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Investment Model for Independent Oil Palm Plantation Development Using Cost Efficiency and Discounted Payback Period

Karina Rahmah[1], Ulidesi Siadari[2], Gina Fauzia[3] and Mirawati Yanita[4]

[1,2,3,4] Department of Agribusiness, Faculty of Agriculture, Universitas Jambi, Jambi, Indonesia

*Coressponding Authors: karina.rahmah@unja.ac.id

Abstract

Investment Model for Independent Oil Palm Plantation Development Using Cost Efficiency and Discounted Payback Period. **Background**: The conversion of rubber plantations into independent oil palm plantations has expanded rapidly in Jambi Province. However, smallholder investment decisions are often made without adequate information on plantation establishment costs, cost efficiency, and capital recovery. **Objective**: This study aims to develop an investment model for independent oil palm plantation development by integrating cost efficiency analysis with the Discounted Payback Period (DPP) approach. **Methods**: A quantitative survey was conducted among 55 independent smallholder farmers who converted rubber land into oil palm plantations in three villages of Muara Bulian District, Jambi Province. Data on land preparation, planting, basic fertilization, seedling procurement, transportation, and plantation cash flows were analyzed using descriptive cost analysis and investment appraisal. **Results**: The average plantation establishment cost was approximately IDR 13.10 million ha^{-1}. The cumulative cash flow remained negative during the establishment and immature stages but became positive by the sixth year of the investment period. Using a 10% discount rate, the estimated DPP was approximately 5.52 years. **Conclusions**: Integrating cost efficiency and DPP provides a practical framework for evaluating capital recovery and supporting financial decision-making in independent oil palm plantation development. The resulting investment model can support more efficient and evidence-based planning of smallholder plantation development.

Keywords: Independent oil palm plantation; Investment model; Cost efficiency; Discounted payback period; Smallholder agriculture

Cite This Article

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INTRODUCTION

The rapid expansion of independent oil palm plantations has become one of the most significant structural transformations in Indonesia's agricultural sector over the last decade. In Jambi Province, this transition has largely been driven by the conversion of rubber plantations into oil palm plantations as farmers respond to declining rubber profitability and the relatively higher economic returns generated by oil palm cultivation. This phenomenon has not only reshaped rural production systems but has also become an important component of regional agricultural development and green economic transformation. Recent statistics indicate that the oil palm plantation area in Jambi has expanded substantially, while rubber plantation areas have continuously declined, reflecting a long-term adjustment in farmers' investment behavior toward more profitable agricultural commodities (1–4).

Independent smallholders now contribute substantially to Indonesia's palm oil production and play an increasingly strategic role in supporting rural livelihoods, employment, and national vegetable oil supply(5). However, unlike estate companies, independent farmers generally finance plantation establishment using personal savings, informal credit, or family capital. Consequently, investment decisions are often made based on practical experience rather than systematic financial evaluation. This condition frequently results in inefficient allocation of production inputs, inappropriate investment timing, and uncertainty regarding capital recovery, thereby increasing financial risks during the immature plantation period (6–9).

The establishment of an oil palm plantation requires considerable initial investment before any economic return can be generated. Major investment components include land clearing, seedling procurement, transportation, field layout, planting operations, basic fertilization, and maintenance during the immature phase. Since fresh fruit bunches (FFB) generally begin commercial production only after four to five years, farmers experience a prolonged period of negative cash flow(10). Consequently, understanding the relationship between investment costs, cost efficiency, and the timing of capital recovery becomes essential for evaluating plantation feasibility and improving financial planning among smallholders (11–13).

Cost efficiency has become an increasingly important issue within the framework of sustainable agricultural investment and green economic development. Efficient utilization of financial resources not only reduces unnecessary production expenditures but also minimizes excessive input use, improves resource productivity, and supports environmentally responsible plantation development. Green economy principles emphasize that agricultural investments should simultaneously achieve economic viability, resource efficiency, and long-term sustainability. Therefore, investment evaluation should extend beyond profitability indicators and incorporate measures capable of assessing financial resilience and efficient capital utilization (14–17).

