Bioculture
Bioculture Journal
Bioculture 4(1): 1–18
ISSN 3025-3632

Institute for Advanced Science, Social and Sustainable Future
MORALITY BEFORE KNOWLEDGE

Government-supported and community-based avocado cultivation for livelihood diversification in post-mining communities: A cost-benefit analysis

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Received Date: April 13, 2026 Revised Date: June 4, 2026 Accepted Date: July 16, 2026

ABSTRACT

Background: Agricultural development is increasingly recognized as an important strategy for supporting livelihood transition in regions historically dependent on extractive industries. In Bangka Belitung Province, declining tin mining activities have increased the need for alternative livelihood systems capable of generating economic benefits while maintaining environmental sustainability. Avocado cultivation has emerged as a promising agricultural commodity in Air Belo Village, West Bangka Regency, where plantations are primarily established within production forest areas and former plantation lands. This study evaluates the economic feasibility and examines how governance capacity influences its long-term implementation. **Methods:** A mixed methods approach combines cost-benefit analysis (CBA) and semi-structured interviews. The analysis uses a 30-year timeframe and a 9% social discount rate. It applies economic net present value (ENPV), economic internal rate of return (EIRR), and benefit-cost ratio (BCR). Governance is measured through four dimensions: actor participation, institutional strength, government support, and market integration, using an organized evaluation framework. **Findings:** The system is economically feasible. ENPV is IDR 118,551,623, EIRR is 27.98%, and BCR is 1.54. Switch value analysis shows robustness during a 32% price decrease and a 45% cost increase. Greater governance performance is associated with better economic outcomes via reduced transaction costs, improved coordination, and stronger market access. **Conclusion:** This study demonstrates that governance capacity contributes to the economic viability of avocado cultivation by improving coordination, market access, and institutional support. The findings highlight the importance of strengthening farmer organizations and stakeholder collaboration to support economically sustainable livelihood transition in resource-dependent regions. **Novelty/Originality of this article:** The originality of this study lies in integrating long-term economic feasibility analysis with a multidimensional governance assessment to explain how institutional capacity shapes the sustainability of livelihood transition in resource-dependent regions.

KEYWORDS: agroforestry; economic resilience; environmental governance; rural transition.

1. Introduction

The plantation sector plays an important role in Indonesia's economy through its contribution to employment generation, regional economic development, and rural livelihood support. According to Statistics Indonesia in 2025, the agriculture and plantation sectors remain among the largest contributors to national employment, particularly within rural regions characterized by relatively limited industrial diversification. This role becomes increasingly important in resource-dependent provinces such as Bangka Belitung,

Cite This Article:
Nugraha, M. P., Herdiansyah, H., & Chairani, E. (2026). Government-supported and community-based avocado cultivation for livelihood diversification in post-mining communities: A cost-benefit analysis. *Bioculture Journal*, *4*(1), 1-18. https://doi.org/10.61511/bioculture.v4i1.2026.3695

where local economic structures have historically relied heavily on extractive activities, especially tin mining. For more than two centuries, tin mining has shaped the socio-economic development of Bangka Belitung Province and served as one of the region's primary economic drivers (Ahmad et al., 2022).

Although mining activities contributed substantially to regional economic growth, prolonged dependence on extractive industries also generated significant structural vulnerabilities. Fluctuating global commodity prices, declining mineral reserves, and environmental degradation have collectively reduced the long-term sustainability of mining-based development systems. As a result, many mining-dependent communities increasingly face economic uncertainty and declining livelihood security.

Despite its substantial contribution to regional economic growth, prolonged dependence on tin mining has also generated significant structural vulnerabilities. Fluctuating global commodity prices, declining mineral reserves, and increasing environmental pressures have collectively reduced the long-term sustainability of mining-based development systems. Consequently, many communities that were previously dependent on mining activities face growing economic uncertainty and challenges in maintaining livelihood security. Previous studies suggest that communities reliant on extractive industries often experience difficulties in sustaining long-term economic resilience due to the finite nature of mineral resources and the limited availability of alternative income-generating opportunities (Holden et al., 2014; Khan et al., 2021).

The environmental consequences of mining activities further reinforce the need for economic diversification. According to the Environmental and Forestry Agency of Bangka Belitung Province in 2024, approximately 167,065 hectares of post-mining land have been identified across the province, with nearly 70% associated with tin mining activities. In addition, mining operations have contributed to broader environmental degradation, including soil quality decline, hydrological disruption, loss of vegetation cover, and reduced ecological functions in many landscapes throughout the province (Agustina, 2023; Syari et al., 2022). These conditions highlight the importance of developing sustainable land-use systems capable of simultaneously supporting environmental sustainability and long-term socio-economic resilience.

Agricultural development has increasingly been recognized as a strategic pathway for facilitating livelihood transition in regions historically dependent on extractive industries. Unlike mining activities, which rely on non-renewable resources, agricultural and plantation systems offer opportunities to generate continuous economic benefits while maintaining productive landscapes and supporting environmental functions. As a result, agricultural diversification is increasingly viewed as an important component of rural transformation strategies aimed at reducing dependence on extractive sectors while strengthening community welfare and regional economic resilience.

Among various agricultural commodities, perennial plantation crops possess particular advantages due to their ability to provide both economic and ecological benefits. Compared with annual cropping systems, perennial crops generally exhibit greater ecological resilience through deeper rooting systems, improved soil stabilization, enhanced carbon sequestration, and long-term vegetation cover. These characteristics make perennial plantation systems particularly relevant within sustainable development frameworks that seek to balance economic productivity with environmental stewardship.

