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Analyzing Key Indicators for Sustainable Pepper Farming in West Kalimantan, Indonesia Using MICMAC Methodology

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ABSTRACT

As a high-value commodity, pepper is currently facing pressures from output price volatility, high input costs, climate change, and low productivity. These challenges are leading to declining interest among farmers and threatening the sustainability of pepper farming. Thus far, farmers have been trying to cope with the existing conditions, but no study has specifically examined the indicators determining the sustainability of pepper farming. This research aims to analyze the key indicators for the sustainability of pepper farming. The study was conducted in West Kalimantan, where 180 pepper farmers and 11 key informants participated. The MICMAC method was used as the analytical tool. The analysis results indicate that the sustainability of pepper farming is significantly influenced by the following indicators: output price, weeds and plant diseases, climate change, agricultural extension services, high-quality seeds, and input costs. These six indicators can disrupt the pepper farming system in the short and long term. Climate change, low production, and soil fertility threaten pepper farming. The study also found that farmer motivation is the most affected indicator in the long-term perspective and tends to decline. Policy implications highlight the need for government and stakeholder involvement in stabilizing pepper prices, ensuring affordable fertilizers, using high-quality varieties, and enhancing informal farmer education through extension activities and technical training in pepper cultivation. This research helps group key indicators that can facilitate decision-making to improve the sustainability of pepper farming businesses. This research provides a reference for using the MICMAC method to determine business sustainability indicators in the agricultural sector.

1. INTRODUCTION

Pepper commodity is vital in supporting Indonesia's economy by significantly contributing to foreign exchange earnings, job creation, and improving farmers' welfare. In 2020, Indonesia's pepper exports reached US$160.388 million, with an export volume of 58,378 tons, highlighting the importance of this commodity in the national economic context [1]. The development of pepper farming faces problems from several complex and interrelated factors. One of the main issues is the significant fluctuation in output prices, which negatively impacts farmers' income. These fluctuations are caused by global market factors, such as changing world demand and supply and unstable international trade policies. Indonesian statistical data shows a downward trend in pepper prices of 7% per year between 2015 and 2021. During this period, pepper prices peaked in July 2015 and have since declined, reaching their lowest point in March 2020. These unstable and generally low prices lead to decreased household income and a lack of motivation in farming activities.

In addition to price fluctuations, declining productivity is a severe concern in pepper farming. Factors such as climate change, irregular rainfall, and unpredictable seasonal patterns can disrupt pepper's growth and harvest processes. Climate change also triggers pest and plant disease attacks, which decrease productivity and farm income [2, 3]. Root rot is pepper plants' primary disease [4-7]. Traditional cultivation techniques, local varieties, and minimal fertilizer application are also suspected as causes of decreased productivity [2, 8, 9]. The decline in pepper productivity in Indonesia between 2014 and 2020 reached 2.29% yearly. During this period, pepper productivity hit its lowest point at 789 kg/ha in 2018 [1].

One of the pepper production centres experiencing productivity declines is in West Kalimantan. Pepper farming in West Kalimantan, managed by smallholder households, covers 13,203 hectares and produces 6,480 tons [1]. The complexity of pepper farming issues has led to decreased farming motivation, with some farmers abandoning pepper farming and switching to other commodities [10]. The decline in productivity and farmer motivation can result in economic instability and reduced household welfare, ultimately threatening the sustainability of pepper farming in West Kalimantan. Comprehensive and coordinated measures are needed to address these challenges and ensure the sustainability of pepper farming. These include improving agricultural productivity by implementing more efficient and sustainable farming practices, providing farmer assistance in facing challenges, providing better government policy support, and enhancing farmer access to technology and markets.

Farm sustainability is crucial for maintaining economic, social, and environmental viability. Factors affecting the sustainability of farming, such as natural resource management, agricultural technology, extension services, and market access, also need to be considered and improved. Collaboration between the government and relevant stakeholders is essential to create a supportive environment for sustainable agriculture.

Several studies on agricultural sustainability with various analysis methods, namely: 1) MICMAC method on rice farming [11], sugar agribusiness [12], duck farming [13], and mango farming [14]; 2) frontier efficiency benchmarks in general livestock farming [15]; and 3) MDS method in coffee farming [16]. This research was built by adopting the MICMAC method to identify indicators of pepper farming sustainability. The focus on pepper farming is considering the limited research on sustainability in pepper farming, some of which focuses only on the concepts of natural farming [17] and contemporary agriculture [18].

This study is novel in examining the factors determining the sustainability of pepper farming in both the short and long term. Additionally, new indicators such as Plant Age and Non-Farm Income are included. Plant age is essential to include as an indicator of sustainability, considering that pepper is an annual plant with a productive age of up to 25 years [19]. Older pepper plants will experience a decline in production, while young plants need time to reach their productive period. This difference will affect productivity and, in the long term, will impact the sustainability of pepper farming. Non-agricultural income is considered an essential indicator in the sustainability of pepper farming because it contributes to income stability, especially when there is a decline in productivity, volatility in output prices, and an increase in input prices. This study's results enable the development of more effective strategies and policies to support the sustainability of pepper farming.

2. MATERIALS AND METHODS

2.1 Study area

The research location was purposively selected in the Province of West Kalimantan, considering it as one of the main pepper-producing centres in Indonesia, with the most significant area and production in Kalimantan Island [1]. The chosen regencies were Bengkayang, Sanggau, and Sambas. Each regency selected one subdistrict: Seluas in Bengkayang, Sekayam in Sanggau, and Galing in Sambas (Figure 1). Subsequently, each subdistrict's central production villages selected were Sahan, Bungkang, and Ratu Sepudak. Data was collected using participatory methods with semi-structured and in-depth interviews in two ways. First, Focus Group Discussions (FGD) were held with key informants relevant to understanding the on-farm and off-farm issues of pepper farming. The key informants included representatives from the West Kalimantan Provincial Estate Crops Office, agricultural extension workers, village heads, and farmer group representatives, with 11 participants attending the FGD. Second, semi-structured interviews were conducted with farmers to collect data on farmer characteristics, current issues, and other aspects related to the research. The sample consisted of 180 pepper farmers, with the sample criteria being farmers with productive pepper plants. The selection of all participants or respondents was intentional, considering communication ability, respondent characteristics, and the information sought. The research was conducted from October 2022 to May 2023.