Various financial appraisal techniques have been widely applied in agricultural investment analysis, including Net Present Value (NPV), Internal Rate of Return (IRR), Benefit-Cost Ratio (BCR), and Payback Period (PP). Among these approaches, the Discounted Payback Period (DPP) offers a practical advantage because it explicitly incorporates the time value of money while determining the length of time required to recover the initial investment. Compared with the conventional payback period, DPP provides more realistic estimates of investment recovery under conditions where future cash flows are discounted, making it particularly suitable for perennial crops such as oil palm that involve substantial establishment costs and delayed revenue generation(18–20).

Previous studies have extensively examined oil palm profitability, production efficiency, sustainability certification, and socioeconomic impacts of plantation development. Several studies have also analyzed the financial feasibility of oil palm farming using conventional investment criteria. Nevertheless, limited research has integrated detailed plantation establishment cost structures with cost efficiency analysis and Discounted Payback Period into a single practical investment model specifically designed for independent smallholder plantations. Existing studies generally evaluate financial feasibility without explicitly linking cost efficiency to capital recovery dynamics, resulting in limited decision-support tools for smallholder investment planning (1,21–23).

From a green development perspective, investment models that incorporate efficient resource allocation are increasingly needed to support evidence-based plantation development policies. Improving financial efficiency during plantation establishment not only enhances farmers' economic resilience but also contributes to more sustainable land-use practices through optimized input utilization and reduced investment waste. Consequently, developing a comprehensive investment framework that combines establishment cost analysis with discounted capital recovery is expected to provide a more practical basis for guiding independent farmers, financial institutions, and policymakers in planning economically viable and environmentally sustainable plantation investments (24,25).

Therefore, this study aims to develop an investment model for independent oil palm plantation development by integrating cost efficiency analysis with the Discounted Payback Period approach. Specifically, the study evaluates plantation establishment costs, estimates discounted capital recovery, and formulates an evidence-based investment model that supports efficient financial decision-making and sustainable plantation development within the framework of green economic transformation(26,27).

METHODS

Study design and setting

This study employed a quantitative cross-sectional survey using a descriptive and investment appraisal approach to develop an investment model for independent oil palm plantation establishment. The study focused on analyzing plantation establishment costs, cost efficiency, and capital recovery using the Discounted Payback Period (DPP) method. The research was conducted from January to April 2026 in Muara Bulian District, Batanghari Regency, Jambi Province, Indonesia, one of the major independent oil palm production areas experiencing rapid conversion from rubber plantations to oil palm. The selected study area represents typical independent smallholder plantation development under local production and market conditions.

Population, samples and sampling

The study population consisted of all independent smallholder farmers who had converted rubber plantations into oil palm plantations in three villages, namely Teratai Village, Aro Village, and Sungai Buluh Village. According to local agricultural records, the total population comprised 55 farmers.

Considering the relatively small population size, a census (total sampling) technique was employed, whereby all eligible farmers were included as research respondents. This approach minimizes sampling bias while improving the representativeness of the collected data.

The inclusion criteria were:

- independent smallholder farmers;
- converted rubber plantations into oil palm plantations;
- plantation age between one and six years;
- willing to participate voluntarily.

Farmers managing company-owned plantations, plasma plantations, or incomplete financial records were excluded from the study.

The variables observed included:

- plantation establishment cost (land preparation, seedlings, transportation, planting, basic fertilization, and maintenance);
- annual cash flow;
- production revenue;
- Discounted Payback Period (DPP);
- cost efficiency indicators.

Instruments and criteria

Primary data were collected using a structured questionnaire developed based on previous studies of oil palm investment and farm financial analysis. The questionnaire consisted of four sections comprising approximately 35 structured questions covering:

1. respondent characteristics;
2. plantation establishment activities;
3. production cost components;
4. annual revenues and expenditure;
5. investment cash flow information.