One commodity that has attracted growing attention in this regard is avocado (*Persea americana*). Avocado possesses relatively high economic value and continues to experience increasing domestic and international demand while functioning ecologically as a perennial tree crop capable of supporting sustainable land management (Dhanaraju et al., 2022; Ramírez-Mejía et al., 2024). Globally, avocado production has expanded rapidly and contributed substantially to agricultural development and rural income generation in countries such as Peru, Mexico, Tanzania, and Rwanda (Boniphace et al., 2023; Collantes-Barturen & Morán-Santamaría, 2025; Mgomezulu et al., 2025). Previous studies have reported positive economic returns associated with avocado cultivation, particularly within smallholder farming systems and export-oriented agricultural sectors. These findings

indicate that avocado cultivation may offer significant potential as an alternative livelihood strategy capable of supporting economic diversification and rural development.

In Air Belo Village, West Bangka Regency, avocado cultivation has emerged as a promising livelihood alternative among local communities. The development of avocado plantations in this area is particularly interesting because the plantations are predominantly established within production forest areas and lands previously utilized for plantation activities rather than on former tin-mining land (Duran-Llacer et al., 2025). Nevertheless, their emergence remains closely associated with the broader socio-economic transition occurring within Bangka Belitung Province, where communities increasingly seek sustainable economic opportunities beyond mining activities. Consequently, avocado cultivation represents not only an agricultural production system but also a potential mechanism for supporting long-term livelihood diversification among communities undergoing post-mining economic transition.

Despite its economic potential, the sustainability of avocado cultivation cannot be evaluated solely through financial performance. Previous studies have highlighted that avocado production may generate environmental pressures, particularly through water consumption, fertilizer use, pesticide application, and transportation activities. For example, avocado production systems have been associated with relatively high water footprints, estimated at approximately 2,000-2,200 liters per kilogram of fruit produced, which may increase pressure on local water resources when production systems are not managed sustainably (Sommaruga & Eldridge, 2021; Becker & Gondhalekar, 2022; Fuerte-Velázquez & Gómez-Tagle, 2024). Therefore, evaluating avocado cultivation requires a broader perspective that considers environmental, social, and economic dimensions simultaneously.

In addition to environmental and economic considerations, the success of sustainable agricultural systems depends strongly on governance effectiveness and stakeholder collaboration. Technical feasibility alone does not guarantee successful implementation if institutional coordination, market access, government support, and stakeholder participation remain weak. Previous studies demonstrate that governance quality, collective action, and institutional integration significantly influence the sustainability and competitiveness of smallholder agricultural systems (Sseruwagi et al., 2025; Vargas-Canales et al., 2020). Consequently, governance should be understood not merely as an administrative mechanism but as a critical factor shaping the long-term sustainability and resilience of agricultural development initiatives.

Although studies on avocado production have increased substantially in recent years, most existing research focuses primarily on profitability, export competitiveness, production efficiency, or value-chain performance under relatively favorable agroecological conditions. Limited attention has been directed toward understanding the sustainability of avocado cultivation within regions undergoing livelihood transition from extractive industries, particularly where environmental performance, social outcomes, economic feasibility, and governance capacity interact simultaneously. As a result, there remains insufficient empirical understanding regarding the extent to which avocado cultivation can function as a sustainable livelihood strategy within post-extractive regional development contexts.

Therefore, this study examines the economic feasibility by Cost-Benefit Analysis (CBA), while simultaneously examining how governance capacity influences implementation effectiveness and long-term sustainability. By integrating economic feasibility analysis with governance considerations, this study contributes to the growing literature on livelihood transition in regions historically influenced by extractive industries. Furthermore, the study provides empirical evidence that avocado cultivation can serve as a financially viable livelihood alternative when supported by effective institutional arrangements, government support, and community participation.

2. Methods

2.1 Study area

This study was conducted in Air Belo Village, West Bangka Regency, Bangka Belitung Province, Indonesia. The plantations are predominantly established within production forest areas and lands previously utilized for plantation activities rather than on former tin-mining land. The study area lies at an elevation of 15 to 150 meters above sea level and receives annual rainfall between 2,200 and 2,800 mm. The predominant soil type is red-yellow podzolic, which is typically low in fertility and necessitates substantial soil improvement to support perennial crops such as avocado(*Persea americana*) (Nursaiidah et al., 2022; Syari et al., 2022). The area was selected because it represents a rural community undergoing an economic transition from mining-dependent livelihoods toward agriculture-based income generation. Existing farmer groups and local agricultural initiatives have supported the introduction and expansion of avocado cultivation, making the village a suitable case for examining both the economic feasibility and governance conditions associated with livelihood diversification.

2.2 Research design

A mixed-methods approach was employed, blending quantitative economic analysis with qualitative data to capture both monetary outcomes and contextual dynamics. The quantitative component utilized Cost-Benefit Analysis (CBA) to assess the long-term economic feasibility of avocado plantation development. The qualitative component relied on semi-structured interviews with key stakeholders, including smallholder farmers and local actors directly involved in plantation activities. Purposive sampling was used to select respondents relevant to the study objectives, resulting in five informants being interviewed. Data collection occurred between February 2020 and February 2026, focusing on production costs, yield assumptions, market conditions, as well as social and governance dynamics such as community participation, institutional support, and stakeholder coordination. Primary data were supplemented with secondary data from government reports, statistical databases, and relevant literature to validate key analytical assumptions.

