HEURISTIC
Vol. 23, No. 2, October 2026
ISSN(p) 1693-8232
ISSN(e) 2723-1585

Life Cycle Cost Analysis of Sugar Cane and Pineapple Production on the Slopes of Mount Kelud, Blitar

Nyoman Sri Widari[1], Desrina Yusi Irawati[2*], Armadeo Ruben Canariesa[3]
[1,2,3] Department of Industrial Engineering, Universitas Katolik Darma Cendika

***Corresponding Author**: desrina.yusi@gmail.com

Article history:
Received: 22 June 2026
Accepted: 2 October 2026
Published: 7 October 2026

Keywords:
Life Cycle Cost (LCC);
Mount Kelud;
Pineapple;
Sugarcane;
Volcanic Agriculture

ABSTRACT

Agricultural commodities cultivated under favorable volcanic agroecological conditions may exhibit substantially different economic performance due to variations in production cycles, input requirements, and investment structures. This study compared the economic performance of sugarcane (*Saccharum officinarum*) and pineapple (*Ananas comosus*) in the volcanic agricultural region of Mount Kelud, Indonesia, using an integrated Life Cycle Costing (LCC) framework. The analysis combined life cycle cost assessment, economic hotspot analysis, investment feasibility indicators, Equivalent Annual Value (EAV), economic sustainability indicators, and sensitivity analysis. Primary data were collected from local farmers, while secondary data were obtained from agricultural statistics and relevant scientific literature. Sugarcane had a substantially lower life cycle cost than pineapple (IDR 536.62 versus IDR 2,521.08 kg^{-1}), largely because of its ratoon production system. However, pineapple achieved considerably higher annual economic productivity (IDR 139.30 million ha^{-1} $year^{-1}$) than sugarcane (IDR 14.25 million ha^{-1} $year^{-1}$). Land rental and labor were the main cost drivers for sugarcane, whereas planting material dominated pineapple production costs. Both commodities were economically feasible, with positive net present values, benefit-cost ratios above one, and internal rates of return exceeding the discount rate. Nevertheless, pineapple demonstrated superior profitability and investment efficiency. These findings show that lower life cycle cost does not necessarily indicate better economic performance when production cycles and investment structures differ, providing valuable insights for commodity diversification, investment planning, and farmer resilience in tropical volcanic regions.

INTRODUCTION

The agricultural sector plays a pivotal role in rural economic development in Indonesia, particularly in regions with agroecological characteristics that support the cultivation of high-value commodities. One such area is the slopes of Mount Kelud in Blitar Regency, East Java Province. This volcanic region is characterized by highly fertile soils resulting from the deposition of nutrient-rich volcanic materials, creating favorable conditions for the cultivation of various agricultural commodities, including sugarcane (Saccharum officinarum) and pineapple (Ananas comosus). These commodities contribute to farmers' income and regional agro-industrial development.

However, favorable agroecological conditions do not necessarily translate into superior economic performance, as production costs, productivity, investment requirements, and production cycles differ substantially among crops [1][2].

Indonesia is among the leading producers of sugarcane and pineapple in Southeast Asia. According to Statistics Indonesia (BPS), national pineapple production exceeded 3.15 million tons in 2023 [3], while sugarcane remains one of the major plantation crops supplying the domestic sugar industry [4]. Despite their economic importance, agricultural production decisions are often based on seasonal production costs and revenues rather than on the economic performance of the entire production cycle. This may obscure an important distinction: a commodity with a lower unit production cost is not necessarily more profitable or economically attractive over its investment life cycle.

Life Cycle Costing (LCC) provides a broader framework for addressing this limitation by evaluating relevant costs and cash flows over a defined life-cycle period [5]. In agricultural systems, LCC can identify dominant cost components, compare alternative production systems, and support economic decision-making beyond conventional short-term cost analysis. A systematic review of 92 agri-food LCC studies found that inputs, labor, machinery, and other cost categories can become major economic hotspots, while differences in system boundaries and cost definitions remain important methodological challenges [6]. Recent research further emphasizes that LCC alone does not fully represent economic sustainability; complementary indicators such as profitability, productivity, stability, and investment performance are needed to capture its multidimensional nature. Life-cycle approaches are therefore increasingly recognized as useful tools for evaluating sustainability in complex agri-food systems [7][8].

Numerous international studies demonstrate the relevance of LCC to agricultural decision-making. Research on apple production systems in Italy found differences in life-cycle cost efficiency between conventional and organic systems [9], while environmental LCC analyses showed that lower environmental externalities can improve long-term economic performance [10]. Irrigation and energy have been identified as major cost contributors in Spanish avocado production, whereas precision irrigation reduced life-cycle costs in Brazilian citrus production despite higher initial investment [11]. In Thailand, nitrogen fertilization represented a substantial share of mango production costs and generated additional economic implications associated with soil degradation [12]. These studies indicate that economic performance is shaped by crop characteristics, production technologies, resource requirements, and local conditions, limiting the transferability of economic conclusions across commodities and regions.

