Research Article

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Sustainability analysis and decision-making strategy for swamp buffalo (*Bubalus bubalis carabauesis*) conservation in Jambi Province, Indonesia

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Abstract: The objective of this study is to analyze the sustainability of swamp buffalo cultivation and develop decision-making strategies. Data were collected through focus group discussions with key informants in swamp buffalo cultivation and surveys of buffalo farmers in three regencies in Jambi Province. This study examines 37 attributes contained in four dimensions: ecological, economic, social, and technological dimensions. Data were analyzed using multidimensional scaling through the Rapid appraisal for buffalo technique and analytical hierarchy process (AHP) The results showed that the sustainability index of swamp buffalo cultivation in Sarolangun Regency was 59.39%, Batanghari 58.23%, and Tebo 55.93%. This study identified 12 leverage attributes obtained from 37 attributes that affect the sustainability of swamp buffalo, i.e., forage feed, agricultural waste, land use, agricultural infrastructure, land ownership, buffalo manure, buffalo ownership, livestock motivation, environmental impact, agricultural waste treatment, land processing, and post-harvest technology. Then, from the results of four-dimensional weighting with 12 attributes using AHP, there are 5 alternative strategies in decision making, namely, (1) build internet network infrastructure, (2) determine the number of livestock that can be raised in an area, (3) establish buffalo farming institutions, (4) prevent land use conflicts, and (5) increase farmer participation in raising buffalo livestock. This research provides input to policy makers to develop swamp buffalo cultivation by considering ecological, economic, social, and technological dimensions.

Keywords: sustainability, decision-making strategy, swamp buffalo

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1 Introduction

Indonesia has 17 Sustainable development goals (SDGs) programs. For implementation, the 17 SDGs are grouped into four pillars, namely, (1) the pillar of social development, (2) the pillar of economic development, (3) the pillar of environmental development, and (4) the pillar of legal development and governance. The implementation of SDGs is regulated through Presidential Regulation of the Republic of Indonesia Number 111 of 2022 concerning the achievement of SDGs. To fulfil the needs of animal protein and food security for the community, it can come from cows, buffalo, goats, sheep and poultry.

The livestock sector contributes greatly to the fulfillment of food security and animal protein needs, but the contribution and performance have not been optimal, including buffalo. In 2019, the buffalo population in Indonesia was 1,141,298 heads [1] and in 2022 it was 1,088,437 heads [2], while the buffalo population in Asia is around 98.16% in India and Pakistan [3,4],

In Indonesia, especially Jambi Province, the existence of buffalo cattle is one of the leading commodities needed by the community. Buffalo farming is able to provide employment, as a source of income and a source of food [5–7]. The need of buffalo cattle will increase on holidays, on traditional occasions, and wedding days. Buffalo cattle have the ability to adapt to the environment, such as swampland, lowland areas to mountainous areas [1,8,9]. Buffaloes are able to utilize low-quality feed, such as dry forage with high crude fiber and low nutrients, and give meat and milk [10–13]. In addition, buffalo feces are used as organic fertilizer for plants and easy management [11,14],

In Jambi Province, buffalo cultivation is mostly carried out in small-scale farming. The buffalo cattle population fluctuates every year. The buffalo cattle population in 2013, was 41,155 heads, and in 2023, it was as many as 45,721 heads. As for Sarolangun Regency, it was as many as 8,696 heads, Batanghari Regency 9,430 heads, and Tebo Regency, 10,820 heads. Buffalo meat production in Jambi Province until 2022 was 1783840.44 kg [2]. Meat production largely depends on the development of livestock populations. Meanwhile, buffalo populations are determined by the availability of feed, land, and management of buffalo cattle rearing [7]. The land used for buffalo grazing are being converted into oil palm plantations, thereby reducing the availability of forage for swamp ecosystems [5,14]. In 2013, the area for oil palm plantations in Jambi Province was 662,213 ha and in 2022, it increased to 1,099,191 ha [2].

Changes in land ecosystems cause climate change which has an impact on the availability of forage [15,16]. The results of the previous studies [9,17] stated that feed availability related to low productivity of female buffalo is the cause of the decline in swamp buffalo population. Other factors that cause the slow development of the swamp buffalo population are: the buffalo cattle business is still a part-time business with limited capital, farmers' knowledge and skills in cultivating buffalo cattle are lacking, land is limited, farmer participation in managing buffalo livestock is still low, and low use of livestock-based technology and information [15,16].

Currently, there has been a massive land use change in Jambi Province, this has caused the development of buffalo populations to be slow, especially for small-scale buffalo cultivation. This will affect the fulfillment of animal protein needs from buffalo livestock, which continues to increase along with the increasing population, this condition is important to be studied. According to the results of the research by Syarifuddin et al. [18], the traditional maintenance of buffalo livestock in Sekernan Subdistrict, Muaro Jambi regency, Jambi Province is less sustainable. Meanwhile, research by Rohaeni et al. [19] states that swamp buffalo farming in Hulu Sungai Utara and Hulu Sungai Selatan is quite sustainable, while in Hulu Sungai Tengah, it is less sustainable. Research on sustainability indices and continued with the preparation of decision-making strategies for swamp buffalo farms in Jambi Province, to our knowledge, is still very limited.

Research with the multidimensional scaling (MDS) technique through the Rapid appraisal for buffalo technique was carried out to obtain the sustainability index of an object and determine sensitive attributes. MDS research such as, beef cattle [20,21], dairy cattle [22,23], buffalo [18,24]. The analytical hierarchy process (AHP) is applied to make a decision.

Studies on sustainability status and decision-making strategies in swamp buffalo farming in Jambi Province are very important. This study emphasizes the application of a multi-criteria decision support system [25] based on AHP to make a decision in a sustainable buffalo livestock business. The purpose of the study was to obtain a sustainability index and develop decision-making strategies in buffalo farming (*Bubalus bubalis carabauesis*). The reason for using AHP is that previous research only obtained sensitive factors that affect sustainability and has not developed a decision-making strategy based on these sensitive factors. So, the novelty of this research will produce alternative strategies in sustainable swamp buffalo farming and provide valuable input for the government in decision making to formulate a policy and program to develop swamp buffalo productivity in Jambi Province.

2 Method

2.1 Areas of study

This research was conducted from August 2022 to July 2023 in three regencies in Jambi Province, namely, Sarolangun Regency (SD), Batanghari Regency (BD), and Tebo Regency (TD) with an area of 5935.894, 5935.516, and 6103.737 km^2 [2], respectively. The sites were selected with the following consideration: (1) is the area with the largest population of swamp buffalo in Jambi Province, (2) have high land use conversion for oil palm plantations, and (3) in accordance with the Regulation of the Minister of Agriculture Number 17 of 2020 concerning Increasing Production of Cattle and Buffalo Mainstay Commodities. The map of the research location is shown in Figure 1.

