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Analysis of the sustainability of paddy rice farming in Percut Sei Tuan District

Amalia Fauziah Hulwani[1]*, Diana Chalil[1], Rungrat Saeyang[2]

[1]*University of Sumatera Utara, Indonesia*
[2]*Prince of Songkla University, Thailand*

**Corresponding author's e-mail: amaliafauziah425@gmail.com*

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ABSTRACT

Rice paddy farming plays a strategic role in supporting regional food security, especially in Deli Serdang Regency, one of the rice production centres in North Sumatera Province. However, pressure from land conversion, excessive use of chemical inputs, and limited technological and institutional support have the potential to threaten the sustainability of paddy rice farming. This study aims to analyse the sustainability status of paddy rice farming and identify sensitive attributes in the ecological, economic, social, institutional, technological, and infrastructure dimensions in the Percut Sei Tuan district. The analytical method used was Multi-Dimensional Scaling (MDS) with the RAP-PADI software. The research was carried out in Tanjung Rejo Village, Cinta Damai Village and Percut Village by involving 100 respondents of paddy rice farmers. The results showed that rice field farming in the Percut Sei Tuan District has a multidimensional value of 57.16 (quite sustainable). The ecological dimension has one sensitive attribute: the use of chemical inputs. The economic dimension has one sensitive attribute: farmers' profits. The social dimension has three sensitive attributes: farming experience, farmers' motivation to farm, and farmer education. In the institutional and legal dimensions, there is one sensitive attribute: farmers' access to government assistance. The technology and infrastructure dimensions have two sensitive attributes: response to technology and village farming roads.

Keywords:
Multi-dimensional scaling, Paddy-rice farming, RAP-PADI, Sustainability

1. Introduction

Food security is a multidimensional and complex issue that encompasses social, economic, political, and environmental aspects. Political aspects are often the dominant factor in the decision-making process for determining food policy. Realising sustainable food security is a priority issue and agenda in various meetings held by countries and international institutions [1]. Rice commodities included in the food crop subsector are important for the Indonesian people because most of them are rice farmers. Rice production continues to increase due to increasing public consumption, making rice commodities agricultural, industrial, and service sector workers, food crop commodities that produce the most production compared to other food crop commodities, considering that rice is still a staple food item for Indonesian society [2].

In data from the BPS-Statistics Sumatera Barat [3] rice production is one of the important indicators in describing the food security of a region. In North Sumatera, the contribution of each district and city to total rice production varies greatly, depending on the area of rice fields, planting intensity, and the use of agricultural technology. Based on the available data, information on rice production is presented in units of thousand metric tons of milled dry rice.

Deli Serdang is ranked second highest after Serdang Bedagai Regency, which recorded a production of 333,128.70 tons. The high rice production in Deli Serdang reflects the effectiveness in the use of agricultural land and the application of good cultivation technology, and shows the significant contribution of this area in meeting the food needs of North Sumatera Province. Based on rice production data from the BPS-Statistics Sumatera Barat in 2024, Percut Sei Tuan sub-district recorded a production of 71,481.25 tons, making it the sub-district with the second largest rice production after Hamparan Perak.

The Percut Sei Tuan District is one of the areas in Deli Serdang Regency, North Sumatera, that has experienced rapid development in recent years. It is suspected that land use in this area has changed as a result of population growth, housing development, industrial estates, and infrastructure with rates of population displacement, forest conversion, and expansion of agricultural land, stating that in the Percut Sei Tuan District area, land use changed significantly between 2018 and 2022. The built-up land class increased by 627 ha, or 37%, whereas forest land use decreased by 521 ha, or 5% [4]. This is due to the increasing need for community infrastructure, which ultimately reduces productive land to become unproductive. Changes in land use have a serious impact on food production, the physical environment, and agricultural communities' welfare.

Rice field farmers in the Percut Sei Tuan District generally use chemical fertilisers at doses that are not in accordance with technical recommendations. This fertilisation practice is based on hereditary habits, personal experience, and the assumption that the use of more fertilisers will increase production yields. Consequently, fertilisation is often carried out excessively or unbalanced between nutrients, without regard to the needs of the soil and plants. This condition not only has the potential to reduce production cost efficiency but can also have a negative impact on soil fertility, the environment, and the sustainability of paddy rice farming in the Percut Sei Tuan District. Environmental damage caused by the use of chemical fertilisers is one of the problems that arise in the agricultural sector [5].

