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Determining Factors for the Sustainability of Arabica Coffee-based Eco-farming in Sembalun, Indonesia

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Authors' contributions

This work was carried out in collaboration among all authors. Author NP designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Author LS and Tajidan supervised the research analysis, provided guidance, and revised sections as necessary. All authors read and approved the final manuscript.

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ABSTRACT

The sustainability of eco-farming based on Arabica coffee in Sembalun, West Nusa Tenggara, Indonesia is influenced by various environmental, economic, social, cultural, institutional, and technological factors. Arabica coffee, known for its high quality, has become an important commodity for farmers and the local economy. However, challenges in implementing sustainable agricultural practices, such as excessive pesticide use and limited knowledge, hinder the adoption of eco-farming. This research adopts a combined qualitative and quantitative approach to evaluate the factors affecting sustainability. The results indicate that improvements in land management and waste disposal, educational and social support for farmers, as well as the active role of women

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farmer groups and community organizations, are crucial for achieving effective sustainability. It is hoped that these findings will provide practical recommendations to enhance eco-farming systems and support sustainable development goals, as well as the welfare of farmers in Sembalun.

Keywords: Ecology; economy; factors; institutional; sustainability; socio-cultural; technology.

1. INTRODUCTION

Arabica coffee (*Coffea arabica*) is one of the key commodities in the plantation sector, playing an essential role as a source of national revenue of Indonesia. Additionally, coffee is a significant source of income for coffee farmers in Indonesia [1]. Known for its smooth flavor, balanced acidity, and rich aroma, Arabica coffee has become the preferred choice for coffee enthusiasts worldwide. Sembalun, a region situated on the slopes of Mount Rinjani, West Nusa Tenggara, has a reputation for producing high-quality Arabica coffee. Based on physical and sensory testing data published by Puslitloka [2], Arabica coffee from Lombok achieved a taste score of 82.25%. This score indicates that Sembalun coffee is of excellent quality, classifying it as "Grade Excellent" [3].

In recent years, sustainability issues have become a growing concern in the coffee industry, including in the Sembalun region. Sustainability here encompasses environmental, economic, and social aspects that are interrelated and impact the continuity of coffee farming in the area. The challenge of measuring environmental sustainability in agriculture and monitoring progress toward more sustainable farming systems lies in the need to integrate various indicators at relevant spatial scales [4]. Sustainable agricultural practices are encouraged as part of a strategy to address environmental degradation caused by intensive farming, including practices such as setting aside or restoring parts of farmland to allow it to return to a natural state. This approach is essential to preserve biodiversity and maintain ecosystem health [5]. One approach considered effective in addressing these sustainability challenges is eco-farming. Eco-farming is a strategy that combines environmentally friendly farming practices with efficient resource use [6]. It emphasizes wise use of natural resources, reduction in chemical inputs, and protection of the local ecosystem.

However, implementing eco-farming in Sembalun faces several challenges that impact its success. Unsustainable farming practices, such as excessive use of pesticides and chemical fertilizers, can harm soil fertility and threaten local ecosystems. Additionally, social challenges also influence the success of eco-farming in Sembalun. Limited land availability, restricted access to agricultural education and training, and longstanding traditional farming practices hinder farmers from transitioning to more environmentally friendly and efficient eco-farming practices [7-11]. Conservative mindsets, coupled with a lack of information about the benefits of eco-farming, often make farmers hesitant to adopt new innovations. They may feel more comfortable with traditional methods and may be wary of change, especially if the risk of failure is perceived to be high.

Therefore, a comprehensive approach is required—one that not only provides new knowledge and skills but also supports the social changes needed to encourage farmers to shift to more sustainable farming systems. In this context, it is important to identify and analyze the factors that determine the sustainability of Arabica coffee-based eco-farming in Sembalun. This study aims to delve into the environmental, economic, socio-cultural, institutional, and technological aspects influencing the sustainability of eco-farming in the region. This comprehensive analysis includes an evaluation of the farming practices employed by local farmers, their impact on the environment and production, and the potential for adopting new technologies and innovations that can support sustainability.

This research will also consider the role of government, non-governmental organizations (NGOs), and the private sector in supporting eco-farming sustainability through policies, training programs, and enhanced access to markets and technology. The findings of this study are expected to reveal effective strategies for enhancing the sustainability of Arabica coffee-based eco-farming in Sembalun. These findings will not only contribute to the scientific literature but also offer practical recommendations for stakeholders at both local and national levels. Thus, these efforts are expected to support the achievement of sustainable development goals

(SDGs), particularly in terms of sustainable agricultural practices, environmental conservation, and the improvement of coffee farmers' welfare in Sembalun.