Most variables were recorded using ratio-scale measurements (Indonesian Rupiah, hectares, kilograms, years), while several socioeconomic variables were collected using categorical scales.

Prior to the survey, the questionnaire was evaluated by three experts in agricultural economics and agribusiness to assess content validity. A pilot survey involving 15 independent farmers outside the study villages was conducted to improve question clarity and consistency. Internal reliability testing produced a Cronbach's Alpha coefficient greater than 0.80, indicating satisfactory reliability for field implementation.

Procedure and data collection

Data collection was conducted through face-to-face interviews with respondents using the structured questionnaire. Field observations were simultaneously undertaken to verify plantation establishment practices and physical conditions.
Secondary information regarding plantation development, production statistics, and regional agricultural characteristics was obtained from the Indonesian Central Bureau of Statistics (BPS), the Provincial Plantation Office, and published scientific literature. For each respondent, detailed investment costs incurred from land preparation until the immature plantation phase were recorded. Annual production, selling prices, operating costs, and cash inflows were subsequently reconstructed to estimate yearly cash flows. All financial variables were standardized into Indonesian Rupiah per hectare to facilitate comparison among respondents.

Statistical analysis

Descriptive statistics were first used to summarize respondents' characteristics and plantation establishment costs. Investment feasibility was then evaluated using Discounted Payback Period (DPP), which estimates the time required for discounted cumulative cash flows to recover the initial investment.
The DPP was calculated as(20):

$$\sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} \geq I_0$$

where:

$\sum_{t=1}^{n}$ = The sum (Sigma) from t = 1 to n

CFt = net cash flow in year t;
r = discount rate (10%);
Io = initial investment cost.

Cost efficiency was evaluated descriptively by comparing expenditure among plantation establishment components. Annual discounted cash flows were accumulated until the investment reached the break-even point. All statistical analyses were performed using IBM SPSS Statistics version 27 for descriptive analysis and Microsoft Excel 365 for investment appraisal and DPP calculations. Data processing and interpretation were conducted independently by the research team.

*Ethical concideration*s

Participation in this study was voluntary. All respondents were informed about the objectives of the research before the interviews were conducted, and verbal informed consent was obtained. The confidentiality of respondents' identities and personal information was strictly maintained. Data were analyzed and reported only in aggregated form for scientific purposes.

RESULTS

Characteristics of Independent Oil Palm Plantation Development

The study involved 55 independent smallholder farmers who had converted rubber plantations into oil palm plantations in Muara Bulian District, Batanghari Regency. The plantation establishment process followed several sequential stages, namely land clearing, field staking, planting hole preparation, basic fertilization, seedling procurement, transportation, and planting. Nevertheless, farmers implemented these activities using different technical approaches, resulting in four distinct plantation establishment patterns (Pattern A, Pattern B, Pattern C, and Pattern D). The differences among patterns primarily originated from the land-clearing technique (manual or mechanical) and the application of basal fertilization during plantation establishment.

Pattern A represented manual land clearing combined with complete plantation establishment practices, including basal fertilization. Pattern B employed mechanical land clearing (stacking) while maintaining all recommended establishment stages. Pattern C omitted basal fertilization but retained manual land clearing, whereas Pattern D combined mechanical land clearing with the omission of basal fertilization. These differences formed the basis for evaluating investment costs and cost efficiency among independent oil palm plantation establishment models.

Cost Structure of Plantation Establishment

The establishment of independent oil palm plantations required substantial initial capital investment before commercial production commenced. The investment covered land clearing, seedling procurement, field preparation, planting, transportation, and basal fertilization.

The average establishment cost reached IDR 13,240,564 ha^{-1}, indicating that plantation development requires considerable financial resources during the immature plantation period. Among all expenditure components, land clearing and seedling procurement accounted for the largest proportion of total investment expenditure.

Table 1. Average plantation establishment cost under different development patterns

Development pattern	Establishment cost (IDR ha^{-1})
Pattern A	11,291,000
Pattern B	16,118,616
Pattern C	11,843,938
Pattern D	16,285,001

Source: Primary data analysis, 2026.