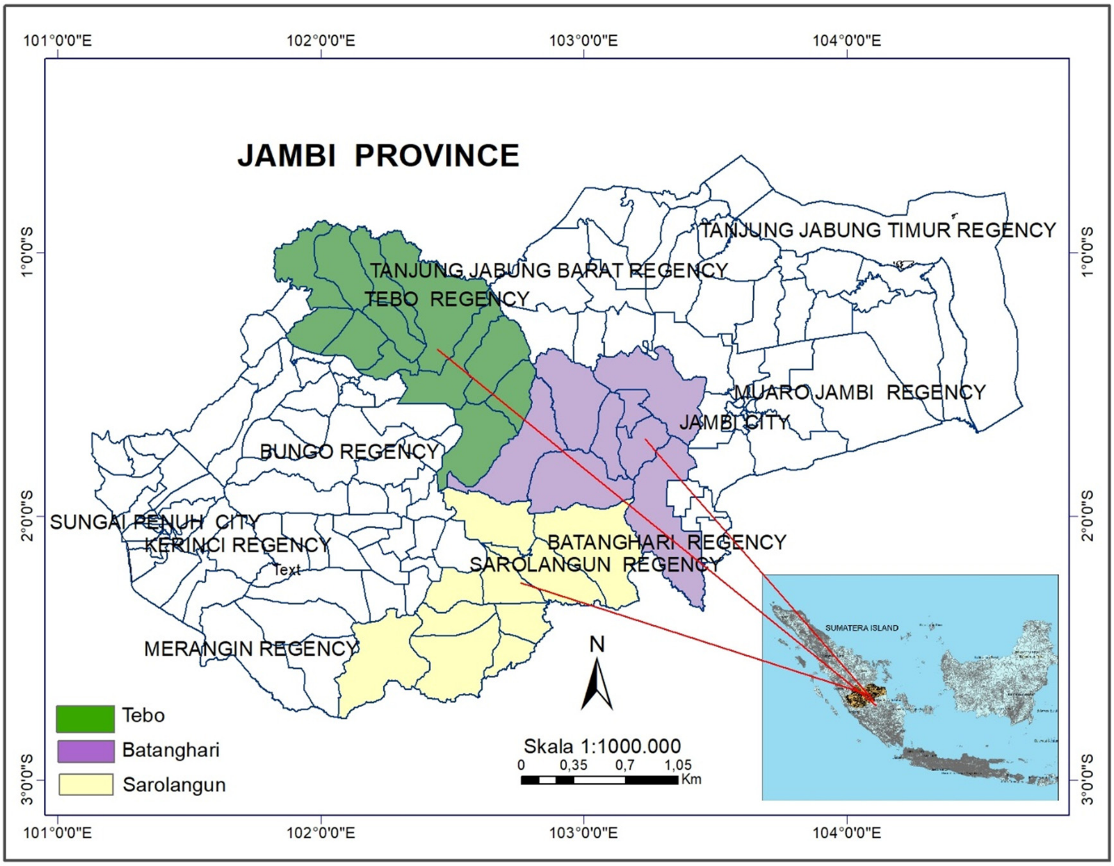

Figure 1: Map of the study area. Source: Map of Jambi Province (2023) obtained from Indonesian Earth Map (IEM), https://tanahair.indonesia.go.id/portal-web.

2.2 Data collection

The study was conducted using a descriptive survey approach to farmers who raise livestock traditionally. The study used primary data and secondary data. Primary data were obtained through a survey of 150 buffalo farmers as purposively determined respondents of 50 breeders from each of Sarolangun Regency, Batanghari Regency, and Tebo Regency. Then, a focus group discussion (FGD) was conducted to compile the attributes of each dimension to be analyzed. Then, consultations were carried out with key informants (academics, livestock office, business actors, researchers, ranchers, and NGOs) to compile a priority order and pairwise comparison between indicators in assessing the sustainability index of buffalo livestock business. The purpose of the FGD is to evaluate the resources available for buffalo farming at the research site, providing buffalo farmers with important insights to formulate decision-making strategies from sustainability attributes.

In measuring the sustainability index of buffalo livestock business using 4 dimensions, namely, the ecological dimension (10 attributes), the economic dimension (9 attributes), the social dimension (9 attributes), and the technological dimension (9 attributes), so that there are a total of 37 attributes (Table 1). The questionnaire was prepared based on the results of the FGD which was used to measure the attributes of each dimension, using the Likert scale for respondents' choices. The assessment is given a score of 0–3 with the following criteria: 0 = very poor, 1 = bad, 2 = good, and 3 = very good [26]. The data collected are used for MDS analysis and sensitive attributes of each dimension will be continued to be analyzed using AHP [27].

2.3 Data analysis

Data analysis was carried out using MDS through Rapid appraisal techniques modified from Rapfish [18,28,29], consisting of MDS analysis, Monte Carlo analysis, and Leverage analysis for swamp buffalo (RapKerbau). Rapid appraisal method for swamp buffalo [29,30], to assess the sustainability of swamp buffalo cultivation, which is determined through the following stages:

Table 1: Dimensions and attributes used in analyzing the sustainability of swamp buffalo farming in Jambi

Ecological	Economic	Social	Technology
(1) Buffalo density level	(11) Number and status of ownership of buffalo	(20) Level of extension for farmers	(29) Availability of buffalo breeds
(2) The use of feces and urine as compost	(12) Weight gain of buffalo	(21) Knowledge in manure management	(30) Manure management technology
(3) Buffalo rearing management	(13) The added value of buffalo manure	(22) Knowledge related to animal feed management	(31) Post-harvest technology
(4) Land use change	(14) Farm income from buffalo	(23) The impact of manure waste on the environment	(32) Land processing for farming
(5) Availability of superior forage feed	(15) Farm infrastructure	(24) Participation of farmers in composting	(33) Technology of processing agricultural waste as animal feed
(6) Utilization of agricultural waste as animal feed	(16) Land tenure of farm business	(25) The degree of conflict in the maintenance of buffalo	(34) Technology of health maintenance of buffaloes from diseases
(7) Availability of grazing fields	(17) Percentage of farmers who own land >0.5 ha	(26) Status of people who own buffalo	(35) Application of artificial insemination
(8) Land carrying capacity in providing feed	(18) Contribution to GDP from the agricultural sector	(27) Motivation in farming	(36) Application of biogas technology
(9) Percentage of land area (10) Availability of wallowing buffalo	(19) Government subsidies in the form of capital and infrastructure	(28) The level of education of farmers in farming	(37) Application for recording the number of swamp buffalo livestock

(1) This study assessed 4 dimensions of sustainability consisting of 37 attributes.

(2) Assess scores on each attribute of each dimension. The value of the attribute score will form a matrix X ($n \times p$), where n is the number of research locations and their reference points, and p is the number of attributes used. The scores are then standardized for each attribute score using formula (1) [19].

$$X_{ik}\text{sd} = \frac{X_{ik} - X_k}{S_k}, \tag{1}$$

where X_{ik}sd = regional standard score with i (including reference points) = 1, 2,..., n for each attribute k = 1, 2,..., p, X_{ik} = standard score with i (including reference points) = 1, 2,..., n for each attribute k = 1, 2,..., p, X_k = average score for each attribute k = 1, 2,..., p, and S_k = score standard deviation for each attribute k = 1, 2,..., p.

