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Sustainability Evaluation of Robusta Coffee Farming in Malinau Regency Using the Sustainable Livelihood Framework

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Abstract: Robusta coffee cultivation in Malinau Regency has been increasingly associated with forest land conversion, thereby intensifying the need for sustainable management practices that align with both environmental conservation and rural livelihood enhancement. To evaluate the sustainability of Robusta coffee farming systems, the sustainable livelihood framework was applied, focusing on five key livelihood capitals: natural, human, social, physical, and financial. A mixed-methods approach involving Multidimensional Scaling (MDS) and thematic analysis was employed to quantify sustainability levels and identify leverage points for strategic intervention. Results indicated that most capitals were classified as either "unsustainable" or "less sustainable." Social capital demonstrated the lowest performance, with an index of 15.10, while financial capital followed at 20.88; both were categorized as "unsustainable." Natural capital (26.13) and human capital (26.09) were deemed "less sustainable," whereas physical capital showed relatively higher resilience with an index of 46.61, though still within the "less sustainable" threshold. Key constraints included insecure land tenure, underdeveloped infrastructure, limited social cohesion, and economic dependence on non-coffee income sources. Strategic interventions were proposed, including the certification of land ownership for 70% of coffee farmers within three years, the revitalization of farmer cooperatives to improve social capital, and the enhancement of rural infrastructure, particularly targeting 85% electricity coverage in coffee-producing areas by the second year. The integration of Geographical Indication (GI) certification with agroforestry-based production systems was identified as a pivotal strategy to reconcile ecological integrity with market competitiveness. By year four, price premiums of up to 40% in domestic markets and 60% in international markets were targeted through value addition and branding. These integrated measures are expected to reinforce livelihood resilience while promoting long-term socio-ecological sustainability in Malinau's coffee landscapes.

Keywords: Sustainable coffee practices; Livelihood resilience; Socio-ecological systems; Agroforestry strategies; Geographical Indication certification

1. Introduction

The development of Robusta coffee in Malinau Regency is closely tied to the challenges of converting forest land into agricultural land in North Kalimantan (Peter, 2013; Suwarno & Campbell, 2005). This trend of land conversion is not unique to Kalimantan but reflects similar patterns regionally and globally (Harvey et al., 2021;

Truong et al., 2022). Given its potentially damaging impacts, special attention is required for sustainable coffee farming practices to ensure that such conversions do not lead to further land degradation (Santana et al., 2023). One sustainable practice that can be implemented is the development of coffee with GI, which balances economic and environmental needs.

To maintain the quality and productivity of Robusta coffee with GI potential, it is necessary to adopt more environmentally friendly and climate-adaptive agricultural practices (Ahmed et al., 2021; Wijayanil et al., 2022). Agroforestry systems, or cultivating coffee under tree canopies, can offer solutions that not only stabilize soil temperature and moisture but also protect the remaining forest ecosystems (de Souza et al., 2012; Gomes et al., 2020). Furthermore, these systems contribute to erosion control and carbon sequestration, enhancing the long-term sustainability of coffee production. The ecological benefits of agroforestry have been widely recognized, making it an ideal strategy for integrating conservation efforts with agricultural productivity. In Malinau, where smallholder farmers are highly dependent on natural resources, adopting agroforestry-based coffee farming can also reduce their vulnerability to climate-induced risks.

The development of GI coffee in Malinau presents an opportunity to promote high-quality and unique local coffee products in the global market. GI ensures that Robusta coffee from this region possesses distinctive characteristics influenced by Malinau's geographical and ecological conditions. With GI protection, Malinau Robusta coffee can achieve stronger market appeal and premium pricing while safeguarding the product from threats of counterfeiting or imitation from other regions. In several areas in Indonesia where GI coffee has been developed, this certification is crucial in strengthening local identity and improving farmers' incomes (Aziz et al., 2023; Cadizza & Rizanizarli, 2023; Kusnaedi et al., 2023). By differentiating their products through GI, farmers in Malinau can establish long-term market positioning and build stronger relationships with specialty coffee buyers. Additionally, GI certification can provide economic stability by mitigating price fluctuations in the global coffee market, which is often influenced by external factors such as climate variability, trade policies, and shifting consumer preferences.

Sustainable livelihoods for Malinau Robusta coffee farmers are a key focus in the development of GI coffee. By promoting sustainable agricultural practices such as agroforestry and the use of environmentally friendly inputs, farmers can enhance land productivity without damaging local ecosystems. The use of GI certification also enables farmers to increase their income in terms of productivity, profitability, and the revenue-cost (R/C) ratio achieved (Herminingsih et al., 2023). However, while GI certification has demonstrated benefits in other coffee-producing regions, its successful implementation in Malinau requires structured farmer training programs, improved post-harvest processing techniques, and strong institutional backing. Without sufficient knowledge and technical capacity, smallholder farmers may struggle to meet the strict quality standards required for certification, limiting their ability to fully capitalize on their market advantages.

The combination of ecosystem protection and improved economic welfare is crucial in creating sustainable livelihoods for coffee farmers in Malinau (Fitch et al., 2022; Wright et al., 2024). The urgency of developing sustainable livelihood indicators for GI coffee farmers in Malinau is increasingly pressing, especially in the context of adapting to environmental and social changes. Understanding the concept of the sustainable livelihood framework is essential for identifying relevant indicators to understand and support the sustainability of coffee farmers' livelihoods (UNDP, 2017). This concept emphasizes the importance of five key assets—human, natural, physical, financial, and social capital—that synergistically influence the resilience and welfare of Robusta coffee farmers in Malinau. Developing appropriate indicators can aid in formulating effective policies and strategies (Bracken et al., 2023). In the context of GI coffee farmers, these policies and strategies can support them in addressing various challenges, such as climate change, market price fluctuations, and fair access to resources (Verburg et al., 2019). A well-integrated approach that includes government support, collaboration with research institutions, and farmer-led initiatives is necessary to ensure that the GI framework strengthens not only market competitiveness but also local environmental sustainability. Without strategic intervention, GI certification alone may not be sufficient to drive long-term improvements in farmer livelihoods. Thus, the success of Malinau’s GI coffee sector depends on the integration of sustainable agricultural practices and inclusive policies that empower smallholder farmers. To achieve this, an evaluation framework is essential for assessing sustainability outcomes and guiding policy improvements.

2. Methodology

2.1 Research Location

This research was conducted in Setulang Village, Malinau Regency, North Kalimantan Province. This area is one of the coffee-producing regions with the potential to obtain GI certification, as presented in Figure 1.

