

## SUSTAINABILITY ANALYSIS OF ARABICA COFFEE PLANTATION AGRIBUSINESS IN NORTH SUMATRA PROVINCE

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**Abstract:** This study examines the sustainability of Arabica coffee agriculture in Samosir Regency, North Sumatra, a significant region for Arabica coffee production in Indonesia. Using a modified Multidimensional Scaling (MDS) approach, Rapid Appraisal Technique Coffee (RAP-Coffee), the research assesses five sustainability dimensions: Ecological, economic, social, institutional, and technological, covering 52 attributes. Furthermore, sensitivity analysis through leverage and Monte Carlo methods is also conducted to evaluate the impact of various factors on the sustainability index. Accordingly, data was gathered from purposively selected locations and key stakeholders. The results reveal that the Arabica coffee agribusiness in Samosir Regency, North Sumatra, is generally sustainable, with sustainability index values exceeding 50 for all dimensions: Economic (57.26), ecological (51.63), social (61.31), institutional (51.90), and technological (50.08). In addition, the report underscores the necessity for ongoing enhancements in these domains to ensure future sustainability. Nevertheless, the findings are crucial for policymaking, suggesting that strengthening the technological, institutional, and economic dimensions will be essential for ensuring the long-term viability of the Arabica coffee industry in North Sumatra.

Keywords: Arabica coffee, multidimensional scaling, sustainability.

### Introduction

Coffee originates from Indonesia and is renowned worldwide. That makes Indonesia one of the coffee-producing countries and ranks fourth after Brazil, Vietnam, and Columbia (Maulani & Wahyuningsih, 2021). Indonesian farmers produce Arabica, Robusta, and Liberalica coffee, with Robusta being the most common type planted in Indonesia (Yusuf *et al.*, 2022b). Notably, coffee is one of the commodity exports; hence, the demand for coffee in the world continues to increase. Arabica coffee is also the coffee type in higher demand than other coffees. Correspondingly, the increased demand for Arabica coffee is accompanied by increased cultivation area. Some provinces have become the centre of Arabica coffee producers; North Sumatra is the centre of Arabica coffee producers, second in Indonesia. Based on known data domination management, coffee cultivation

is still more than 98% (Widaningsih, 2022). Several Arabica coffee types famous in North Sumatra include Lintong, Mandailing, Samosir, and Sidikalang coffee.

Coffee as a commodity export is crucial in the Indonesian economy since it contributes to foreign exchange. In particular, potency coffee exports influence farmers to ensure that they own the spirit to increase the cultivation and yield of coffee plants. This opportunity opens room for Indonesian farmers to innovate in increasing coffee production and slowly and gradually increase their understanding of the cultivation of coffee plants. Furthermore, it positively impacts the growth and increase of Arabica coffee production, improving the community's welfare, coffee farmers, and the country's economic growth (Martauli, 2018). However, the management of people's coffee

remains not optimal. This is due to the farmers not understanding the combining effects of several dimensions, which is mandatory in Arabica coffee cultivation.

Indonesian people's coffee refers to coffee produced by farmers or public locals in various regions in Indonesia. This is from a scale coffee production smaller than the company's big or plantation industry. On the other hand, people's coffee is a general effort performed by small or large farmers in rural areas. One characteristic that distinguishes Indonesian people's coffee is the diversity of flavours it produces, which is greatly influenced by the environment where the coffee is grown. In Indonesia, there are various area coffee producers with characteristics of diverse soils, climates, and altitudes. These factors contribute to the opportunity to produce coffee with various unique flavour profiles, such as coffee from Sumatra.

The issue of coffee sustainability is critical. Coffee sustainability will be realised if aspects of agricultural activities are considered. Aspects of coffee sustainability include economic, ecological, social, institutional, and technological aspects. In North Sumatra, the research location, several problems do not support the sustainability of Arabica coffee cultivation. Notably, problems based on economic aspects include inefficient marketing due to the asymmetric price transmission pattern between wholesalers and consumers in the short and long term. At the same time, problems based on ecological aspects include farmers ignoring the environment, especially in providing shade and managing coffee residues. Moreover, problems from the social aspect include the farmers' lack of motivation and knowledge in cultivating coffee. Additionally, problems from the institutional aspect include the lack of institutions that play a role in facilitating coffee cultivation activities for farmers, such as financial institutions and others. In line with this, the problem from the technological aspect is that farmers do not apply technology in their activities. Instead, they tend to use traditional methods. Previous research explained that in

coffee plant cultivation in North Sumatra, only 32% of the population planted shade trees, with an average population of 45 shade trees per hectare, far below the recommendation of 400 trees per hectare. For example, returning coffee skin to the garden as mulch is still a land conservation practice used by farmers, especially in Arabica coffee farming. Therefore, the social and ecological aspects of Arabica coffee farming still need to be improved (Saragih, 2018). Correspondingly, this study aims to analyse the sustainability of Arabica coffee in Samosir Regency based on economic, ecological, social, institutional, and technological dimensions. It also aims to increase national coffee production and expand global understanding of Indonesian coffee.