The shortest distance of the Euclidian distance is calculated using equation (2) and then projected into a two-dimensional Euclidian space (d) based on the regression formula in equation (3) [28,38]. The regression process uses the ALSCAL algorithm to iterate so that the intercept value in the equation is equal to zero (a = 0). Thus, equation (3) becomes equation (4). The repeat process is stopped when the voltage value (S) < 0.25. The value of S is achieved based on equations (2)–(5)

$$d = \sqrt{(X1 - X2)^2 + (Y1 - Y2)^2 + \dots}, \tag{2}$$

$$d = a + bD12 + e, \tag{3}$$

$$d = bD12 + e, \tag{4}$$

$$S = \sqrt{\frac{1}{m}\sum_{ki}^{m}\left[\frac{\sum_i\sum_i(D_{ijk} - d_{ijk})^2}{\sum_i\sum_j d_{ijk}^2}\right]}. \tag{5}$$

(3) Assess and determine the sustainability index. The sustainability status category of swamp buffalo development in South Kalimantan refers to the following sustainability index categories: 0.00–25.00 (unsustainable), 25.01–50.00 (less sustainable), 50.01–75.00 (moderately sustainable), and 75.01–100.00 (very sustainable), as adopted from the study by Syarifuddin et al. [18].

(4) Conduct a sensitivity analysis (leverage) to determine the sensitive attributes that greatly affect the sustainability of swamp buffalo cultivation. This analysis is based on the priority order of changes in the ordinate root mean square (RMS) on the x-axis. If RMS has significant value, it means that the role of this attribute is increasingly prominent towards sustainability status (more sensitive).

(5) Perform Monte Carlo analysis with the Buffalo Rap-Swamp method to estimate the random error rate of the MDS analysis model for all dimensions at a 95% confidence level. The smaller the difference in values between the results of MDS and Monte Carlo analysis, the better the Monte Carlo model produced by the Buffalo Rap-Swamp method. Goodness of fit in MDS is reflected by the value of S and the coefficient of

Table 2: Scale to compare factors in AHP paired comparison

Factor *i* compared to factor *j*	Quantitative value
Equally important	1
More important	3
Much more important	5
Quite more important	7
Absolutely more important	9
Intermediate values	2, 4, 6, 8

determination (R^2). A low S value indicates a match, while a high S value indicates the opposite. With the Buffalo Rap-Swamp approach, a good model is shown with an S value of less than 0.25. An R^2 value close to 1 indicates that the attribute used to check the dimension is accurate enough [18,38].

After obtaining the sustainability index and sensitive attributes of each dimension using the MDS method, it is continued by using the method (AHP) to develop a decision-making strategy [31]. The method used in AHP is based on the following stages:

Stage 1: Determining critical factors. the AHP can be used to make decisions, establish the sequence of criteria to be considered and take the most reasonable decisions [30,32]. According to Akter et al. [33], the comparative value of factors will be determined based on a priority comparison scale (Table 2).

Based on the scale [33], Table 2 shows that pairwise comparisons between equally important factors have a quantitative value of 1. The more important factor has a quantitative value of 3. The much more important factor has a quantitative value of 5. Quite more important factor has a quantitative value of 7. The absolutely more important factor has a quantitative value of 9. An intermediate value factor will have values of 2, 4, 6, and 8.

Stage 2: Normalize the matrix. To normalize the criterion importance matrix, divide the value of each cell in a column by the total value of that column. The weighted average (W_i) is calculated, based on the sum of the weights of the X_i factor relative to X_j after normalization divided by n. To determine the reliability of the weight (W_i), it is necessary to calculate the consistency index CR (consistency ratio), CR < 0.1, to obtain the consistency value. The formula for calculating CR is given by equations (6)–(8).

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \text{ with } \mathrm{CI} = \frac{\lambda - n}{n - 1}, \tag{6}$$

$$\mathrm{RI} = \frac{\mathrm{CI}_1 + \mathrm{CI}_2 + \ldots + \mathrm{CI}_n}{n}, \tag{7}$$

Table 3: Standardized RI values of mean random consistency index

Hierarchy matrix	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.12	1.32	1.41	1.45	1.49

$$\lambda_{\max} = \frac{1}{n} \times \left(\frac{\sum_{n+1}^{n} W_{1n}}{W11} + \frac{\sum_{n=1}^{n} W_{2n}}{W12} + \frac{\sum_{n=1}^{n} W_{nn}}{W1n} \right), \tag{8}$$

where RI is the random index (Table 3) and $\lambda_{\max}$ is the eigenvalue of the matrix.

Calculation of S_{i} value: The total S value will be calculated according to equation (9).

$$S = \sum (W_i \times X_i) \text{ with } i = 1 \ldots n. \tag{9}$$

Stage 3: Hierarchy of total S values. Reclassification methods and regression algorithms are used to classify total S values [34] according to their respective range of values depending on the research content. The hierarchical structure in decision-making of the sustainability strategy of swamp buffalo cultivation is presented in Figure 2.

3 Results and discussion

3.1 Sustainability analysis

The results of multidimensional analysis [35] of the integration of ecological, economic, social, and technological dimensions shows that swamp buffalo cultivation in Sarolangun Regency, Batanghari Regency, and Tebo Regency is moderately sustainable, with a sustainability index of 59.39, 55.93, and 58.23% (Figure 3) with an R^2 value of 0.95. The average sustainability index of swamp buffalo cultivation in three regencies in Jambi Province is 57.85% (moderately sustainable). The results of research by Syarifuddin et al. [18] on swamp buffalo cultivation in Sekernan Subdistrict, Muaro Jambi Regency showed less sustainable with an index of 42.81%. Meanwhile, Rohaeni et al. [19] obtained the sustainability index of swamp buffalo farming in Hulu Sungai Utara, Hulu Sungai Selatan, and Hulu Sungai Tengah, respectively, at 51.70, 53.13, and 48.87%. Tatipikalawan et al. [24] stated that buffalo farming on Moa Island, Maluku Province is moderately sustainable with a sustainability index of 52.72%. This shows that in the cultivation of swamp buffalo in addition to the availability of seeds and feed, the habitat of swamp buffalo is one of the determining factors