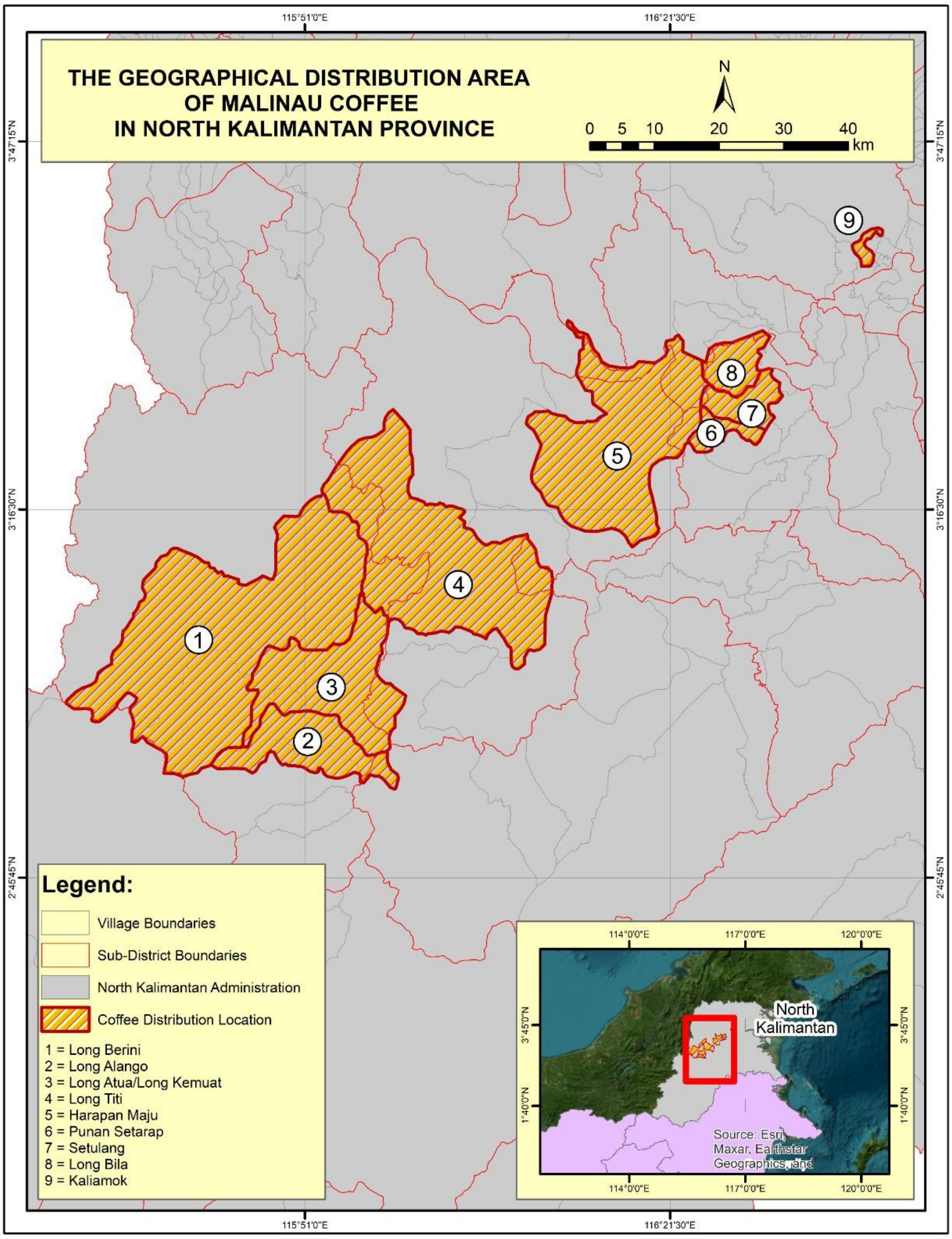

Figure 1. Geographical distribution of Robusta coffee in Malinau, North Kalimantan Province

2.2 Data Collection

Primary data were collected through Focus Group Discussions (FGDs) and interviews with 30 experts and stakeholders involved in the coffee value chain and GI. Secondary data were obtained from relevant literature, including policy documents, research reports, scientific journals, and other sources related to GI and sustainability in the coffee industry. From these data sources, relevant variables related to the sustainability of Robusta coffee farming practices in Malinau were compiled (Appendix). As an initial step, a literature review was conducted to understand theoretical concepts and identify previous research relevant to GI and sustainable value chains in the coffee industry (Moahmmed & Adham, 2021; Snyder, 2019). Subsequently, to deepen the analysis, FGDs were carried out involving experts in agriculture, stakeholders from coffee farmer cooperatives, and parties related to the GI certification process. The results of these discussions provided in-depth insights and significant input regarding the implementation of GI in the coffee value chain, which were then represented through indicators formulated based on literature analysis to measure the sustainable livelihoods of GI coffee farmers (Akyıldız & Ahmed, 2021; Newing et al., 2011).

2.3 Data Analysis

This study employed thematic analysis and Multidimensional Scaling (MDS) to evaluate the sustainability of coffee with Geographical Indication (GI) potential. Thematic analysis mapped the coffee value chain in the context of sustainable livelihoods (Braun & Clarke, 2012; Strang et al., 2022), forming the basis for sustainability evaluation using the MDS method with RAPFish software and Monte Carlo validation (Pitcher & Preikshot, 2001; Pitcher et al., 2013). The MDS results are presented on a 0–100 scale, with categories: Unsustainable (0–<25), Less Sustainable (25–<50), Moderately Sustainable (50–<75), and Sustainable (75–100). These categories reflect progressive improvements in sustainability performance, with goodness of fit indicated by S-stress values (<0.25) and high R^2 values (approaching 1). When differences between MDS and Monte Carlo results are less than one unit, the model accurately represents real-world conditions (Alder et al., 2000). Building on this classification, leverage factor analysis was conducted using mode value assessment for each indicator within the five capital dimensions, where mode represents the most frequently occurring response category among expert respondents (Ostrom, 2009; Scoones, 2013).

To analyze complex interactions among livelihood capital dimensions, correlation analysis was performed between identified leverage factors across different capitals to quantify inter-dimensional relationship strength using Spearman rank correlation for ordinal data (Reed et al., 2009). Network analysis techniques were applied to map dependency relationships and identify critical pathways where improvements in one capital dimension serve as prerequisites for effective interventions in others, validated through structured expert consensus during FGDs (Borgatti et al., 2009; Prell et al., 2009). Cascade effect analysis employed scenario modeling to trace how targeted interventions in specific leverage factors propagate through the livelihood capital system, examining intervention pathways through three strategic entry points: natural capital interventions, physical capital interventions, and financial capital interventions (Folke et al., 2010; O'Brien et al., 2009). Implementation framework development utilized comparative benchmarking methodology with documented GI certification programs, integrating expert assessment through structured consensus-building processes to establish realistic intervention targets and sequencing strategies based on dependency relationships and feasibility considerations (Belton & Stewart, 2012; Yin, 2017).

3. Results

3.1 Analysis of Sustainable Livelihood Capitals of Malinau Robusta Coffee

Natural capital is a key aspect in the sustainable management of coffee plantations in Malinau, encompassing various indicators related to natural resources that support land productivity and quality. Based on the analysis presented in the natural capital indicator mode diagram (Figure 2), agroforestry water sources and shade tree density achieved the highest scores of 4. This indicates that, on average, the plantations have water sources that are very close or located within the plantation area and a very high density of shade trees, with more than 30 trees per hectare. The indicator of shade tree species diversity also scored highly, suggesting a rich variety of tree species that support the agroforestry ecosystem.

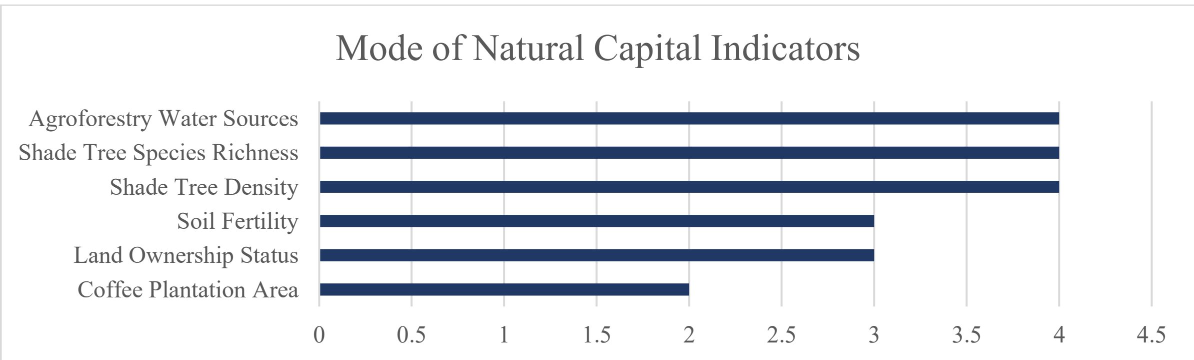

Figure 2. Mode of indicators for natural capital in Malinau Robusta coffee

On the other hand, soil fertility scored 3, reflecting that, on average, the land is moderately productive, though there is still room for improvement in soil quality. Land ownership status scored 3, indicating that most of the land is managed at a medium scale (0.6–1 hectare) but has not yet reached a large-scale operation. The coffee plantation area indicator scored 2, showing that most land is managed under a sharecropping system.