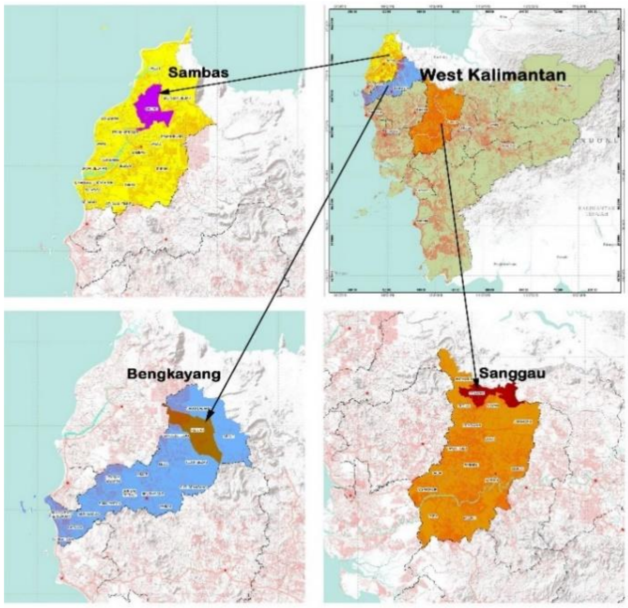


Figure 1. Map area

2.2 Data analysis

Data analysis used the MICMAC method (Matrix of Cross Impact Multiplications Applied to a Classification), developed by Godet [20]. MICMAC has been suggested for continuous analysis in various cases [21, 22]. The MICMAC method has advantages in identifying relationships between variables that influence complex systems and understanding variables in depth. MICMAC is often used in decision-making because it can map the relationships between variables. MICMAC also makes a model that enables the review, analysis, and planning of real (dynamic) scenarios [23]. The biases and limitations of this study are sample limitations or bias in expert judgment, which can influence the interpretation of research results. MICMAC analysis relies on analytical thinking through systematic problem-solving. In this research, the MICMAC framework is depicted in Figure 2 as follows:

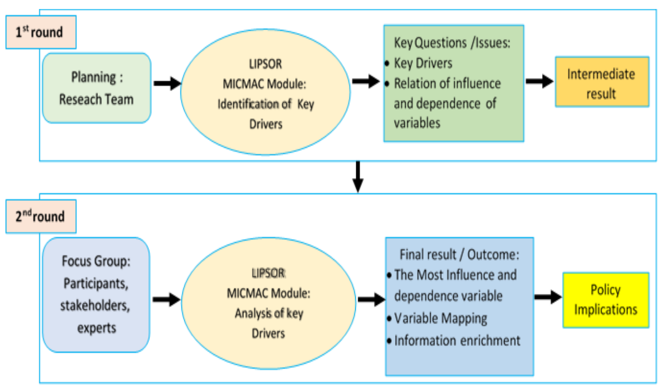


Figure 2. MICMAC framework
Source: Adoption and modification from Stratigea and Papadopoulou [24]

The steps of the MICMAC method include identifying sustainability indicators and identifying issues or questions about key drivers and relationships between indicators. The next step is conducted through FGDs, followed by data processing and analysis. Data were processed using MICMAC software developed by LIPSOR [25-27].

Determining short-term sustainability in MICMAC analysis uses the Matrix Direct Influence (MDI). In this analysis, each indicator is grouped into four quadrants based on their dependency and influence: influence variables (quadrant I), relay variables (quadrant II), depending variables (quadrant III), and excluded variables (quadrant IV), as shown in Figure 3, consisting of four quadrants.

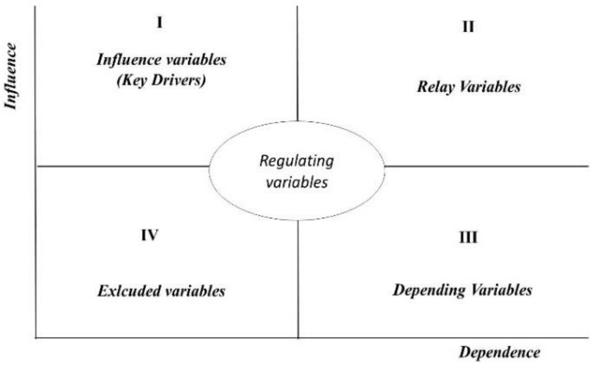


Figure 3. Variable mapping in MICMAC
Source: Studies [14, 25]

Quadrant I (influence variables) includes highly influential variables with low dependency, making them essential elements that can act as key factors. Quadrant II (relay variables) includes influential but highly dependent variables, indicating system instability. Any changes in these variables have significant consequences on other variables. Quadrant III (depending variable) includes variables with high dependency but low influence. These variables are quite sensitive to changes in influence variables and relay variables. Quadrant IV (excluded variables) includes variables with low influence and dependency, thus neither stopping nor benefiting from the system.

The MDI matrix, illustrating the relationships between variables, is filled by quantifying the relationships on a scale of 0 to 3 and P as follows [20]:

0=non-existent influence
1=weak influence
2=moderate influence
3=strong influence
P=potential influence

The relationships between variables in the MDI matrix in MICMAC are formulated in a cross-matrix and presented in Table 1.

Next, the influence of dependency or sustainability of indicators in the long term is analyzed using the Matrix of Indirect Influence (MII). MICMAC analysis helps to rank each indicator based on its level of influence and dependency on other indicators, both in the short and long term.

Table 1. Inter-variable relationships in MICMAC

Variable	Var 1	Var 2	Var 3...	Var n	Influence (Y-Axis)
Var 1	0	(V 1,2)	(V 1,3)...	(V 1,n)	$\sum_{j=1}^{n} Var_1, j$
Var 2	(V 2,1)	0			
Var 3			0		
.	.				
.	.				
.	.				
Var n	(V n,1)			0	
Dependence (X-Axis)	$\sum_{i=1}^{n} Var_i, 1$			....	

Source: Studies [25, 28]

3. RESULTS AND DISCUSSIONS

3.1 Determining indicators of sustainability

The factors influencing sustainability in this study are classified into four dimensions: economic, social, ecological, and technological. The FGD process generated 28 indicators related to the sustainability of pepper farming in West Kalimantan, as presented in Table 2. Initially, the FGD stage produced 32 indicators, but through discussions, some were deemed irrelevant, and others were merged because they fell within the same scope. The merged indicators include: 1) herbicide and pesticide use, 2) weeds and plant diseases, and 3) farmer education and experience. The “distance to farm” indicator was disregarded as it was considered less relevant; pepper farms are typically located near farmers’ residences. Additionally, this research introduces new indicators such as plant age and non-farm income.