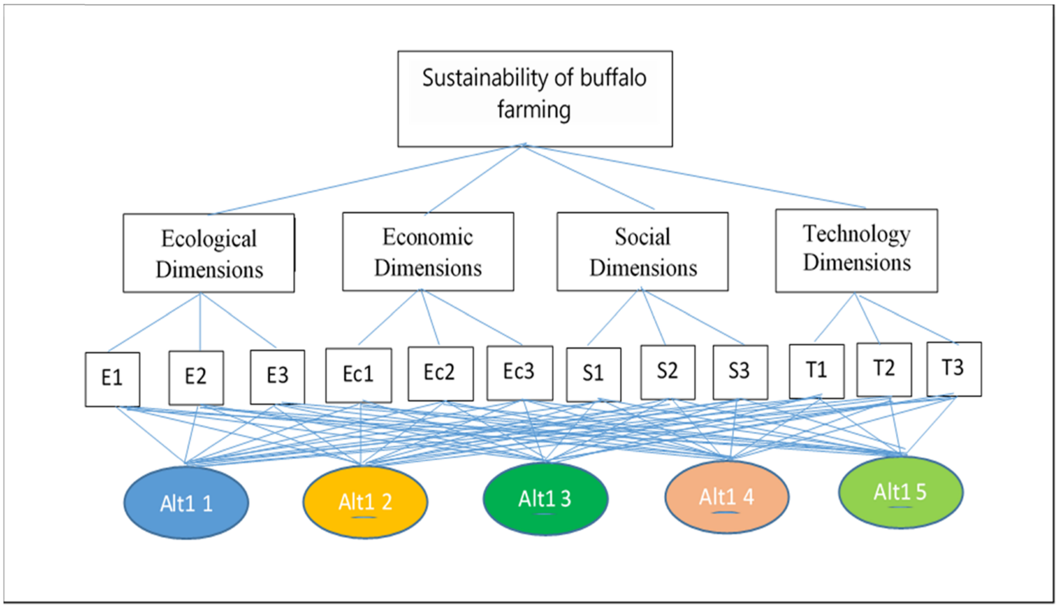

Figure 2: Process structure of the analytics hierarchy. Remark - Ecological dimensions: (E1) Availability of superior forage, (E2) utilization of agricultural waste as animal feed, and (E3) land use change. Economic dimension: (Ec1) Agricultural infrastructure, (Ec2) percentage of farmers who own land > 0.5 ha, and (Ec3) added value of buffalo manure. Social dimension: (S1) Status of buffalo owner people, (S2) motivation in farming, and (S3) impact of sewage waste on the environment. Technology dimensions: (T1) Technology of processing agricultural waste as animal feed, (T2) tillage for agriculture, and (T3) post-harvest technology. Alternative strategies: (Alt 1) Build internet network infrastructure, (Alt 2) determine the number of livestock that can be raised in an area, (Alt 3) establish buffalo farming institutions, (Alt 4) prevent land use conflicts, and (Alt 5) increase farmer participation in raising buffalo livestock.

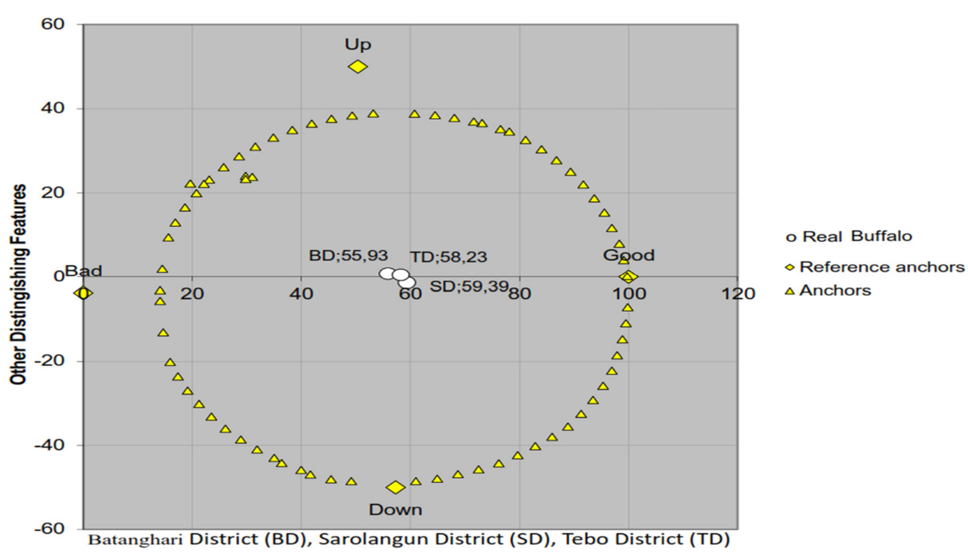

Figure 3: Ordination of RAPs for swamp buffalo farming in three regencies, Jambi Province, 2023.

for the success of buffalo cattle cultivation. According to Deb et al. [36], a holistic approach is needed for addressing the factors that affect the sustainability of swamp buffalo cultivation. The sustainability index of swamp buffalo cultivation in the three regencies is shown in Table 4.

Although the cultivation of swamp buffalo is considered multidimensionally sustainable, it does not mean that every dimension is sustainable. The cultivation of swamp buffalo in Sarolangun Regency is moderately sustainable. But of the four dimensions, there is one dimension that is

Table 4: Sustainability index of swamp buffalo farming in the three study areas by dimension

No.	Dimensions	MDS	Monte Carlo	Difference	Stress	R^2	Status
1	Ecological						
	SR	48.79	48.82	0.03	0.15	0.95	LS
	BR	51.12	51.17	0.05	0.15	0.95	MS
	TR	50.33	50.38	0.05	0.15	0.95	MS
2	Economic						
	SR	52.19	52.23	0.04	0.15	0.95	MS
	BR	50.32	50.41	0.09	0.15	0.95	MS
	TR	54.65	54.71	0.06	0.16	0.94	MS
3	Social						
	SR	63.32	63.39	0.07	0.15	0.95	MS
	BR	52.79	52.85	0.06	0.15	0.95	MS
	TR	52.43	52.48	0.05	0.15	0.95	MS
4	Technology						
	SR	51.47	51.52	0.05	0.15	0.95	MS
	BR	48.66	48.71	0.05	0.15	0.95	LS
	TR	50.93	5099	0.06	0.15	0.95	MS
5	Multiple dimensions						
	SR	5531	55.39	0.08	0.13	0.96	MS
	BR	52.64	52.71	0.07	0.13	0.96	MS
	TR	54.18	54.25	0.07	0.13	0.96	MS

Remark: Sarolangun Regency (SR), Batanghari Regency (BR), Tebo Regency (TR), Less Sustainable (LS), Moderately Sustainable (MS).

less sustainable, namely, the ecological dimension. Swamp buffalo farming in Batanghari Regency is moderately sustainable, but there is one dimension that is less sustainable, namely, technology. As for Tebo Regency, it shows that all dimensions are moderately sustainable. Multidimensionally, buffalo farming in Batanghari Regency has the lowest sustainability index compared to the other two regencies. However, the social dimension has the highest sustainability index among other dimensions.

In the ecological dimension, the results of the analysis show that swamp buffalo farming in Sarolangun Regency is less sustainable, while in Batanghari Regency and Tebo Regency, it is moderately sustainable, this is indicated by sustainability indices of 48.79, 51.12, and 50.33%, respectively (Table 4). The average sustainability index of the ecological dimension is 50.08%. The low ecological dimension sustainability index in Sarolangun Regency is due to land use change for plantations and mining, which has an impact on the provision of feed and wallowing sites. Land conversion causes the area of swamp buffalo grazing land to decrease, especially for foraging and wallowing, arable land is more widely used for food crops and plantations [37].

Previous research has shown that most buffalo farms are less sustainable due to ecological factors. According to Syarifuddin et al. [18], the sustainability index of swamp buffalo cattle in Sekernan Subdistrict, Muaro Jambi Regency is only 42.81%. Under the same conditions, Tatipikalawan et al. [24] reported that moa buffalo farming is less ecologically sustainable with a sustainability index of 41.15%. Ecological conditions such as land use change need to be a concern for various parties for the protection and development of buffalo livestock. Especially the availability of grazing land and standing water that is unable to compete with other commodities [7,38].

Swamp buffalo farming from an economic dimension shows that in all three locations, it is quite sustainable (Table 4). The sustainability index values of Sarolangun Regency, Batanghari Regency, and Tebo Regency were 52.19% (SR), 50.32% (BR), and 54.65% (TR), respectively with an average value of 52.39%. This result is similar to the results of the research by Syarifuddin et al. [12], where the sustainability index of swamp buffalo cultivation is 55%, and Tatipikalawan et al. [24] stated that the economic dimension of moa buffalo cultivation in Maluku Province is in the sustainable status (56.73%). The results of this study show that swamp buffalo has good prospects because it has high economic value in supporting the economy of farmers.