Although agricultural LCC research has expanded internationally [13], important gaps remain in tropical agricultural systems in Indonesia. First, empirical applications of LCC in Indonesian volcanic agricultural regions remain limited. Second, previous studies have predominantly examined individual commodities or production systems, providing limited evidence from direct comparisons between different crops cultivated under the same agroecological conditions. Third, LCC studies do not always integrate life-cycle costs with investment feasibility, annualized economic value, economic hotspots, and sensitivity analysis, limiting their ability to explain both the magnitude and drivers of economic performance. These gaps are important because volcanic soils can provide favorable conditions for agricultural production, while crop-

specific production characteristics may determine whether these conditions translate into economically sustainable outcomes.

Sugarcane and pineapple provide a particularly relevant comparative case because their production systems differ fundamentally. Sugarcane uses a ratoon system in which subsequent harvests can be obtained from an established crop, allowing initial establishment costs to be distributed across multiple production cycles [14]. Pineapple, in contrast, requires substantial planting-material expenditure for each production cycle. Consequently, differences in production duration, establishment costs, input intensity, and revenue timing may generate different relationships between unit cost, profitability, and investment efficiency.

The research problem addressed in this study is therefore whether lower life-cycle cost necessarily corresponds to superior economic performance when comparing crops with different production and investment structures. This study addresses this problem by comparing sugarcane and pineapple production in the Mount Kelud volcanic agricultural region using an integrated LCC framework. The analysis combines life-cycle cost estimation, economic hotspot analysis, Net Present Value (NPV), Internal Rate of Return (IRR), Benefit-Cost Ratio (BCR), Payback Period, Equivalent Annual Value (EAV), economic sustainability indicators, and sensitivity analysis.

The novelty of this study lies in integrating these complementary economic perspectives to compare two crops with contrasting production cycles within the same tropical volcanic agroecological context. The study contributes theoretically by demonstrating that life-cycle cost efficiency and investment profitability are complementary rather than interchangeable dimensions of agricultural economic performance. Practically, it provides farmers and agricultural decision-makers with evidence for commodity selection and diversification based not only on unit production costs but also on profitability, investment recovery, cost hotspots, and economic resilience. The findings are expected to strengthen the scientific basis for economically sustainable agricultural strategies in tropical volcanic regions.

MATERIALS AND METHODS

Study Area and Research Object

The study was conducted in the agricultural area located on the slopes of Mount Kelud, Blitar Regency, East Java, Indonesia. This region represents a major production area for sugarcane and pineapple cultivated on fertile volcanic soils. The agroecological characteristics of Mount Kelud provide favorable conditions for high-value agricultural commodities. The study adopted a comparative farm-level case study design to evaluate the economic performance of two commodities with contrasting production systems under the same broad agroecological context.

The study area was selected for three reasons. First, sugarcane and pineapple are among the important agricultural commodities cultivated by local farmers. Second, the two commodities have substantially different production characteristics, providing an appropriate basis for comparing life-cycle economic performance. Third, farmers in the region face economic uncertainties associated with input-price fluctuations, yield variability, and changes in market prices. These characteristics make Mount Kelud an appropriate empirical setting for examining whether differences in production-cycle structure translate into differences in life-cycle cost efficiency and investment performance.

Sugarcane cultivation was evaluated over one complete production cycle consisting of one plant cane phase followed by five ratoon crops, resulting in a six-year production period on a cultivated area of 0.8 ha. Pineapple cultivation was evaluated over one production cycle of approximately 12-14 months on a cultivated area of 0.25 ha. The research object was defined as the farm-gate production system, covering activities from land preparation and planting through crop maintenance, harvesting, and transportation until the products were ready for sale to local collectors. Post-farm-gate processing, distribution, and retail activities were excluded from the system boundary.

Research Design and Methodological Framework

A comparative life-cycle economic assessment was employed to evaluate the two production systems. The methodological framework consisted of five sequential stages: (1) definition of the goal, scope, system boundary, and functional units; (2) collection and validation of primary and secondary data; (3) calculation of life-cycle costs and economic hotspots; (4) evaluation of investment feasibility and economic sustainability; and (5) sensitivity analysis, comparison, and interpretation of the results.

The methodological design was informed by established life-cycle costing principles and previous applications of LCC in agri-food systems. The relevance of Life Cycle Costing (LCC) has been demonstrated for evaluating economic performance in agri-food systems, while the importance of complementary economic indicators beyond conventional LCC has been emphasized for assessing economic sustainability [6][13].