To enhance the understanding of natural capital sustainability, the ordination results indicate an index of 26.13, placing it in the "less sustainable" category. The coefficient of determination (R^2) is 94%, and the average stress and Monte Carlo simulation results produce a mean of 27.02, indicating no significant errors in the scoring of natural capital attributes. This ensures the reliability of the analysis results.

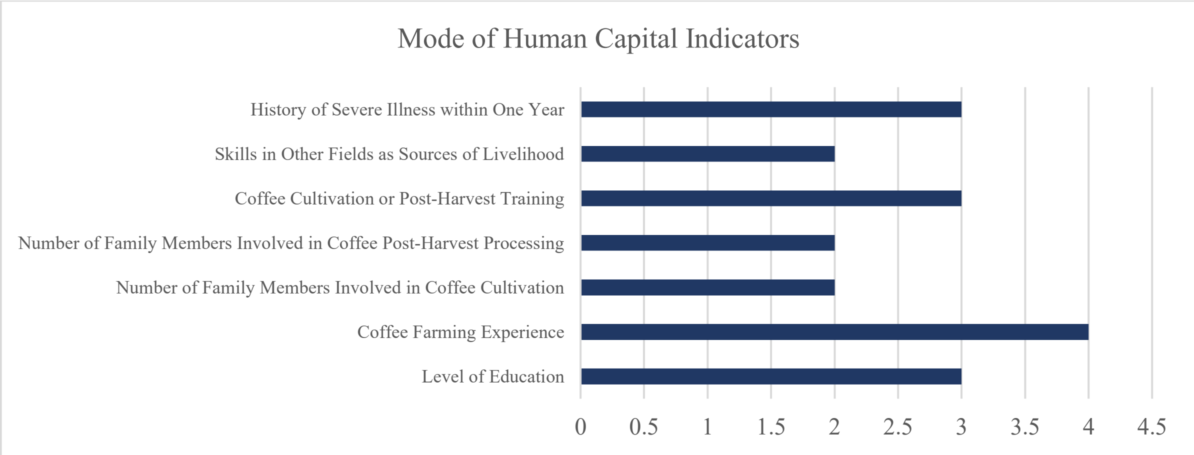

Figure 3. Mode of indicators for human capital in Malinau Robusta coffee

Human capital is a critical dimension in the sustainability of coffee management in Malinau, encompassing the capacity, skills, and conditions of farmers. Indicator analysis (Figure 3) shows that coffee farming experience achieved the highest score (4), indicating that the majority of farmers have over seven years of experience. Training in coffee cultivation and post-harvest activities, family involvement in coffee farming, as well as education level scored 3, reflecting a fairly good contribution. However, family involvement in post-harvest activities and additional skills scored only 2, revealing limitations in these aspects. Overall, while certain aspects of human capital have developed well, education and additional skills require greater attention to further support sustainability.

Although the indicators for coffee farming experience and training show relatively good results, the overall sustainability analysis of human capital still requires attention. This is reflected in an ordination index of 26.09, categorized as "less sustainable." The MDS model demonstrates high reliability, with a stress value of 0.14 and a coefficient of determination (R^2) of 0.95, indicating that the data variation is well explained. The Monte Carlo simulation produced an average value of 27.09 with a dense repetition distribution, further supporting these analytical results.

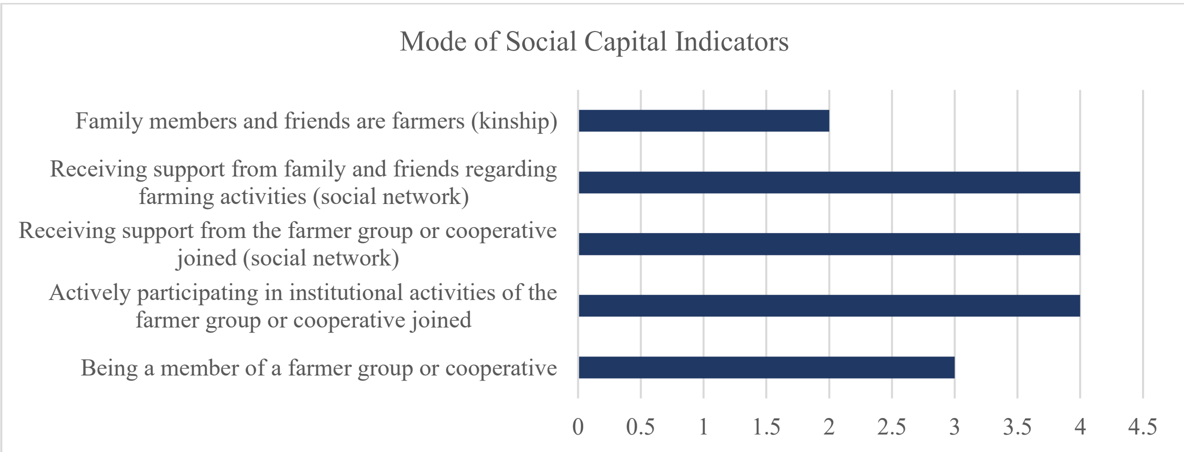

Figure 4. Mode of indicators for social capital in Malinau Robusta coffee

Social capital is a crucial dimension in the sustainability of coffee management in Malinau, encompassing membership, participation, and social support. As shown in Figure 4, the highest mode score (4) was observed for three indicators: receiving support from family and friends regarding farming activities, receiving support from farmer groups or cooperatives, and active participation in institutional activities. These results highlight strong social networks and a high level of farmer engagement in group-based activities, which are essential for knowledge sharing and collective action. Membership in farmer groups or cooperatives followed with a slightly lower mode of 3, suggesting that while many farmers are affiliated with institutions, not all may be formally registered. In contrast, kinship-based connections, such as having family members or friends who are also farmers, showed the lowest mode score of 2. While institutional participation is strong, strengthening kinship networks could enhance social support in agricultural activities.

Despite the positive results regarding active participation in farmer group institutions, the overall sustainability analysis of social capital still reveals significant challenges. The ordination index for the social capital sustainability of Robusta coffee in Malinau is 15.10, placing it in the "unsustainable" category. The MDS model demonstrated high reliability with a stress value of 0.15 and a coefficient of determination (R^2) of 0.94. These results are further supported by the Monte Carlo simulation, which produced an average value of 16.63 with a dense repetition distribution, indicating that the analysis results are reliable.