Based on the social dimension, it shows that the three research locations are quite sustainable with sustainability indices of 63.32% (SR), 52.79% (BR), and 52.43% (TR), respectively (Table 4). The average social sustainability index of the three regencies is 56.18%. On the same dimension, according to Tatipikalawan et al. [24], moa buffalo cultivation is sustainable with a sustainability index of 60.28%.

The sustainability of swamp buffalo farming business is supported by the active role of breeders to continue to preserve buffalo livestock by reducing conflicts with agricultural and plantation land owners.

Based on the technology dimension, swamp buffalo farming is quite sustainable in Sarolangun Regency (51.47%) and Tebo Regency (50.93%), while Batanghari Regency is less sustainable (48.66%) (Table 4), with an average technology sustainability index of 50.35%. The maintenance of swamp buffalo is all done extensively and the introduction of technology applied to the three research sites has not been maximized. According to Kushwaha et al. [39], buffalo that are kept extensively generally receive less attention from their owners. Increasing the productivity of swamp buffalo needs paying attention to aspects of breeding, feed availability, livestock environment, housing, livestock health, and maintenance management. The support of modern technology is decisive in the conservation of swamp buffalo.

3.2 Leverage analysis

The results of the leverage analysis showed that out of 37 attributes, 12 attributes were sensitive to the sustainability of swamp buffalo farms in three study sites, each dimension accounted for three sensitive attributes (Table 5).

3.2.1 Ecological dimensions

In the ecological dimension (Figure 3), there are three sensitive attributes that greatly affect the sustainability of swamp buffalo cultivation, namely, the availability of superior forage feed, the use of agricultural waste as animal feed, and changes in land use. Currently, the land specifically used for raising swamp buffalo has been reduced due to land conversion for plantations and agriculture. Swamp buffalos have the ability to digest low-quality feed with high crude fiber, such as agricultural waste and plantation waste. Swamp buffalos only consume naturally growing forages such as *Axonopus compressus*, *Eleusine indica*, *Brachiaria* sp., and others while forages such as grass species and superior legumes are still very limited. The main products of swamp buffalo livestock are meat and milk. Forage production of swamp buffalo cattle currently faces various challenges, such as climate change, and land use competition. Therefore, more sustainable feed production and habitat conditions need attention [37,40].

At the research site, the foliage of trees and shrubs became the preferred feed for swamp buffaloes such as cassava leaves (*Manihot esculenta*), *Leucaena* sp., and *Flemingia* sp. Integrating forage feed with agricultural and plantation by-products is a system that can sustainably improve the performance of swamp buffalo in small farms, as well as provide good feed to meet the needs of swamp buffalo livestock in producing a production.

Other factors affecting feed availability are climate change and land suitability. According to the government report [41], climate change has a significant impact on agriculture and plantations [42]. Varying climatic conditions make marshlands vulnerable to flooding and extreme drought. Excessive high and low water levels can have a negative impact on plant growth [43], including swamp buffalo animal feed. Therefore, climate change could significantly harm swamp buffalo.

Some alternatives that can be used to overcome the problem of limited forages are by conducting adaptive

Table 5: Recapitulation of attributes most sensitive to sustainability of swamp buffalo farms at three study sites

No.	Dimension	No.	Attribute	RMS change (%)
1	Ecological	1	Availability of superior forage feed	1.47
		2	Utilization of agricultural waste as animal feed	1.46
		3	Land use change	1.11
2	Economic	4	Farm infrastructure	1.48
		5	Percentage of farmers who own land > 0.5 ha	1.40
		6	Added value of buffalo manure	1.00
3	Social	7	Status of people who own buffalo	2.77
		8	Motivation in farming	1.85
		9	The impact of manure waste on the environment	1.85
4	Technological	10	Technology of processing agricultural waste as animal feed	1.40
		11	Land processing for farming	1.34
		12	Post-harvest technology	1.26

local HMT cultivation on limited grazing land, introduction of superior grass and legumes, rotation of swamp buffalo livestock in grazing, application of HMT processing technology in the form of straw, silage, and ammoniated hay [31,44].

Swamp buffalo farmers must be able to raise livestock efficiently by adapting to climate change and habitats that have the potential for environmental degradation [40,45]. The maintenance of a herd of marsh buffalo is perfect for the tropics, but it is necessary to provide access to water for wallowing. As the climate changes and temperatures rise, swamp buffalo will experience heat stress. Some strategies can be built by providing access to drinking water, wallowing with water, planting more trees as shelter and as feed for swamp buffalo, and designing the integration of plants and livestock. In addition, utilizing plantation crop land by introducing forage (grass and superior) that is able to withstand the stampede of swamp buffalo livestock efficiently [45] (Figure 4).

The availability of suitable land as habitat for swamp buffalo [40] is very important to support the sustainability of swamp buffalo cultivation. The available land can be used for grazing and activities. Therefore, swampland must be maintained for the conservation of swamp buffalo to be sustainable. Swampland filled with forage feed is a major factor in raising swamp buffalo [18,46]. The development of swamp buffalo requires swampland agroecological zones, this can be achieved with the support of various stakeholders in the form of laws and regulations so that swamp buffalo farming can be sustainable [47,48].

3.2.2 Economic dimension

The results of the leverage analysis showed that there were three sensitive attributes that influenced the sustainability of swamp buffalo cultivation in the three study sites. Based on the RMS value of livestock infrastructure, the percentage of land ownership is more than 0.5 ha and the added value of swamp buffalo manure is 1.48, 1.40, and 1.00%, respectively. This shows that to maintain swamp buffalo, facilities and infrastructure as well as land selection greatly determine the sustainability of swamp buffalo cultivation in addition to seed and feed (Figure 5). Swamp buffalo dung also provides added value because it can be sold as an organic fertilizer that can increase soil fertility. Swamp buffalo farmers will benefit from the sale of livestock and manure [49], but to date, in three study sites, none of the farmers have made compost from swamp buffalo dung. The pattern of integration of food crops and animal husbandry will provide benefits to both commodities [50–52], so that the sustainability of swamp buffalo farming is highly expected by farmers in fulfilling the family economy.

From land ownership to the maintenance and grazing of swamp buffalo, few ranchers own more than 0.5 ha of land. Land owned by farmers is generally used to develop agricultural and plantation businesses. On the other hand, swamp buffalo also need land for forage, shelter, and wallow. The solution to keep swamp buffalo sustainable is to integrate crops and animal husbandry [50].

Livestock manure as a by-product of swamp buffalo livestock, also provides additional income for the breeders.