The economic feasibility assessment applied a 30-year time horizon to represent the productive lifespan of avocado trees, using a social discount rate of 9% in accordance with national project evaluation standards from Bank Indonesia in 2024. The analysis used three primary indicators: Economic Net Present Value (ENPV), Economic Internal Rate of Return (EIRR), and Benefit-Cost Ratio (BCR). Cost components comprised capital expenditure (CAPEX) and operational expenditure (OPEX), while benefit components included revenue from avocado production, carbon sequestration, and employment generation. To improve economic accuracy, cost values were adjusted using the Standard Conversion Factor (SCF) to reflect shadow prices.

Cost-Benefit Analysis (CBA) is widely applied to evaluate the economic feasibility of investment projects by comparing the total benefits and costs generated over a specified period (Hao et al., 2024; Poudel et al., 2024). In the context of avocado plantation systems, CBA is used to assess farm profitability by comparing different management practices based on their respective cost and benefit structures, while also supporting policy formulation and sustainable land management strategies.

To evaluate long-term economic feasibility and investment efficiency, this study employs three key indicators: Economic Net Present Value (ENPV), Economic Internal Rate of Return (EIRR), and Benefit-Cost Ratio (BCR). ENPV measures the difference between the present value of total economic benefits and total economic costs over the project lifespan. A positive ENPV (ENPV > 0) indicates that the project is economically feasible, while a negative value suggests infeasibility. This indicator is particularly relevant for perennial crop investments, as it accounts for the time value of money over long-term horizons

(Fürtner et al., 2022; Goñas et al., 2024). The ENPV is calculated using the following formula (Equation 1), with R_t as net cash flow (inflows and outflows) in period *t*; i as discount rate; and t as time period.

$$ENPV = \sum_{t=0}^{n} \frac{R_t}{(1+i)^t} \quad \text{(Eq. 1)}$$

In this study, cost flows are adjusted using the Standard Conversion Factor (SCF) to reflect economic prices, while benefit flows represent economic returns. The discount rate applied corresponds to the Social Discount Rate (SDR). However, ENPV is sensitive to key assumptions such as discount rates, commodity prices, and land productivity. It also has limitations in capturing climate variability and extreme risks faced by smallholder farmers. Therefore, sensitivity analysis is conducted to enhance the robustness of the results (Coulibaly et al., 2024; Espinoza et al., 2023). The Economic Internal Rate of Return (EIRR) represents the discount rate at which the present value of benefits equals the present value of costs. A project is considered economically feasible if the EIRR exceeds the social discount rate or the opportunity cost of capital. The EIRR is calculated using the following equation (Equation 2), with C_t as cash flow in period *t* (positive for inflows, negative for outflows); r as internal rate of return; n as total of the period; t = time period.

$$0 = \sum_{t=0}^{n} \frac{C_t}{(1+r)^t} \quad \text{(Eq. 2)}$$

EIRR is widely used due to its intuitive interpretation as a percentage return, facilitating comparisons across projects. However, it is sensitive to economic assumptions and may result in multiple IRRs in cases of non-conventional cash flows, requiring careful interpretation and complementary analysis (Velasquez-Pinas et al., 2023; Vilani et al., 2024). Beside ENPV and EIRR, third indicator is the Benefit-Cost Ratio (BCR) measures the relative efficiency of an investment by comparing the present value of total benefits to total costs. The BCR is calculated using the following equation 3.

$$BCR = \frac{\sum Present\ value\ of\ benefits}{\sum (Present\ value\ of\ cost)} \quad \text{(Eq. 3)}$$

A BCR greater than 1 indicates economic feasibility, while a value below 1 indicates that costs exceed benefits. Although practical and widely used, BCR has limitations, including its inability to fully capture non-monetary benefits and its sensitivity to parameter assumptions (Feyrer et al., 2023; Manisha et al., 2024).

By integrating ENPV, EIRR, and BCR, this study's cost–benefit analysis offers a robust and comprehensive evaluation of the economic feasibility, profitability, and efficiency of avocado cultivation systems. The combined use of these three indicators allows for a more nuanced and multidimensional assessment, capturing not only financial performance but also long-term economic sustainability. In this context, the complementary nature of ENPV, EIRR, and BCR strengthens the analytical framework for evaluating community-based avocado plantation systems in the Bangka Belitung region.

The estimation of costs and benefits covers the entire avocado production lifecycle, including nursery establishment, land preparation, seedling planting, crop maintenance, harvesting, and distribution. By adopting a full-lifecycle approach, this study ensures that the economic contribution of each production stage is systematically captured, thereby enhancing the accuracy and reliability of the overall economic evaluation. Moreover, this comprehensive scope provides a stronger basis for policy-relevant insights, particularly in designing sustainable agriculture.

2.3 Governance assessment

Beyond the economic analysis, attention was also given to the governance context surrounding avocado cultivation in Air Belo Village. Governance was considered important because the development of smallholder plantation systems depends not only on financial feasibility but also on the capacity of local institutions and stakeholders to support production, coordination, and market access.The governance assessment focused on four aspects frequently discussed in the literature on rural development and agricultural livelihoods: stakeholder participation, farmer-group coordination, government support, and market integration. These aspects were explored through semi-structured interviews with farmers and other relevant stakeholders involved in the implementation of the avocado plantation program.