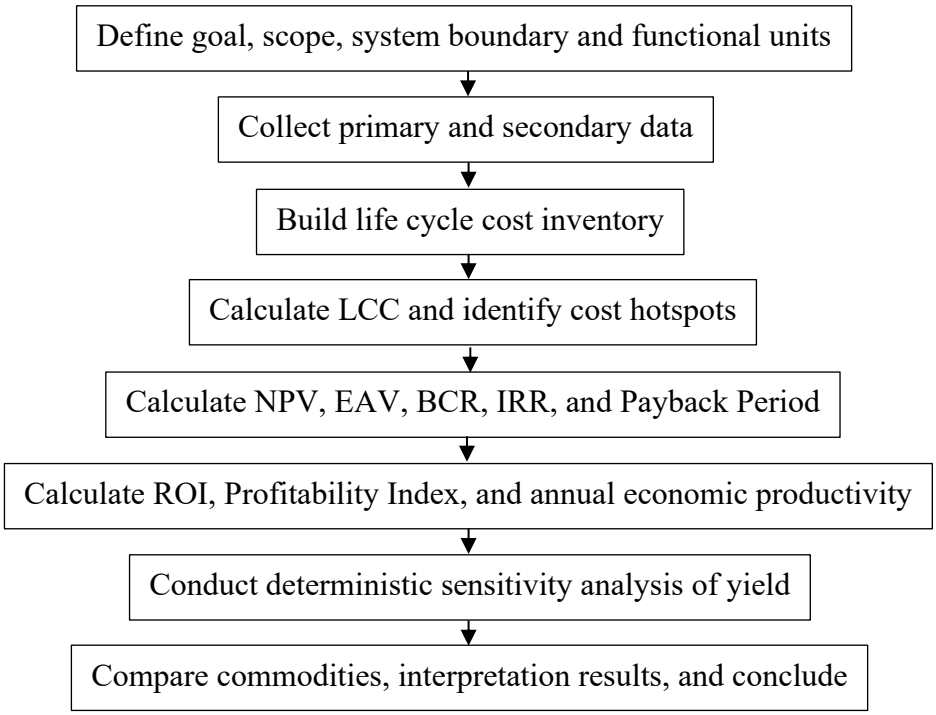


Figure 1. Research flowchart

Goal, Scope, and System Boundary

The primary objective of the study was to compare the economic performance of sugarcane and pineapple cultivation in a volcanic mountainous agricultural region from a life-cycle perspective. The system boundary was defined from farm establishment and

land preparation to the point at which harvested products were transported and ready for sale at the farm-gate/collector level. The analysis included land preparation, planting, fertilization, crop maintenance, harvesting, labor, land rental, transportation, and other production-related expenditures incurred within the defined production cycle. Costs occurring beyond the farm-gate, such as processing, wholesale distribution, retailing, and consumption, were excluded. For sugarcane, the life-cycle boundary covered one plant cane followed by five ratoon crops over six years. For pineapple, the boundary covered one production cycle with a harvesting period of approximately 12-14 months.

Functional Units

Because sugarcane and pineapple differ substantially in production duration, cultivated area, and output, two complementary functional units were used to avoid interpreting economic performance from a single dimension:

1. Product-based functional unit: one kilogram of fresh product at the farm-gate level (IDR kg^{-1}). This functional unit was used to compare unit life-cycle cost and production cost efficiency between the two commodities.
2. Area-time functional unit: one hectare per year (IDR ha^{-1} $year^{-1}$). This functional unit was used to compare annualized economic productivity and economic performance of land resources while accounting for differences in production duration.

Using complementary functional units is particularly important in comparative agricultural assessments because a product-based unit emphasizes cost per physical output, whereas an area-time unit captures the economic return generated from land over time [13].

Data Collection

Primary data were collected through direct interviews with local farmers and field observations. A structured data-collection framework was used to record physical inputs, production activities, costs, yields, and revenues for each production stage. The collected information included planting-material costs, organic and chemical fertilizer costs, plant growth regulator costs, labor costs, land rental costs, transportation costs, production yields, and selling prices. For sugarcane, data were collected separately for the plant cane and each ratoon cycle to capture differences in input requirements and production costs over the six-year life cycle. For pineapple, data were recorded for the complete 12-14 month production cycle.

Secondary data were obtained from agricultural statistical reports, scientific publications, government sources, and technical references related to sugarcane and pineapple cultivation. Secondary information was used to cross-check field observations, validate production assumptions, and provide contextual information for the economic analysis. Where discrepancies occurred between primary and secondary information, the values representing the observed local production conditions were prioritized and documented.

Life Cycle Cost (LCC) Approach

Life Cycle Costing was used as the principal economic assessment framework. The approach follows the general principles of life-cycle cost analysis, in which relevant costs and cash flows are evaluated over a defined period of analysis [6]. ISO 15686-5:2017 provides general principles for LCC analysis, and its application has been successfully demonstrated within agri-food systems. Total production costs encompass

land rental, planting materials, fertilizers, crop-maintenance inputs, labor, harvesting, transportation, and other directly attributable production expenses [6]. Economic hotspot analysis was subsequently conducted by calculating the contribution of each cost component to total LCC. Cost components with the largest percentage contributions were identified as economic hotspots and interpreted as the primary drivers of life-cycle expenditure.