2. MATERIAL AND METHODS

This study employs a mixed-method approach, combining both qualitative and quantitative methods. This choice of methodology is based on the complementary strengths of these two approaches, which allow researchers to obtain results that are objective, structured, measurable, as well as in-depth and accurate. By using this approach, researchers gain a better understanding of the context and characteristics of Arabica coffee farming in Sembalun, East Lombok. The analysis focuses on Arabica coffee farming, encompassing the entire production process from planting to harvest. The research was conducted over two months in Sembalun, involving 60 farmers selected through random sampling to minimize bias and ensure representative results. The data consists of primary data gathered through interviews and questionnaires with farmers, as well as secondary data from existing literature. Data collection was carried out through in-depth interviews and documentation, enabling a thorough exploration of the sustainability of eco-farming practices. Data analysis was conducted using Multi-Aspect Sustainability Analysis (MSA) to assess various dimensions of sustainability.

3. RESULTS AND DISCUSSION

The sustainability of an agricultural system, including coffee farming, is greatly influenced by the underlying attributes within each dimension of sustainability analysis. To achieve effective sustainability in the future, it is essential to identify and improve any weak attributes within each dimension, including ecological, economic, socio-cultural, institutional, and technological aspects. By intervening and making improvements in these attributes, it is expected that the sustainability status of each dimension can be significantly enhanced. This effort will not only support the continuity of farming but also contribute to community welfare and environmental preservation, thereby creating a more balanced and sustainable ecosystem.

3.1 Determinants of Ecological Sustainability

The sustainability analysis of the ecological dimension employs Multi-Criteria Sensitivity Analysis (MSA) to evaluate the variables affecting the sustainability of Arabica coffee cultivation. Each variable is assessed based on its sensitivity level, indicating the impact of changes on the ecological environment.

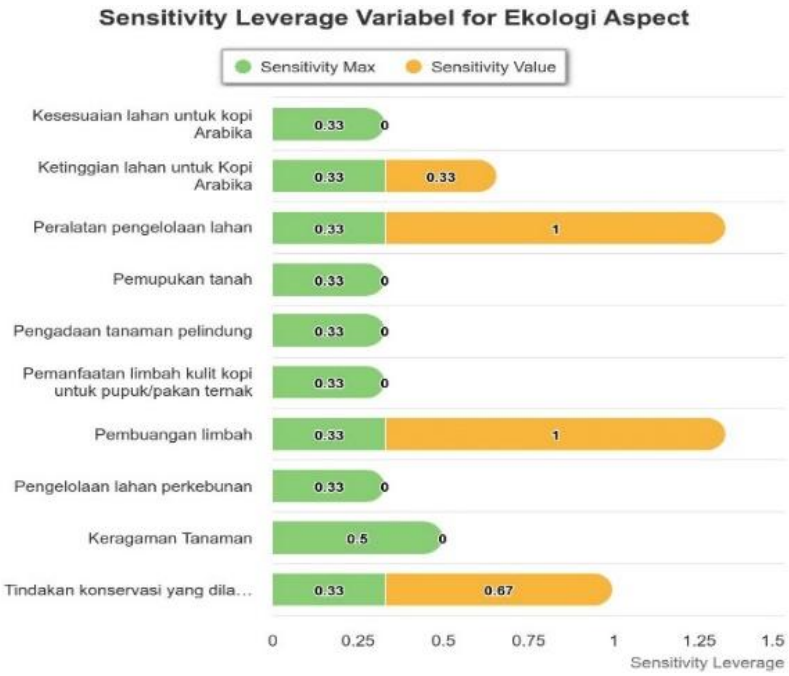

Fig. 1. Leverage sensitivity variables for the ecological dimension

The analysis results indicate that the attributes requiring improvement include land management tools and waste disposal, both with a sensitivity value of 1.0, highlighting the need for more efficient, eco-friendly equipment and better waste management methods. Land conservation shows a sensitivity value of 0.67, emphasizing the importance of practices that maintain soil quality. Elevation also plays a significant role, with a sensitivity value of 0.33, indicating that planting Arabica coffee at appropriate elevations supports quality yields. On the other hand, land suitability, soil fertilization, and shade tree provision show no sensitivity (value of 0), suggesting that these aspects are currently optimal. Overall, this analysis underscores the strong influence of land management equipment and waste disposal on the ecological dimension, while other variables have minimal impact.