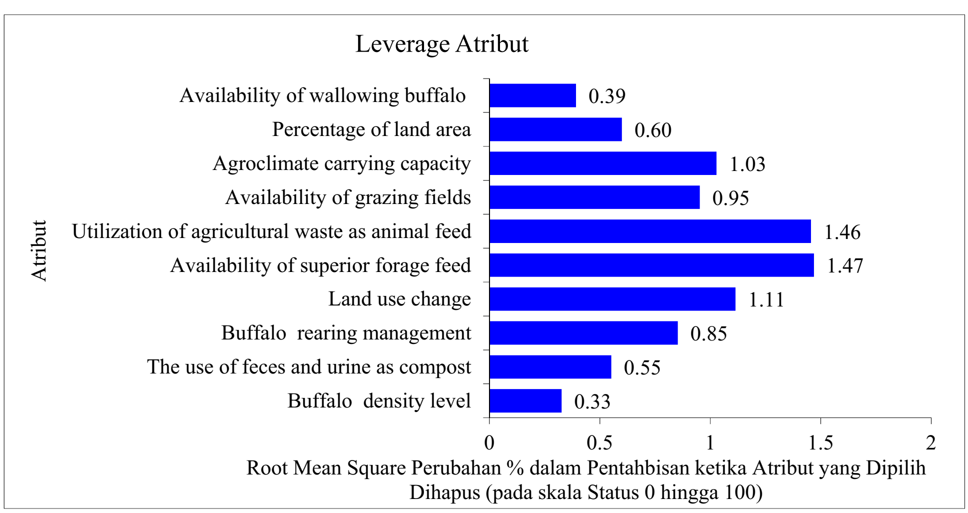

Figure 4: Leverage of ecological dimension attributes in the sustainability analysis of swamp buffalo farming in Jambi.

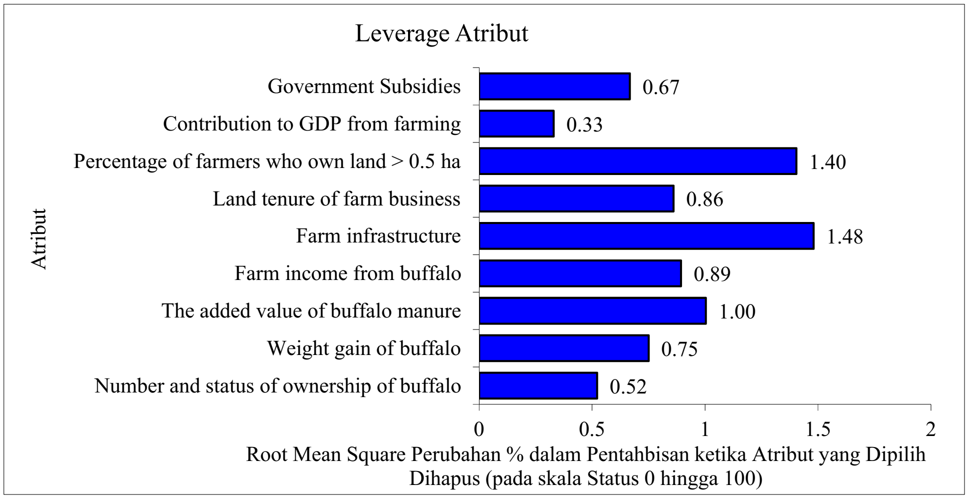

Figure 5: Leverage of economic dimension attributes in the sustainability analysis of swamp buffalo farming in Jambi.

Livestock manure can be used as biogas, as a renewable energy source, methane gas reduction, and as organic fertilizer. According to previous studies [49,53], there is a need for processing, commercialization, and marketing of organic fertilizer from buffalo dung so that it can be utilized by the government and other stakeholders in carrying out established programs and policies. Through good marketing, small-scale farmers can improve their livelihoods, reduce poverty while improving food security [45].

3.2.3 Social dimension

In the social dimension, there are three sensitive attributes that affect the sustainability of swamp buffalo cultivation, namely, the ownership status of swamp buffalo, the motivation to raise livestock and the impact of manure waste on the environment (Figure 6). Ownership of swamp buffalo cattle will determine the status of farmers in the community environment at the three study sites. The more the number of swamp buffalos owned, the higher their status or economic ability is compared to others. The level of livestock ownership is driven by the motivation of farmers in breeding. Ownership of swamp buffalo cattle can come from their own capital or from the inheritance of parents given to their children. Farmers who have a lot of swamp buffalo will build cattle sheds and release their cattle on their own land, and can afford to pay labor wages to take care of their livestock. From these conditions, it shows that the sustainability of swamp buffalo cultivation business is

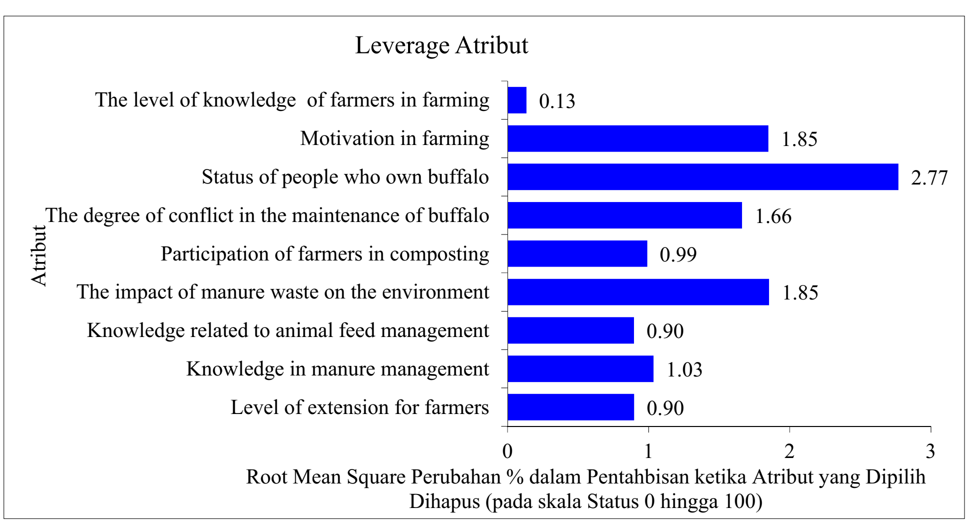

Figure 6: Leverage of social dimension attributes in the sustainability analysis of swamp buffalo farming in Jambi.

driven by business motivation. In Indonesian culture, farmers who have a lot of livestock will help each other in the community, especially during the celebration of holidays or religious holidays and local customs. The efforts made by farmers are one way to support sustainable development [54,55].

In addition to ownership and motivation in raising livestock, the by-product of swamp buffalo is livestock manure, if livestock manure is not managed properly, it will cause pollution to the environment and public health. According to Kushwaha et al. [39], widely released swamp buffalo will produce dung piles around the buffalo foraging grounds. The effort made is to increase the knowledge and insight of farmers in managing swamp buffalo dung. Farmers are given training, counseling and mentoring, especially in improving the ability to utilize modern technological advances to support sustainable farming [56]. Through the use of technology and counseling, farmers are expected to be able to adopt science, so that their capacity increases, thus increasing income to meet family welfare.

3.2.4 Technological dimensions

The technology dimension (Figure 7) shows that there are three sensitive attributes that affect the sustainability of swamp buffalo cultivation, such as agricultural waste treatment technology as animal feed, land treatment for agriculture, and post-harvest technology. Current conditions at the research site show that feed processing technology and postharvest technology have not developed well, while land processing for agriculture is still carried out traditionally. Land conversion for agriculture, plantations, and mining led to reduced land for grazing swamp buffalo cattle. The slow pace of buffalo cattle farming in Jambi Province is related to feed technology, reproductive technology, low productivity of females, and limited land for swamp buffalo cultivation. According to previous studies [14,57], success in buffalo farming is influenced by production systems, land use, availability of feed, and water for drinking and wallowing.