Table 2. Determining indicators of sustainability

No.	Indicators	Reference	CODE	Dimension
1	Output Price	[16, 28, 29]	Outp.Price	economic
2	Input Price	[12, 28, 29]	Inpt.Price	economic
3	Production	[12, 16, 29-31]	Production	economic
4	Farm Size	[16, 30, 32-35]	Farm Size	economic
5	Non Farm Income	[36]	NonFarmInc	economic
6	Market availability	[12, 16, 28]	MarketAv.	economic
7	Capital	[14, 31, 32]	Capital	economic
8	Off Farm Income	[32, 37]	OffFarmInc	economic

9	Infrastructure	[12, 16, 28, 32]	Infrastruc	economic
10	Farm Tenure	[37]	Ownership	social
11	Education and Experience	[32, 35, 38-40]	Edu&Exper	social
12	Family Labor	[32, 38, 39]	FamLabor	social
13	Farmer’s Perception	[41]	Perception	social
14	Farmer’s motivation	[28, 39, 42, 43]	Motivaton	social
15	Farmer’s Group	[11, 28, 39]	F.Group	social
16	Extension	[16]	Extension	social
17	Anorganic fertilizer	[12, 29, 30, 32, 33]	AnOrganicF	ecology
18	organic fertilizer	[12, 29, 44]	Organic.F	ecology
19	Herbicide and fungicide	[29, 30, 32, 33]	Her&fungi	ecology
20	Climate Change	[12, 16, 31, 45]	Climate	ecology
21	Soil Fertility	[11, 29]	SoilFert.	ecology
22	Crop diversification	[12, 32, 46]	CropDiv.	ecology
23	Weeds and plant diseases	[16, 46]	Weeds&Dis	ecology
24	Plant Age	[47]	PepperAge	ecology
25	Superior Variety	[18, 48]	SuperVar.	technology
26	Seed availability	[16, 28]	SeedAvai.	technology
27	Tillage	[34, 35]	Tillage	technology
28	Market’s Information Acces	[13, 14, 18, 30]	MarktInf.	technology

Source: From various literature and Focus Group Discussions

	1 : Outp.Price	2 : Inpt.Price	3 : Production	4 : Farm Size	5 : NonFarmInc	6 : MarketAv.	7 : Capital	8 : OffFarmInc	9 : Infrastruc	10 : Ownership	11 : Edu&Exper	12 : Fam.Labor	13 : Perception	14 : Motivation	15 : F.Group	16 : Extension	17 : AnOrganicF	18 : Organic.F	19 : Herb&Fungi	20 : Climate	21 : SoilFert.	22 : CropDiv.	23 : Weeds&Dis.	24 : PepperAge	25 : SuperVar.	26 : SeedAvai	27 : Tillage	28 : MarketInf.
1 : Outp.Price	0	2	3	3	2	3	3	3	3	2	0	1	3	3	0	3	3	3	3	0	3	3	3	0	3	3	2	3
2 : Inpt.Price	3	0	3	3	0	0	3	0	0	1	2	3	3	3	0	3	3	3	3	3	2	3	3	0	2	2	1	2
3 : Production	0	1	0	0	1	3	2	2	0	0	0	2	2	2	0	2	0	2	0	0	2	1	2	0	0	0	0	1
4 : Farm Size	1	1	3	0	2	2	2	2	2	2	0	2	2	2	0	3	3	3	3	2	2	3	2	2	3	3	2	0
5 : NonFarmInc	0	0	1	0	0	0	2	2	0	1	0	1	1	3	0	0	0	1	1	0	1	0	0	2	0	1	0	1
6 : MarketAv.	2	1	1	1	0	0	2	2	0	0	0	0	1	1	2	0	0	0	0	0	1	0	2	0	0	1	0	3
7 : Capital	1	0	2	1	0	0	0	3	3	2	0	1	2	3	3	1	1	2	2	0	3	2	2	0	1	1	1	3
8 : OffFarmInc	0	0	3	3	0	0	3	0	1	1	0	0	3	3	2	1	1	2	2	0	3	0	2	1	0	1	1	2
9 : Infrastruc	2	3	1	0	0	2	2	2	0	0	0	0	3	3	0	1	1	1	1	0	1	0	0	0	1	1	0	3
10 : Ownership	0	0	1	0	0	0	2	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11 : Edu&Exper	0	0	3	1	2	0	2	2	0	0	0	1	2	3	1	1	3	3	3	1	1	1	3	1	1	0	1	3
12 : Fam.Labor	2	2	3	3	3	0	3	3	1	0	3	0	3	3	3	1	1	3	3	2	2	0	0	0	1	1	1	0
13 : Perception	0	0	2	1	0	2	2	1	0	0	2	0	0	3	1	1	1	1	1	1	3	1	0	0	0	1	0	2
14 : Motivation	0	0	1	1	2	1	2	2	0	1	2	0	3	0	3	1	1	1	1	0	3	2	0	0	0	1	1	1
15 : F.Group	0	1	1	0	0	2	1	1	0	0	3	1	2	2	0	1	1	1	1	0	2	1	2	0	2	1	0	2
16 : Extension	2	3	3	2	1	2	3	1	3	0	0	3	2	3	0	0	2	3	1	3	3	2	3	3	3	3	1	3
17 : AnOrganicF	3	3	3	2	0	0	3	0	3	0	0	3	2	1	0	2	0	1	3	3	2	1	3	0	2	2	1	3
18 : Organic.F	1	3	3	1	1	0	3	0	3	0	0	3	3	3	2	2	2	0	1	3	3	3	3	0	3	3	1	3
19 : Herb&Fungi	0	0	3	1	0	3	0	3	3	0	0	0	3	3	0	2	2	2	0	3	3	3	0	0	2	2	2	2
20 : Climate	3	3	3	3	3	3	3	3	3	3	0	1	3	3	0	2	1	1	1	0	3	3	3	0	3	3	3	1
21 : SoilFert.	1	1	3	1	3	3	3	2	2	0	0	2	3	3	2	2	1	2	1	1	0	1	0	0	1	1	0	0
22 : CropDiv.	2	0	2	1	3	2	3	3	2	2	0	2	3	3	2	2	0	3	1	0	3	0	0	0	2	1	2	2
23 : Weeds&Dis.	2	3	3	3	3	3	3	3	3	3	2	1	3	1	3	1	1	1	3	0	2	3	0	2	2	3	3	2
24 : PepperAge	0	0	3	3	2	0	3	3	0	0	0	3	3	3	0	2	2	2	2	3	3	3	3	0	1	1	0	0
25 : SuperVar.	3	3	3	3	2	3	3	3	2	0	0	0	3	3	3	2	2	0	0	0	3	3	3	3	0	2	3	3
26 : SeedAvai	3	1	2	2	1	2	3	3	2	0	0	0	3	3	3	2	2	0	0	2	3	1	2	3	3	0	0	3
27 : Tillage	0	0	1	1	0	0	1	0	1	0	0	0	0	1	0	1	1	0	0	0	1	1	1	0	0	0	0	0
28 : MarketInf.	3	1	2	0	1	3	2	1	3	0	1	0	2	3	3	1	1	2	1	0	3	1	0	0	1	1	0	0

Figure 4. Matrix of indirect influence on MICMAC

3.2 Determining indicators for the sustainability of pepper farming in the short-term

The mapping of 28 interdependent indicators is depicted as a Matrix of Direct Influence, using scores ranging from 0 to 3 and P. Scores of 1, 2, and 3 denote weak, moderate, and strong influence, respectively. In contrast, a score of 0 indicates no direct influence of the indicator on itself or other indicators. Figure 4 presents the Matrix of Direct Influence for the sustainability of pepper farming.