Sustainable agriculture is an approach that can maintain high agricultural production and profits without resulting in environmental damage, and development is expected to always be environmentally friendly. Environmentally friendly agriculture is an agricultural system that can create an optimal and sustainable agroecosystem that is ecologically, economically, and socially sustainable [6]. This research is important because rice farming in the Percut Sei Tuan District has a strategic role in supporting regional food security; however, in practice, it still faces various problems that have the potential to threaten sustainability, such as farmers' dependence on chemical fertilisers, high production costs, declining land quality, and limited access to agricultural technology and extension services. In addition, institutional and legal aspects, such as the effectiveness of farmer organisations, access to government support programs, and the implementation of agricultural policies, also influence the sustainability of farming systems. Furthermore, the availability and quality of infrastructure—including irrigation networks, farm roads, and supporting facilities—play a crucial role in ensuring production efficiency and distribution.

This condition shows that the sustainability of rice farming is not only determined by production aspects but also by ecological, economic, social, institutional and legal, as well as technological and infrastructure dimensions that are interrelated. Therefore,

this research is important to measure and analyse the sustainability of paddy farming and identify the determinants of sustainability as the basis for formulating policy recommendations and strategies for more sustainable rice farming in the region.

2. Methods

The research was conducted in Percut Sei Tuan District, Deli Serdang Regency, North Sumatera Province. The location was selected purposively by choosing three villages—Tanjung Rejo, Cinta Damai, and Percut—which represent the rice paddy production centres in the area. The population of this study consisted of all paddy rice farmers in the three selected villages, totaling 2,124 farmers. The sample size was determined using the Slovin formula with a 10 percent margin of error, resulting in 100 respondents. The sampling technique applied was proportionate stratified random sampling, where samples were distributed proportionally across each village and selected randomly within each stratum.

The data used in this study consisted of primary and secondary data. Primary data were collected using structured questionnaires, direct interviews with farmers, and field observations. Secondary data were obtained from the BPS-Statistics Sumatera Barat, relevant agricultural institutions and related scientific literature.

Data analysis was conducted using descriptive statistics to describe the characteristics of respondents and farming conditions. Sustainability analysis was conducted using the Multi-Dimensional Scaling (MDS) method with the Rap-Padi approach to determine the sustainability index and status across five dimensions: ecological, economic, social, institutional and legal, and technological and infrastructure.

Furthermore, a leverage analysis was performed to identify sensitive attributes influencing sustainability, and a Monte Carlo analysis was used to test the stability and reliability of the MDS results. The categories of the sustainability status of paddy rice farming are listed in Table 1.

Table 1. Sustainability Index

Index value	Category
0.00–25.00	Poor (Unsustainable)
25.01–50.00	Less (Less sustainable)
50.01–75.00	Enough (Fairly sustainable)
75.01–100.00	Good (Highly sustainable)

Source: Yusuf [7]

3. Results and Discussion

3.1. Ecology Dimension

The ecological dimension in sustainable agriculture is an approach that emphasises the surrounding environment. Therefore, to maintain agricultural land resources, sustainable agriculture is needed [7]. The results of the average analysis shown in Figure 1 reveal that there is one sensitive attribute, namely, the use of chemical fertilisers. The results of the multidimensional analysis of scaling shown in Figure 2

reveal that the sustainability status of paddy rice farming in the Percut Sei Tuan District in the ecological dimension has a value of 54.58, which is categorised as quite sustainable.