3.2 Determinants of Economic Sustainability

The economic sustainability analysis is crucial for understanding how economic activities can continue over the long term without compromising ecosystem balance and social well-being. This analysis focuses on assessing resource use and investment that contribute to sustainable economic growth. The evaluation considers not only short-term financial gains but also the long-term impact on economic stability and the environment.

The Leverage Sensitivity analysis results for the economic dimension reveal that the most critical variables are market size and dependence on third parties, both with a sensitivity value of 1.0. This indicates that changes in these two attributes can significantly impact the overall economic dimension. Expanding the coffee market and reducing dependence on third parties through the development of marketing networks and farmer training are therefore essential. Additionally, improving market access and product diversification, with a sensitivity value of 0.5, is also necessary. Meanwhile, variables such as subsidies and government support show no sensitivity, indicating that current subsidy levels have a negligible impact due to a stable system.

3.3 Determinants of Socio-Cultural Sustainability

The socio-cultural sustainability analysis focuses on assessing how practices and changes in the community influence social and cultural aspects sustainably. This includes evaluating the impact of policies, projects, and initiatives on

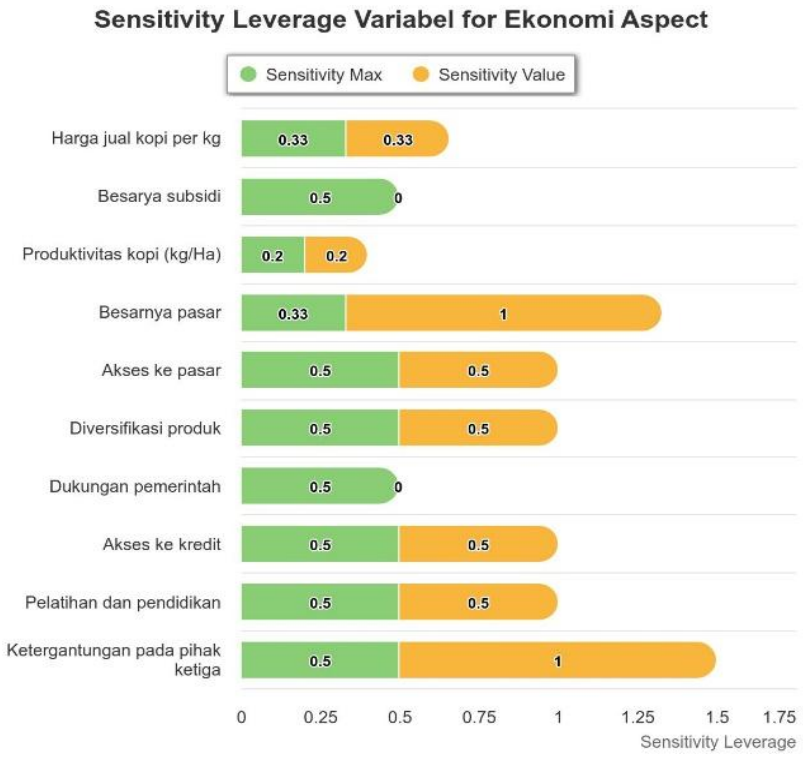

Fig. 2. Leverage sensitivity variables for the economic dimension

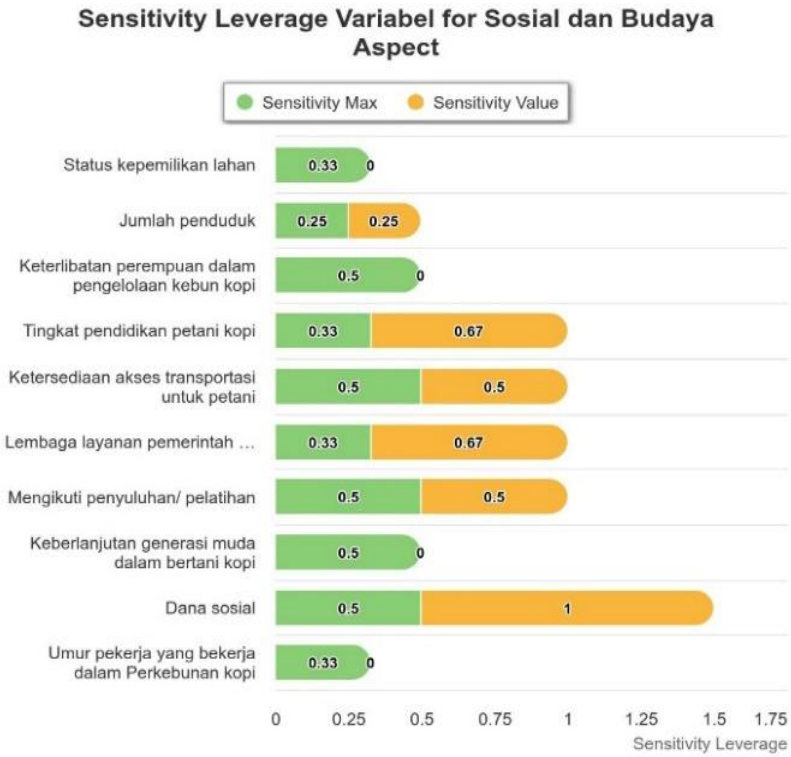

Fig. 3. Leverage sensitivity variables for the socio-cultural dimension

social structures, cultural norms, and interpersonal interactions. Sustainability involves not only preserving traditional values but also adapting to changing times to strengthen social cohesion and respect cultural diversity.