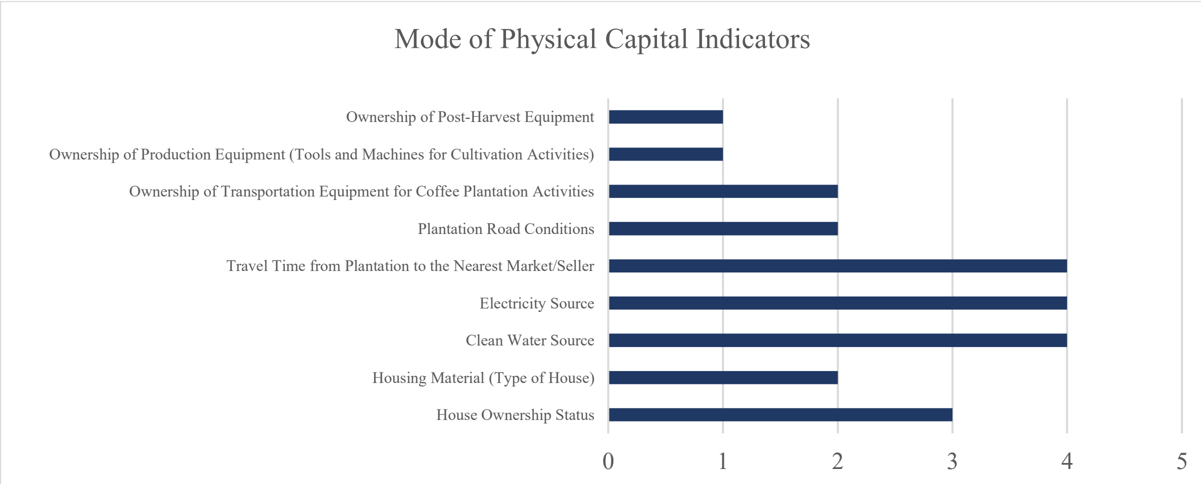

Figure 5. Mode of indicators for physical capital in Malinau Robusta coffee

Physical capital plays a crucial role in the sustainability of coffee management in Malinau, encompassing infrastructure, facilities, and accessibility (Figure 5). The highest mode score (4) was recorded for access to clean water, electricity, and travel time to the nearest market, indicating strong basic service provision and market connectivity. A score of 3 was observed for house ownership status, reflecting relatively secure housing conditions. Moderate scores (2) appeared for housing material, road conditions, and transportation equipment, suggesting partial adequacy in physical infrastructure. The lowest mode (1), found in production and post-harvest equipment, highlights critical gaps in tools needed for cultivation and processing, pointing to the need for investment in agricultural infrastructure.

While some indicators, such as access to clean water, electricity, and transportation, show positive results, the overall sustainability of physical capital still faces challenges. The ordination index for the physical capital sustainability of Robusta coffee in Malinau is 46.61, placing it in the "less sustainable" category. The MDS model demonstrated high reliability with a stress value of 0.14 and a coefficient of determination (R^2) of 0.95. These results are further validated by the Monte Carlo simulation, which produced an average value of 46.85 with a dense repetition distribution, indicating consistent and reliable analysis results.

Financial capital is a critical component in the sustainability of coffee management in Malinau, encompassing income, expenditures, savings, and financial support. The analysis shows that income from non-coffee plantation sources scored the highest (4), indicating that most farmers depend on alternative livelihoods outside coffee farming (Figure 6). Household savings and income from agroforestry crops scored 2, reflecting moderate financial capacity and limited diversification benefits. Meanwhile, income from coffee plantations scored only 1, showing that coffee remains a minor income source. Notably, assistance for coffee plantations, loans or debts, and expenditures on plantation labor all scored 0, revealing a complete absence of external financial support and minimal reinvestment in labor, which could hinder long-term productivity and development.

The ordination index for the financial capital sustainability of Robusta coffee in Malinau is 20.88, categorized as "unsustainable." This is the lowest score among all capital dimensions. The MDS model demonstrated high reliability, with a stress value of 0.14 and a coefficient of determination (R^2) of 0.94. The Monte Carlo simulation produced an average value of 22.17 with a dense repetition distribution, further confirming the consistency and reliability of these findings.

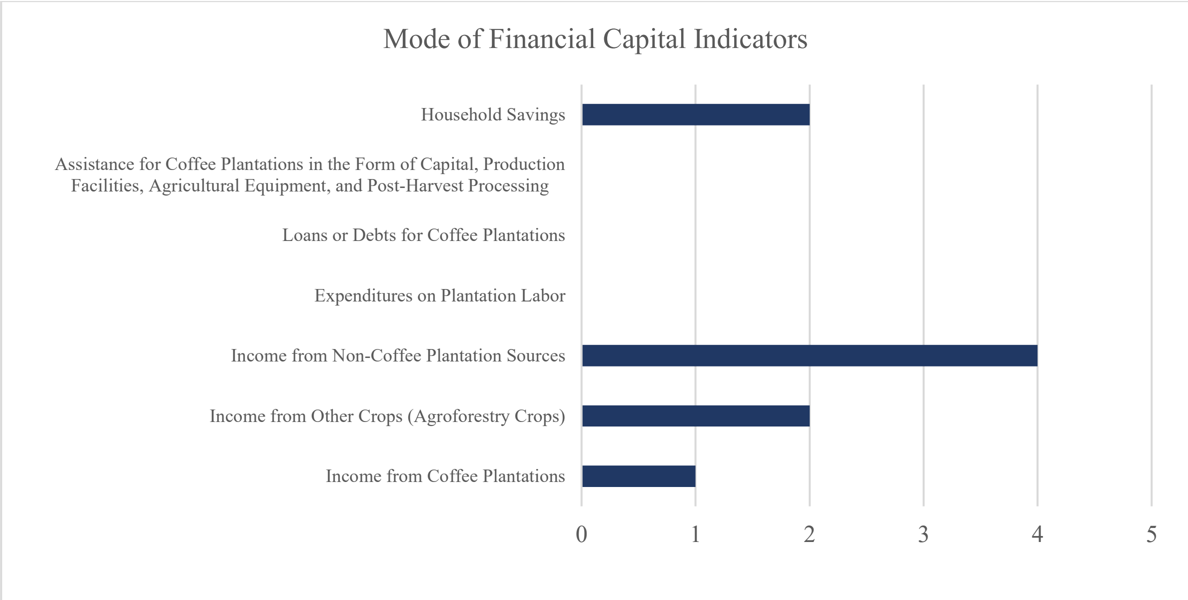

Figure 6. Mode of indicators for financial capital in Malinau Robusta coffee

3.2 Key Leverage Factors for the Sustainability of Malinau Robusta Coffee

To further the sustainability analysis of Robusta coffee in Malinau, it is essential to identify factors that serve as leverage points to strengthen each dimension of livelihood capital. These leverage factors aim to provide a robust foundation for formulating more effective and targeted intervention strategies.

For natural capital, the leverage analysis results indicate that land ownership status and soil fertility are the most critical components for enhancing the sustainability of Malinau Robusta coffee. These findings align with various studies, both domestic and international, which highlight that clear and secure land ownership incentivizes farmers to manage natural resources responsibly and sustainably. Moreover, secure land ownership encourages investment in environmentally friendly farming practices (Mugure et al., 2013; Mutiani et al., 2021; Suyanto et al., 2005).

In the context of human capital, four components emerge as key leverage factors: education level, skills in other livelihood areas, training in coffee cultivation or post-harvest processes, and the number of family members involved in post-harvest activities. This underscores the importance of improving education and training for farmers as a strategic step. With enhanced knowledge and skills, farmers can sustainably increase their yields while preserving environmental quality, particularly in terms of soil health (Handayani et al., 2024; Lassoie et al., 1994; Várallyai et al., 2016).

