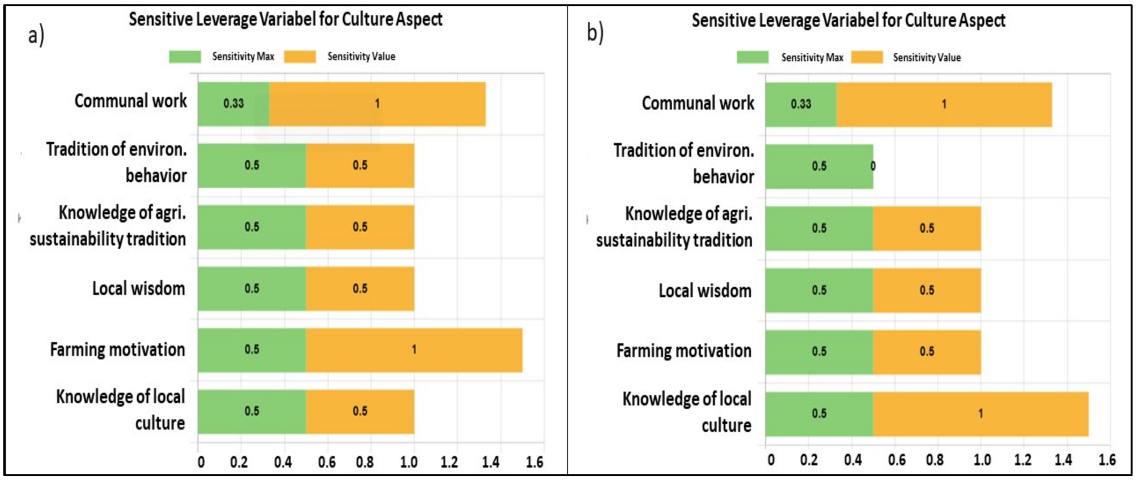

Fig. 9: Sensitivity values for culture factors in (a) FE farming, (b) non-FE farming

was 41.67%, at the moderate level, while FE farming was 33.33%, at the low level. This disparity can be attributed to several factors, particularly the profit-oriented approach of FE farming, which prioritizes financial gain over social togetherness. Farmers tend to be more dependent on service providers for land cultivation machinery due to the profit-oriented mindset. Substantial assistance by the government has also led to a more individualistic approach. According to Kovacs (2021), government aid, such as subsidies, alters traditional societal values, which, in turn, impacts subsidized labor. Non-FE farming was more inclined towards communal work initiatives in farmer groups. Family or other colleagues often assist non-FE farming farmers with land cultivation due to the small land area and limited capital. Based on the results, two significant factors were sensitive for FE farming, namely farming motivation and communal work (Fig. 9a). In non-FE farming, the most sensitive factor was knowledge of local culture and communal

Table 3: Comparison of simulation results on sustainability value of FE Farming.

No.	Aspect	Sustainability value FE Farming			
		Existing	1st Scenario: Cultural aspect improvement	2nd Scenario: Economic aspect improvement	3rd Scenario: All aspect improvement
1.	Economy	47.57	54.71	66.57	71.43
2.	Social	50	50	50	72.17
3.	Environment	72.22	72.22	77.22	72.22
4.	Institution	50	50	50	73.4
5.	Technology	50	50	50	66.71
6.	Market	53.4	53.4	53.4	83.4
7.	Culture	33.33	55.5	33.33	55.5
Total average		50.93	55.12	53.65	70.69
Sustainability status		Moderate sustainability	Moderate sustainability	Moderate sustainability	High sustainability

work (Fig. 9b). Culture and communal work were found as critical factors for both FE and non-FE farming.

The decline of communal work culture is a matter of concern for both FE and non-FE farming, with unity and local identity playing a crucial role in this context (Hoogesteger *et al*., 2023). To revive the dwindling culture, the government should engage farmers through groups in program implementation. Motivation is a sensitive factor and farmers subsidized for FE farming often show a greater sense of individualism, as the formation of groups is initiated from the top. These groups are formed to attain government assistance in the form of subsidized fertilizers, seeds, and other necessary inputs. As stated by Mellon *et al*. (2022) and Oniki *et al*. (2023), the participation of top-down farmer groups declined when subsidies were provisionally offered but later discontinued. Farmer groups that do not receive external maintain commodities at a higher rate. On the downside, non-FE farming had a sensitive cultural knowledge factor. This expertise takes the shape of agricultural customs practiced in the local area.