Table 1 demonstrates considerable variation in establishment costs among the four plantation development patterns. Pattern D recorded the highest investment requirement (IDR 16,285,001 ha^{-1}), followed by Pattern B (IDR 16,118,616 ha^{-1}). Conversely, Pattern A required the lowest establishment cost, averaging only IDR 11,291,000 ha^{-1}. Overall, mechanical land clearing substantially increased initial investment compared with manual land clearing.

Comparison of Development Patterns

The comparison of plantation establishment patterns indicates that technical decisions made during the initial development phase strongly influenced investment expenditure. Pattern A required the lowest financial investment because land preparation was conducted manually while maintaining complete agronomic practices, including basal fertilization. This pattern relied on approximately 42 HOK ha^{-1} of labor, resulting in lower capital expenditure but higher labor utilization.

Pattern B adopted a mechanized land-clearing system (stacking), reducing labor requirements to approximately 18 HOK ha^{-1}. Although investment costs increased considerably, mechanization accelerated field preparation and improved operational efficiency for larger plantation areas. Patterns C and D omitted basal fertilization during plantation establishment. Although this practice reduced initial expenditure, it potentially affected early vegetative growth and therefore was considered less preferable for sustainable plantation establishment.

Statistical Comparison of Investment Costs

Differences in plantation establishment costs were further examined using One-Way Analysis of Variance (ANOVA). The statistical results demonstrated that establishment costs differed significantly among the four development patterns.

Subsequent Bonferroni multiple comparison analysis revealed that:

- Pattern A and Pattern C were not significantly different ($p > 0.05$);
- Pattern B and Pattern D were not significantly different ($p > 0.05$);
- Pattern A differed significantly from Patterns B and D ($p < 0.001$);
- Pattern C also differed significantly from Patterns B and D ($p < 0.001$).

These findings indicate that the primary source of cost variation was the land-clearing technique rather than basal fertilization. Manual land clearing generated significantly lower establishment costs than mechanical land clearing.

Table 2. Summary of Bonferroni multiple comparison analysis

Comparison	Significance	Interpretation
Pattern A vs Pattern B	$p < 0.001$	Significant
Pattern A vs Pattern C	$p = 0.941$	Not significant
Pattern A vs Pattern D	$p < 0.001$	Significant
Pattern B vs Pattern C	$p < 0.001$	Significant
Pattern B vs Pattern D	$p = 1.000$	Not significant
Pattern C vs Pattern D	$p < 0.001$	Significant

Source: Primary data analysis, 2026.

Investment Cost During the Immature Plantation Phase

Investment expenditures remained concentrated during the first three years of plantation establishment.

Table 3. Investment expenditure during the immature plantation phase

Investment component	Year 1	Year 2	Year 3
Plantation establishment	13,240,564	0	0
Fertilizer	648,325	1,612,480	2,438,915
Pesticides	284,76	398,54	517,285
Labor	986,42	1,138,675	1,297,540
Equipment	1,396,275	0	0
Total investment	16,556,344	3,149,695	4,253,740

Source: Primary data analysis, 2026.

As presented in Table 3, the first year required the highest investment (IDR 16,556,344 ha^{-1}), mainly because plantation establishment and equipment procurement occurred only during the initial development stage. Investment requirements declined sharply during Years 2 and 3, consisting primarily of maintenance activities such as fertilization, pesticide application, and labor inputs.

Discounted Payback Period Analysis

The investment appraisal demonstrated that cumulative discounted cash flows gradually improved following the immature plantation period. Using a discount rate of 10%, the initial investment was fully recovered after approximately 5.52 years, indicating the estimated Discounted Payback Period (DPP) of the plantation investment. The cumulative discounted cash flow remained negative throughout the establishment and immature phases but reached the break-even point during the sixth year of operation. This result indicates that independent oil palm plantation development is financially feasible because the initial investment can be recovered relatively early compared with the economic life of oil palm plantations, which generally exceeds 25 years. Consequently, the investment is expected to generate positive discounted returns over a substantial portion of the plantation's productive period.