For social capital, the analysis reveals that all components require improvement. However, the most influential attribute for the sustainability of social capital is kinship, i.e., relationships with family members and friends who are also farmers (Figure 4). This finding emphasizes the critical role of family- and friend-based social networks in supporting the sustainability of farmers' social capital. Strong social connections facilitate collaboration, knowledge exchange, and cooperation in various agricultural activities (Jia & Xu, 2021; Kassem, 2022; Yu & Gambrah, 2023).

In terms of physical capital, leverage factors include electricity access, travel time from farms to markets, ownership of production equipment, ownership of post-harvest equipment, access to clean water, transportation ownership, and housing status. According to Figure 5, electricity access is the most influential attribute, followed by travel time from farms to markets and ownership of production equipment.

These findings underscore the importance of adequate electricity access in supporting the use of modern agricultural tools and post-harvest processing. Shorter travel times from farms to markets ensure quicker distribution of harvests, maintaining product freshness and quality. Meanwhile, production equipment ownership enhances efficiency in processing harvests and increases farmer incomes (Urgessa Waktola & Fekadu, 2021; Yuniarsih et al., 2024). Collectively, these three attributes contribute significantly to the sustainability of coffee farming in Malinau.

Additionally, attributes such as access to clean water, ownership of post-harvest equipment, and transportation also play essential roles. Clean water is crucial for maintaining crop quality and processing, while post-harvest equipment and transportation support the efficiency of farming activities and harvest distribution. Although not top priorities, these attributes should still be addressed to achieve holistic farming sustainability.

For financial capital, leverage factors include all components except household savings. The most influential attribute for the financial capital sustainability of Robusta coffee farmers in Malinau is loans, followed by labor expenditures, assistance, income from non-coffee sources, income from other crops, and lastly, income from coffee farming.

Loans are a key factor as they provide working capital for productive investments. Labor expenditures ensure the availability of a workforce to support farming operations, while assistance reduces production costs. Income diversification, including non-coffee farming and other crops, enhances economic resilience and adaptation to climate change by reducing dependence on a single commodity (Anderzén et al., 2020; Iqbal et al., 2021; Kiani et al., 2021). Although coffee farming income has the least influence, it remains the primary livelihood foundation that requires increased productivity.

4. Discussion

After identifying the key performance drivers for each capital, it can be concluded that the sustainability of Robusta coffee farmers' livelihoods in Malinau depends on the synergy among natural, human, social, physical, and financial capital. MDS analysis reveals alarming conditions where social capital demonstrates the lowest index of 15.10 (unsustainable) and financial capital shows 20.88 (unsustainable), while natural capital (26.13), human capital (26.09), and physical capital (46.61) fall within the less sustainable category. These findings confirm that none of the livelihood capital dimensions achieve sustainable levels, indicating the necessity for coordinated systemic interventions. The development and promotion of GI certification for Malinau Robusta coffee offers a strategic pathway to enhance these capitals while boosting product competitiveness, requiring an integrated and phased sustainable livelihood strategy that prioritizes capitals with the most significant influence on sustainability outcomes.

This strategic approach aligns with successful GI certification models across Indonesia and internationally. Colombia's Protected Geographical Indication, managed by the Federación Nacional de Cafeteros since 1927, coordinates over 500,000 federated growers and has secured authorization for 230 brands from 62 international roasters, demonstrating the market access potential of well-implemented GI systems (Anderzén et al., 2020; Oakley, 2022). Similarly, Indonesia's Toraja Coffee Farmers' Cooperative achieved measurable productivity gains from 350 kg/ha to 370 kg/ha through systematic capacity building (Halim & Oktaviani, 2024; Neilson & Shonk, 2014), while Brazil's Cerrado Mineiro became the country's first Designation of Origin through comprehensive institutional development and quality standardization (de Almeida & Tarabal, 2020; Silva et al., 2018). Lessons learned from these successful cases provide validation that the developed framework possesses high feasibility for implementation in the Malinau context.

The MDS ordination results demonstrate high consistency with Monte Carlo validation, where differences between MDS results and Monte Carlo simulations for all dimensions are less than one unit, indicating accurate representation of real-world conditions (Alder et al., 2000). Natural capital with a stress value of 0.14 and R^2 of 0.94 shows excellent model fit, strengthened by advantages in agroforestry water sources and shade tree density (mode=4), yet constrained by land tenure insecurity with the majority of farmers managing land under sharecropping systems (mode=2), consistent with findings by Mugure et al. (2013) and Suyanto et al. (2005) that secure land ownership incentivizes farmers to manage natural resources responsibly. Human capital shows high reliability, with a stress value of 0.14 and an R^2 of 0.95. Extensive experience in coffee farming (mode = 4, representing >7 years) serves as the primary asset. However, limitations in diversification skills and low family involvement in post-harvest activities (mode = 2) emerge as significant bottlenecks. These findings highlight the strategic importance of improving education and training for farmers (Handayani et al., 2024; Lassoie et al., 1994; Várallyai et al., 2016). Social capital faces the greatest challenges with an index of 15.10 and stress 0.15, showing a paradox where active participation in institutional activities is very high (mode=4) yet kinship relationships among farmers remain weak (mode=2), emphasizing the critical role of family- and friend-based social networks in supporting farmers' social capital sustainability (Jia & Xu, 2021; Kassem, 2022; Yu & Gambrah, 2023).

Physical capital displays relatively the best performance with an index of 46.61, where access to basic services such as electricity, clean water, and market connectivity shows high scores (mode=4), but ownership of production and post-harvest equipment remains minimal (mode=1), highlighting critical gaps in tools needed for cultivation and processing and the need for investment in agricultural infrastructure (Urgessa Waktola & Fekadu, 2021; Yuniarsih et al., 2024). Financial capital is in the most critical condition with an index of 20.88, where the dominance of non-coffee income (mode=4) indicates that coffee has not yet become a viable livelihood source, reinforced by the absence of formal credit access and external assistance (mode=0), consistent with the importance of income diversification in enhancing economic resilience and adaptation to climate change (Anderzén et al., 2020; Iqbal et al., 2021; Kiani et al., 2021). Leverage analysis identifies that land ownership status (natural capital) becomes the most critical leverage factor due to its positive correlation with training motivation (human capital) and opening access to formal financing (financial capital), while electricity access (physical capital) proves to be the primary enabler for post-harvest modernization and technology adoption.

During the first three years, the strategy focuses on strengthening natural and physical capital as the foundation for sustainability. This approach requires collaboration among multiple stakeholders through a District Coffee

Development Task Force that integrates the Malinau District Agriculture Agency, Public Works Agency, Industry and Trade Agency, BPN, PT. PLN, coffee exporters, and farmer cooperatives. The task force oversees progress through quarterly reviews targeting land certification for 70% of coffee farmers by year three through the Complete Systematic Land Registration Program (PTSL), which streamlines the process and secures legal tenure as a prerequisite for GI certification. Simultaneously, rural electrification efforts are coordinated with PT. PLN targeting 85% electricity coverage in coffee-producing villages by year two, supported through government subsidies and special credit schemes from Bank Kaltara with below-market interest rates of 5% compared to the standard 12%.

Training in coffee cultivation and post-harvest handling is delivered by the Agricultural Extension Agency in collaboration with the Indonesian Coffee and Cocoa Research Institute (ICCRI), with the goal of certifying at least 500 farmers annually in Good Agricultural Practices (GAP) and Good Manufacturing Practices (GMP), targeting a 30% increase in bean quality scores and a 25% reduction in post-harvest losses by year three. Investment priorities are developed based on leverage factor analysis with the highest multiplication effects, integrating investment in critical points that open access to other dimensions with a balanced portfolio approach in resource allocation. The resulting sequencing strategy shows that land certification must be the primary priority, as it forms dependency relationships where certain improvements in natural capital become prerequisites for effective interventions in other dimensions.