Land use planning strategies for sustainability of FE and non-FE farming

Table 3 shows a comparison between the existing sustainability score and status with the three scenarios simulated for FE Farming. The first scenario, simulating the improvement of the cultural aspect only, resulted in an increase of sustainability score by 55.12%, with a fixed status of moderate. The second scenario, simulating the improvement of the economic aspect only, resulted in a slight improvement of sustainability score by 53.65%, which was lower than the first scenario. To improve sustainability of FE farming, it is necessary to increase the value of indicators in other aspects. The simulation of improvements in all aspects in the third scenario resulted in a sustainability value of 70.69%, indicating a high level.

Table 4 shows a comparison between the existing sustainability scores and status with the three scenarios simulated for non-FE farming. The first scenario, which only focused on improving the economy aspect, led to an increase of sustainability value by 50.36%, while the status remained at a moderate level. The second, through the simulation of only improving the marketing aspect, slightly increased sustainability value by 52.75%, with the status remaining at a moderate level. This implies that to enhance sustainability status of non-FE farming, it is crucial to increase the value of indicators in other aspects. In the third scenario, where improvements were made in all aspects, sustainability value increased to 70.69%, categorized as high status.

The simulation in the third scenario on FE farming led to improved indicator values in various aspects. These include: 1) economic aspect with codes EC5, EC6 and EC7, 2) social with codes SC3, SC4 and SC6, 3) environment with codes EV2, EV5, and EV9, 4) institution with codes IS2, IS4, and IS5, 5) technology

Table 4: Comparison of simulation results on sustainability value of non-FE Farming.

No.	Aspect	Sustainability value			
		Existing	1st Scenario: Economic aspect improvement	2nd Scenario: Marketing aspect improvement	3rd Scenario: All aspect improvement
1.	Economy	33.29	49.86	49.86	49.86
2.	Social	47.17	47.17	47.17	78.83
3.	Environment	77.78	77.78	77.78	85.22
4.	Institution	56.6	56.6	56.6	80
5.	Technology	42.86	42.86	42.86	54.71
6.	Market	36.6	36.6	53.4	53.4
7.	Culture	41.67	41.67	41.67	75.22
Total average		48	50.36	52.76	68.17
Sustainability status		Moderate sustainability	Moderate sustainability	Moderate sustainability	High sustainability

Table 5: Comparison of indicator value improvements in the third scenario for FE and non-FE farming

No	Aspects	Indicator codes	
		FE farming	non-FE farming
1.	Economy	EC5, EC6, EC7	EC1. EC4, EC5
2.	Social	SC3, SCS, SC6	SC2, SC4, SC6
3.	Environment	EV2, EV5, EV9	EV2, EV4, EV6
4.	Institution	IS2, IS4, IS5	IS2, IS4, IS5
5.	Technology	TC3, TC4, TC5	TC4, TC5, TC7
6.	Market	MR2, M4, MR5	MR1, M2, MR4
7.	Culture	CL2, CL4, CL5	CL1, CL3, CL6

with codes TC3, TC4 and TC5, 6) marketing with codes MR2, MR4 and MR5, 7) culture with codes CL2, CL4, and CL5. The simulation in the third scenario for non-FE farming also resulted in improved indicator values in various aspects. These include the economic aspect with codes EC1, EC4, and EC5, social with codes SC2, SC4, and SC6, environmental with codes EV2, EV4, and EV6, institutional with codes IS2, IS4, and IS5, technological with codes TC4, TC5, and TC7, marketing with codes MR1, MR2, and MR4, as well as cultural with codes CL1, CL3, and CL6. Table 5 shows a comparison of the improved indicator values between FE and non-FE farming in the third scenario.

A total of 21 out of 45 indicators improved through simulation in the third scenario will be used to develop land use planning strategies for sustainability of both FE and non-FE farming. The 21 indicators were selected based on the relevance to land use planning, as determined by previous studies. Table 6 compares some of the indicators of FE and non-FE farming in relation to land use planning.