In the context of Arabica coffee farming management, the analysis results indicate that social funds are the most sensitive attribute, significantly contributing to the well-being of the farming community. In addition, farmers' education levels and access to transportation are also important, with education contributing to productivity and market access. While female involvement has high potential, its current impact remains minimal. Land ownership status and worker age have minimal impact, while population density contributes to social dynamics but also poses challenges in resource management. Therefore, improving education, transportation access, and social fund management should be key focus areas in policy development within the Arabica coffee sector to support long-term sustainability.

3.4 Determinants of Institutional Sustainability

The institutional sustainability analysis evaluates the effectiveness and resilience of institutions in supporting long-term goals. This aspect encompasses the ability of institutions to manage resources, adapt to environmental changes, and maintain integrity and credibility.

Fig. 4 illustrates the sensitivity of several institutional variables. Women's farming groups have the highest sensitivity (0.5) in coffee farming sustainability due to their significant role in production and household economy. Targeted support, such as training and resource access, strengthens the independence of these groups. Group savings, with a sensitivity of 0.75, play a key role as a source of capital. Business and marketing institutions have high sensitivity (0.5) in operations and market access. Group meetings (0.5) strengthen communication and social bonds, while institutional legality and influence indicate stability (0.33). Institutional conflicts, although present, remain stable (0.33), showing minimal impact. Overall, group savings and marketing institutions are crucial to the sustainability of farmer groups.

3.5 Determinants of Technological Sustainability

The technological sustainability analysis focuses on the role of technology in supporting long-term sustainability. This evaluation includes assessing

technology's contribution to improving efficiency, safety, and reducing negative environmental impacts. The technology applied is expected to optimize resource use and enhance quality of life. Additionally, the analysis considers challenges in adopting new technologies and mitigation strategies to maintain their integrity and sustainability.