In the third to fourth years, the strategy shifts to reinforcing social and financial capital, with GI certification acting as the central driver. Based on the estimated number of coffee farmers in Malinau of approximately 18,000 (Central Statistics Agency of North Kalimantan Province, 2024b; Halijah, 2020), the District Cooperative Agency should formalize at least 15 farmer groups into legally registered cooperatives, with each group comprising a minimum of 50 members. These targets are based on a comparative case from Gayo coffee in Aceh where only 20-30% of approximately 100,000 coffee farmers are estimated to be actively engaged in GI-certified cooperatives, consistent with successful Indonesian models including Toraja's PPKT cooperative which formalized multiple farmer groups while creating employment for 20 women as coffee sorters (Halim & Oktaviani, 2024; Neilson & Shonk, 2014). The formation of these cooperatives, supported by technical assistance grants from the Indonesian Coffee Exporters Association (GAEKI), can enhance coordination, knowledge-sharing, and collective marketing efforts under the GI brand.

Financially, GI certification provides access to premium pricing with the Malinau Trade Agency and Indonesia Export Promotion Agency targeting a 40% price premium in domestic markets and 60% in international markets by year four, figures informed by comparative price data between domestic and international markets in Indonesia from 2022 to 2025 (Berita BRMP TRI, 2025). These premium targets are validated by international GI success stories including Vietnam's coffee region where companies have established significant production operations with substantial export volumes to European markets at premium prices (Pick et al., 2017) and Brazil's Cerrado Mineiro which demonstrates premium capture through rigorous quality standards requiring specialty-grade coffee and high-altitude cultivation (de Almeida & Tarabal, 2020; Silva et al., 2018). Correlation analysis of leverage factors reveals systematic interaction patterns: natural-financial linkage shows the highest coefficient (0.78), where secure land ownership strongly correlates with credit access, followed by physical-financial correlation (0.72), confirming the role of infrastructure in increasing income. Human-social interaction (0.65) demonstrates that highly educated farmers tend to be more organizationally active, while natural-human linkage (0.58) confirms that land status influences capacity enhancement motivation.

To complement capital improvements, a public-private partnership fund should be established involving contributions from the provincial government and private sector firms, offering matching grants for production equipment that reduces costs associated with GAP and GMP compliance. Income diversification through non-coffee farming and agroforestry should be prioritized, with the Agricultural Extension Service providing training and starter packages to 60% of farmers for cultivating vanilla, pepper, and shade trees. Studies show that Indonesian coffee farmers perceive diversification as more desirable than other climate-smart agricultural practices (Djufry et al., 2022), with agroforestry systems providing both ecosystem services and socioeconomic benefits (Ulya et al., 2023). Coffee agroforestry enhances food security by increasing dietary diversity by 20%, and commercial applications have been shown to raise incomes fivefold (Duffy et al., 2021), with Indonesia's agricultural extension network, particularly at the district level, well-positioned to support this initiative as evidence indicates that extension officers significantly influence family food security (Warnaen et al., 2022). The program aims for 40% of coffee farmer households to generate at least 30% of their income from non-coffee sources by year four, leveraging documented successes in Indonesia and amplified by linking non-coffee products to GI branding, thereby capitalizing on the region's reputation for high-quality goods (Neilson et al., 2018).

In the fourth to fifth years, the focus turns to resolving supporting issues and consolidating GI as a central economic pillar with the District Transportation Agency upgrading at least 75 kilometers of farm-to-market roads annually, aiming to reduce transport costs by 40% and delivery times by 50%. Meanwhile, the District Health Agency should implement a Clean Water Access Program ensuring 90% of coffee-producing villages have reliable clean water systems by year five, which is essential for maintaining GI-standard processing quality based on data showing only 73% of households had access to clean water in 2023 (Central Statistics Agency of North Kalimantan Province, 2024a). Economic security initiatives are expanded by the District Economic Empowerment Agency, with at least 200 farmers trained annually in alternative income-generating activities, financial literacy training delivered by Bank Kaltara reaching 75% of farmers participating in the GI program, and household savings rates expected to increase by 50% by year five.

The institutional framework for GI management reflects proven governance models from successful regions. Colombia's experience demonstrates the critical importance of "robust and context-sensitive institutions, clear geographical and social boundaries, and supportive national GI legislation" for sustained GI success, with their PGI recognized by the European Union (Barjolle et al., 2017; Ruiz et al., 2020). Indonesia's Bali Kintamani, which established the country's first Geographic Indication through traditional Subak Abian farming systems, illustrates how cultural integration strengthens community ownership and compliance with GI standards (Hananto & Prananda, 2019). To institutionalize the GI system, a GI Management Board should be established by year three and become fully operational by year five. This board, composed of government representatives, cooperatives, and private sector actors, is responsible for securing external market access for at least 60% of GI-certified production. The District Planning Agency (Bappeda) is responsible for implementing annual monitoring and evaluation protocols across all indicators, ensuring that the program remains adaptive and sustainable while maximizing the long-term economic benefits of GI certification.

The analysis reveals distinct cascade effects when interventions target specific leverage factors across different capitals. Land certification interventions demonstrate how securing tenure rights creates a comprehensive transformation pathway. When farmers obtain legal land ownership, their willingness to invest in training programs increases significantly, as they perceive greater long-term returns from improved practices. This enhanced human capital subsequently drives more active participation in farmer organizations, where collective bargaining power enables shared access to production equipment that individual farmers could not afford independently. The resulting productivity improvements establish creditworthiness that opens formal financial channels, creating opportunities for sustained reinvestment in all capital dimensions.

Physical capital interventions through rural electrification generate equally transformative but distinct pathways. Access to reliable electricity enables farmers to adopt post-harvest processing technologies that substantially improve product quality and reduce losses. Higher quality outputs command premium prices in specialty markets, generating increased revenues that farmer groups can pool for further infrastructure investments. These collective infrastructure improvements strengthen social bonds and institutional capacity, creating positive feedback loops that reinforce community-level decision-making and resource management. Financial capital interventions through microcredit programs establish a third transformation mechanism, where initial access to working capital allows farmers to purchase essential production equipment, leading to immediate productivity gains that generate surplus income for technical training investments and networking opportunities with successful farmers, ultimately facilitating sustainable business diversification strategies.

The successful implementation of this framework depends critically on recognizing that interactions among livelihood capital dimensions are dynamic and context-specific, requiring continuous adaptation based on monitoring feedback and changing circumstances. An integrated monitoring system is developed to track cross-dimensional interactions using Key Performance Indicators that measure inter-capital synergy: Synergy Index targeting >0.7 for all dimensional pairs, Cross-capital Investment Rate to measure the proportion of cross-dimensional investments, Collective Action Index to measure collaborative activity levels, and Livelihood Diversification Ratio to measure income source diversification. The framework provides a foundation for replication in similar smallholder agricultural systems with appropriate adjustments in specific leverage factors and local contextual considerations, making it a valuable tool for sustainable development planning beyond the coffee sector in Indonesia and regions with similar characteristics, particularly in smallholder systems facing similar challenges in balancing economic viability with ecological sustainability.