On the other hand, the need for buffalo meat is very high, especially for the manufacture of local foods such as rendang, with the price of buffalo meat being more expensive than beef. Also, buffalo milk can be fermented into nutritious food [58]. There are habits of people who prefer to consume buffalo meat compared to other livestock meat. This led to increased slaughter of buffalo which was not offset by an increase in the birth rate [59].

By improving post-harvest technology, the overall quality and competitiveness of both buffalo meat and milk can be improved. Previous studies [60,61] state that post-harvest technology will determine the competitiveness of the global buffalo meat trade. Diversification of buffalo products is expected to increase animal protein consumption.

In the technological dimension, another attribute that is also influential is the application of artificial insemination (AI) technology which can improve the quality of swamp buffalo production. Additional feeding such as minerals is needed to support buffalo reproduction [60,62]. Previous literature [61,63] state that the success of the AI program is determined by the response of buffalo farmers to increased buffalo livestock productivity. According to Singh and Balhara [63], the application of AI techniques

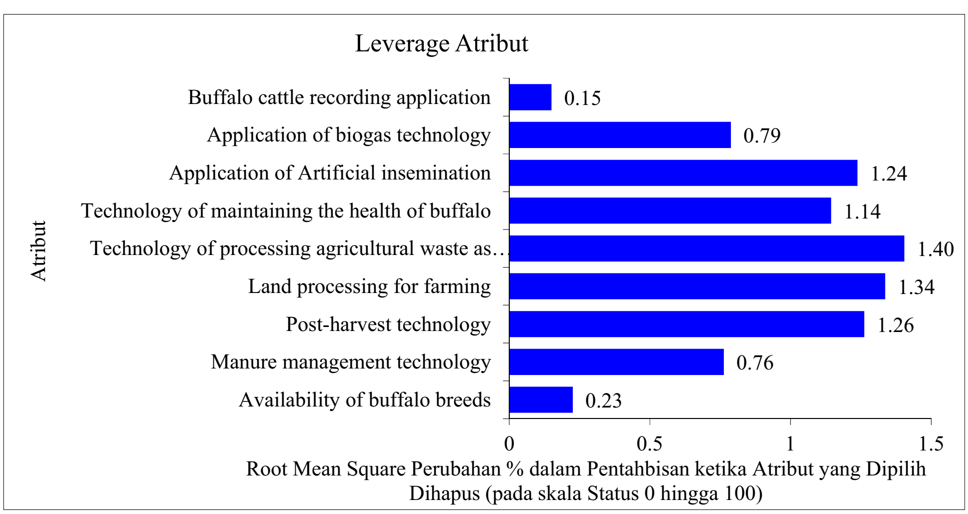

Figure 7: Leverage of technological dimension attributes in the sustainability analysis of swamp buffalo farming in Jambi.

has seen a significant increase in buffalo livestock productivity. Also, AI programs can reduce the occurrence of inbreeding which negatively impacts the livestock performance [64]. Inbreeding reduces genotype and phenotype quality [59]. The rate of buffalo inbreeding in Indonesia ranges from 10–30% [65].

3.3 Alternative decision-making strategy

Decision-making strategies using AHP techniques on four dimensions and relevant attributes in supporting the sustainability of swamp buffalo can be developed based on the weight of AHP as shown in Figures 8 and 9. The weights of

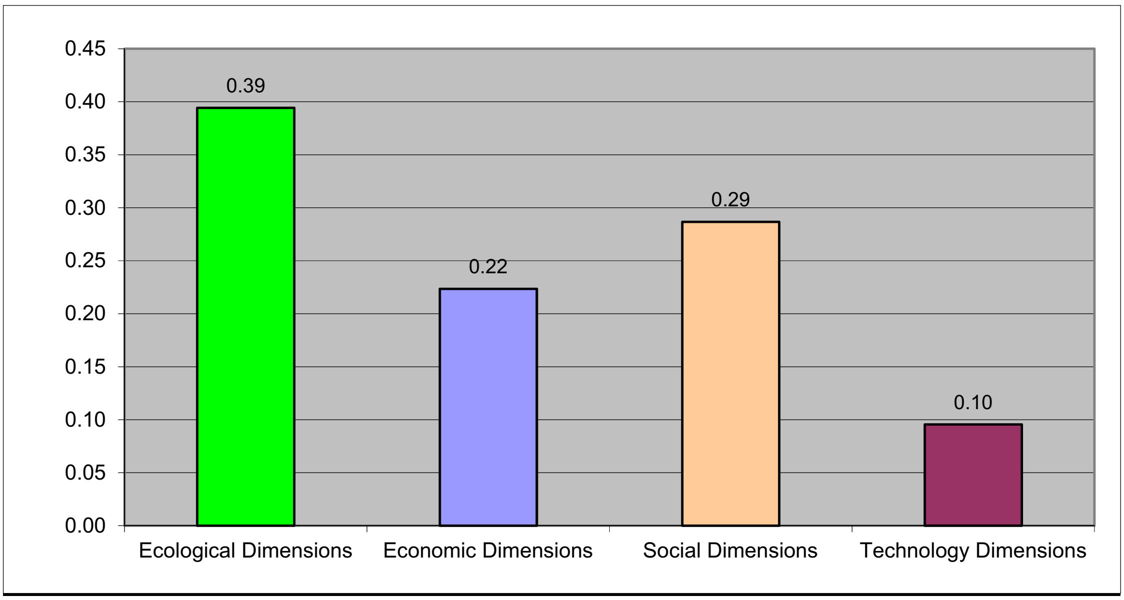

Figure 8: Weights from four dimensions using the AHP technique.

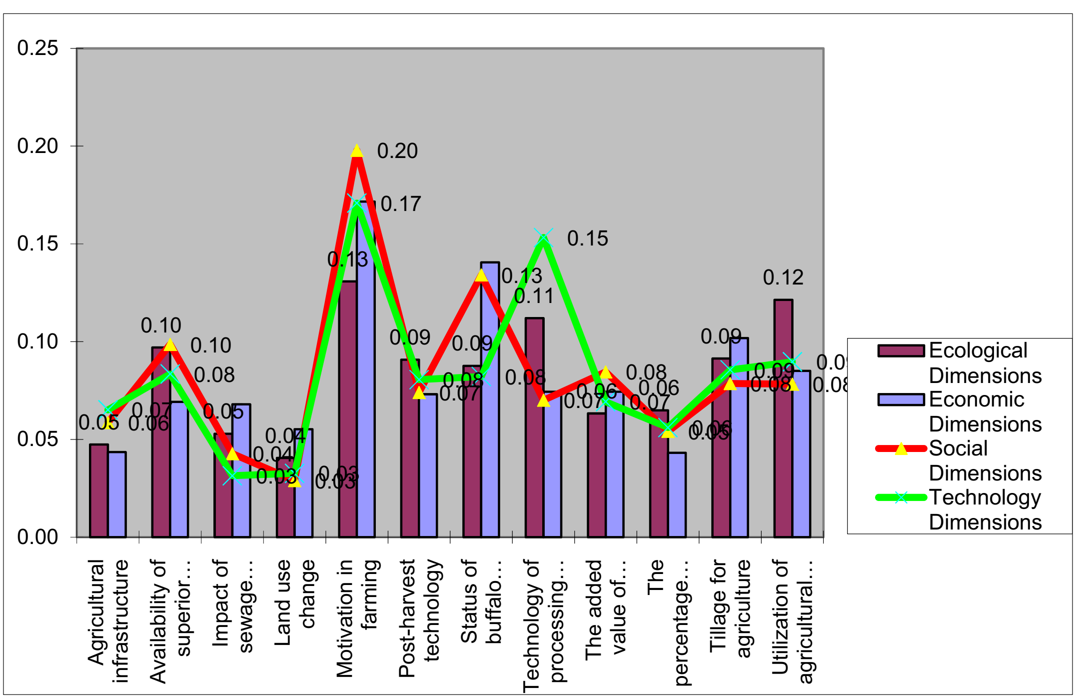

Figure 9: Weights for 12 attributes of four dimensions.

ecological dimension is 0.39, economic dimension is 0.22, social dimension is 0.29, and technological dimension is 0.10, with CR of 99.94%.