Interview transcripts were reviewed and analysed using a thematic approach. The analysis sought to identify recurring patterns related to the roles of different actors, forms of institutional support, collective action among farmers, and relationships with market actors. Themes that appeared consistently across interviews were subsequently compared with information obtained through field observations and secondary sources. This process was undertaken to strengthen the credibility of the findings and to ensure that the interpretations reflected the conditions observed in the study area. Rather than developing a quantitative governance index, the assessment aimed to understand how institutional arrangements and stakeholder interactions influence the implementation of avocado cultivation and its long-term sustainability.

2.4 Integration of governance and economic analysis

The qualitative and quantitative components of the study were brought together during the interpretation stage. Governance findings were not converted into numerical scores nor statistically tested against economic indicators. Instead, the interview results were used to provide an institutional perspective for understanding the economic performance observed in the Cost-Benefit Analysis (CBA).

Several governance-related themes emerged consistently across respondents, particularly the role of government support, farmer-group coordination, stakeholder participation, and market integration. These themes were then examined in relation to the key variables influencing economic feasibility, including investment requirements, production performance, market access, and revenue generation. For instance, government assistance in the form of seedling provision, extension services, and technical training helped reduce barriers faced by farmers during the establishment phase of the plantation.

Farmer groups facilitated information exchange, coordinated production activities, and improved access to agricultural inputs, thereby lowering transaction costs and supporting more efficient farm management. Market linkages contributed to broader commercialization opportunities and greater revenue stability. These institutional conditions were subsequently used to interpret the positive ENPV, EIRR, and BCR values obtained from the economic analysis, as well as the system's ability to remain feasible under the sensitivity and switching value scenarios. In this way, the governance assessment provides additional insight into the institutional factors that contribute to the long-term viability of avocado cultivation as an alternative livelihood strategy in communities transitioning away from mining-based economic activities.

3. Results and Discussion

The Smallholder Avocado Plantation Program in Air Belo Village serves broader development objectives beyond agricultural production by supporting livelihood diversification among communities historically dependent on mining activities. For decades, tin mining has been a major economic driver in Bangka Belitung Province; however, declining resource availability and increasing economic uncertainty have

highlighted the need for alternative livelihood opportunities capable of generating sustainable long-term income. At the same time, mining activities have contributed to environmental degradation across many parts of the province, including reduced soil quality, altered hydrological conditions, and declining ecological functions (Miller & Spoolman, 2018; Syari et al., 2022; Agustina, 2023). These challenges have increased interest in agricultural development as a pathway for strengthening rural economic resilience and reducing dependence on extractive industries.

In Air Belo Village, avocado plantations are predominantly established within production forest areas and lands previously utilized for plantation activities rather than on former tin-mining land. Nevertheless, avocado cultivation remains closely linked to the broader process of livelihood transition occurring within Bangka Belitung, where communities increasingly seek sustainable economic alternatives beyond mining. Within this context, avocado (*Persea americana*) was selected due to its relatively high market value, growing domestic demand, and suitability as a perennial crop capable of generating long-term economic returns (Merino et al., 2024). Compared with annual crops, perennial plantation systems generally provide more stable production cycles and longer investment horizons, making them attractive options for supporting sustainable rural development and household income diversification.

The program adopts a development approach that combines farmer income generation with institutional strengthening. During the initial implementation phase, government support is provided through seedling assistance, technical training, extension services, and farmer-group facilitation to reduce investment barriers commonly faced by smallholder farmers. As plantations become productive, farmers gradually transition toward more independent production systems supported by local market networks, collective organizations, and institutional coordination mechanisms. This combination of government support and community participation is expected to improve production performance while strengthening long-term economic sustainability.

To evaluate the long-term viability of the program, the Cost-Benefit Analysis (CBA) distinguishes between two implementation phases: the government-supported establishment phase during Years 1-3 and the independent production phase during Years 4-30. The analysis applies a 30-year project horizon and a 9% social discount rate to reflect the productive lifecycle of avocado trees and the time value of investment flows. Economic feasibility is assessed using Economic Net Present Value (ENPV), Economic Internal Rate of Return (EIRR), and Benefit-Cost Ratio (BCR), enabling an evaluation of the profitability, efficiency, and long-term economic resilience of avocado cultivation as an alternative livelihood strategy for communities undergoing post-mining economic transition.

3.1 Cost assumption

The economic cost analysis consists of two main components: Capital Expenditure (CAPEX) and Operational Expenditure (OPEX). CAPEX represents the initial investment provided by the government for establishing the smallholder avocado plantations, while OPEX reflects the annual maintenance costs required throughout the production cycle until harvesting. The key assumptions applied in this analysis are as follows. Total plantation area is 20 hectare; planting density is 156 trees per hectar; total number of trees is 3,120 trees; analysis horizon is 30 years; subsidy phase is years 1-3; Social Discount Rate (SDR) is 9%; Standard Conversion Factor (SCF) is 0,85.

Table 1. Basic assumptions for economic cost calculation

Cost component	Value (IDR/ Ha)	Notes
CAPEX (Year-0)	IDR 44,258,775	Initial capital investment covering land clearing, equipment procurement, seedling acquisition and planting, as well as the application of vegetative fertilizers, compost, and water inputs per-hectare basis.

OPEX (Average)	IDR 46,627,222	Labor costs (farm workers), vegetative and generative fertilizer, agricultural lime, compost, agrochemicals (pesticides, fungicides, and insecticides), water inputs, equipment rehabilitation and maintenance, fuel, and transportation costs for fruit distribution to Jakarta, expressed on a per-hectare basis.
SCF	0.85	Shadow price
SDR	9%	Social project evaluation
Inflation	2.9%	Assumed average annual inflation rate in Indonesia

3.2 Benefit assumption

The economic benefits of the Smallholder Avocado Plantation Program arise from two main sources: first, avocado yields, which begin in the fourth year and grow as production stabilizes; and second, broader social and environmental impacts. These broader benefits result from the properties of perennial crops, which support ongoing benefit streams, and from government intervention. Government action in the early years creates employment and supports environmental restoration through carbon sequestration.