Total life-cycle cost was calculated as:

$$LCC_{total} = \sum C_t \quad (1)$$

where C_t is the production cost incurred in year t within the defined system boundary.
Unit life cycle cost was calculated as:

$$LCC_{kg} = LCC_{total}/Q_{total} \quad (2)$$

where Q_{total} is the total quantity of fresh product obtained during the corresponding analysis period.

Economic hotspot analysis was then performed by calculating the contribution of each cost component to total LCC:

$$Hotspot_i\ (\%) = (C_i/LCC_{total}) \times 100 \quad (3)$$

where C_i is the cost of component i. Cost components with the largest percentage contributions were classified as economic hotspots.

Investment Feasibility Analysis

The economic feasibility assessment was performed using a discounted cash flow approach with a discount rate of 7.5%. Inflation effects and environmental costs associated with Life Cycle Assessment (LCA) were not included in the analysis. Furthermore, the assessment was based on a representative production cycle for each commodity. Since sugarcane and pineapple have different economic lifespans, direct comparison of NPV may introduce temporal bias. Therefore, the EAV method was employed to convert NPV into an equivalent annual economic value, enabling direct comparison between production systems with different project horizons [6][15][16]. The NPV was calculated as:

$$\text{Net Present Value (NPV)} = \sum_{t=1}^{n} \frac{(B_t - C_t)}{(1+r)^t} \quad (4)$$

where:
Bt = benefit obtained in year t;
Ct = cost incurred in year t;
r = discount rate;
t = year of analysis;
n = project lifetime.
A positive NPV indicates that the project is economically feasible.

To normalize the NPV over different project durations, the Equivalent Annual Value (EAV) was calculated as:

$$EAV = NPV \times \frac{i\,(1+i)^n}{(1+i)^n - 1} \quad (5)$$

where:
i = discount rate (7.5%);
n = project lifetime.

The Benefit–Cost Ratio (BCR) was calculated as:

$$BCR = \frac{\sum \frac{B_t}{(1+r)^t}}{\sum \frac{C_t}{(1+r)^t}} \quad (6)$$

A BCR value greater than one indicates that the project is financially viable.

The Internal Rate of Return (IRR) was defined as the discount rate at which the NPV equals zero. Meanwhile, the Payback Period (PP) was used to estimate the time required to recover the initial investment.

Economic Sustainability Indicators

LCC was complemented by profitability and productivity indicators because economic sustainability cannot be adequately represented by cost alone. Economic indicators for life-cycle sustainability assessment have been reviewed and categorized into key dimensions, including profitability, productivity, stability, innovation, customers, and autonomy [13]. In line with this perspective, the present study used ROI, Profitability Index (PI), and annual economic productivity.

a. Return on Investment (ROI) = (Net Profit / Total Cost) × 100% (7)
   This indicator measures the profitability generated from the invested capital.
b. Profitability Index (PI) = PV Benefits / PV Costs (8)
   The Profitability Index reflects the economic return generated for every unit of investment expenditure.
c. Economic Productivity per Hectare (EP)= Annual Net Profit / Cultivated Area (9)
   Economic Productivity per Hectare was calculated as the annual net profit generated per hectare of cultivated land.

Sensitivity Analysis

A deterministic one-way sensitivity analysis was conducted to evaluate the robustness of profitability against changes in crop yield. The baseline case was compared with a 20% reduction in yield, consistent with the scenario reported in the results and discussion. The purpose of sensitivity analysis is to examine how changes in key assumptions affect the economic results and thereby assess uncertainty in the decision context. This use is consistent with prior LCC literature in which sensitivity analysis is employed to test the effect of changing key assumptions and reduce uncertainty in interpretation.

For each commodity, total revenue and the resulting economic indicators were recalculated under the yield-reduction scenario while other baseline assumptions were held constant. The percentage change in profit relative to the baseline was then calculated as:

$$\text{Profit (\%)} = [(\text{Profit_scenario} - \text{Profit_baseline}) / \text{Profit_baseline}] \times 100 \quad (10)$$

RESULTS AND DISCUSSIONS

Life Cycle Cost Structure of Sugarcane and Pineapple Production

The cost structure analysis revealed fundamental economic differences between sugarcane and pineapple production systems. These differences were reflected not only in the magnitude of production costs but also in the distribution of expenditures among production components, indicating distinct resource dependencies and economic drivers for each commodity.

The total life cycle cost of sugarcane production amounted to IDR 139,342,000 over a six-year production cycle on 0.8 ha of land. After normalization by cultivated area and project duration, the average annual cost was estimated at IDR 29,029,583 ha^{-1} $year^{-1}$. In contrast, pineapple production required a total investment of IDR 32,774,000 for a single production cycle on 0.25 ha, equivalent to IDR 131,096,000 ha^{-1} $year^{-1}$.