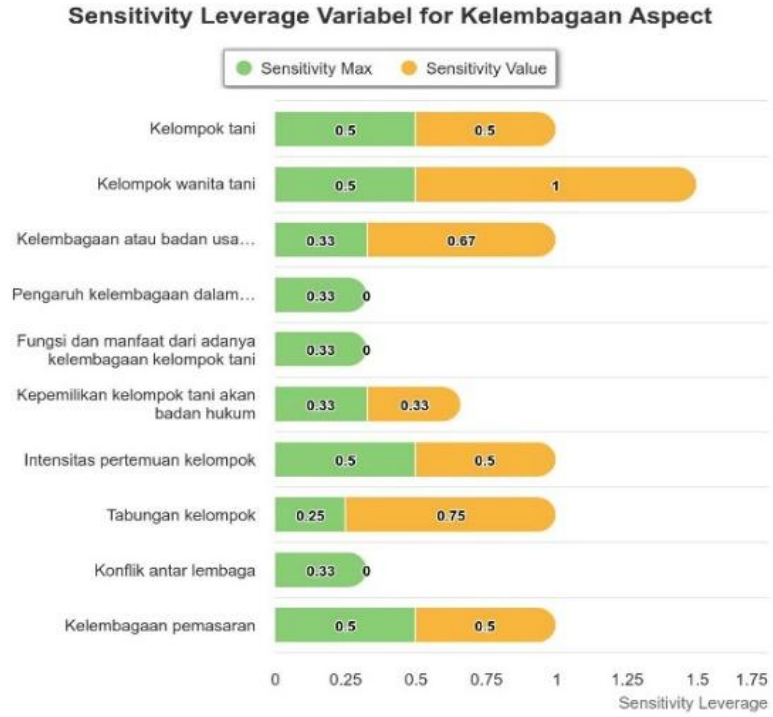

Fig. 4. Leverage sensitivity variables for the institutional dimension

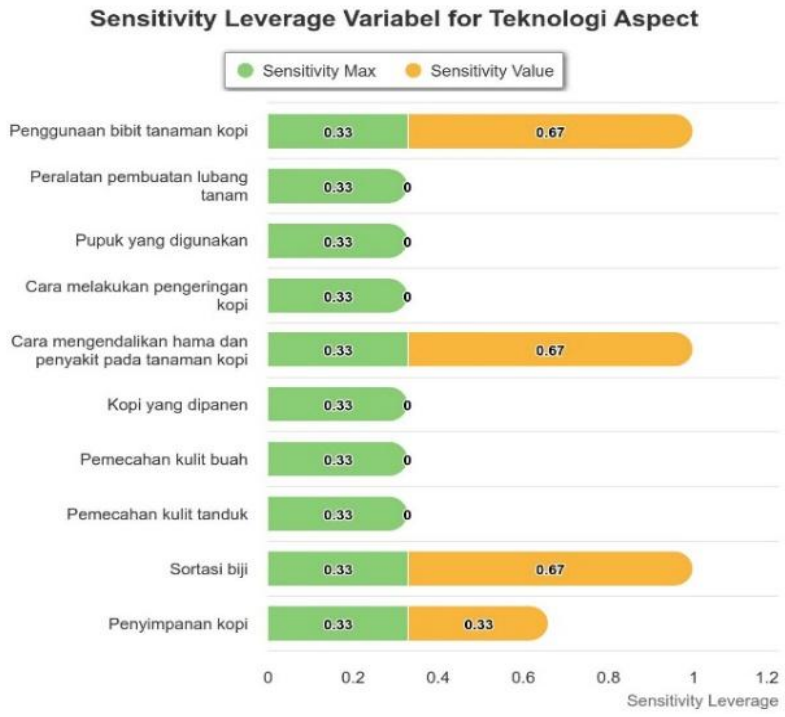

Fig. 5. Leverage sensitivity variables for the technological dimension

According to Fig. 5, the analysis highlights several technological variables in Arabica coffee sustainability in Sembalun, East Lombok. Variables such as the use of quality seedlings, pest and disease control, and coffee bean sorting processes show high sensitivity (0.67) to sustainability. Superior seedlings are essential as they contribute to plant resilience against pests and diseases and boost productivity. The government and stakeholders need to provide farmers with easy access to quality seedlings, for example, through subsidized distribution programs. Education on seedling and maintenance techniques should also be promoted. Environmentally friendly pest and disease control methods, such as organic pesticides, should be prioritized to reduce negative environmental impacts. The government can provide training and incentives for farmers who adopt safer control methods, and support for pest control facilities and materials is also needed to enable farmers to implement learned methods.

The coffee bean sorting process is crucial for ensuring final product quality. Enhancing this process can be achieved by providing modern sorting equipment and training in sorting techniques. Subsidies or low-interest loans for equipment purchases would greatly assist farmers in improving coffee quality to meet international market standards and strengthen their competitiveness. Other variables, such as planting hole equipment, fertilizer, drying, and skin removal, show no significant sensitivity (value of 0), indicating that these practices are already optimal. However, coffee storage has a fairly high sensitivity (0.33), indicating that proper storage is essential for maintaining coffee quality and quantity.

4. CONCLUSION

Based on the research findings, it can be concluded that the sustainability of Arabica coffee cultivation is influenced by various dimensions, each with different levels of sensitivity. From an ecological perspective, land management equipment and waste disposal practices have a significant impact on ecological sustainability, necessitating improvements and innovations to reduce negative environmental effects. In the economic dimension, factors such as market size and dependence on third parties are key elements affecting economic sustainability. Meanwhile, the social and cultural dimension indicates that social funding support, farmer education, and transportation access are critical components for supporting the well-being of the farming community. The institutional dimension highlights the importance of the role of women's farming groups and institutional mechanisms in ensuring long-term sustainability. Finally, the technological dimension emphasizes the importance of high-quality technology in sustainable coffee production, particularly in selecting superior seeds, implementing environmentally friendly pest control, and optimizing the sorting process to maintain product quality and support environmental resilience.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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