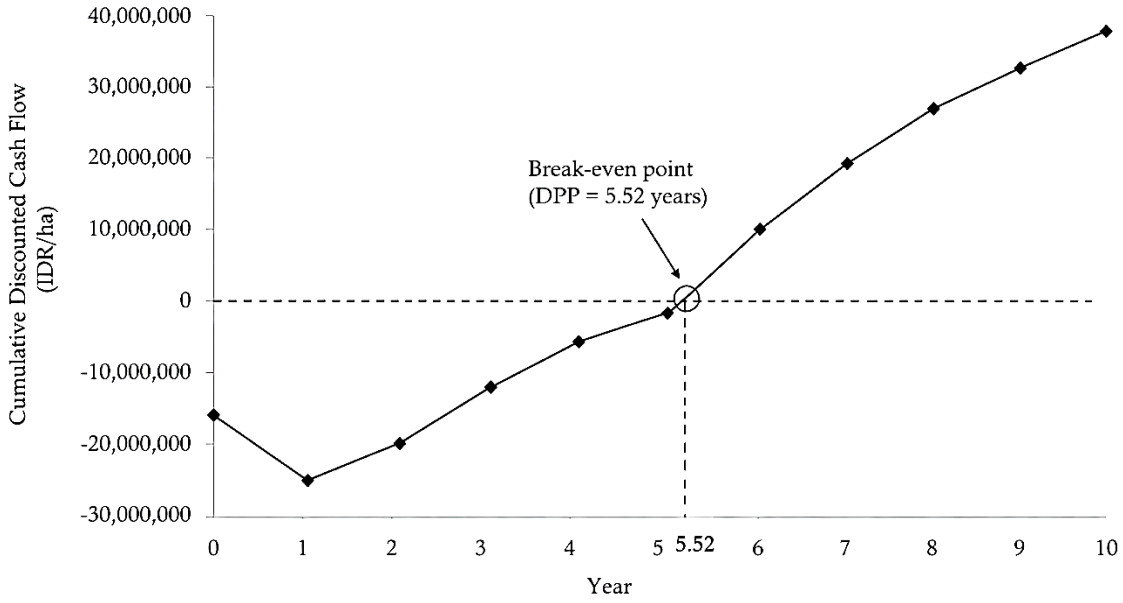

Figure 1. Cumulative discounted cash flow and estimated payback period of independent oil palm plantation investment.

The investment model further suggests that cost-efficient plantation establishment, particularly through optimized land-clearing methods and efficient allocation of establishment inputs, can shorten capital recovery and improve investment attractiveness among independent smallholders. These findings provide a practical basis for developing evidence-based green investment strategies in sustainable oil palm plantation development.

DISCUSSION

The findings demonstrate that the investment required for establishing independent oil palm plantations is strongly influenced by the technical choices made during the establishment stage. Although the average establishment cost reached IDR 13.24 million ha^{-1}, considerable variation was observed among the four development patterns. This indicates that investment performance is not determined solely by the amount of capital available but also by how efficiently production inputs are allocated during plantation establishment. Efficient investment planning therefore becomes a critical prerequisite for improving the long-term financial sustainability of independent oil palm farming. The observed variation among development patterns further confirms that technical decisions regarding land preparation and plantation establishment directly affect overall investment efficiency and future financial performance.

One of the most notable findings is that manual land clearing (Pattern A) generated substantially lower establishment costs than mechanized land clearing (Patterns B and D). Although mechanization can reduce labor requirements and shorten field preparation time, the additional operational costs associated with heavy equipment significantly increased the initial investment. This finding suggests that, for relatively small landholdings managed by independent farmers, manual land preparation may remain economically advantageous when labor availability is sufficient. Similar observations have been reported in studies of Indonesian independent smallholders, where investment efficiency depends more on appropriate resource allocation than on maximizing mechanization. Mechanization should

therefore be adopted selectively according to farm scale, labor availability, and expected productivity gains rather than being considered the universally optimal option (1,2).