These findings indicate that pineapple cultivation is considerably more capital-intensive than sugarcane cultivation. Nevertheless, higher production costs should not be interpreted as economic inefficiency, as pineapple also generates substantially greater economic returns.

The cost structure of sugarcane was dominated by land rental (51.67%) and labor expenses (25.26%), together accounting for more than three-quarters of total production costs. This finding suggests that sugarcane production is highly dependent on access to land resources. In the Mount Kelud region, where productive agricultural land is constrained by topography and competing land uses, land rental costs become a critical determinant of farm profitability.

In contrast, the largest cost component in pineapple production was planting material, accounting for 45.77% of total production costs. This result indicates that the economic performance of pineapple cultivation is more strongly influenced by the quality and availability of production inputs than by land availability. Consequently, investments in local seedling production systems may generate greater economic benefits than land expansion strategies. Conceptually, sugarcane can therefore be classified as a land-intensive farming system, whereas pineapple represents an input-intensive farming system. This distinction is important because economic improvement strategies for these commodities require fundamentally different approaches.

The dominance of land rental costs in sugarcane production is consistent with observations in Spanish avocado cultivation, where land and irrigation-related expenses represented the major share of total life cycle costs [17]. However, unlike avocado systems where water scarcity was identified as the primary cost driver, sugarcane production in the Mount Kelud region is mainly constrained by land access and rental prices. In contrast, the high contribution of planting material costs in pineapple production differs from the results reported for mango production systems in Thailand [12], where fertilizer expenditures represented the largest cost component. The discrepancy may be attributed to differences in crop propagation systems. Pineapple cultivation requires large quantities of planting material for each production cycle, whereas mango orchards rely on perennial trees with relatively low replanting requirements.

The importance of the ratoon system in reducing sugarcane establishment costs is also supported by comparative studies of plant and ratoon sugarcane. Ratoon sugarcane has been reported to generate a higher benefit-cost ratio than plant cane because subsequent crops require lower establishment expenditures [18]. Similar evidence has been reported in other sugarcane-producing regions, where ratoon cultivation has been associated with lower production costs and competitive profitability. The present study extends these findings from a single-crop comparison to a multi-year life-cycle perspective, showing how the economic advantage of ratooning accumulates across five ratoon cycles following the initial plant cane.

For pineapple, the dominance of planting material is consistent with studies emphasizing the importance of planting materials and other variable inputs in determining pineapple profitability. For example, expenditure on suckers, fertilizers, plant-protection chemicals, and labor has been identified as major cost components in pineapple cultivation in India [19]. Similarly, pineapple profitability studies in Malaysia and Bangladesh have demonstrated that input costs and production prices substantially affect farm returns [20][21]. Unlike these studies, which primarily evaluate profitability within a single production period, the present analysis places planting-material expenditure within a life-cycle framework and compares its economic significance

directly with the ratoon-based sugarcane system. The results of the sugarcane and pineapple Life Cycle Cost (LCC) analysis are presented in Table 1.

Table 1. Life cycle cost structure of sugarcane and pineapple production

Cost Component	Sugarcane (IDR)	Contribution (%)	Pineapple (IDR)	Contribution (%)
Planting Material	7,200,000	5.17	15,000,000	45.77
Organic Fertilizer	2,800,000	2.01	2,000,000	6.10
Urea Fertilizer	3,870,000	2.78	630,000	1.92
NPK Fertilizer	3,772,000	2.71	644,000	1.96
Growth Regulator	-	-	1,500,000	4.58
Transportation	14,500,000	10.41	3,000,000	9.15
Land Rental	72,000,000	51.67	-	-
Labor	35,200,000	25.26	6,000,000	18.31
Total Cost	139,342,000	100	32,774,000	100

Economic Hotspot Analysis

Economic hotspot analysis was conducted to identify cost components that contribute most significantly to total production costs and therefore exert the greatest influence on farm profitability.

For sugarcane production, land rental costs represented the primary economic hotspot, contributing 51.67% of total life cycle costs. This substantial contribution indicates that the economic sustainability of sugarcane farming is highly sensitive to fluctuations in land rental prices. For example, a 10% increase in rental costs would increase total production costs by approximately IDR 7.2 million over the production cycle, directly reducing farmers' net income. Labor costs constituted the second-largest hotspot, accounting for 25.26% of total expenditures. The dominance of labor expenses suggests that many cultivation activities remain labor-intensive, highlighting the potential benefits of mechanization in crop management and harvesting operations.

In pineapple cultivation, planting material represented the principal economic hotspot. The strong dependence on seedlings makes profitability highly sensitive to seedling prices and establishment success rates. Unlike sugarcane, which can be harvested repeatedly through ratooning, failure during the early establishment stage of pineapple cultivation directly affects the entire production cycle. These findings indicate that the primary economic risk in sugarcane production originates from external factors related to land access, whereas pineapple production is more vulnerable to internal factors associated with input management. Overall, the hotspot analysis confirms that sugarcane and pineapple possess fundamentally different economic risk structures, requiring commodity-specific management strategies to improve profitability and resilience.