## Methods

A study was conducted in the Samosir District, located in North Sumatra Province, which is known as one of the regions producing Arabica coffee. The location was selected purposively since Samosir Regency has a reputation as a producer of Arabica coffee, particularly the debt sugar variety, one of the region's flagship commodities. This location was selected to explore the factors influencing Arabica coffee production in the area in greater depth.

The study was conducted in January 2024, with respondents selected using a purposive sampling method, which involved choosing individuals with relevant knowledge and experience related to the research topic. The selected respondents included coffee farmers, plantation managers, and other stakeholders involved in the Arabica coffee supply chain in Samosir District. Specifically, the purposive sampling process was intended to ensure that the data collected would provide in-depth and specific insights into the research subject.

However, to strengthen the validity of the research findings, further discussion is needed regarding the extent to which the selected sample can represent broader conditions, both at the district and provincial levels. Although

respondents were selected purposively, allowing the researcher to select competent individuals, it would be beneficial to explain whether the sample encompasses a range of characteristics, such as farmers' ages, land sizes, and experience in coffee cultivation. This will help ensure that the research findings can be applied or adjusted to the broader population of Arabica coffee farmers in Samosir District or even in other areas of North Sumatra Province. Details of the respondents are presented in Table 1.

The data analysis used in the research is a modified Multidimensional Scaling (MDS) method, namely the RAP-Coffee Approach (Rapid *et al.*, 2021). MDS is a technique of transformational statistical analysis of every dimension, and nature is multidimensional in dimensions continuity. This method is employed as it has produced stable parameter estimates. Note that several studies utilise the MDS approach by integrating the five fields above. Some add the field of institutional, six fields with the field of ethics, and even seven fields with the field of law and infrastructure. In contrast, this study focuses solely on the social dimension, which encompasses eight specific attributes related to the sustainability who also concentrated exclusively on the social dimension in their MDS-based sustainability assessment.. (Dahlani & Maharani, 2018).

Attributes based on dimensions were classified through discussions with experts, literature reviews, and field observations. It determined five dimensions and 52 attributes, as listed in Table 2.

Every attribute in the ordinal scale is evaluated to determine continuity at each dimension, yielding a score ordinally from 0 (bad) to 3 (good) based on the survey field. Furthermore, analysis coordination with MDS is used to determine the sustainability status of each dimension in scale index continuity. In essence, determination attributes are sensitive at each dimension analysed with leverage analysis. Plot the attribute's mark Root Mean Square (RMS) on the x-axis. An increase in the RMS value reflects an increasing sensitivity in recognising one's role in supporting continuity. Meanwhile, Monte Carlo analysis was used to consider dimension uncertainty, with a level of 95% confidence. The index value of the Monte Carlo, compared to the MDS index, S-Stress value, and coefficient  $R^2$ , serves to identify the need for additional attributes and reflect accuracy dimensions, namely what is being explored with circumstances. Note that a low S-Stress value indicates a good fit. Following this scale index, continuity has a dimension interval of 0% to 100%.

Table 1: Details of respondent characteristics in research

No.	Occupation	Total
1.	Samosir Regency Agriculture Office	1
2.	Cooperatives, Industry and Trade Office	1
3.	Village Head	1
4.	Exporter	1
5.	Middleman	1
6.	Coffee shop owner	1
7.	Roastery	1
8.	Village Secretary	1
9.	Farmer	27
<b>Total</b>		<b>35</b>