The overall assessment of the matrix can be seen through its stability. A matrix is considered good if it achieves a stability range of 100%. The matrix in Figure 4 exhibits good stability, as after two iterations, it achieved 100% stability for influence indicators and 99% for dependency indicators. More detailed information regarding matrix stability is presented in Table 3.

Table 3. Matrix stability

Iteration	Influence	Dependent
1	101%	100%
2	99%	101%
3	100%	100%

Source: Primary data analysis (2023)

The next stage involves classifying the indicators into four quadrants, as depicted in Figure 5. In the Matrix of Direct

Influence, the higher the influence of an indicator, the higher its position on the matrix; conversely, indicators positioned lower depict lower levels of influence. Indicators with the highest dependency levels are positioned furthest to the right, while those on the far left represent the lowest levels of dependency.

Figure 5 illustrates four groups of variables, proceeding clockwise: Influence Variables (Quadrant I), Relay Variables (Quadrant II), Depending Variables (Quadrant III), and Exclude Variables (Quadrant IV). Within each dimension, Influence Variables are represented by output price, input price, and land area (economic); climate, plant age, inorganic fertilizers, and pesticides & medications (ecological); extension services, education, labour availability (social); and superior seedlings and seed availability (technological). Five key variables stand out based on their positions indicating influence levels: output price, extension services, climate, superior seedlings, and input price.

The output price is the aspect with the strongest influence on the overall sustainability of pepper farming. Output price and production volume affect farm income [49, 50]. Decreased output prices lead to reduced household income, impacting purchasing power, quality of life, and the ability to meet basic needs. Price variability adversely affects income and household food security [51], potentially causing financial and social instability within farming communities. Price fluctuations also influence farmers' decisions regarding investment, resource allocation, and adoption of new technologies. Output price is considered the most sensitive attribute in assessing farm sustainability [16]. Changes in output prices can trigger production reactions that lead to long-term instability [29]. A good understanding of price dynamics can help farmers mitigate the impacts of price fluctuations and enhance farm sustainability.

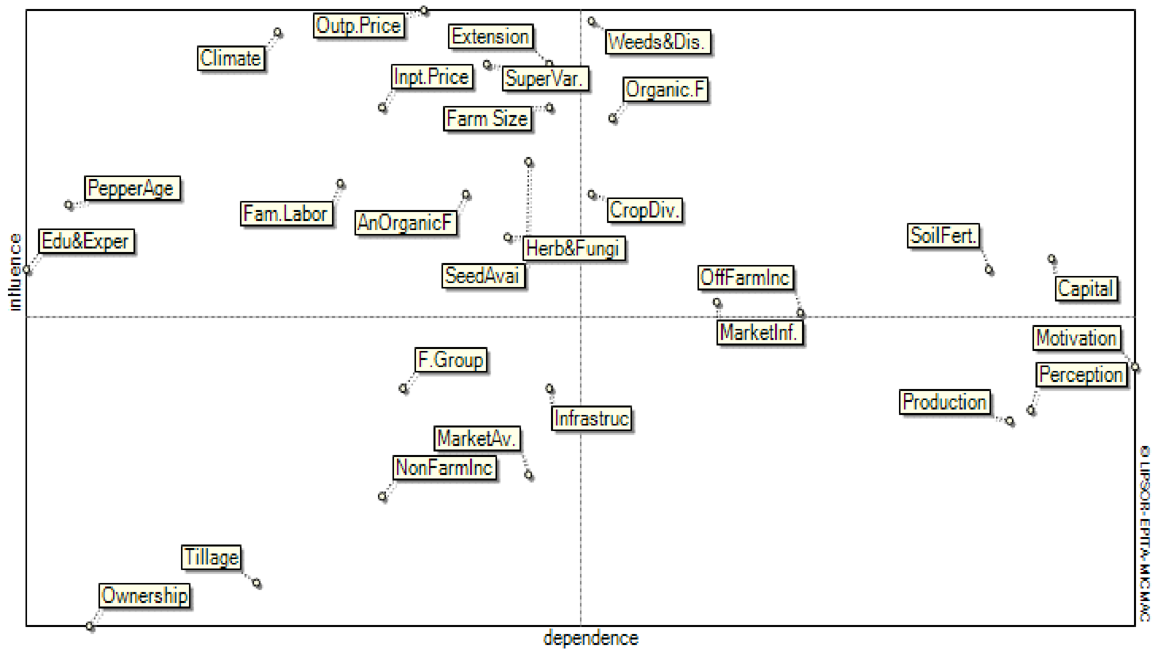


Figure 5. Direct influence/dependence map

Extension services are crucial in improving farm sustainability by providing farmers with the necessary knowledge, skills, and support to adopt sustainable and efficient agricultural practices [51, 52]. Extension services facilitate farmers' access to up-to-date information, improve resource use efficiency, and promote technology adoption [53]. They also help farmers understand agricultural risks, including climate change, plant diseases, and market fluctuations. Through extension services, farmers can learn to collaborate within farmer groups or cooperatives, share resources and knowledge, and develop collective strategies to enhance farm sustainability. Access to agricultural extension and consultation can improve productivity [54, 55] and farm income [56]. A study by Yusuf et al. [16] also highlights the importance of extension services in supporting plantation sustainability.

Climate change's impact on pepper farming sustainability can be significant. Climate variability, characterized by fluctuations in rainfall patterns, temperature increases, changing seasons, and water availability, disrupts the pepper growth cycle and stresses plants, leading to decreased productivity [57]. Previous studies provide evidence of climate change's impact on farming sustainability [16]. A study by Evizal and Prasmatiwi [58] emphasizes climate change adaptation's importance in maintaining pepper farming sustainability through mixed cropping systems and plant rejuvenation.

Using superior seedlings can significantly contribute to the sustainability of pepper farming by enhancing productivity, quality, resource use efficiency, climate resilience, and farmer welfare. The use of Bengkayang pepper as a superior variety in West Kalimantan is claimed to possess superior traits such as disease resistance, high productivity, and good adaptability [59]. Superior pepper varieties are generally more plant disease tolerant, potentially increasing productivity [19]. A study by Wossen et al. [51] demonstrates that adopting superior seedlings effectively reduces climate change and price variability impacts.