The identification of land rental as the principal economic hotspot in sugarcane production corroborates previous findings from Mediterranean fruit production systems, where fixed production factors were reported to exert the strongest influence on profitability [17]. Similarly, the dominance of seedling costs in pineapple production confirms observations from tropical horticultural systems, in which establishment costs often determine long-term economic performance. Compared with previous studies, the present research expands existing knowledge by demonstrating that hotspot structures vary substantially even among crops cultivated within the same agroecological region.

This suggests that economic sustainability strategies should be commodity-specific rather than region-specific.

Life Cycle Cist (LCC)

Life Cycle Cost was calculated as the ratio between total production costs and total output over the production cycle. The results showed that sugarcane production had an LCC of IDR 536.62 kg^{-1}, whereas pineapple production reached IDR 2,521.08 kg^{-1}. At first glance, these values suggest that sugarcane production is considerably more cost-efficient than pineapple production.

However, such an interpretation requires caution. The relatively low LCC of sugarcane is largely attributable to the ratoon system, which distributes initial planting costs across multiple harvests. Conversely, pineapple cultivation requires new planting material for every production cycle, resulting in higher production costs per unit of output.

When normalized by cultivated area and production duration, the LCC amounted to IDR 29.03 million ha^{-1} $year^{-1}$ for sugarcane and IDR 131.10 million ha^{-1} $year^{-1}$ for pineapple. These results indicate that pineapple production requires substantially higher annual investment levels. Nevertheless, this higher investment also creates opportunities for significantly greater economic returns. Therefore, LCC should not be used as a stand-alone indicator for determining the superior commodity; profitability and investment feasibility analyses are necessary to obtain a more comprehensive assessment.

The relatively low LCC observed for sugarcane is consistent with the findings of apple production studies in Italy [9], where high productivity and efficient utilization of production inputs reduced life cycle costs per unit output. Similarly, the ratoon system in sugarcane enables the distribution of establishment costs over multiple harvests, resulting in lower production costs per kilogram. However, unlike the Italian apple production system where low LCC was associated with high profitability, the present study demonstrates that a lower LCC does not necessarily translate into greater economic returns. Pineapple exhibited a higher LCC but generated substantially greater profits due to its higher market value. This finding highlights the limitation of relying solely on LCC as an indicator of economic performance.

Table 2. Economic performance of sugarcane and pineapple production

Indicator	Sugarcane	Pineapple
Production Cycle	6 years	1 year
Cultivated Area	0.8 ha	0.25 ha
Total Revenue (IDR)	207,736,000	67,600,000
Total Cost (IDR)	139,342,000	32,774,000
Net Profit (IDR)	68,394,000	34,826,000
LCC (IDR kg^{-1})	536.62	2,521.08
Profit per ha per year (IDR)	14,248,750	139,304,000

Profitability Analysis

The total profit generated from sugarcane cultivation reached IDR 68,394,000 over the six-year production cycle. After normalization, this corresponds to an annual profit of IDR 11,399,000 or IDR 14,248,750 ha^{-1} $year^{-1}$. In contrast, pineapple cultivation generated a profit of IDR 34,826,000 within a single year, equivalent to IDR 139,304,000 ha^{-1} $year^{-1}$.

These results demonstrate that pineapple generates nearly ten times greater annual profit per hectare than sugarcane. Interestingly, the physical productivity of both commodities was relatively similar, ranging from approximately 52-54 tons ha^{-1} $year^{-1}$.

Therefore, differences in profitability were not driven by production volume but rather by differences in value creation per unit of output.

This finding is consistent with the economic sustainability literature, which distinguishes productivity from profitability and emphasizes that economic performance should be evaluated using multiple dimensions. Profitability and productivity are classified as distinct economic impact categories, supporting the use of both indicators in agricultural sustainability assessment [13]. The pineapple result is also directionally consistent with empirical evidence from Bangladesh, where pineapple production generated positive net returns and a BCR above one, although profitability varied with production costs, market conditions, labor availability, and input quality.

Investment Feasibility Analysis: NPV, BCR, IRR, and Payback Period

The Net Present Value (NPV) of sugarcane production was estimated at IDR 58,465,398, while pineapple production generated an NPV of IDR 30,109,721. The positive NPV values obtained for both commodities indicate that both investments are financially feasible.

However, direct comparison between the two NPVs is inappropriate because the production horizons differ considerably. Sugarcane was evaluated over a six-year period, whereas pineapple was evaluated over a single production cycle. To overcome this temporal bias, the Equivalent Annual Value (EAV) method was applied.

After normalization, the annual equivalent economic value of pineapple was approximately 2.44 times greater than that of sugarcane. This result suggests that pineapple provides substantially higher annual economic benefits despite its shorter production cycle.