The statistical comparison among plantation establishment patterns further strengthens this conclusion. Significant differences in establishment costs were identified between manually and mechanically prepared plantations, whereas differences associated with basal fertilization were relatively limited during the initial investment phase. These results imply that land preparation constitutes the dominant component influencing investment expenditure. Consequently, improving cost efficiency should first focus on optimizing land preparation methods before attempting to reduce other relatively smaller cost components. From an investment perspective, reducing unnecessary expenditure during the establishment stage contributes directly to lower capital requirements and improved financial resilience among smallholders.

Another important finding concerns the Discounted Payback Period (DPP) of approximately 5.52 years. Unlike the conventional Payback Period, DPP incorporates the time value of money by discounting future cash flows. Therefore, the estimated recovery period provides a more realistic assessment of investment feasibility under actual financial conditions. Considering that commercial oil palm plantations generally remain productive for approximately 25 years, recovering the initial investment within the first six years indicates a financially attractive investment. Once the investment has been recovered, farmers may benefit from nearly two decades of positive net returns, assuming proper plantation management and stable market conditions. Recent studies likewise recognize DPP as a more robust indicator for evaluating long-term agricultural investments because it explicitly accounts for inflation, capital opportunity costs, and investment risk (3).

The gradual transition from negative to positive discounted cash flow also reflects the biological characteristics of perennial plantation crops. During the immature period, farmers experience substantial expenditures without receiving production revenue. Financial pressure is therefore concentrated within the first several years following plantation establishment. As fresh fruit bunch (FFB) production begins to increase, cumulative discounted cash flows gradually improve until the investment reaches its break-even point. This financial pattern explains why many independent farmers experience liquidity constraints despite the long-term profitability of oil palm cultivation. Previous studies similarly report that the immature plantation phase represents the greatest financial barrier for independent smallholders, particularly when external financing remains limited (4,5).

The findings also have important implications within the framework of the green economy. Green economic development emphasizes that investment decisions should simultaneously generate economic returns, improve resource efficiency, and support environmental sustainability. Cost efficiency contributes directly to these objectives by minimizing unnecessary financial expenditures while encouraging more efficient utilization of production inputs. Efficient investment does not necessarily imply reducing essential agronomic practices; rather, it involves allocating financial resources toward activities that generate the highest long-term economic value. Consequently, the proposed investment model supports both financial sustainability and more responsible resource management during plantation establishment (6,7).

From a policy perspective, the proposed investment model provides practical guidance for several stakeholders. Independent farmers may use the model to estimate initial capital requirements, compare alternative establishment strategies, and determine expected investment recovery periods before making planting decisions. Financial

institutions may utilize the estimated DPP to evaluate credit feasibility and repayment schedules for plantation financing programs. Likewise, government agencies implementing replanting programs may employ the model to design more targeted financial support mechanisms by considering the duration of negative cash flow experienced by smallholders. Recent policy analyses similarly conclude that financial incentives should not merely subsidize plantation establishment costs but should also address the prolonged period of limited income during the immature plantation stage (5,8).

Another contribution of this study lies in integrating cost efficiency with Discounted Payback Period into a single investment evaluation framework. Previous studies have frequently analyzed investment feasibility using Net Present Value (NPV), Internal Rate of Return (IRR), or conventional Payback Period independently. In contrast, the present study demonstrates that combining detailed establishment cost analysis with discounted capital recovery provides more comprehensive information for investment decision-making. This integrated approach enables farmers to identify major cost drivers while simultaneously understanding the expected duration required to recover invested capital. Consequently, investment decisions become more evidence-based and financially transparent.