5. Conclusion

This study evaluated the sustainability of Robusta coffee farming in Malinau Regency using the sustainable livelihood framework, revealing alarming conditions across all five livelihood capital dimensions that necessitate urgent and coordinated intervention. The Multidimensional Scaling (MDS) analysis demonstrates that current coffee farming practices operate at critically unsustainable levels, with none of the capital dimensions achieving sustainable status. Social capital exhibited the most severe deficiency with an index of 15.10 (unsustainable), followed by financial capital at 20.88 (unsustainable), while natural capital (26.13), human capital (26.09), and physical capital (46.61) all remained within the "less sustainable" category. These findings underscore a systemic crisis requiring comprehensive transformation rather than isolated interventions.

The leverage factor analysis revealed critical interdependencies among capital dimensions, with land ownership status (natural capital) emerging as the primary catalyst for systemic change due to its strong correlation with training motivation (human capital) and access to formal financing (financial capital). Electricity access (physical capital) proved essential for post-harvest modernization and technology adoption, while kinship relationships (social capital) and formal credit access (financial capital) represented the most constraining bottlenecks. The correlation analysis quantified these interactions, showing natural-financial linkages (0.78), physical-financial correlations (0.72), human-social interactions (0.65), and natural-human linkages (0.58), confirming that sustainable transformation requires simultaneous multi-capital interventions rather than sequential approaches.

The cascade effect analysis identified three distinct transformation pathways that demonstrate how targeted interventions propagate through the livelihood capital system. Land certification interventions create comprehensive transformation from secure tenure to enhanced training motivation, collective action, shared equipment access, improved productivity, and sustained financial reinvestment. Rural electrification enables post-harvest technology adoption, quality improvements, premium market access, and collective infrastructure development. Microcredit programs facilitate equipment investment, immediate productivity gains, technical training funding, and sustainable business diversification. These pathways confirm that strategic entry points can generate multiplicative impacts across multiple dimensions when properly sequenced and coordinated.

A phased implementation strategy spanning five years emerges as essential for addressing these sustainability challenges systematically. The first phase (years 1-3) must prioritize foundational improvements in natural and physical capital through land certification for 70% of farmers and achieving 85% electricity coverage in coffee-producing villages, implemented through multi-stakeholder coordination involving the District Coffee Development Task Force. This foundation enables subsequent phases to focus on social capital development through formalizing 15 farmer cooperatives with minimum 50-member participation, and financial capital enhancement through Geographical Indication certification targeting 40% domestic and 60% international price premiums by year four. The strategy's success depends on coordinated action among district-level agencies, national institutions, and private sector partners, institutionalized through a GI Management Board by year three.

GI certification emerges as a pivotal strategy that simultaneously addresses ecological integrity and market competitiveness by integrating agroforestry practices with premium market positioning. Income diversification through non-coffee crops should target 40% of farmers generating at least 30% of household income from alternative sources by year four, reducing vulnerability to coffee market fluctuations while maintaining ecological sustainability. The comparative analysis with Colombia's cooperative system managing over 500,000 farmers, Indonesia's Toraja Coffee Farmers' Cooperative achieving productivity gains from 350 kg/ha to 370 kg/ha, and Brazil's Cerrado Mineiro validates the viability of these targets while highlighting the importance of context-specific adaptation.

This study acknowledges important limitations that should guide future research directions. The absence of cost-benefit analysis in policy recommendations reflects original research design constraints and represents a critical gap for implementation planning. Future studies should incorporate comprehensive economic assessments to evaluate financial feasibility and trade-offs of proposed interventions, particularly regarding substantial infrastructure investments and institutional development requirements. Additionally, while leverage analysis identifies key intervention points, longitudinal studies are needed to validate causal relationships between specific capital improvements and sustainability outcomes. The dynamic and context-specific nature of livelihood capital interactions requires continuous monitoring and adaptive management based on feedback and changing circumstances.

The transformation of Malinau's Robusta coffee sector from its current unsustainable state to a resilient, GI-certified system represents both a significant challenge and substantial opportunity. The integrated approach combining livelihood capital strengthening with GI certification can establish Malinau as a model for sustainable coffee production that balances economic viability with ecological integrity. Success requires recognizing that interactions among livelihood capital dimensions are dynamic and interconnected, demanding systems thinking rather than sectoral approaches. When implemented comprehensively through the proposed phased strategy, this framework can contribute to Indonesia's broader sustainable agriculture objectives while improving rural livelihoods in North Kalimantan, providing a replicable model for similar smallholder agricultural systems facing comparable challenges in balancing economic development with environmental sustainability.

Author Contributions

A.S., E.W., M.W.A., T.T.H., and M.D.S. conceived and designed the analysis. E.W., M.W.A., D.S., D.T., and E.K. collected the data. E.W., M.W.A., D.S., D.T., and E.K. contributed data or analysis tools. A.S., E.W., M.W.A., T.T.H., and M.D.S. performed the analysis. A.S., T.T.H., M.D.S., E.N., R.P., and D.M.R. interpreted the results. A.S., E.W., M.W.A., T.T.H., M.D.S., E.N., R.P., and D.M.R. wrote the paper.

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Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

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Conflicts of Interest

The authors declare no conflict of interest.

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Appendix

Table A1. Scoring criteria for sustainable livelihood indicators in coffee farming in Malinau

No.	Indicators	Descriptions
	A. Natural Capital	
1.	Land Ownership Status	0 = Very small coffee farm (less than 0.1 hectares); 1 = Small coffee farm (0.1 - 0.5 hectares); 2 = Medium-sized coffee farm (0.6 - 1.0 hectares); 3 = Large coffee farm (1.1 - 2.0 hectares); 4 = Very large coffee farm (more than 2 hectares).
2.	Size of Coffee Farm	0 = Leased; 1 = Shared profit arrangement; 2 = Temporary use agreement; 3 = Land use rights (Community Forest/Village Forest/People's Farm Forest).
3.	Land Fertility	0 = Non-productive; 1 = Slightly productive; 2 = Productive; 3 = Highly productive.
4.	Shade Tree Density	0 = No shade trees in the farm area; 1 = Very low shade tree density (fewer than 10 trees per hectare); 2 = Moderate shade tree density (10-20 trees per hectare); 3 = High shade tree density (21-30 trees per hectare); 4 = Very high shade tree density (more than 30 trees per hectare).
5.	Agroforestry Water Source	0 = No permanent water source, relying solely on rainfall; 1 = Distant water source (more than 1 km) with difficult access; 2 = Water source available but with limited access; 3 = Nearby water source (less than 1 km) with easy access; 4 = Readily available and very close water source (within or near the farm area).
	B. Human Capital	
6	Educational Level	0 = No formal education; 1 = Did not complete primary education; 2 = Completed primary education (elementary school or equivalent); 3 = Completed secondary education (junior/senior high school or equivalent); 4 = Completed higher education (diploma/undergraduate degree or equivalent).
7	Experience in Coffee Farming	0 = No experience in coffee farming; 1 = Very minimal experience (< 1 year); 2 = Moderate experience (1-3 years); 3 = Good experience (4-7 years); 4 = Extensive experience (> 7 years).