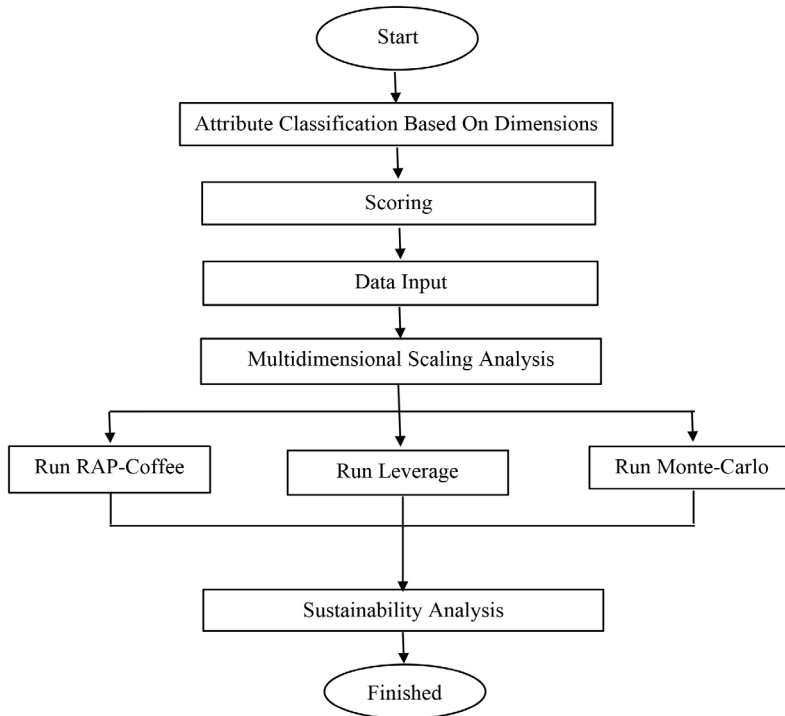


Figure 1: Stages and methods analysis sustainability of Arabica coffee in the Samosir Regency

Table 2: Variable study

Dimensions	Attribute
Ecology/Environment	1. Control pests and diseases in coffee plants 2. Use fertiliser 3. Procurement plant shade 4. Conservation actions taken 5. Disposal waste 6. Utilisation and processing of waste 7. Intensity attack pest disease 8. Understanding farmers to conservation land and water 9. The size of the farmer’s coffee land 10. Conformity land used for coffee plant 11. Understanding farmers to adaptation and mitigation change climate
Economy	1. Income besides coffee cultivation 2. Condition price input materials 3. Coffee commodity prices 4. Marketing results in coffee farming seen from scope base 5. Eligibility of business coffee farmers against income 6. Origin of business capital farmer 7. Stability price selling coffee 8. Added value coffee processing 9. Production and productivity from coffee cultivation 10. Subsidies obtained 11. Independence economy local

Social	<ol style="list-style-type: none"> <li>1. Knowledge about sustainable community coffee farming</li> <li>2. Frequency conflict</li> <li>3. Farmer’s formal education level</li> <li>4. Liveliness in group farmer</li> <li>5. Views of coffee farming</li> <li>6. Family member participation in coffee farming</li> <li>7. Education and accessibility communication farmer</li> <li>8. Relationship level farmer with perpetrator marketing</li> <li>9. Age level farmer</li> </ol>
Institutional	<ol style="list-style-type: none"> <li>1. Intensity counselling farming is carried out</li> <li>2. Ownership group farmer of legal entities</li> <li>3. Role institution finance</li> <li>4. Role institution private</li> <li>5. Facilities and infrastructure adequate transportation</li> <li>6. Existence group farmer</li> <li>7. Role service related</li> <li>8. Role association related</li> <li>9. Facility institutions production and control pests as well as nursery</li> <li>10. Institutional or business/service entities in the input and output fields</li> </ol>
Technology	<ol style="list-style-type: none"> <li>1. Use seeds of the coffee plant</li> <li>2. Coffee harvesting</li> <li>3. Internal water content coffee beans</li> <li>4. Storage coffee beans</li> <li>5. Implementation of technology shade and intercropping</li> <li>6. Mastery and application of coffee GAP</li> <li>7. Existence and use of machine cultivation agriculture</li> <li>8. Mastery and application of coffee GHP</li> <li>9. Coffee pruning</li> <li>10. Coffee drying</li> <li>11. Coffee processing</li> </ol>

Table 3: Category index and sustainability status

Index Value	Sustainability Status
0.00-25.00	Not sustainable
25.01-50.00	Not sustainable
50.01-75.00	Enough sustainable
75.01-100.00	Sustainable

Source: Purwaningsih & Santosa, 2015.

## Results And Discussion

### *Sustainability Analysis Based on Dimensions*

The results of the sustainable status ordination analysis are compiled as an aggregate of analysis units based on the perceived value of each attribute based on the opinions of related stakeholders. The horizontal axis suggests the

difference in continuous status in the ordination of bad (0%) to good (100%) for each dimension analysed. In contrast, the vertical axis presents the difference in attribute scores between the relevant stakeholders analysed.