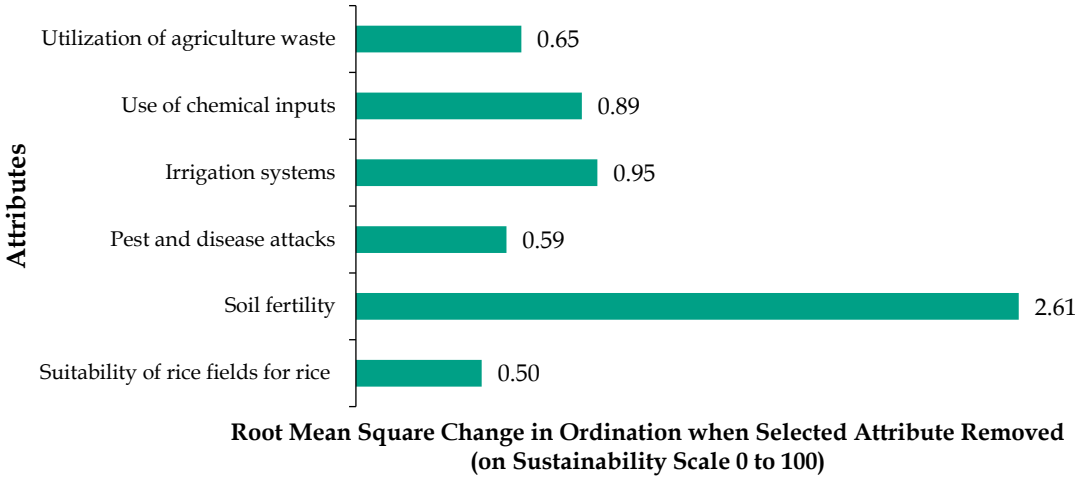


Figure 1. Research attributes of the ecological dimension

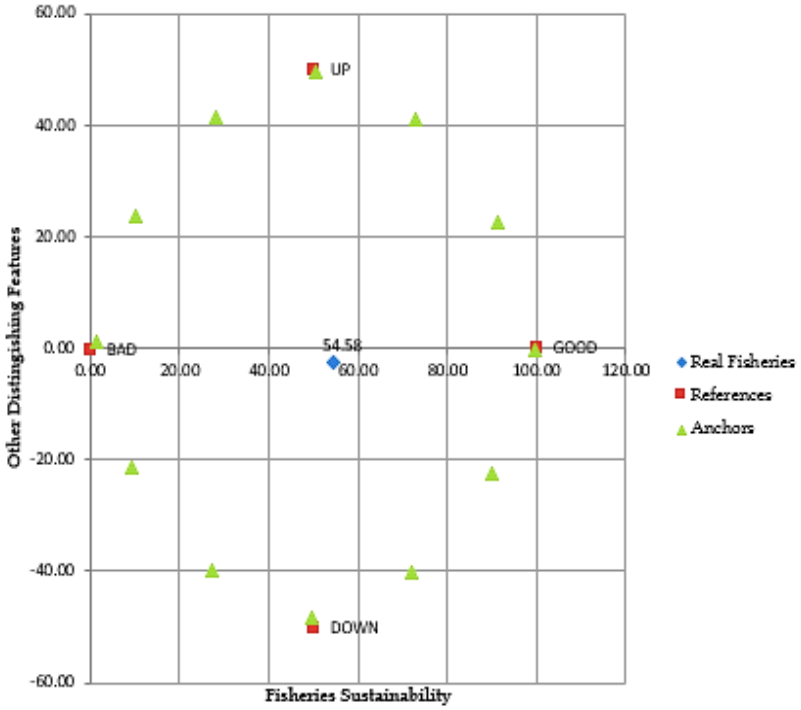


Figure 2. Sustainability status of farming with an ecological dimension

The use of fertilisers and pesticides provides benefits in overcoming various problems in the agricultural sector. However, if applied in excess of the recommended dose, these ingredients can pose a risk to human health and reduce the quality of food products. Excessive and continuous use of pesticides can lead to the accumulation of residues in the soil and water, which ultimately interferes with the existence and activity of soil microorganisms that play an important role in maintaining fertility. In

addition, the degradation of the agricultural environment is also triggered by the use of fertilisers, pesticides, herbicides, agricultural tools and machinery, as well as CO_2 emissions [8]. Therefore, efforts to realise sustainable agriculture need to be directed at reducing environmental impacts and protecting human health, without sacrificing productivity; one such effort is to reduce the use of chemical fertilisers, pesticides, and synthetic herbicides and replace them with more environmentally friendly plant-based pesticides [9].

3.2. Economy Dimension

The economic dimension focuses on the efficiency and sustainability of agriculture [10]. The economic dimension of paddy farming is an aspect that describes the performance and economic feasibility of rice cultivation activities, which includes farmers' income and profits, grain prices, marketing structure, capital availability, and production levels. This dimension emphasizes the ability of paddy rice farming to provide decent and sustainable economic benefits for farmers and support business sustainability in the long term. The results of the analysis of the average in Figure 3 show that there is one sensitive attribute, namely the farmer's profit. The results of the multidimensional analysis of scaling in Figure 4 show that the sustainability status of paddy rice farming in Percut Sei Tuan District in the economic dimension has a value of 60.27 which is categorized as quite sustainable.