Input prices significantly influence farm sustainability by affecting production costs, accessibility, input quality, dependency, and technological innovation. Rising input prices pressure farmers to use low-quality inputs or inefficient practices, which can reduce long-term productivity and sustainability. High input prices can hinder technology adoption due to the initial investment costs borne by farmers. Changes in input prices can trigger production reactions that lead to long-term instability [29].

3.2.1 Relay variable

Indicators in this quadrant depict instability within the pepper farming system. Based on their positions, the three indicators with the strongest influence are plant pest and disease attacks, organic fertilizer use, and other commodities.

Plant pest and disease attacks significantly impact the sustainability of pepper farming by causing crop damage, reduced productivity, and economic losses. The primary disease affecting pepper plants is root rot, leading to decreased productivity and even plant death [4, 7, 60]. The impact of plant pest and disease attacks on farming activities and the adoption of sustainable agricultural practices has been reported in previous studies [61-63].

Using organic fertilizers affects farm sustainability by increasing organic matter content and soil nutrient levels, thus enhancing soil fertility. Organic fertilizers contain essential nutrients and beneficial microbes for plant growth, and they are environmentally friendly. Organic fertilizers also help reduce dependence on chemical fertilizers, which are often expensive and have negative environmental and health impacts, indicating that using organic fertilizers is a form of climate change adaptation in white pepper farming. Organic fertilizers can serve as alternatives to chemical fertilizers, reducing their use [64]. The presence of other commodities influences sustainability by aiding farmers in income diversification. It can reduce the financial risks associated with dependence on a single crop, such as pepper. Crop diversification enhances farmers' economic resilience and overall farm sustainability.

3.2.2 Depending variable

Indicators in this quadrant include motivation, production, and farmer perception. Motivation is the aspect with the highest dependency level in the entire pepper farming system. High motivation strengthens farmers' commitment to sustainable farming practices and encourages innovation [42, 43]. High motivation enhances farmers' resilience in facing climate change and market fluctuations, enabling them to adapt creatively. Furthermore, motivation for social and economic well-being motivates farmers to maintain farm sustainability, thereby improving their quality of life.

Stable production in farming significantly impacts sustainability, particularly in increasing farm income, farmer welfare, and local economic development. Stable and consistent production makes farmer income more predictable and stable over time, providing certainty for planning expenditures and investments. Unstable production can affect farm sustainability [29]. Production and productivity are indicators of the economic subsystem in sustainable agricultural development [30].

Positive farmer perception of farming has the potential to drive positive changes in agricultural and environmental practices, thereby creating farm sustainability. Farmers with positive perceptions are more likely to adopt sustainable farming practices. Farmers who recognize the importance of maintaining soil fertility, ecosystem balance, and natural resource sustainability tend to use organic farming techniques, soil and water conservation practices, and environmentally friendly fertilizers and pesticides.

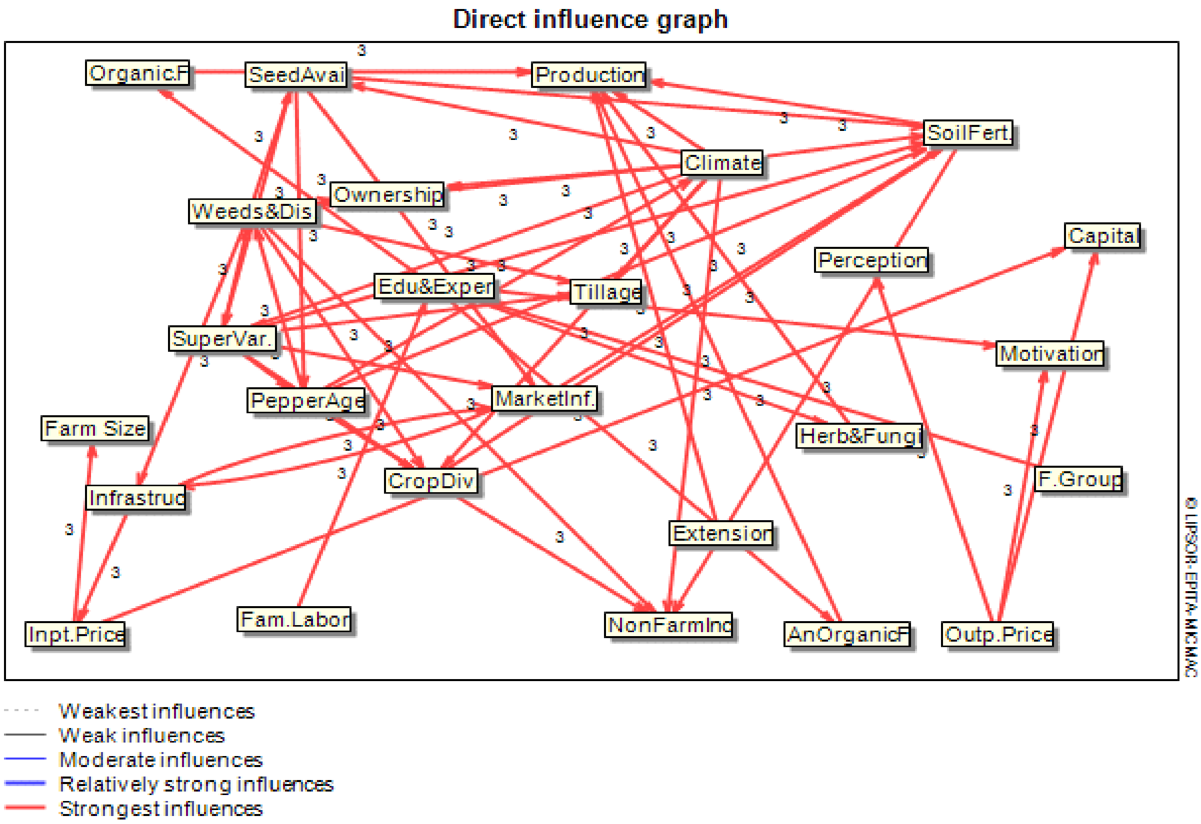


Figure 6. Direct influence/dependence graph

3.2.3 Excluded variable

Indicators in this quadrant include land status, tillage systems, off-farm income, markets, farmer group presence, and supporting facilities and infrastructure. Variables in this quadrant do not stop the functioning of the pepper farming system. Land status has the lowest dependency level in the entire farming system. It means that land status minimally influences farmers' decisions in farming practices because the land is privately owned rather than leased, giving farmers greater decision-making freedom.