The present findings are also consistent with broader international discussions concerning the resilience of independent oil palm farmers. Recent studies emphasize that improving the long-term sustainability of smallholder oil palm production requires not only productivity enhancement but also stronger financial resilience through improved investment planning, efficient resource utilization, and better access to financing. Investment models capable of estimating capital recovery therefore represent valuable decision-support tools that strengthen farmers' capacity to manage long-term production risks while supporting sustainable agricultural development (2,4).

Nevertheless, several limitations should be acknowledged. First, the analysis was conducted using data collected from independent smallholders in Muara Bulian District, Jambi Province; therefore, regional differences in labor costs, land preparation practices, and fresh fruit bunch prices may influence the applicability of the investment model elsewhere. Second, the DPP calculation assumed a constant discount rate of 10% throughout the investment period. Changes in inflation, borrowing costs, or commodity prices may alter the estimated capital recovery period. Third, this study primarily evaluated financial investment efficiency and did not incorporate environmental valuation, carbon sequestration benefits, biodiversity indicators, or climate-related risks that increasingly influence sustainable plantation investment. Future studies should therefore integrate financial, environmental, and social dimensions into a more comprehensive green investment assessment framework.

Overall, the study demonstrates that efficient allocation of establishment costs combined with Discounted Payback Period analysis provides a practical and scientifically robust framework for evaluating independent oil palm plantation investments. The proposed investment model not only improves financial decision-making at the farm level but also contributes to evidence-based policy formulation supporting green economic transformation, sustainable plantation development, and long-term resilience of independent smallholder agriculture.

CONCLUSIONS

This study developed an investment model for independent oil palm plantation establishment by integrating cost efficiency analysis with the Discounted Payback Period (DPP) approach. The findings demonstrate that plantation establishment requires an average initial investment of IDR 13.24 million ha^{-1}, with land preparation representing the largest cost component influencing overall investment expenditure. Differences in establishment methods significantly affected investment costs, particularly the choice between manual and mechanical land-clearing systems. Manual land preparation resulted in lower establishment costs and greater cost efficiency for small-scale independent farmers, whereas mechanized systems required substantially higher initial capital investment.

The financial analysis further revealed that the estimated Discounted Payback Period (DPP) was approximately 5.52 years at a 10% discount rate, indicating that independent oil palm plantation development is financially feasible under the observed production and cost conditions. Integrating establishment cost analysis with discounted capital recovery provides a practical investment framework that supports evidence-based financial planning and improves investment decision-making among independent smallholders.

From a practical perspective, the proposed investment model may serve as a decision-support tool for farmers in estimating capital requirements, selecting cost-efficient plantation establishment strategies, and planning long-term investment recovery. The model may also assist financial institutions in evaluating agricultural credit feasibility and support policymakers in designing more effective financing mechanisms for independent oil palm plantation development within the framework of green economic transformation.

Future research should expand the investment model by incorporating additional variables, including market price volatility, inflation, climate-related production risks, carbon valuation, and environmental performance indicators. Furthermore, comparative studies involving different oil palm-producing regions are recommended to improve the generalizability and applicability of the proposed investment model across diverse production systems.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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DECLARATION OF ARTIFICIAL INTELLIGENCE USE

This study used artificial intelligence (AI) tools during manuscript preparation in the following capacities:

- Manuscript writing support: AI-based language models, including ChatGPT (OpenAI), were employed to:
    1. improve the grammar, sentence structure, and readability of the manuscript;
    2. assist in summarizing research findings and conclusions;
    3. provide technical writing assistance by suggesting more effective scientific organization and presentation of the manuscript.
- Language refinement: QuillBot was used to assist in language refinement through paraphrasing and improving sentence fluency and academic writing style.

No AI tools were used for data collection, data analysis, statistical computation, visualization, predictive modeling, hypothesis testing, or interpretation of research findings. All research data were analyzed manually by the authors using conventional statistical methods and investment appraisal techniques. We confirm that all AI-assisted processes were critically reviewed by the authors to ensure the integrity, accuracy, and reliability of the manuscript. The final decisions regarding data interpretation, scientific arguments, conclusions, and all intellectual content presented in this article were made solely by the authors.

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