**Ecological Dimensions of Sustainability**

The ecological dimension or environmental dimension consists of eleven attributes for sustainability analysis. Ecological dimension attributes, namely (1) control of pests and plant diseases in coffee, (2) use of fertiliser, (3) procurement of shade plants, (4) conservation actions taken, (5) waste disposal, (6) waste utilisation and processing, (7) intensity of pest and disease attacks, (8) farmers’ understanding of land and water conservation, (9) farmer’s land area, (10) suitability of land used for coffee plants, and (11) farmers’ understanding of climate change adaptation and mitigation.

The results of the ordination analysis of the sustainability status of coffee based on MDS using the RAP-Coffee Approach on the ecological dimension in the research location area presented an average score of 57.26 or in the entirely sustainable category based on 11 research attributes. Note that all ecological dimension factors are assessed using specific criteria with a rating range from the sustainable category with a scale of 3, entirely sustainable with a scale of 2, less sustainable with a scale of 1, and the unsustainable category with a scale of 0.

To observe an overview of the most sensitive attributes that influence business leverage, leverage analysis is calculated based on the standard error of the difference between the scores and those obtained without the

attributes. Based on the results of the leverage analysis, at least three attributes are most sensitive: Waste utilisation and processing, fertiliser use, and farmers’ understanding of climate change adaptation and mitigation. Notably, changes in rain and dry patterns have an impact on agriculture. As such, changes in rain and dry patterns are the impact of climate change. In line with this, cropping patterns using an agroforestry system are a solution that can reverse abiotic and biotic stress as a result of seasonal changes and climate change (Yusuf *et al.*, 2022a). Furthermore, many smallholder farmers in North Sumatra cultivate coffee without being accompanied by protective plants, which protect coffee plants from pest attacks and direct heat from the sun (Saragih, 2018). Climate change is occurring as a result of farmers’ use of chemical fertilisers. Another impact of using chemical fertilisers is the occurrence of soil erosion. Consequently, the topsoil of the soil will become thin, and the microorganisms in the soil cannot help the growth of coffee plants since the microorganisms in the soil have been damaged (Fajar *et al.*, 2023).

Many coffee farmers in North Sumatra still do not utilise and process waste properly. Coffee waste in the environment can harm aquatic life and humans as it contains a chemical that can destroy Deoxyribonucleic Acid (Fernandes *et al.*, 2017). Therefore, it is essential to use coffee

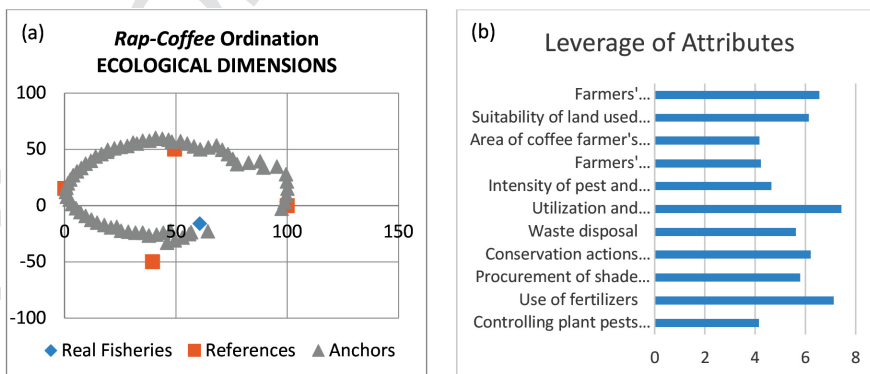


Figure 2: (a) Ecological dimension sustainability index; (b) Analysis of the attributes that most sensitively influence the sustainability of the ecological dimension

waste to reduce its impact on human health and the environment, for example, as fertilisers, absorbents for the extraction of dyes and heavy metals from aqueous solutions, production of fuel pellets or briquettes, substrates for biogas, and bioethanol or biodiesel production. This also includes composting materials, the production of reusable cups, substrates for mushroom production, sources of natural phenolic antioxidants, and others (Blinová et al., 2017).

**Economic Dimensions of Sustainability**

The economic dimension has eleven attributes, including (1) income other than coffee cultivation, (2) price conditions for input materials, (3) coffee commodity prices, (4) marketing of coffee farming products observed from the essential scope, (5) feasibility of coffee farming for income, (6) origin of farming capital, (7) stability of selling prices, (8) added value of coffee processing, (9) production and productivity from coffee cultivation, (10) subsidies obtained; and (11) local economic independence.