The recommended land use planning strategies for FE and non-FE farming were multiple cropping, and crop rotation respectively. The strategies were designed in line with each land condition and access to production inputs to improve farming sustainability. FE farming is a large-scale agricultural approach with easy access to production inputs due to government subsidies and private company engagement in on-farming and off-farming activities. The land use planning strategy model based on the role of stakeholders is shown in Fig. 10a. The role of government is to facilitate agricultural insurance, as FE farming land is new and lacks nutrients, making

Table 6: Indicators related to land use planning for FE and non-FE farming

No.	Indicators of FE farming		Indicators of non-FE farming	
	Code	Sources	Code	Sources
1.	EC6	Assima *et al.*, 2022	EC1	Tesfay, 2021
2.	EC7	Biswal and Bahinipati, 2023	SC2	Tian *et al.*, 2015
3.	SC3	Agegnehu, 2023	SC4	Arfasa *et al.*, 2024
4.	SC4	Arfasa *et al.*, 2024	EV2	Higgins *et al.*, 2018
5.	EV2	Higgins *et al*, 2018	EV4	Hailu *et al.*, 2021
6.	EV5	Cabrini *et al.*, 2019	EV6	Jussaume *et al.*, 2021
7.	EV9	Drewry *et al.*, 2021	IS2	Yenibehit *et al.*, 2024
8.	IS2	Yenibehit *et al.*, 2024	IS4	Yegbemey, 2021
9.	TC4	Chang *et al.*, 2015	IS5	Ochieng *et al.*, 2018
10.	TC5	Fisher *et al.*, 2018	TC3	Carlisle, 2016
11.	CL3	Marouf *et al.*, 2015	TC7	Rivas *et al.*, 2019
12	CL5	Voss, 2022	CL1	Celio and Gret-regamey, 2016

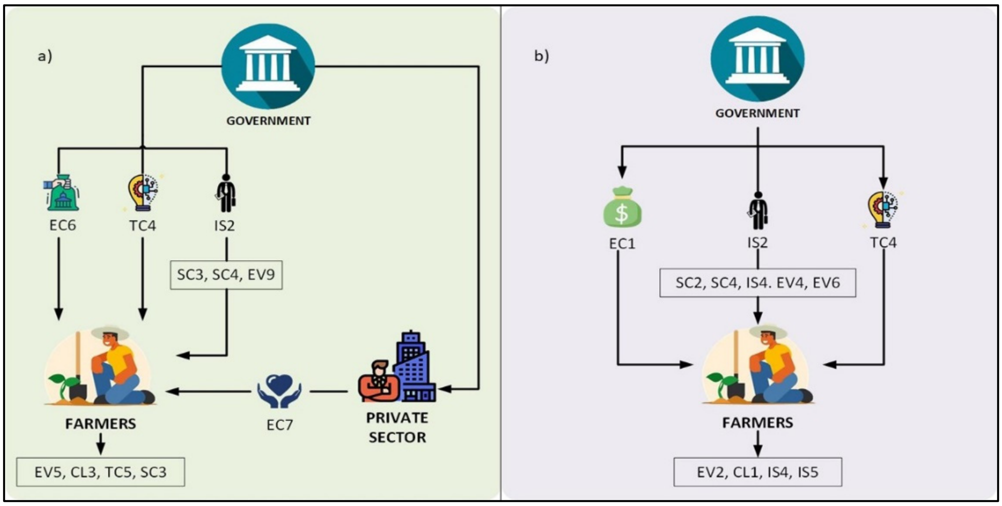

Fig. 10: Strategy design of land use planning based on the third scenario (a) FE farming, (b) non-FE farming

the potential for crop failure relatively high. To promote sustainable agriculture in highland and hill areas, production input subsidies are needed for multiple commodities and appropriate agricultural technology that suits farming land conditions. The agriculture ministry should increase the frequency of extension activities on sustainable agriculture knowledge, land tenancy standards, and irrigation systems to enhance the level of response to new technology. Meanwhile, the role of farmers in land use entails conducting crop rotation to reduce the risk of losses due to unsuitable land and low commodity prices or planting several commodities. The frequency of burning crop residues on agricultural land on a large scale should also be reduced to avoid polluting the environment. It is crucial to maintain traditional values in land cultivation and increase social solidarity in preserving the environment. The role of private companies includes providing agricultural insurance for FE farmers operating on a large scale. Non-FE farms have limited land, as well as restricted access to capital and subsidized inputs. Government intervention is also limited in motivating private enterprises in on-farming and off-farming activities. The land use planning strategy model was based on the roles of two stakeholders, namely the government and farmers (Fig. 10b). The roles of the government include providing low-interest farming loans through the national bank for land expansion, as well as motivating the agriculture department to increase extension activities. This will accelerate technology adoption on land tenure knowledge, sustainable agriculture, land conversion, dosage of inorganic fertilizer use, weed management, and agricultural technology for small areas. Meanwhile, the roles of farmers include reducing the frequency of burning crop residue and increasing the level of communal work in land cultivation. Communal work can help to reduce the cost of land cultivation, which is often a burden for farmers with limited capital. It also promotes community values and reduces the frequency of conflicts in farmer groups, often caused by uncertainty about user rights.