8	Number of Family Members Involved in Coffee Cultivation	0 = No family members involved in coffee cultivation; 1 = Only 1 family member involved in coffee cultivation; 2 = More than 1 family member involved in coffee cultivation.
9	Number of Family Members Involved in Coffee Post-Harvest	0 = No family members involved in the post-harvest stage; 1 = Only 1 family member involved in the post-harvest stage; 2 = More than 1 family member involved in the post-harvest stage.
10	Training in Coffee Cultivation or Post-Harvest	0 = No family members trained in coffee cultivation or post-harvest; 1 = Only 1 family member trained in coffee cultivation or post-harvest; 2 = More than 1 family member trained in coffee cultivation or post-harvest.
11	Skills in Other Fields for Livelihood Sources	0 = No other skills for alternative livelihoods; 1 = Has 1 other skill for alternative livelihoods; 2 = Has more than 1 other skill for alternative livelihoods.
12	History of Severe Illness in the Past Year	0 = Recurrent severe illness (e.g., dengue fever, diarrhea, dysentery, typhoid, malaria, tuberculosis, stroke); 1 = 3-4 episodes of severe illness (e.g., dengue fever, diarrhea, dysentery, typhoid, malaria, tuberculosis, stroke); 2 = 1-2 episodes of severe illness (e.g., dengue fever, diarrhea, dysentery, typhoid, malaria, tuberculosis, stroke); 3 = No severe illness (e.g., dengue fever, diarrhea, dysentery, typhoid, malaria, tuberculosis, stroke).
	C. Social Capital	
13	Membership in Farmer Groups or Cooperatives	0 = Not a member of any farmer group or cooperative; 1 = Recently joined a farmer group or cooperative (less than 1 year); 2 = Member of a farmer group or cooperative for 1-3 years; 3 = Member of a farmer group or cooperative for 4-7 years.
14	Active Participation in Farmer Group or Cooperative Activities	0 = Never participated in institutional activities; 1 = Very limited participation in institutional activities (less than once a year); 2 = Participated in a few institutional activities (once or twice a year); 3 = Regularly participated in institutional activities (several times a year); 4 = Actively and consistently involved in various institutional activities.
15	Support from Farmer Groups or Cooperatives (Social Network)	0 = Receives no support at all from farmer groups or cooperatives; 1 = Support received is minimal and not very beneficial; 2 = Support received is adequate but not always available when needed; 3 = Support received is good and consistently available; 4 = Receives full and sustainable support from farmer groups or cooperatives, with clear and significant benefits.
16	Support from Family and Friends for Farming Activities (Social Network)	0 = Receives no support at all from family or friends; 1 = Support received is minimal and unsustainable; 2 = Support received is adequate but not always available when needed; 3 = Support received is good and consistently available; 4 = Receives full and sustainable support from family and friends for farming activities.
17	Family Members and Friends as Farmers (Kinship)	0 = No family members or friends are farmers; 1 = Only one family member or friend is a farmer; 2 = More than one family member or friend is a farmer.
	D. Physical Capital	
18	House Ownership Status	0 = Rented; 1 = Borrowed use; 2 = Owned.

19	House Material Quality (Type of House)	0 = House made of very basic materials (e.g., bamboo walls and dirt floors); 1 = House made of less durable materials (e.g., thin wooden walls and rough cement floors); 2 = House made of fairly good materials (e.g., brick or concrete block walls and smooth cement floors); 3 = House made of strong and durable materials (e.g., brick or concrete block walls and ceramic floors); 4 = House made of very high-quality, modern materials (e.g., concrete walls and marble or granite floors).
20	Clean Water Source	0 = No access to clean water sources, relying on rainwater or unsafe water sources; 1 = Clean water source is far away (more than 1 km) and difficult to access; 2 = Clean water source is available but of poor quality or limited access; 3 = Clean water source is nearby (less than 1 km), easily accessible, and of adequate quality; 4 = Clean water source is very close (within the house or yard) and of excellent quality.
21	Electricity Source	0 = No access to electricity; 1 = Limited electricity access with frequent outages; 2 = Electricity is available but with low or unstable capacity; 3 = Stable electricity access with adequate capacity for daily needs; 4 = Stable and reliable electricity access, sufficient for all needs with dependable energy sources.
22	Travel Time from Farm to Market/Seller	0 = Very long travel time (more than 4 hours); 1 = Long travel time (3-4 hours); 2 = Moderate travel time (2-3 hours); 3 = Short travel time (1-2 hours); 4 = Very short travel time (less than 1 hour).
23	Condition of Farm Roads	0 = Very poor road conditions, impassable by vehicles (muddy, large rocks, or cut off); 1 = Poor Road conditions, difficult for vehicles but passable with extra effort (holes, small rocks, or slippery); 2 = Fair road conditions, easily passable by vehicles despite minor obstacles (flat soil, light rocks, or slight holes).
24	Ownership of Transportation for Coffee Farming Activities	0 = No vehicle ownership; 1 = Owns one type of vehicle (two-wheeler or four-wheeler); 2 = Owns two types of vehicles (two-wheeler and four-wheeler).
25	Ownership of Production Equipment (Tools and Machines for Cultivation Activities)	0 = No production equipment; 1 = Owns manual production tools; 2 = Owns automatic production tools.
26	Ownership of Post-Harvest Equipment	0 = No post-harvest equipment; 1 = Owns manual post-harvest equipment; 2 = Owns automatic post-harvest equipment.
	E. Financial Capital	
27	Income from Coffee Farms	0 = No income from coffee harvest sales; 1 = Very low income, sufficient to cover only a small portion of production costs (less than 25% of total production costs); 2 = Low income, sufficient to cover most production costs (25-50% of total production costs); 3 = Moderate income, covering all production costs and providing a small profit (50-75% of total production costs); 4 = High income, providing significant profit (more than 75% of total production costs).

28	Income from Other Crops (Agroforestry Crops)	0 = No income from agroforestry crop sales; 1 = Very low income, sufficient to cover only a small portion of household expenses (less than 25%); 2 = Low income, sufficient to cover most household expenses (25-50%); 3 = Moderate income, covering almost all household expenses (50-75%); 4 = High income, covering all household expenses and allowing savings (more than 75%).
29	Income from Non-Coffee Farming Sources	0 = No income from non-agricultural sources; 1 = Very low income from non-agricultural sources, insignificant to total household income; 2 = Moderate income from non-agricultural sources, contributing a small portion to total household income; 3 = Good income from non-agricultural sources, significantly contributing to total household income; 4 = High income from non-agricultural sources, serving as the main source of household income.
30	Expenditures on Labor for Coffee Farming	0 = No expenditures on hired labor, as no external labor is used; 1 = Very low expenditures, hiring labor only for minor tasks (less than 10% of total production costs); 2 = Moderate expenditures, hiring labor for some essential tasks (10-30% of total production costs); 3 = High expenditures, regularly hiring labor for most tasks (30-50% of total production costs); 4 = Very high expenditures, with almost all work performed by hired labor (more than 50% of total production costs).
31	Loans or Debt for Coffee Farming	0 = No loans or debt at all; 1 = Very small loans or debt, easily manageable (less than 10% of total annual income); 2 = Moderate loans or debt, with manageable burdens (10-30% of total annual income); 3 = Large loans or debt, with significant burdens (30-50% of total annual income); 4 = Very large loans or debt, constituting a major financial burden (more than 50% of total annual income).
32	Assistance for Coffee Farming (Capital, Production Facilities, Agricultural Tools, and Post-Harvest Processing)	0 = No assistance received for capital, production facilities, agricultural tools, or post-harvest processing; 1 = Received one type of assistance (capital/production facilities/agricultural tools/post-harvest processing); 2 = Received two types of assistance (capital/production facilities/agricultural tools/post-harvest processing); 3 = Received three types of assistance (capital/production facilities/agricultural tools/post-harvest processing); 4 = Received all four types of assistance (capital, production facilities, agricultural tools, and post-harvest processing).
33	Household Savings	0 = No savings at all; 1 = Minimal savings, insufficient for emergency needs (less than 10% of total annual income); 2 = Moderate savings, sufficient for small emergencies (10-20% of total annual income); 3 = Good savings, sufficient for emergencies or small investments (20-30% of total annual income); 4 = Excellent savings, sufficient for major emergencies or significant investments (more than 30% of total annual income).