The weighting of 12 attributes (Table 5) contained in four dimensions (ecological, economic, social, and technological) based on AHP is shown in Figure 9.

Figure 9 shows that based on the weighting of 12 attributes (Table 5), the highest weight is motivation in farming, with 0.13 for ecological dimension, 0.17 for economic dimension, 0.20 for social dimension, and 0.17 for technological dimension. The ecological dimension gives the greatest weight, this is supported by the land area in each regency that is still able to provide animal feed. From the aspect of animal feed obtained from natural pastures, agricultural land, and plantations, the wallowing buffalo area is decreased due to use of land for other purposes such as palm oil or rubber plantation. Buffalo cattle can be integrated with agriculture and plantations with crop-livestock systems. Swamp buffalo rearing in Sarolangun Regency, Batanghari Regency, and Tebo Regency have their own areas, 5,935,894, 5,935,516, and 6,103,737 km^2, respectively, which are still used for raising livestock traditionally. According to Serrapica et al. [66], traditional cattle rearing still uses naturally grown forage as feed, such as buffaloes, which are integrated with oil palm plantations, are still able to meet feed needs by utilizing oil palm leaves. The area of plantations such as oil palm in each regency as a research location in 2022 is 92,953, 217,215, and 98,062 ha [2].

Furthermore, from the economic dimension, it shows that the maintenance of buffalo livestock is very helpful for the economy of farmers. Buffalo cows can be used as family deposits, and if in urgent circumstances can be sold mainly for education and medical expenses. In addition, buffalo dung has added value from biogas energy sources and organic fertilizers [63,64]. The social dimension and technological dimension have weights that are not much different. This shows that farmers need to gain new knowledge related to modern technology in increasing the productivity of swamp buffalo. Technology that can be applied by farmers are forage processing technology in the form of straw, silage, and ammonia [67], health technology, and AI technology [63] to improve buffalo quality. Information system technology continues to evolve and support the sustainable development of swamp buffalo [68]. Alternative strategies from four dimensions are shown in Figure 10.

Based on the weighting results, it can be analyzed that the current need for a swamp buffalo farming sustainability strategy is (1) building an information technology network (0.09), (2) determining the number of livestock that can be raised in an area (0.18), (3) forming buffalo livestock institutions (0.18), (4) increasing farmer participation in raising swamp buffalo (0.42), and (5) preventing land use conflicts (0.14). The main priority now is to increase the participation of buffalo farmers to utilize the available land in livestock business, and prevent conflicts with agricultural businesses, plantations, and others. Then, to strengthen the buffalo livestock business, an institution is to be formed, such as a cooperative, and a field school, as assistance to farmers. And then adjusting the

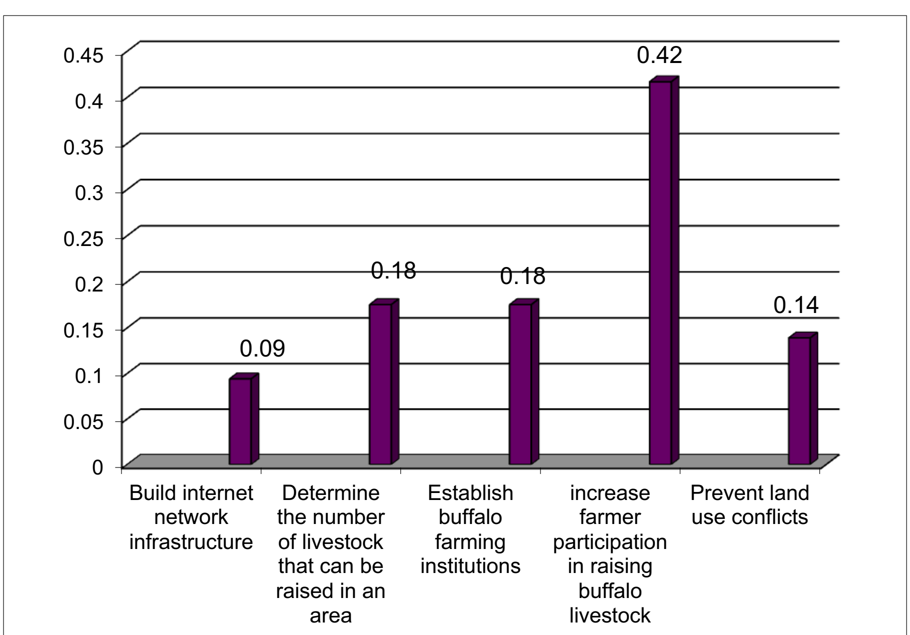

Figure 10: Five alternative decision-making strategies from four dimensions based on weighted values.

number of buffalo livestock to be raised in accordance with the land carrying capacity and building information technology network infrastructure. Information is needed by farmers in order to gain new knowledge about swamp buffalo, and be able to communicate with farmers and stakeholders in the livestock sector by forming e-buffalo, especially to increase livestock productivity and reduce threats such as diseases in buffaloes. According to previous studies [68,69], Internet of things and Precision livestock farming are currently indispensable for activities in the field of animal husbandry.

Then, the strategy in determining the carrying capacity of buffalo livestock business land in meeting feed needs can be done using the pattern of integration of livestock crops, and from the carrying capacity of the land can be determined the number of livestock to be raised by farmers, especially to overcome limited land use in raising swamp buffaloes. The results of the study by Zahara et al. [70] showed that the ruminant concentration index in South Lampung Regency that utilizes plant residues as forage has a value of 0.15–2.49 with an average value of 1.00. This means that with a well-managed pattern of integration of livestock crops, it can increase the capacity of ruminant populations.

4 Conclusion

The results of the buffalo cattle business sustainability index in Sarolangun Regency are 59.39%, Batanghari Regency is 58.23%, and Tebo Regency is 55.93%. There are 12 sensitive attributes that affect the sustainability of swamp buffalo business, and the most sensitive is the status of buffalo owners. There are five alternative strategies in decision making, namely, (1) building internet network infrastructure, (2) determining the number of livestock that can be raised in an area, (3) establishing buffalo farming institutions, (4) preventing land use conflicts, and (5) increasing farmer participation in raising buffalo livestock.

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Informed consent: Informed consent has been obtained from all individuals included in this study.

Data availability statement: The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request. All data generated or analysed during this study are included in this published article.

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