The Benefit-Cost Ratio (BCR) of sugarcane was 1.53, compared with 2.06 for pineapple. This indicates that every IDR 1 invested in pineapple cultivation generated IDR 2.06 in economic benefits, whereas sugarcane generated only IDR 1.53. Therefore, pineapple exhibited superior investment efficiency.

Similarly, the Internal Rate of Return (IRR) reached 30.35% for sugarcane and 106.27% for pineapple. Although both values greatly exceeded the discount rate of 7.5%, the exceptionally high IRR observed in pineapple production indicates a substantially greater capacity to generate returns on invested capital.

The Payback Period further emphasized this difference. Sugarcane required approximately 9-10 months to recover the initial investment, whereas pineapple required only 5.8 months. Faster capital recovery makes pineapple particularly attractive for farmers facing financial constraints and requiring rapid cash turnover. The pattern is consistent with comparative LCC research in other agricultural systems. A comparison of multiple Mediterranean crops using LCC together with economic and financial indicators demonstrated that investment rankings can change when the analysis moves from life-cycle cost to profitability and financial performance [7]. Their study also used sensitivity analysis to test changes in prices, costs, subsidies, and discount rates

Table 3. Investment feasibility indicators

Indicator	Sugarcane	Pineapple
NPV (IDR)	58,465,398	30,109,721
EAV (IDR year^{-1})	12,355,540	30,109,721
BCR	1.53	2.06
IRR (%)	30.35	106.27
Payback Period (Months)	9.7	5.8

The positive NPV, favorable BCR values, and high IRR observed for both commodities are comparable to findings reported for citrus production systems in Brazil [11], where investments in improved production technologies remained economically attractive despite higher initial capital requirements. The use of Equivalent Annual Value (EAV) in the present study extends previous agricultural LCC research by enabling a fair comparison between commodities with substantially different production horizons. Many previous studies reported only NPV values, potentially introducing temporal bias when comparing alternative farming systems.

Sensitivity Analysis of Yield Productivity

Sensitivity analysis demonstrated that both production systems remained profitable under yield reductions of up to 20%. However, the magnitude of economic impacts differed considerably between the two commodities. For sugarcane, a 20% reduction in productivity resulted in a 60.75% decline in profit. In contrast, profit in pineapple production decreased by only 38.83% under the same scenario. These results indicate that pineapple possesses a greater capacity to absorb productivity-related risks due to its higher profit margin per kilogram of output. In practical terms, each unit of production loss has a more severe economic impact on sugarcane than on pineapple. Consequently, pineapple appears to be more resilient to fluctuations in agricultural productivity and environmental uncertainties.

The sensitivity analysis results align with previous studies in agricultural economics, which indicate that profit margins are critical determinants of systemic resilience to productivity shocks. A similar trend was observed in Thai mango production systems, where yield reductions led to a substantial decline in profitability; conversely, systems incorporating higher value-added products successfully maintained economic viability under adverse scenarios [12].

This methodological interpretation is further supported by prior Life Cycle Costing (LCC) research, which affirms that sensitivity analysis serves to evaluate how shifts in key assumptions impact outcomes and mitigate uncertainty [5]. Consistent with this approach, variations in price, cost, and discount-rate assumptions have also been integrated into agricultural LCC investment analyses [7].

Economic Sustainability Indicators

The Return on Investment (ROI) of sugarcane reached 49.08%, whereas pineapple achieved 106.27%. This indicates that every IDR 100 invested in pineapple production generated IDR 106.27 in profit, compared with only IDR 49.08 in sugarcane production. The Profitability Index (PI) was 1.53 for sugarcane and 2.06 for pineapple. Since both values exceeded unity, both farming systems can be considered economically viable. Nevertheless, the higher PI observed in pineapple production indicates superior investment performance. Economic Productivity per Hectare provides perhaps the clearest representation of land-use efficiency. Pineapple generated IDR 139,304,000 ha^{-1} $year^{-1}$, whereas sugarcane generated only IDR 14,248,750 ha^{-1} $year^{-1}$. Despite exhibiting comparable physical productivity, pineapple produced nearly ten times greater economic value per unit of land area. These findings suggest that strategies aimed at improving farmer income in the Mount Kelud region should focus not only on increasing crop yields but also on promoting commodities capable of generating higher economic value.

Table 4. Economic sustainability indicators

Indicator	Sugarcane	Pineapple
ROI (%)	49.08	106.27
Profitability Index	1.53	2.06
Economic Productivity (IDR ha^{-1} $year^{-1}$)	14,248,750	139,304,000

The economic sustainability indicators further reinforce conclusions drawn from previous studies emphasizing the importance of integrating profitability, productivity, and investment efficiency into sustainability assessments. According to Arulnathan et al. economic sustainability cannot be adequately represented by production costs alone and should incorporate broader indicators such as ROI and profitability indices [13]. The present study confirms this perspective by demonstrating that pineapple outperformed sugarcane across all economic sustainability indicators despite exhibiting higher life cycle costs.