The coffee sustainability status ordination analysis result based on MDS using the RAP-Coffee Approach on the economic dimension in the research location area demonstrates an average score of 51.63 or in the entirely sustainable category based on 11 research attributes. Consequently, all ecological dimension factors are assessed using specific criteria with a rating range from the sustainable

category with a scale of 3, entirely sustainable with a scale of 2, less sustainable with a scale of 1, and the unsustainable category with a scale of 0.

Furthermore, leverage analysis is conducted to obtain an overview of the most sensitive and influential attributes. In particular, leverage analysis is calculated based on the standard error of the difference between the score and the score attribute obtained without the attribute. At least three attributes are most sensitive based on the results of the leverage analysis, namely, input price conditions, stability of coffee selling prices and added value of coffee processing. The price of Arabica coffee can fluctuate, which is influenced by the quality of the Arabica coffee itself. If the coffee is of poor quality, the price of coffee will decrease and vice versa. Apart from that, increased coffee prices are also influenced by increased demand for Arabica coffee, both nationally and globally (Parmawati et al., 2022).

**Social Dimensions of Sustainability**

The social dimension has nine attributes, including (1) knowledge about sustainable community coffee farming, (2) frequency of conflict, (3) level of farmer’s firm education, (4) activeness in farmer groups, (5) views on satanic coffee, (6) participation of family members in coffee farming, (7) farmer communication outreach and accessibility, (8) the level of relationship between farmers and marketing actors, and (9) farmer age level.

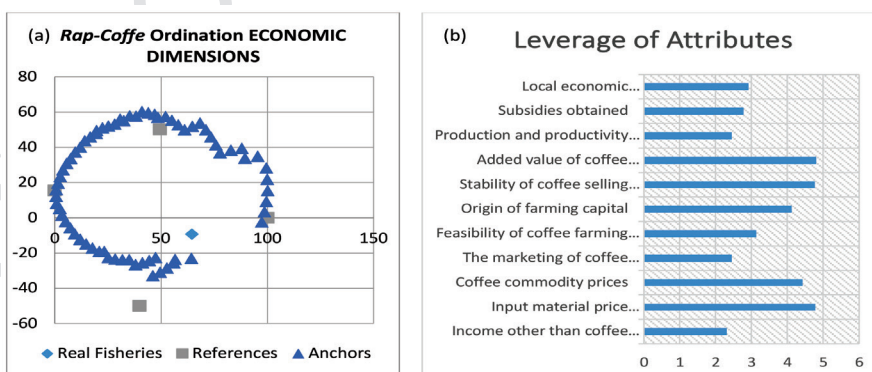


Figure 3: (a) Economic dimension sustainability index; (b) Analysis of the most sensitive attributes influencing the sustainability of the economic dimension

The results of the ordination analysis of the sustainability status of coffee based on MDS using the RAP-Coffee Approach on the economic dimension in the research location area indicated an average score of 61.31 or in the entirely sustainable category based on 11 research attributes. Correspondingly, all ecological dimension factors are assessed using specific criteria with a rating range from the sustainable category with a scale of 3, entirely sustainable with a scale of 2, less sustainable with a scale of 1, and the unsustainable category with a scale of 0.

Based on the results of the leverage analysis, there are at least three most sensitive attributes, namely, participation of family members in coffee farming, extension and accessibility of farmer communication, and frequency of conflict. The social influence on coffee sustainability is influenced by the social dimension. Building on this, the social dimension plays a vital role in the information obtained by farmers and the energy needed by farmers to manage Arabica coffee plants (Klarin, 2018). For instance, coffee farmers in Samosir Regency join farmer groups. Through these farmer groups, farmers discuss how they can manage Arabica coffee commodities in the area. According to Syarifatullah *et al.* (2022), farmer groups that are running well will inform farmer group members regarding the management of Arabica coffee, which must be conducted by farmers who manage smallholder plantations.

**Sustainability of Institutional Dimensions**

The institutional dimension has ten attributes, including (1) The intensity of agricultural extension carried out, (2) ownership of farmer groups as legal entities, (3) the role of financial institutions, (4) role of private institutions, (5) adequate transportation facilities and infrastructure, (6) existence of farmer groups, (7) the role of related agencies, (8) the role of related associations, (9) institutions for production and pest control facilities and nurseries, and (10) institutions or service business entities in the field of input and output.