The resulting benefit structure shows that the program delivers comprehensive total economic value. This forms a strong basis for Cost-Benefit Analysis (CBA) to assess the long-term viability of avocado agriculture as post-mining livelihood. This study assumes avocado yields stabilize from year seven, with an average output of 50 kilograms per tree and a market price of IDR 15,000 per kilogram.

Table 2. Basic assumptions for economic benefit calculation

Benefit components	Value (IDR/ Ha)	Notes
Avocado yield	Rp 46,800,000	First harvest in Year 5
Avocado yield	Rp 93,600,000	Second harvest in Year 6
Avocado yield	Rp 117,000,000	Harvest stabilizes from Year 7 to 29
Carbon sequestration	Rp 1,851,200	Carbon sequestration 35,6 Ton CO_2e x IDR 52,000
Job creation	Rp 3,500,000	Wages received by the community during Years 1-3

Avocado-based agroforestry systems have been reported to store approximately 9.7 ± 2.5 Mg C ha^{-1}, equivalent to around 35.6 tCO_2 ha^{-1}, indicating their potential contribution to climate change mitigation through biomass carbon accumulation (Kuyah et al., 2024). The economic valuation of carbon sequestration in Indonesia is reflected in the emerging carbon market. Recent transactions in the Indonesia Carbon Exchange (IDXCarbon) indicate an average carbon price ranging from approximately IDR 52,000 to IDR 58,800 per ton CO_2e. Although relatively lower than international voluntary carbon markets, these values provide a baseline for incorporating carbon benefits into economic analysis.

3.3 Economic feasibility analysis results

The economic feasibility analysis demonstrates that the smallholder avocado plantation system in Air Belo Village generates positive long-term economic returns under post-mining land conditions. The positive Economic Net Present Value (ENPV), calculated using a 9% Social Discount Rate (SDR), indicates that the present value of total economic benefits exceeds total project costs throughout the 30-year analytical horizon. From a welfare economics perspective, this finding suggests that the program contributes net economic value not only to participating farmers but also to broader rural development objectives.

The estimated ENPV of IDR 118,551,623 reflects the capacity of avocado cultivation to generate sustained economic benefits throughout the project period. This finding is particularly relevant in the context of livelihood diversification in Bangka Belitung, where communities are increasingly seeking alternative income sources beyond mining activities. Although avocado cultivation requires substantial upfront investments for plantation

establishment and maintenance, the positive ENPV demonstrates that the long-term benefits exceed the total costs incurred. This result indicates that avocado cultivation represents a financially feasible and economically attractive livelihood option capable of supporting long-term rural economic resilience.

The Economic Internal Rate of Return (EIRR) of 27.98% substantially exceeds the applied Social Discount Rate of 9%, demonstrating strong investment efficiency and relatively low long-term economic risk. In public investment evaluation, projects are generally considered economically viable when EIRR surpasses the SDR, as this indicates that the project produces returns greater than the minimum acceptable social opportunity cost of capital. The considerable gap between EIRR and SDR observed in this study suggests that the avocado plantation system possesses relatively strong adaptive capacity under fluctuating economic conditions.

Similarly, the Benefit-Cost Ratio (BCR) of 1.54 indicates that every IDR 1 invested in the rehabilitation system generates approximately IDR 1.54 in economic benefits. A BCR greater than one confirms that the overall benefit stream outweighs total project costs, reflecting relatively efficient resource allocation within the production system.

Several structural factors contribute to the relatively strong economic performance identified in this study. First, the phased implementation approach, particularly the government-supported establishment stage, lowers early-stage financial barriers and reduces adoption risks among smallholder farmers. Second, the inclusion of additional economic values, including carbon sequestration and employment generation, strengthens overall project benefits beyond direct agricultural production.

The results also indicate that economic feasibility is closely associated with governance conditions and institutional coordination. Farmer-group involvement contributes to reduced transaction costs, improved access to agricultural inputs, and stronger coordination among participating actors. Government facilitation during the establishment phase further reduces production uncertainty and supports technology adoption, while market integration improves revenue stability and distribution efficiency. These institutional factors collectively influence production performance and contribute to the positive ENPV, EIRR, and BCR outcomes observed in the study.

Table 3. Result of the economic feasibility analysis of the smallholder avocado plantation

Indicator	Value	Notes
ENPV	IDR 118,551,623	Positive
EIRR	27.98%	>SDR 9%
BCR	1.54	>1

From a broader rural development perspective, the findings suggest that avocado cultivation can serve not only as an economically viable agricultural enterprise but also as a strategic livelihood diversification option for communities transitioning away from mining-dependent activities. The integration of government support, farmer participation, and institutional coordination enhances the long-term viability of the production system and reduces barriers commonly faced by smallholder farmers. These findings underscore the importance of governance arrangements in supporting economically sustainable rural development and strengthening regional economic resilience.

3.4 Sensitivity analysis

While the Cost-Benefit Analysis (CBA) results demonstrate a high degree of economic feasibility, the evaluation of development projects should consider potential changes in future economic conditions. Agricultural commodity prices, production costs, and other external factors frequently fluctuate, potentially impacting project profitability. Consequently, a sensitivity analysis was performed to assess the program's economic feasibility under variations in key analytical assumptions.