CONCLUSION

In conclusion, sustainability assessment of FE and non-FE farming was found to be at a moderate level with scores of 50.93% and 48%, respectively. In the economy aspect, FE farming scored 47.57% compared to 33.29% for non-FE farming. In the social aspect, the score was 50% and 47.17%, while in the environmental aspect, it was 72.22% and 77.78%. For the institutional aspect, FE farming also had a lower sustainability score of 50%, and non-FE farming had a higher score of 56.6%. In the technological aspect, the scores were 50% and 42.86% respectively. Furthermore, in the cultural aspect, FE farming was found to have a lower sustainability score of 33.33 compared to 41.67% for non-FE. Analysis of sensitivity values to determine the factors affecting sustainability in land use planning showed differences between FE and non-FE farming. The availability of agricultural industry and insurance, with sensitivity values of 1.33 and 1.5, respectively, were found to influence sustainability of the economic aspects of both farming types. Sustainability of social aspects in FE farming was influenced by land lease (1.5) and farm share mechanisms (1.33). In non-FE farming, knowledge of land tenure (1.5) and agricultural sustainability (1.5) were found as the main factors. The environmental aspect of FE Farming was influenced by the practice of burning agricultural waste (1) and crop rotation (1), while in non-FE farming, it was influenced by the practice of burning agricultural waste (1.33) and weed management (1). Furthermore, the institutional aspects of both FE and non-FE farming were influenced by the frequency of extension (1) and farmer group conflicts (1). The technological aspect was influenced by the adoption level (1) and the relevance of agricultural technology (1.33). The market aspect was influenced by promotion activities (1.5) and farmer-consumer relations (1). The cultural aspect of FE farming was influenced by agricultural motivation (1.5) and community work (1.33), while in non-FE farming, it was influenced by knowledge of local culture (1.5) and community work (1.33). Moreover, the simulation results for improving sustainability of both FE and non-FE farming were evaluated using three scenarios. In FE farming, sustainability value increased to 55.12, 53.65%, and 70.69% by improving cultural, economic, and all aspects, respectively. In non-FE farming, sustainability value was increased to 50.36%, 52.76%, and 68.17% by improving the economic, marketing, and all aspects, respectively. The development of land use planning strategies to increase sustainability based on the best scenario (third) in FE and non-FE farming led to different strategies. This difference in strategy design was due to the simulation of indicators that have the potential to be improved. The indicators selected were those having a relationship with land use planning based on previous studies. A total of 12 indicators were related to land use planning in both FE and non-FE farming. This study recommended multiple cropping for FE and crop rotation for non-FE farming, with both strategies having different implications for stakeholders. In FE farming, the government should increase fertilizer subsidies and provide relevant farming technology. The agriculture ministry is also expected to increase extension activities on land tenancy knowledge, as well as sustainability and water management. Insurance companies should engage in reducing the losses of farmers who fail to harvest on new land. Meanwhile, in non-FE farming, the government should provide capital loans at low interest rates to enable farmers expand business scale through land expansion. Extension activities need to also be increased to improve knowledge on land tenure, agricultural sustainability, land conversion, inorganic fertilizer application rate, and weed management rate.

AUTHOR CONTRIBUTIONS

D. Juhandi conducted a through literature review, designed the study, and drafted the manuscript; D.H. Darwanto, the corresponding author, played a key role in conceptualizing the study and interpreting the data, Masyhuri contributed to the preparation of the manuscript; J.H. Mulyo preparation and supervised

manuscript; N.A. Sasongko critically analyzed the manuscript's crucial substantive value; H.L. Susilawati contributed to data processing and statistical analysis; A. Meilin supported data collection; T. Martini drafted the manuscript, validation, and generation.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication or submission, and redundancy have been completely observed.