Farmer profits are directly related to the farmer's ability to earn a decent income after deducting production costs, which in turn affects the motivation, investment, and sustainability of the farming business in the long run. Net income and profits from paddy farming are key indicators for assessing the economic sustainability of farming. This condition shows that to improve economic sustainability, there is a need for a strategy to increase farmers' profits by increasing production efficiency, strengthening market access, and implementing fairer price policies, so that paddy farming can become a business that is not only productive but also economically profitable [11].

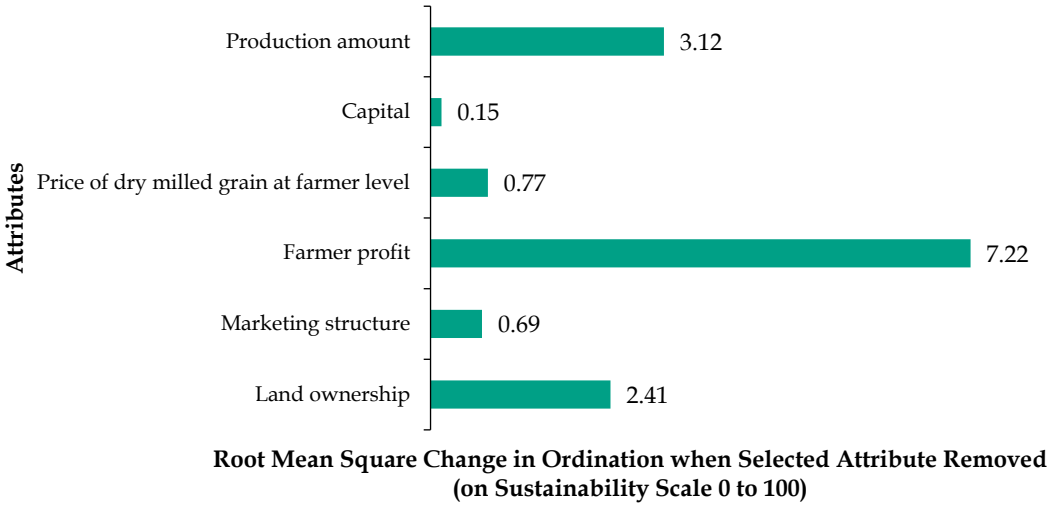


Figure 3. Economic dimension research attributes

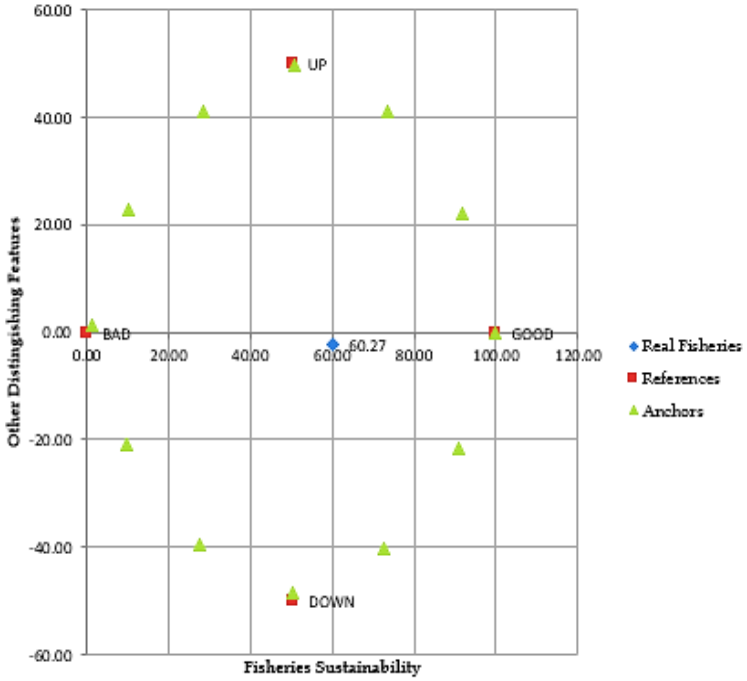


Figure 3. Economic dimension research attributes

3.3. Social Dimension

The social dimension of paddy rice farming describes the conditions and social roles of farmers in carrying out rice cultivation activities, including the characteristics of farmers, family involvement, education level, farming experience, motivation, culture of mutual cooperation, and the intensity of counselling and training. The results of the average analysis in Figure 5 show that there are three sensitive attributes: farming experience, farmer motivation to farm, and farmer education. The results of the multidimensional analysis of scaling in Figure 6 show that the sustainability status of paddy rice farming in the social dimension in the Percut Sei Tuan District is 57.76, which is categorised as quite sustainable.