The sensitivity analysis in this study examines two critical variables that significantly influence economic outcomes. These variables are the selling price of avocados and operational production costs. They were selected because, in horticultural systems, commodity prices and input costs are major sources of economic uncertainty for farms.

The first scenario simulated a 20% decrease in avocado prices compared to the baseline. Such a reduction could result from increased market supply, changes in consumer demand, or disruptions in distribution. Despite the 20% price decline, the simulation shows that ENPV remains positive and BCR exceeds one. These findings indicate the program remains economically viable under adverse price conditions, showing resilience to market risks.

The second scenario simulated a 20% increase in operational costs, which may result from higher prices for fertilizers, pesticides, labor, or transportation. The results demonstrate that, despite increased production costs, the program maintains a positive ENPV and an EIRR above the social discount rate. This outcome indicates that the program possesses a strong capacity to withstand cost-related pressures, reinforcing its economic robustness under varying production conditions.

Table 4. Sensitivity analysis of the smallholder avocado plantation

Scenario	ENPV	EIRR	BCR	Feasibility
Baseline scenario	IDR 118,551,623	27.98%	1.54	Feasible
20% decrease in benefits	IDR 46,011,026	18.24%	1.24	Feasible
20% increase in CAPEX and OPEX	IDR 67,304,659	19.58%	1.28	Feasible

The results of the sensitivity analysis indicate that the smallholder avocado plantation program demonstrates high economic resilience. Even under adverse conditions, the program continues to generate economic benefits that exceed its costs. These findings support the conclusion that the program possesses significant potential for long-term development and scalability. This finding can be interpreted within the framework of socio-economic resilience, where the capacity of a system to absorb shocks without losing functionality is a key indicator of sustainability. In this case, the ability of the avocado plantation system to maintain feasibility under price and cost fluctuations suggests that it possesses adaptive capacity, which is particularly important in marginal environments characterized by uncertainty and resource constraints.

3.5 Switching value analysis

In addition to the sensitivity analysis, a switching value analysis was conducted. This determined the maximum change in key variables before the project becomes economically unfeasible. This analysis is crucial for identifying the level of risk the project can tolerate and defining the critical thresholds for the variables that influence economic feasibility.

This study analyzes two key variables using switching value analysis: avocado selling price and operational production costs. The avocado price is included because it drives the program's economic benefits. Operational costs are included because they account for the majority of the farming system's overall costs. Avocado prices can fall to a set threshold before the economic net present value (ENPV) reaches zero or the benefit-cost ratio (BCR) drops below 1. This shows that the program can withstand significant price fluctuations before becoming economically infeasible. Operational costs can also rise to a defined limit before the project's economic viability is at risk.

Table 5. Switching value analysis of the smallholder avocado plantation program

Variable	Change limits	ENPV	EIRR	BCR
Avocado price	Decrease by 32%	IDR 3,420,202	9.84%	1.06
CAPEX and OPEX costs	Increase by 45%	IDR 3,245,953	9.52%	1.06

Switching value analysis shows the program can handle economic risks from changes in key variables. This is crucial for horticultural agriculture, which faces uncertainties like market price swings and shifting production costs. The identification of these threshold values provides important insight into the system's economic boundaries. It indicates the extent to which key variables can change before the project becomes unfeasible, offering practical guidance for risk management and policy design. In particular, understanding these limits is essential for decision-makers in designing intervention strategies that minimize exposure to market and cost volatility.

3.6 Comparative analysis of cost-benefit analysis results with international studies

The economic feasibility results indicate that the smallholder avocado plantation system in Air Belo Village demonstrates strong long-term economic performance. The positive ENPV, EIRR of 27.98%, and BCR of 1.54 collectively suggest that the system is economically viable and capable of generating sustained economic benefits throughout the project lifetime. These findings indicate that avocado cultivation represents a financially attractive livelihood option that can support income diversification and enhance economic resilience among communities undergoing post-mining economic transition.

Compared with international studies, the economic outcomes observed in Air Belo Village are relatively competitive. Research conducted in Tanzania reported Internal Rates of Return (IRR) ranging from 11% to 14% for export-oriented avocado production systems among smallholder farmers (Boniphace et al., 2023). Although these systems benefited from export market opportunities, profitability remained constrained by limited institutional support, technological capacity, and market accessibility. Relative to the Tanzanian case, the higher EIRR identified in Air Belo Village may be associated with lower land acquisition costs, phased government support, and the incorporation of additional benefit components, including carbon sequestration benefits and employment generation, within the Cost-Benefit Analysis framework.

Similarly, studies in Rwanda highlight that avocado value-chain development contributes significantly to employment creation and rural economic activity, particularly through processing, distribution, and market integration mechanisms (Mgomezulu et al., 2025). However, these studies primarily emphasize value-chain performance and employment generation. In contrast, the Air Belo case highlights the role of avocado cultivation as a livelihood diversification strategy for communities seeking alternative income sources beyond mining-related activities. This broader objective expands the economic significance of avocado cultivation beyond conventional commercial production by linking agricultural development with long-term rural economic transition.

In Peru, avocado production has become strongly integrated with global export markets and contributes substantially to national agricultural growth (Viera et al., 2023; Collantes-Barturen & Morán-Santamaría, 2025). The Peruvian production model benefits from advanced infrastructure, intensive technological systems, and strong international market connectivity. Nevertheless, these advantages are generally associated with higher capital intensity and greater dependence on export-oriented production systems. By comparison, the Air Belo model operates within a smallholder farming context and demonstrates that favorable economic outcomes can also be achieved through government support, institutional coordination, and locally adapted production systems.