The results of the ordination analysis of the sustainability status of coffee based on MDS using the RAP-Coffee Approach on the economic dimension in the research location area demonstrated an average score of 51.90 or in the entirely sustainable category based on 11 research attributes. Notably, all ecological dimension factors are assessed using specific criteria with a rating range from the sustainable category with a scale of 3, entirely sustainable with a scale of 2, less sustainable with a scale of 1, and the unsustainable category with a scale of 0. Based on the results of the leverage analysis, there are at least three most notable attributes. Sensitive, namely, the intensity of agricultural extension conducted, institutions for production facilities and pest control, and institutions and business/service entities subject to input.

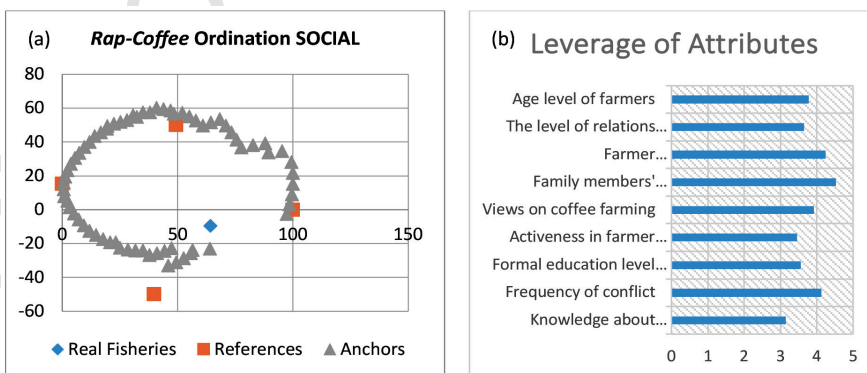


Figure 4: (a) Social dimension sustainability index; (b) Analysis of the attributes that most sensitively influence the sustainability of the social dimension

The intensity of agricultural extension is the most sensitive attribute for sustainability in the institutional dimension. Since the location is far away, the counselling provided by the local office is not intense. In addition, only some farmers are present during agricultural extension activities, which is also why agricultural extension is not intensely implemented. Therefore, there is a need for cooperation between traditional leaders or local policymakers to coordinate to increase farmers' attendance to attend extension services.

The following sensitive attributes are the institution of production facilities, pest control, and business/service entities. Institutions play a vital role in supporting coffee agribusiness sustainability. However, there are no related institutions in the research location. Farmers only depend on a few people who are considered to have control and significant capital to provide production advice and pest control. Consequently, it is a serious concern for several parties to create sustainability in Arabic coffee in Samosir. Thus, establishing relevant institutions will help farmers produce the best quality coffee. For example, the existence of coffee farmer cooperatives in several villages in Indonesia has provided training on sustainable agricultural practices. This helps farmers improve their understanding of land conservation and post-harvest techniques. In addition, cooperative members demonstrate much better economic performance than their non-member counterparts, and non-members

will perform even better economically if they join cooperatives (Mojo *et al.*, 2017). The following includes the expectation from the establishment of related institutions in Samosir.

Institutions have a much-needed role in managing Arabica coffee from upstream to downstream. In this way, institutions can conduct training and extension activities to develop farmers' human resources (Hendri *et al.*, 2021). Apart from that, farmers can also obtain capital and input from institutions. Note that each institution has a different management system, which is expected to help smallholder farmers (Ratna *et al.*, 2023).

### Sustainability Dimensions of Technology

The technology dimension consists of eleven attributes, including (1) use of coffee plant seeds, (2) coffee harvesting, (3) water content in coffee beans, (4) coffee bean storage, (5) application of shade and intercropping technology, (6) mastery and application of coffee Good Agriculture Practice (GAP), (7) the existence and use of agricultural cultivation machines, (8) mastery and application of coffee Good Handling Practice (GHP), (9) coffee pruning, (10) coffee drying, and (11) coffee processing.

The coffee sustainability status ordination analysis results based on MDS using the RAP-Coffee Approach on the economic dimension in the research location area indicated an average score of 50.08 or in the entirely sustainable

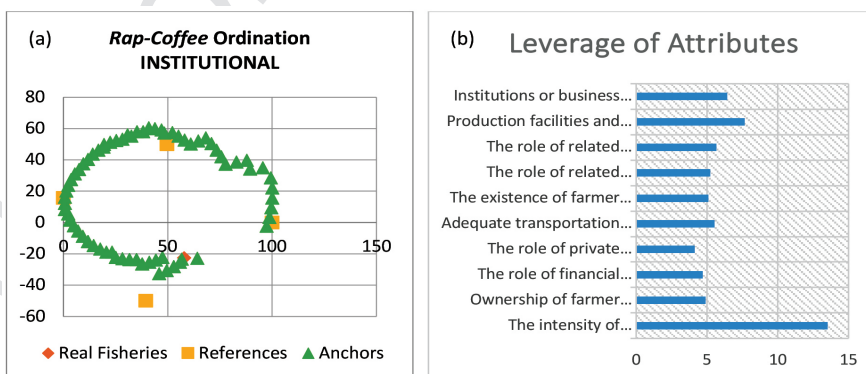


Figure 5: (a) Institutional dimension sustainability index; (b) Analysis of the attributes that most sensitively influence the sustainability of institutional dimensions