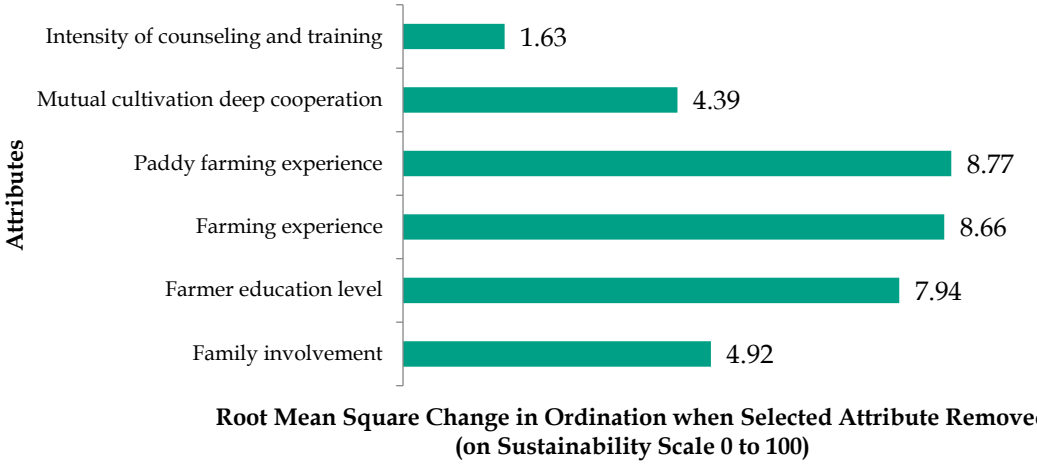


Figure 5. Social dimension research attributes

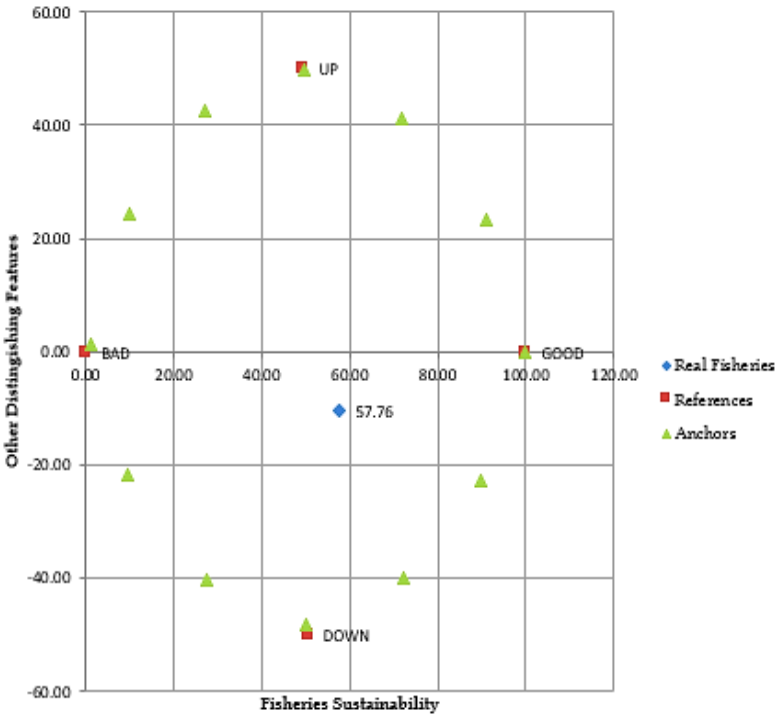


Figure 6. The sustainability status of social dimension farming

The length of farmers' involvement in paddy farming has a significant influence on the sustainability of the social dimension. Farmers with longer experience generally have better technical and managerial skills in managing farming, including in decision- making and adjustment to changing environmental and market conditions. External support and the accumulated experience of farmers in ensuring the sustainability of farming [12].