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ABBREVIATIONS

%	Percent
$US	Dollar United State
°C	Degree celcius
1D	1 – Dimension
2D	2 – Dimension
3D	3-component
APBN	Anggaran Pendapatan dan Belanja Negara (State Budget)
BMKG	Badan Meteorologi Klimatologi dan Geofisika (Meterological, Climatological and Geophysical Agency of Indonesia)
BRIN	National Research and Innovation
cm/y	Centimeter per year
CL1	Level of communal work activity
CL2	Level of knowledge that traditions are valuable for environmental conservation
CL3	Level of knowledge regarding the significance of tradition in contributing to sustainable agriculture
CL4	Level of knowledge on the importance of keeping local wisdom to support sustainable agriculture
CL5	The farming knowledge level is oriented towards social solidarity
CL6	Knowledge level of local agricultural culture
DBR	Degree By Research
e.g	Exempli gratia (for example)
E	East
EC1	Frequency of financial loans for farming
EC2	Farm profit level for daily needs
EC3	Spending of farm income on children's education
EC4	Percentage of farm income to overall household income
EC5	Degree of availability in the agricultural industry
EC6	Degree of availability in input subsidy
EC7	Level of agricultural insurance utilization
EV1	Frequency of land use suitability assessments
EV2	Frequency of burning crop residue
EV3	Organic fertilizer application rate as recommended
EV4	Anorganic fertilizer application rate as recommended
EV5	Crop rotation rates
EV6	Weed management rates

EV7	Pesticide application rate as recommended
EV8	Knowledge levels for water availability
EV9	Level of knowledge to supply the accurate volume of water
f_0	Dominant frequency
FE	Food estate
GMT	Generic mapping tools
H020	HVSR observation point number 20
H053	HVSR observation point number 53
ha	Hectares
HVSR	Horizontal to vertical spectral ratio
H/V	Horizontal over vertical
Hz	Hertz
i.e.	Id est (that is)
IS1	The availability level of financial institutions
IS2	Frequency of extension activities
IS3	Existence and activity level of farmer groups
IS4	Level of extension for land conversion
IS5	Frequency of conflicts in farmer groups
kg	Kilogram
km	Kilometer
LTA	Long-Term Average
m	Meter
M	Magnitude
MASW	Pearson correlation coefficient
MIFEE	Merauke Integrated Food and Energy Estate
MDS	Multidimensional Scaling
Mhl	Halang formation (lower member)
mm	Millimeters
MSA	Multiaspect sustainability analysis
Msc	Subang formation
Mw	Magnitude moment
m/s	Meter per second (velocity unit)
m^2	Meter square
mm/y	Millimeter per year
M005	MASW observation point number 05
M024	MASW observation point number 24
MSPAC	Modified spatial auto-correlation
MR1	Number of marketing institutions buying the harvest
MR2	Promotional activities to sell the harvest
MR3	Level of knowledge about the importance of having a reasonable selling price
MR4	The presence of a buyer-seller linkage.
MR5	Knowledge level of selling crops to intermediate agents
N	North
NN	Neural Network
Pk	Kaliwangu formation
Pt	Tjijalang formation
Ptl	Tjijalang formation with limestone
PSN	Proyek Strategis Nasional (National Strategy Projects)
Qa	Alluvium formation
Qmtl	Tjinambo formation with sandstone
Qmtu	Tjinambo formation with shale
Qvu	Undifferentiated old volcanic products
Qyu	Undifferentiated volcanic and pyroclastic sediments
R^2	Coefficient of determination
RAPFIST	Rapid appraisal for fisheries
RMS	Root mean square
s	Second
SC1	Level of completed education
SC2	Knowledge level of land tenure
SC3	Level of knowledge on land lease standards
SC4	Knowledge level of sustainable agriculture
SC5	Transport access to the field
SC6	Percentage share of farm income
SDGs	Sustainable development goals
SMEs	Small and medium enterprises
SPAC	Spatial auto-correlation
STA	Short-term average
S wave	Shear wave
SOM	Self-organizing maps
TC1	Frequency of accessing the internet for agricultural technology information
TC2	Level of awareness of the use of digital technology for price information
TC3	Adoption level of new technology
TC4	The relevancy level of agricultural technology to farmers' habits

TC5	The level of response to new technology by farmers
TC6	The level of compatibility of new technologies with farmers' capabilities
TC7	Level of availability of appropriate agricultural technology
ton/ha	Tonnes per hectares
Type 1	First type of neural network results
Type 2	Second type of neural network results
Type 3	Third type of neural network results
Type 4	Fourth type of neural network results
Vs	Shear wave velocity
Vs_{30}	Shear wave velocity at depth of 30 m

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