category based on 11 research attributes. Accordingly, all ecological dimension factors are assessed using specific criteria with a rating range from the sustainable category with a scale of 3, entirely sustainable with a scale of 2, less sustainable with a scale of 1, and the unsustainable category with a scale of 0. Based on the results of the leverage analysis, there are at least three most notable attributes: The use and application of GAP, coffee processing, and the use and application of GHP.

The use and implementation of GAP is the most sensitive attribute in this dimension. However, the coffee cultivation technology farmers have implemented and run has not fully implemented GAP. Note that the harvest highly depends on using seeds and the cultivation process. Meanwhile, coffee production activities conducted by Samosir farmers mainly include maintenance activities, such as fertilisation, pruning, spraying, and harvesting. Furthermore, the age of the farmers' coffee plants is also over eight years, which will cause a decrease in productivity and coffee production. Thus, implementing GAP must be performed to ensure no decrease in harvest yields. By following GAP, farmers can improve and optimise the use of resources that can manage pests and diseases effectively, resulting in a more efficacious and fragrant Arabica coffee harvest.

In addition, in post-harvest handling, applying GHP by utilising post-harvest technology and related agricultural equipment

can maintain the quality of the coffee produced. Consequently, technological innovation in agriculture is crucial in increasing yields, especially in developing countries (Mohammed, 2018).

Considering this perspective, increasing the sustainability of Arabica coffee must occur; what farmers can do is continue to innovate in conducting Arabica coffee cultivation activities or post-harvest management. Moreover, the selection of quality seeds will also influence the production and productivity of Arabica coffee plants. If quality seeds are used, Arabica coffee production and productivity will increase (Sunanto *et al.*, 2019).

The kite diagram of sustainability analysis presents that the dimension with the highest sustainability index value is the social dimension at 61.31. This is followed by the ecological dimension at 57.26, the institutional dimension at 51.90, the economic dimension at 51.63, and the technological dimension at 50.08. The five dimensions analysed are pretty sustainable. This suggests that although the five dimensions are entirely sustainable categories, they have different analysis figures.

Improvement and development are necessary for every dimension. Accordingly, increasing and developing overall dimensions will support the level of coffee sustainability to ensure that the sustainable category will increase to sustainable. In particular, each sensitive

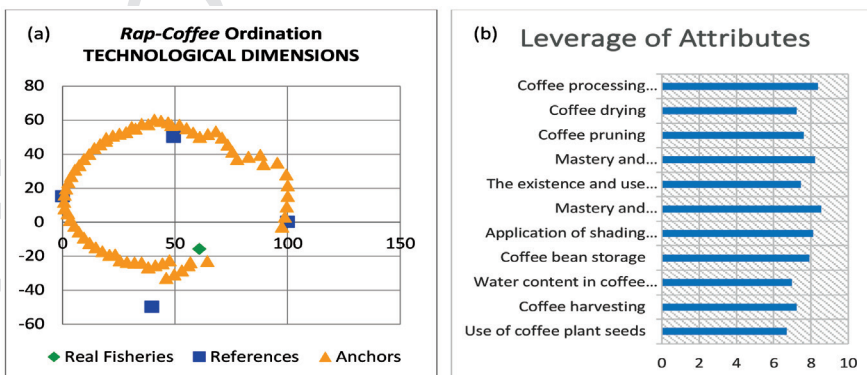


Figure 6: (a) Technology dimension sustainability index; (b) Analysis of the attributes that most sensitively influence the sustainability of the technological dimension

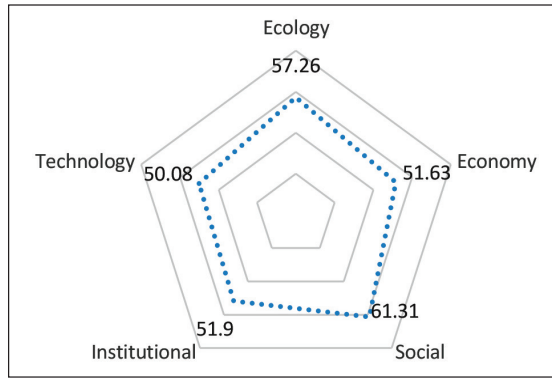


Figure 7: Flyover diagram of the sustainability status of Arabica coffee in Samosir Regency

attribute in a dimension has the opportunity to optimise that or other dimensions. Additionally, to continue to encourage coffee sustainability in Samosir Regency, cooperation and a holistic and comprehensive approach are required from all levels involved. Moreover, the sustainability of Arabica coffee can also be impacted by hazards like deforestation, market volatility, and climate change. Hence, coffee farmers must adopt climate-adaptive agricultural mitigation techniques to be sustainable (Hasibuan *et al.*, 2023).