The comparison further reveals that economic feasibility is highly context-dependent and influenced not only by market orientation but also by governance structures, agroecological conditions, and production objectives. In export-oriented systems such as Peru and Tanzania, profitability is strongly linked to international market integration and infrastructure availability. Conversely, the Air Belo model demonstrates that smallholder avocado cultivation can achieve economic viability through institutional support, reduced transaction costs, stakeholder collaboration, and adaptive community-based governance arrangements.

An important distinction of the Air Belo system lies in its role as a livelihood diversification strategy within a region historically dependent on mining activities. Unlike conventional commercial avocado systems that primarily emphasize productivity and export growth, the Air Belo approach seeks to strengthen local economic resilience by providing sustainable income-generating opportunities for rural communities undergoing post-mining economic transition. This broader development objective influences both production decisions and benefit distribution by emphasizing long-term community welfare alongside economic performance.

The findings therefore, contribute to the broader literature on rural development and livelihood transition by demonstrating that economically feasible agricultural systems can emerge in regions seeking alternatives to extractive economic activities. The results suggest that long-term economic performance is influenced not only by productivity and market conditions but also by the capacity of governance systems to facilitate coordination, strengthen stakeholder engagement, reduce uncertainty, and support adaptive production strategies. These findings highlight the importance of government support, institutional capacity, and collective action in improving the economic viability and long-term resilience of smallholder agricultural systems.

From a broader rural development perspective, the findings suggest that avocado cultivation can simultaneously function as an income-generating activity and a livelihood diversification strategy in regions undergoing post-mining economic transition. The combination of perennial crop production, government support, and community-based institutional arrangements provides a more resilient development pathway compared with continued dependence on extractive activities. By demonstrating long-term economic viability and incorporating additional benefits such as carbon sequestration and employment generation, the study highlights the potential of avocado cultivation to strengthen household income stability and contribute to regional economic resilience.

3.7 Social and institutional implications

Beyond its economic feasibility, the smallholder avocado plantation system in Air Belo Village illustrates how community-based governance can support livelihood diversification and rural development in regions historically dependent on mining activities. The findings indicate that governance capacity functions as a critical mediating factor influencing how financial resources, institutional support, and stakeholder collaboration are translated into realized economic outcomes. Within the production system, local farmers serve not only as producers but also as decision-makers responsible for farm management, resource allocation, and adaptive production strategies. This reflects a broader socio-economic transition in which communities increasingly diversify their income sources beyond extractive activities. Rather than functioning solely as beneficiaries of external interventions, farmers actively adjust cultivation practices according to local conditions, market opportunities, and production constraints. These dynamics are consistent with adaptive governance frameworks, which emphasize flexibility, collective learning, and stakeholder participation in responding to changing economic and institutional conditions.

Farmer groups play a particularly important institutional role within the production system. The findings suggest that collective organization contributes to stronger coordination among producers, facilitates knowledge exchange, and improves access to agricultural inputs, technical assistance, and market networks. From an institutional economics perspective, these functions reduce transaction costs associated with information acquisition, input procurement, labor coordination, and product distribution. Lower transaction costs subsequently improve operational efficiency and contribute to more stable economic performance.

Government involvement also significantly shapes implementation outcomes, particularly during the establishment and development phases of avocado cultivation. Public support through seedling provision, technical training, extension services, and institutional facilitation helps reduce investment risks commonly encountered by

smallholder farmers. Such support is particularly important because avocado cultivation requires substantial initial investments and relatively long maturation periods before productive returns can be fully realized. In this context, government intervention functions not only as a source of financial and technical assistance but also as a mechanism for reducing uncertainty and encouraging farmer participation in livelihood diversification initiatives.

At the same time, market integration strongly influences the long-term viability of the production system. Stable market access and effective distribution networks improve price certainty, strengthen farmers' bargaining positions, and support sustained revenue generation. The findings indicate that stronger market connectivity contributes directly to economic resilience by reducing income volatility and improving production incentives. This observation reinforces previous studies suggesting that the performance of smallholder agricultural systems depends not only on production capacity but also on value-chain integration and institutional coordination (Sseruwagi et al., 2025; Vargas-Canales et al., 2020).

The interaction among farmers, farmer groups, government institutions, and market actors forms a collaborative governance structure that combines community participation, institutional facilitation, and market mechanisms. The findings demonstrate that governance quality directly affects economic outcomes by influencing coordination efficiency, resource accessibility, stakeholder engagement, and production stability. Consequently, governance should be viewed as a productive institutional asset that enhances economic performance rather than merely as an administrative support mechanism.

The relationship between governance and economic feasibility becomes particularly evident when interpreting the sensitivity and switching value analyses. The ability of the system to remain economically feasible under a 32% decline in avocado prices and a 45% increase in operational costs suggests that governance capacity contributes to economic resilience under uncertain market conditions. Strong coordination mechanisms, collective action, institutional support, and market connectivity reduce vulnerability to external shocks and improve adaptive capacity during periods of economic stress.

Nevertheless, several institutional challenges remain. Variations in organizational capacity among farmer groups may create unequal participation and uneven benefit distribution among community members. Continued dependence on government assistance during the early stages of development may also limit long-term institutional independence if capacity-building efforts are insufficient. In addition, fluctuations in avocado prices and changing market conditions continue to generate uncertainty regarding future income stability. These challenges indicate that strengthening local institutional capacity, enhancing farmer organizations, and improving long-term market integration remain essential for sustaining economic performance.