Next, the analysis identifies the relationships of influence-dependency among indicators of black pepper farming, presented graphically in Figure 6. The thick red lines indicate indicators with very strong influence-dependency on others. The climate indicator stands out as having the most influence on other indicators. In the graph, the climate indicator influences nine other indicators: production, soil fertility, other commodities, superior seeds, soil preparation, seed availability, land status, off-farm income, and pest and disease management. It signifies that climate significantly impacts the sustainability of black pepper farming. The agricultural sector heavily relies on resources sensitive to climate change [65, 66].

Furthermore, the production indicator shows the highest dependency on other indicators. It depends on six other indicators: soil fertility, climate, organic fertilizers, inorganic fertilizers, education, and extension services. Soil fertility and land suitability are crucial for increasing black pepper production. Land with limiting factors such as nutrient availability and drainage can be improved through applications like lime, organic materials, fertilizers, and irrigation [18]. Soil fertility can also be enhanced by using Trichoderma spp. as a biological agent to degrade organic matter, thus increasing nutrient availability for black pepper growth [60, 64]. Other factors influencing black pepper production include climate change [57, 58] and the use of organic and chemical fertilizers [64, 67]. Education and extension services also play a role in enhancing agricultural productivity through the adoption of modern technologies [53, 56, 68, 69].

3.3 Determining indicators for the sustainability of pepper farming in the long-term

The sustainability determinants of black pepper farming are reassessed to explain indirect influences. Each indicator is reclassified into four quadrants. Some indicators have changed positions, as depicted in Figure 7.

The indicators that changed positions are the indicators of plant diseases and the presence of other commodities, moving from the relay variable quadrant to the influence variable quadrant. It indicates that these two variables could threaten the sustainability of black pepper farming. Plant diseases such as foot root disease have seriously threatened pepper farmers nationwide. This disease significantly reduces productivity, with mortality rates of pepper trees reaching 100% in some cases [6]. Meanwhile, other plantation commodities such as oil palm and rubber can serve as alternative commodities for pepper farmers.

Additionally, other alternative business indicators have moved from the relay variable quadrant to the dependent variable quadrant, and the market indicator, previously in the exclude variable quadrant, has moved into the dependent variable quadrant.

Based on Figure 8, the numbers on each arrow depict the degree of influence-dependency obtained from Boolean matrix iterations. In this graph of indirect influence, there are three thick red lines: extension services, output prices, and input prices, with values of 234,414, 198,281, and 228,381, respectively. These red lines have the highest ratings concerning farmer motivation. Figure 8 indicates that farmer motivation is the most influential indicator within the entire black pepper farming system, both in the short and long term. Extension services, output prices, and input prices influence farmer motivation.