Previous studies have demonstrated the usefulness of LCC for evaluating agricultural cost structures and identifying economic hotspots. Based on a systematic review of 92 agri-food studies, it has been emphasized that LCC results are strongly influenced by production systems, system boundaries, and cost categories. The present study extends this approach by providing a direct farm-level comparison of sugarcane and pineapple production under the volcanic agroecological conditions of Mount Kelud [6].

The findings are also consistent with the argument that LCC should be complemented by profitability and productivity indicators to obtain a more comprehensive assessment of economic sustainability. Accordingly, this study integrates LCC with NPV, EAV, BCR, IRR, Payback Period, ROI, Profitability Index, economic productivity, and sensitivity analysis. This integrated approach allows economic performance to be evaluated from both cost-efficiency and investment perspectives [13].

The lower LCC of sugarcane is further explained by its ratoon-based production system. Ratooning can reduce production costs by avoiding repeated establishment operations. The present study extends this finding by demonstrating its economic implications through a six-year production cycle and comparing them directly with pineapple [14]. Similarly, the integration of LCC, financial indicators, and sensitivity analysis has proven valuable in agricultural sustainability assessments. However, unlike that Mediterranean cropping context, this study examines tropical sugarcane and pineapple with substantially different production cycles and input structures [7].

The main contribution of this study is therefore the integration of LCC, investment feasibility, profitability, and sensitivity analysis within a direct cross-commodity comparison. The results reveal that lower life-cycle cost does not necessarily indicate superior economic performance. Sugarcane had a lower LCC per kilogram, whereas pineapple showed higher annual profitability, ROI, PI, BCR, IRR, and economic productivity, together with a shorter payback period. This finding supports a multidimensional interpretation of agricultural economic sustainability in which cost efficiency and investment profitability should be considered complementary rather than interchangeable indicators.

Practically, the results suggest that sugarcane may be advantageous where lower unit costs and production continuity are prioritized, while pineapple may be more attractive where higher land productivity and faster capital recovery are desired. Thus, the study provides empirical evidence for differentiated commodity strategies in the Mount Kelud region while extending previous LCC research to a tropical volcanic agricultural context.

Implications for Economic Sustainability in the Mount Kelud Region

Overall, the findings reveal a clear trade-off between stability and profitability. Sugarcane offers lower production costs, a stable ratoon production system, and relatively low technical risk. Conversely, pineapple provides substantially higher profitability, faster capital recovery, and significantly greater economic productivity per unit area. From a sustainable agricultural development perspective, the two commodities should not be viewed as competitors. Instead, they can play complementary roles within the regional farming system. Sugarcane serves as a relatively stable source of long-term income, while pineapple functions as a high-return commodity capable of accelerating income growth. Therefore, a diversification strategy integrating sugarcane and pineapple production may represent a more resilient agricultural development model. Such an approach could strengthen household economic resilience, reduce dependence on a single commodity, and contribute to the long-term sustainability of agricultural development in the volcanic landscapes of Mount Kelud.

CONCLUSION

This study compared the economic performance of sugarcane and pineapple cultivation in the volcanic agricultural region of Mount Kelud using a LCC approach integrated with investment feasibility, economic hotspot, sensitivity, and sustainability analyses. The results indicate that sugarcane has a lower life cycle cost (IDR 536.62 kg^{-1}) than pineapple (IDR 2,521.08 kg^{-1}), mainly due to its ratoon system, which distributes establishment costs over multiple harvests. However, pineapple generated substantially higher economic returns. Economic hotspot analysis showed that land rental and labor were the dominant cost components in sugarcane production, whereas planting material represented the largest cost contributor in pineapple cultivation. Both commodities were economically feasible, as demonstrated by positive NPV values, BCR values greater than one, and IRR values exceeding the discount rate. Nevertheless, pineapple consistently outperformed sugarcane in profitability, investment efficiency, and economic productivity per hectare. The Equivalent Annual Value (EAV) analysis further confirmed that pineapple provided greater annual economic benefits despite its shorter production cycle. Sensitivity analysis revealed that both systems remained profitable under yield reductions of up to 20%, although pineapple exhibited greater resilience to productivity fluctuations. The central conclusion is that life-cycle cost efficiency and investment profitability are complementary rather than interchangeable measures of agricultural economic performance. A lower cost per kilogram does not automatically identify the economically superior commodity when production cycles, market values, capital requirements, and revenue timing differ. This conclusion is consistent with international LCC literature advocating integration of life-cycle costing with broader economic indicators. From a practical perspective, sugarcane and pineapple can support differentiated economic strategies in the Mount Kelud region: sugarcane provides a lower-cost, ratoon-based production structure, whereas pineapple offers higher land-use productivity and faster capital turnover. However, the study does not establish an optimal crop-mix ratio; future research should incorporate market-price uncertainty, input-price uncertainty, climate and disease risks, and farmer-specific resource constraints to identify economically robust diversification strategies.

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