Overall, the findings demonstrate that governance should not be interpreted merely as a supporting administrative component but rather as a productive institutional asset that influences the efficiency, resilience, and long-term viability of smallholder agricultural systems. While financial investment provides the material foundation for production, governance capacity determines the extent to which resources can be effectively coordinated, distributed, and transformed into sustained economic benefits. The findings, highlight the importance of government support, institutional capacity, and stakeholder collaboration in supporting economically viable livelihood transition strategies in regions historically dependent on extractive industries.

4. Conclusions

The study demonstrates that avocado cultivation can provide a financially feasible livelihood diversification option for communities in Air Belo Village seeking to reduce their dependence on mining-related livelihoods. Positive ENPV, EIRR, and BCR values indicate that the economic benefits generated over the project lifetime outweigh the associated

investment and operational costs. The results further suggest that avocado can be economically attractive under local agroecological conditions, provided that appropriate farm management practices are maintained to sustain productivity over time.

The findings also show that the feasibility of smallholder avocado production depends not only on financial performance but also on institutional support. Government assistance during the establishment phase helps reduce investment risks associated with perennial crop production, while farmer organizations facilitate value chain integration through improved access to information, inputs, technical knowledge, and markets. These institutional functions contribute to reducing transaction costs and strengthening commercialization opportunities, thereby enhancing overall economic performance.

Taken together, the results indicate that livelihood diversification away from mining-related activities is influenced by the interaction between economic viability, local production conditions, and institutional arrangements. The successful development of avocado-based farming systems therefore depends not only on commodity profitability but also on the availability of supportive governance structures that strengthen market integration and farmer participation.

From a theoretical perspective, the study highlights the importance of incorporating governance considerations into economic feasibility assessments. Economic outcomes are shaped not only by costs and revenues but also by institutional factors that influence coordination, information exchange, market access, and risk management throughout the value chain.

Several limitations should be acknowledged. The analysis relies on assumptions regarding productivity, commodity prices, and operational costs that may change over time. In addition, variations in site-specific biophysical conditions and climate-related risks affecting long-term productivity were not explicitly incorporated into the economic model. Future research should integrate more detailed biophysical assessments, climate risk analysis, and quantitative institutional indicators to provide a more comprehensive understanding of the long-term sustainability of agricultural livelihood diversification in mining-affected regions.

This study demonstrates that avocado cultivation represents a financially feasible livelihood diversification strategy for communities in Air Belo Village seeking to reduce their dependence on mining-related livelihoods. The positive Economic Net Present Value (ENPV), Economic Internal Rate of Return (EIRR), and Benefit-Cost Ratio (BCR) indicate that the long-term economic benefits exceed the associated investment and operational costs, suggesting that avocado cultivation can become a viable agricultural alternative under local agroecological conditions when supported by appropriate farm management practices.

The findings further indicate that long-term economic feasibility is determined not only by financial performance but also by governance capacity. Government support during the establishment phase reduces investment risks, while farmer organizations improve coordination, facilitate access to information, production inputs, technical knowledge, and markets, and strengthen value chain integration. These institutional mechanisms reduce transaction costs and enhance commercialization opportunities, thereby improving the overall economic performance of smallholder avocado farming.

The study also contributes theoretically by demonstrating that governance should be incorporated into economic feasibility assessments of agricultural livelihood transitions. Economic outcomes are influenced not only by production costs and revenues but also by institutional arrangements that shape coordination, market access, information exchange, and risk management. This integrated perspective provides a broader understanding of how governance capacity supports sustainable livelihood transformation in resource-dependent regions.

Several limitations should be acknowledged. The economic analysis is based on assumptions regarding productivity, commodity prices, and operational costs that may change over time, while variations in site-specific biophysical conditions and climate-related risks were not explicitly incorporated into the model. Future research should

integrate detailed biophysical assessments, climate risk analysis, and quantitative governance indicators to provide a more comprehensive evaluation of the long-term sustainability of agricultural livelihood diversification in mining-affected regions.

Acknowledgement
The authors gratefully acknowledge the support of the local community and farmer groups in Air Belo Village, West Bangka Regency, for their valuable insights and participation. Appreciation is also extended to the local government and stakeholders for providing data and facilitating this research. The authors further thank colleagues and reviewers for their constructive feedback.

Author Contribution
Conceptualization, M.P.N and H.H.; Methodology, M.P.N; Validation, H.H., E.C.; Formal Analysis, M.P.N; Investigation, M.P.N; Resources, M.P.N.; Data Curation, M.P.N.; Writing – Original Draft Preparation, M.P.N; Writing – Review & Editing, H.H; Visualization, M.P.N; Supervision, H.H and E.C; Project Administration, H.H.; and Funding Acquisition, M.P.N.

Funding
Lembaga Pengelola Dana Pendidikan (LPDP) Indonesia funded this research.

Ethical Review Board Statement
The study was conducted in accordance with the Law Number 11 of 2019 on the National System of Science and Technology and approved by the Institutional Review Board (or Ethics Committee) of The Research Ethics Committee Faculty of Psychology (protocol code B-090/KEP-FPsi/TL.00/III/2026 and March 24th, 2026)

Informed Consent Statement
Written informed consent has been obtained from the participants to publish this paper.

Data Availability Statement
Not available

Conflicts of Interest
The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Declaration of Generative AI Use
During the preparation of this work, the authors used Grammarly to assist in improving grammar, clarity, and academic tone of the manuscript. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

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