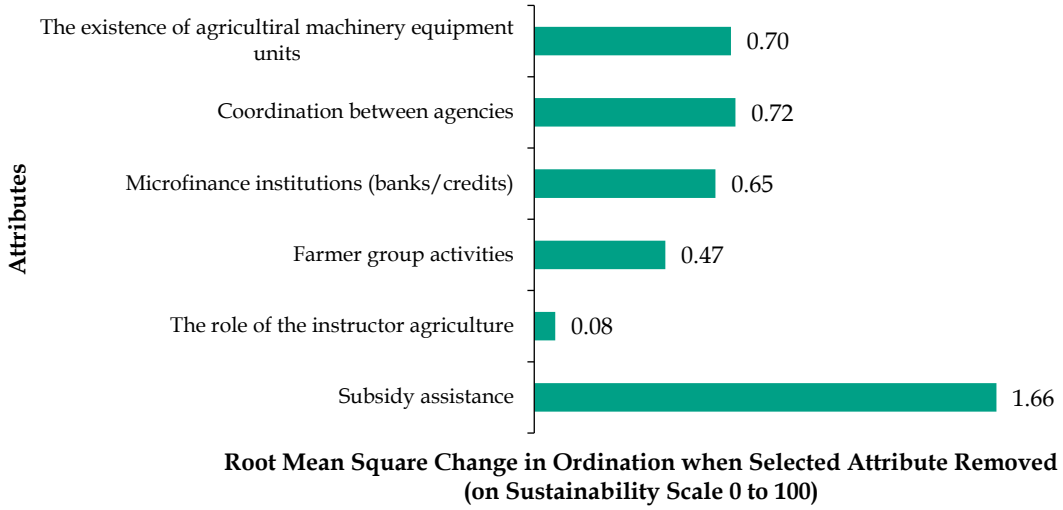
Farmers' motivation to farm shows that the encouragement of farmers in running paddy rice farming is very decisive for social sustainability. A high level of motivation will encourage farmers to continue to maintain and develop farming, as well as be more open to innovation and improvement of cultivation practices. In contrast, low motivation can hinder the sustainability of farming, especially in the face of economic and environmental challenges. The area of land owned by farmers turns out to motivate farmers in managing their rice fields.

Importance of formal education levels in supporting the sustainability of the social dimension of paddy rice farming. The level of education affects farmers' ability to understand information, accept technological innovations, and manage farming more efficiently. Education can accelerate the understanding of new technologies or agricultural regulations; however, the impact is only felt when supported by access to information and field practices. Better education also plays a role in increasing the capacity of farmers' human resources, thereby contributing positively to the sustainability of paddy rice farming [13].

3.4. Institutional and Law Dimensions

The institutional dimension and law of paddy rice farming describe institutional support and the legal framework for the implementation of rice cultivation activities, including the existence and role of farmer groups, farmers' access to government

assistance, counselling assistance, financial institutions, alsintan service units, and coordination between related agencies. This dimension emphasises the importance of institutional governance and legal certainty in supporting the smoothness, efficiency, and sustainability of paddy rice farming. The results of the leverage analysis in Figure 7 show that there is one sensitive attribute: farmers' access to government assistance. The results of the multidimensional analysis of scaling in Figure 8 show that the sustainability status of paddy rice farming in the Percut Sei Tuan District in the institutional and legal dimensions has a value of 55.70, which is categorised as quite sustainable.