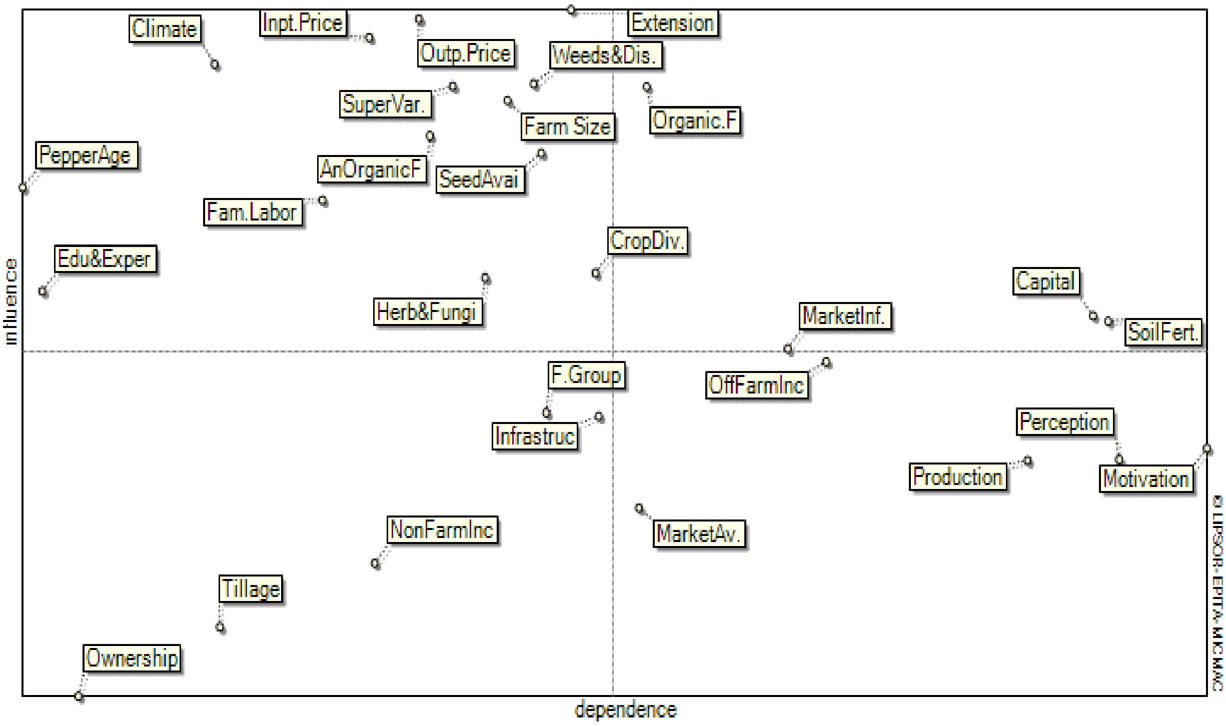


Figure 7. Indirect influence/dependence map

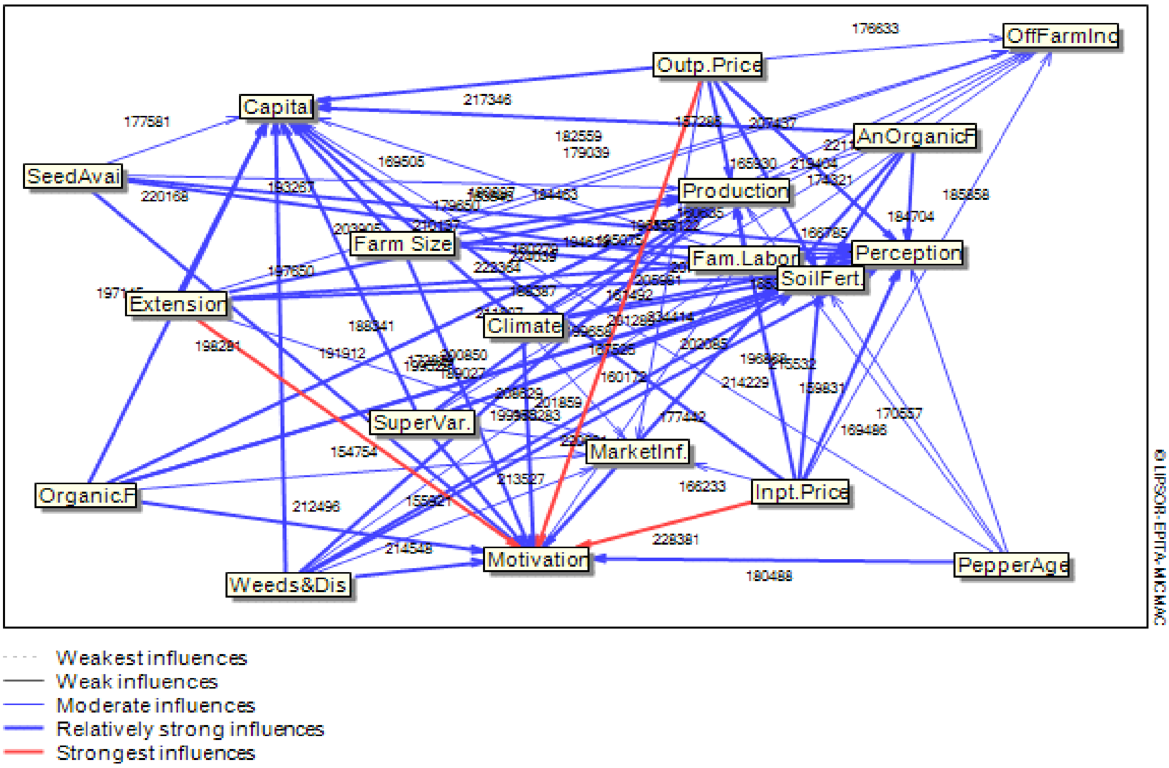
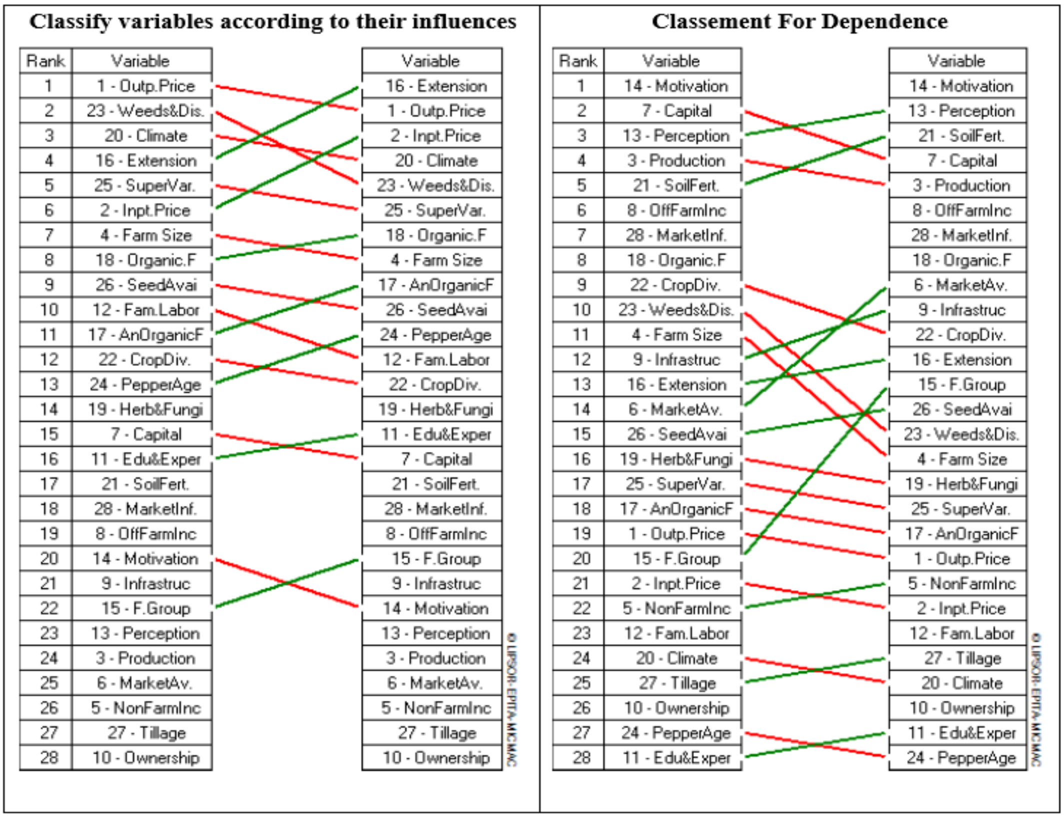


Figure 8. Indirect influence graph



Classify variables according to their influences

Rank	Variable	Variable
1	1 - Outp.Price	16 - Extension
2	23 - Weeds&Dis.	1 - Outp.Price
3	20 - Climate	2 - Inpt.Price
4	16 - Extension	20 - Climate
5	25 - SuperVar.	23 - Weeds&Dis.
6	2 - Inpt.Price	25 - SuperVar.
7	4 - Farm Size	18 - Organic.F
8	18 - Organic.F	4 - Farm Size
9	26 - SeedAvai	17 - AnOrganicF
10	12 - Fam.Labor	26 - SeedAvai
11	17 - AnOrganicF	24 - PepperAge
12	22 - CropDiv.	12 - Fam.Labor
13	24 - PepperAge	22 - CropDiv.
14	19 - Herb&Fungi	19 - Herb&Fungi
15	7 - Capital	11 - Edu&Exper
16	11 - Edu&Exper	7 - Capital
17	21 - SoilFert.	21 - SoilFert.
18	28 - MarketInf.	28 - MarketInf.
19	8 - OffFarmInc	8 - OffFarmInc
20	14 - Motivation	15 - F.Group
21	9 - Infrastruc	9 - Infrastruc
22	15 - F.Group	14 - Motivation
23	13 - Perception	13 - Perception
24	3 - Production	3 - Production
25	6 - MarketAv.	6 - MarketAv.
26	5 - NonFarmInc	5 - NonFarmInc
27	27 - Tillage	27 - Tillage
28	10 - Ownership	10 - Ownership