**Monte Carlo Analysis**

Monte Carlo analysis assessed the dimensions of uncertainty in the MDS. The RAP-Coffee model has been employed in this research. Note that the level of confidence in this research is 95%. As a result, the MDS analysis results are adequate and valid. The following is a table of differences in sustainability indices between RAP-Coffee and Monte Carlo.

The results of the comparative analysis of the Monte Carlo analysis with 25 repetitions of the Scatter Plot method for each dimension and MDS can be observed in the table above. Overall, the resulting difference between the two analyses can be deemed valid and adequate. The slight difference in the value of the sustainability status of the analysis of the two methods indicates that the error in scoring each attribute score is relatively small. Meanwhile, the variation caused by differences in opinion is relatively small, the analysis process conducted repeatedly presents relatively stable, and errors in data entry and missing data can be avoided.

The assessment of accuracy (Goodness of Fit) in MDS is determined by the resulting S-Stress value. A good model is indicated by a stress value of < 0.25 and an R<sup>2</sup> or RSQ value close to 1. The results of the accuracy analysis are summarised in the table above. Overall, the S-Stress value in this research is < 0.25. Thus, it can be concluded that the model has been

Table 4: Differences in Sustainability Index between RAP-Coffee and Monte Carlo

Dimensions	MDS	Monte Carlo	Difference
Ecology	57.26	56.87	0.39
Economy	51.63	50.67	0.96
Social	61.31	60.97	0.34
Institutional	51.90	51.12	0.78
Technology	50.08	49.76	0.32

Source: Processed data, 2024.

Table 5: Statistical Parameters (*Goodness of Fit*) from Sustainability Status Analysis

Dimensions	S-Stress	RSQ	Iterations
Ecology	0.12	0.87	2
Economy	0.18	0.91	2
Social	0.16	0.89	2
Institutional	0.14	0.84	2
Technology	0.19	0.90	2

Source: Processed data, 2024.

prepared well and can be utilised to analyse the accuracy of the sustainability of the coffee business.

### Limitation of Study

This study has limits, although it offers valuable insights into the sustainability of Arabica coffee cultivation. Several limitations must be acknowledged. First, the sample size is relatively small, with only 35 farmers and eight stakeholders. Consequently, the study results cannot be generalised to the entire region beyond the study sites. Second, the study is limited to a small area in North Sumatra, Samosir Regency. Therefore, it may overlook practices and problems or challenges faced by Arabica coffee farmers in other locations. Moreover, neglecting specific facets of sustainability, such as a longitudinal viewpoint, may hinder the study's comprehension of temporal variations in agricultural practices or market dynamics. Hence, to thoroughly address these limitations, future research should expand geographic coverage, employ a longitudinal approach, and use mixed methods for data collection.

### Conclusions

The sustainability analysis of Arabica coffee in Samosir Regency, North Sumatra, was conducted based on five dimensions. In particular, the ecological dimension (57.26) indicates full sustainability, with sensitive attributes such as waste utilisation, fertiliser use, and farmers' understanding of climate change. Furthermore, the economic dimension (51.63)

is fully sustainable, with sensitive attributes related to input prices, coffee price stability, and the added value of coffee processing. Meanwhile, the social dimension (61.31) is fully sustainable, with sensitive attributes concerning family participation, farmer communication, and conflict frequency. At the same time, the institutional dimension (51.90) also suggests full sustainability, with sensitive attributes related to agricultural extension, production facilities, and pest control institutions. Conversely, the technological dimension (50.08) is relatively sustainable, with sensitive attributes regarding applying GAP, coffee processing, and using GHP. Overall, this analysis suggests that the Arabica coffee sector in Samosir has a good level of sustainability, although some areas require further attention. The Goodness of Fit assessment, which is  $< 0.25$ , indicates that the model is well-constructed and can be used to analyse the accuracy of the sustainability of the coffee business.

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### Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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