Gambar 7. Institutional and law research attributes

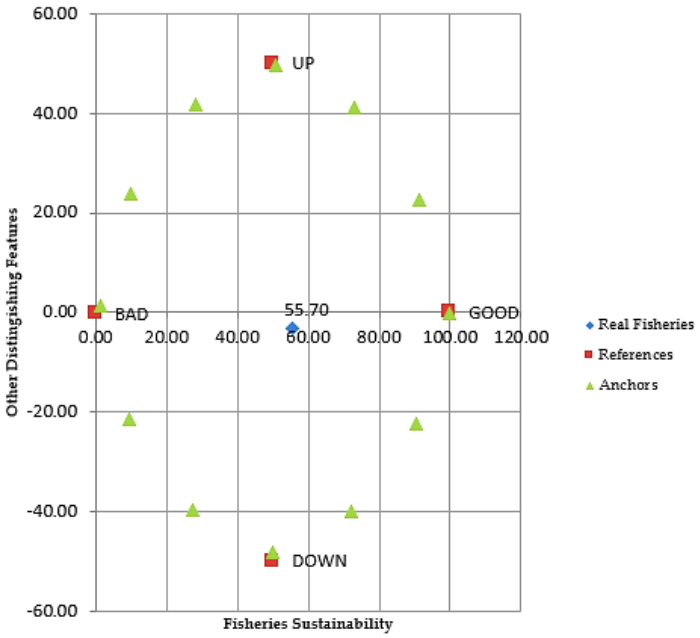


Figure 8. Status of agricultural sustainability institutional and legal dimensions

Subsidised fertiliser access is identified as a sensitive attribute in the institutional and legal dimensions. Subsidised fertilisers play an important role in reducing production

costs and maintaining the stability of farming businesses; therefore, limited access or inaccurate distribution can have a direct impact on farmers' productivity and income [14]. The sensitivity of this attribute indicates that even small changes in policies, distribution mechanisms, and the accuracy of targeting subsidised fertilisers can significantly affect institutional performance and the sustainability of paddy rice farming. Therefore, improving the distribution system, enhancing the accuracy of farmer data, and strengthening the role of related institutions are strategic steps to improve sustainability in the institutional and legal dimensions.

3.5. Technology and Infrastructure Dimensions

The technology and infrastructure dimensions of paddy rice farming describe the level of utilisation of agricultural technology and the availability of supporting facilities and infrastructure in rice cultivation activities, such as access to certified superior seeds, the use of cultivation technology, the availability of information through extension workers, farmers' response to innovation, the condition of farming roads, and the availability of agricultural tools and machinery. This dimension

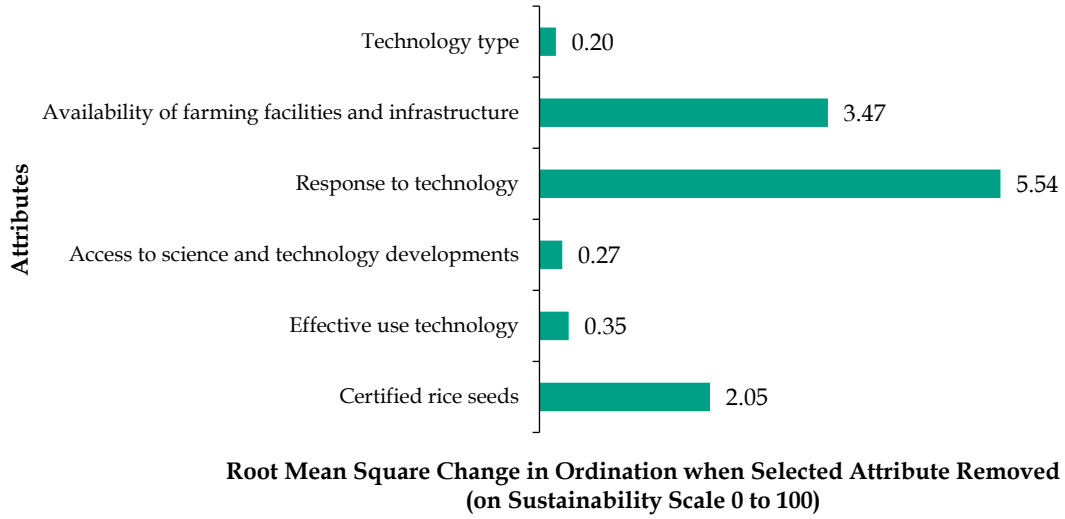


Figure 9. Research attributes, technology dimension and infrastructure

emphasises the role of technology and infrastructure in improving the efficiency, productivity, and sustainability of paddy rice farming. The results of the average analysis in Figure 9 show that there are two sensitive attributes: response to technology and the way of village farming. The results of the multidimensional analysis of scaling in Figure 10 show that the sustainability status of paddy rice farming in the technology and infrastructure dimensions in Percut Sei Tuan District is 54.58, which is categorised as quite sustainable.