Classement For Dependence

Rank	Variable	Variable
1	14 - Motivation	14 - Motivation
2	7 - Capital	13 - Perception
3	13 - Perception	21 - SoilFert.
4	3 - Production	7 - Capital
5	21 - SoilFert.	3 - Production
6	8 - OffFarmInc	8 - OffFarmInc
7	28 - MarketInf.	28 - MarketInf.
8	18 - Organic.F	18 - Organic.F
9	22 - CropDiv.	6 - MarketAv.
10	23 - Weeds&Dis.	9 - Infrastruc
11	4 - Farm Size	22 - CropDiv.
12	9 - Infrastruc	16 - Extension
13	16 - Extension	15 - F.Group
14	6 - MarketAv.	26 - SeedAvai
15	26 - SeedAvai	23 - Weeds&Dis.
16	19 - Herb&Fungi	4 - Farm Size
17	25 - SuperVar.	19 - Herb&Fungi
18	17 - AnOrganicF	25 - SuperVar.
19	1 - Outp.Price	17 - AnOrganicF
20	15 - F.Group	1 - Outp.Price
21	2 - Inpt.Price	5 - NonFarmInc
22	5 - NonFarmInc	2 - Inpt.Price
23	12 - Fam.Labor	12 - Fam.Labor
24	20 - Climate	27 - Tillage
25	27 - Tillage	20 - Climate
26	10 - Ownership	10 - Ownership
27	24 - PepperAge	11 - Edu&Exper
28	11 - Edu&Exper	24 - PepperAge

Figure 9. Classify variables according to their influences and classment for dependence

Effective extension services can enhance farmers' knowledge, attitudes, and skills [55]. It can encourage them to adopt new techniques and provide motivation to improve their agricultural performance continually. Well-directed extension services are crucial in boosting farmer motivation to achieve sustainability in agriculture. Access to extension services positively impacts technology adoption and household welfare [51]. Access to agricultural extension services and consultations enhances farm productivity and income [53, 54].

Farmer motivation is heavily influenced by the prices of agricultural outputs they produce. High output prices can increase farmers' motivation to enhance production and deliver quality. Conversely, low output prices reduce farmers' motivation to expand their farming operations. Motivation is crucial in adopting sustainable agricultural practices [42, 43]. Farmer motivation can be influenced by economic conditions, farmer characteristics, social environment, and government roles [70].

Moreover, increases in input prices can also diminish farmers' motivation to expand their farming operations. Rising input prices can increase production costs and reduce potential profits [17]. Stable or declining input prices can motivate farmers to increase production and operational efficiency.

In the MICMAC analysis, Boolean iterations were also conducted to determine the changes in indicator order from the Matrix of Direct Influence (MDI) to the Matrix of Indirect Influence (MII). The higher the indicator's rank, the greater its influence and dependency, necessitating prioritization of indicators with the highest ranks. Changes in order from MDI to MII based on their influences are presented in Figure 9.

Based on their dependencies in Figure 9, sustainability determinants are re-ranked to assess long-term dependency levels. This result is presented in the right column of Figure 9. The indicators with the highest ranks in the MDI refer to the top five: farmer motivation, capital, perception, production, and soil fertility. The motivation indicator does not change as it remains the indicator with the highest dependency level both in the short and long term. Figure 9 also shows that the social and economic dimensions have the highest dependency levels in both the short and long terms.

The farmer motivation indicator is considered highly sensitive to the sustainability of black pepper farming because it influences several key factors in their agricultural practices [42, 43]. High motivation can drive farmers to adopt more sustainable farming practices, enhance productivity and efficiency, and tackle emerging challenges such as climate change or market fluctuations. Farmer motivation can be influenced by economic conditions, farmer characteristics, social environment and the role of government [70]. The complexity of pepper farming problems such as low output prices, high input prices and low production can reduce farmer motivation. In some cases, a decrease in motivation to cultivate pepper makes farmers abandon their farming or switch to other commodities [10].

Furthermore, the indicator of farmer group existence has shown the highest increase in position, moving from rank 20 to rank 15. It indicates that the dependency of the farmer group existence indicator on other indicators in the long term is increasing. Farmer groups enable collaboration and the exchange of knowledge, experience, and sustainable farming practices. It can enhance farmers' understanding of best practices and generate new, more integrated solutions to achieve sustainable farming [71].

Moreover, indicators like land area and plant diseases also experienced a significant decline. It suggests that the dependency of the land area and plant disease indicators on other indicators in the long term is decreasing. Land area and plant diseases are high-influence indicators because they directly impact agricultural productivity, natural resource availability, and farming sustainability. Increasing land area positively impacts net profit, technical efficiency, economic aspects, and farm labour [33]. Land area is one of the subsystem indicators in sustainable agricultural development [30].

Based on their influences on the left column in Figure 9 shows that six indicators have changed positions in the MII, referring to the top ranks: output price (economic dimension), plant diseases and climate (ecological dimension), extension services (social dimension), and superior seeds (technological dimension). The green indicates an increase in ranking, while red indicates a decrease. The indicators that experienced the most significant changes in the long term are extension services and input prices. Extension services rose from rank 4 in the short term to rank 1 in the long term. It indicates that effective extension services positively influence long-term sustainability. Effective extension services help farmers address agricultural issues and increase farm productivity and income [53, 54]. The government and policy makers are expected to be able to optimize agricultural extension programs that can provide information regarding efficient and environmentally friendly farming practices, the latest innovations in pepper farming, and information related to climate change and market analysis.

Furthermore, in the long term, there was also a significant increase in the indicator of input prices, which moved from rank 6 to rank 3. It suggests that increasing input prices can raise production costs, potentially reducing farmers' profitability and hindering their ability to invest in sustainable farming practices. Fluctuating input prices can lead to uncertainty in farm business planning, further impeding sustainability efforts. This requires the government to provide subsidies to farmers in the form of agricultural inputs such as fertilizer, pesticides, and agricultural tools.

Another finding from the top five ranks is that indicators like climate and plant diseases are expected to decline. It indicates that intensive extension services for farmers on good agricultural practices (GAP) can help them mitigate the impacts of climate and pest diseases over the long term. The government also needs to ensure that farmers have access to adequate technology and information so they can anticipate climate change and plant pest attacks.

4. CONCLUSIONS

The sustainability of pepper farming in West Kalimantan is determined by 28 indicators grouped into four dimensions: economic, social, ecological, and technological. The research results show that the sustainability of pepper farming is strongly influenced by six main indicators: output prices, weeds and plant diseases, climate change, extension, superior seeds, and input prices. These six indicators are very important because they can disrupt the pepper farming system in the short and long term. Other indicators, such as climate change, low production, and soil fertility, threaten pepper farming. Other factors, such as plant pests and competition from other commodities, are variables that can threaten the sustainability of farming businesses in the long term. Farmer motivation is also one of the most affected indicators and tends to decline in the long term.

The findings of this study underscore the importance of policy implications that support the development of extension programs, technology access, and input-output price stabilization to help farmers face challenges in pepper farming, such as plant diseases, climate change, and price fluctuations. In facing these challenges, farmers are expected to be able to adopt agricultural technology, use superior seeds that are resistant to disease and climate change, and participate actively in farmer groups. This activity is expected to increase farmers' capacity in managing risks and sustainable farming productivity while strengthening farmers' bargaining position to get better prices and expand market access.

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