The attitude and ability of farmers to accept and apply agricultural technology innovations have a considerable influence on the sustainability of the technology and infrastructure dimensions. A positive response to technology can encourage an increase in the efficiency and productivity of paddy rice farming, whereas a low response can hinder the adoption of innovation and slow down improvements in farming performance. Therefore, increasing farmers' understanding and trust in

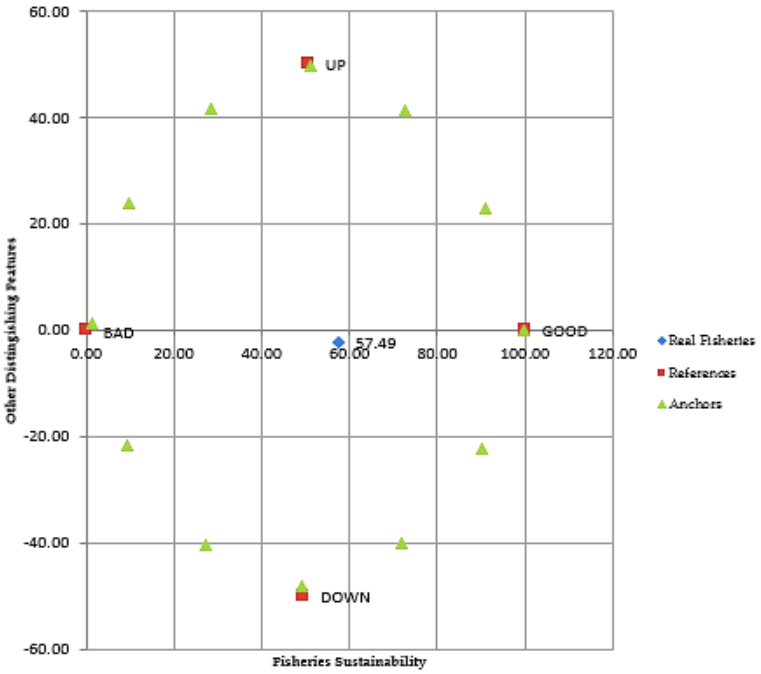


Figure 10. Status of farming sustainability technology and infrastructure dimension

technology through counselling and mentoring is an important factor in strengthening the sustainability of this dimension. The quality of road infrastructure plays a significant role in supporting the sustainability of paddy rice farming. Many agricultural locations have not been supported by good infrastructure, especially roads, which hinders the development of farming businesses. Good road conditions facilitate farmers' access to production facilities, facilitate the cultivation process, and support the distribution of crops. In contrast, unsuitable road conditions can increase transportation costs and hinder farming efficiency. The sensitivity of this attribute emphasises the importance of improving and maintaining village farming road infrastructure as part of efforts to improve the sustainability of the technology and infrastructure dimensions [15].

3.6. Monte Carlo Sustainability of Rice Field Farming Analysis

Monte Carlo analysis was performed to assess the dimension of uncertainty in the Multidimensional Scaling (MDS) method. The results of Monte Carlo's analysis showed a 95 percent confidence level in each dimension; there was not much

Table 2. Differences in MDS and Monte Carlo sustainability index values

Dimensions	Rice Farmers Sustainability index (%)		
	MDS	Monte Carlo	Differences
Ecology	54.58	54.61	0.03
Economy	60.27	60.16	0.1
Social	57.76	56.65	1.11
Institutional and legal	55.70	56.06	0.36
Technology and infrastructure	57.49	57.31	0.18
Mean	**57.16**	**56.95**	**0.35**

difference or it could be called a relatively small difference. These circumstances suggest that the use of Rapfish (MDS) in sustainability analysis has a high level of trust of Kavanagh et al. [16].

4. Conclusion

The sustainability analysis of paddy rice farming in Percut Sei Tuan District indicates that the overall sustainability status is moderately sustainable with an index value of 57.16, suggesting that the farming system performs reasonably well but still requires improvement. Among the five dimensions assessed, the economic dimension shows the highest performance, while ecological, social, institutional and legal, and technology and infrastructure dimensions remain moderate. Key sensitive attributes influencing sustainability include chemical fertiliser use, farmer profit, education and motivation, access to government support, and technology adoption. The Monte Carlo analysis confirms the reliability of the results, showing minimal differences from the MDS values. Therefore, efforts to promote sustainable paddy farming should focus on reducing chemical input dependence, increasing farmer income, strengthening institutional support, improving the effectiveness of government assistance, and enhancing technology adoption and infrastructure development.

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