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Economic And Ecological Benefit-Cost Analysis Of The Impact Of Oil Palm Expansion In The Tesso Nilo National Park Area, Pelalawan

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Abstract

Oil palm expansion inside Tesso Nilo National Park (TNTN), Pelalawan Regency, generates short-term financial gains for its actors, while the loss of carbon stocks and forest ecosystem services is rarely accounted for in conventional economic calculations. This study estimates the economic benefits and ecological losses of oil palm expansion in TNTN and analyzes their benefit-cost ratio (BCR). A descriptive-quantitative approach with an ex-post Benefit-Cost Analysis (BCA) under a with-without principle was applied from a regional social perspective, using secondary data, an expansion area of 40,000 hectares, a 25-year horizon, and a base discount rate of 8% tested at 4% and 12%. Ecological losses comprise carbon stock loss valued by the social cost of carbon (US$185 per tCO2). The results show a net economic benefit of IDR 6.70 trillion, an ecological loss of IDR 57.82 trillion, a BCR of 0.24, and a social NPV of −IDR 51.12 trillion, indicating that oil palm expansion in TNTN is net-negative for the region. This conclusion holds in all sensitivity tests using the social cost of carbon, including a lower carbon baseline of plantation forest (BCR 0.61). The BCR exceeds 1 only if the carbon price falls below US$21.4 per tCO2, for example at market carbon prices of US$5–10 (BCR 1.29–1.48). These findings highlight the need for economic valuation to support law enforcement, restoration, and conservation area management policies.

Keywords : benefit-cost analysis; oil palm expansion; carbon stock; social cost of carbon; Tesso Nilo National Park

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INTRODUCTION

As an equatorial country, Indonesia is unique due to its abundant natural resources, making its resources highly sought after by various parties. Natural resources are generally defined as anything with economic value and a component of an ecosystem that provides goods and services for human benefit.(Purba et al. 2020 in Annurroin, 2026)Riau is one of the provinces in Indonesia with significant natural resource potential. One area in Riau Province with diverse natural resources is Tesso Nilo National Park in Pelalawan Regency. The concept of a national park, based on Law No. 5 of 1990 concerning the Conservation of Biological Natural Resources and Ecosystems, is a nature conservation area containing a natural ecosystem managed through a zoning system and utilized for research, scientific development, education, cultivation, tourism, and recreation.

According to data from the Ministry of Forestry, Tesso Nilo National Park (TNTN) was first established in 2004 with an area of approximately 38,576 hectares. In 2009, the Ministry of Forestry decided to expand the TNTN area to approximately 83,068 hectares. The area boasts approximately 360 species of flora, 107 species of birds, 50 species of fish, 23 species of mammals, 18 species of amphibians, 15 species of reptiles, and 3 species of primates.(Mulawarman et al., 2026). Structured land encroachment and exploitation by various parties, both individuals and corporations, are the cause of the ecological crisis in the National Park (TNTN). The Inventory and Verification of Unlicensed Construction Activities (IKK) within the TNTN area in 2023 reached 2,666.29 hectares, or 210.61% of the target of 1,266 hectares. Palm oil expansion is one of the causes of the damage to the TNTN's ecological function.(Mulawarman et al., 2026).

Oil palm plantation expansion in Riau reached 2.65 million hectares (29.77% of the province's area) between 1990 and 2018. This rapid expansion is inextricably linked to land conversion, with the reduction of forest cover, shrubland, and fields being converted to oil palm plantations. Several studies on the environmental impacts of oil palm expansion have been conducted by Carlson et al. (2012) in Rafli & Buchori.(2022a), namely calculating carbon availability due to the conversion of forest land to oil palm plantations in 1990–2010 using Landsat image interpretation and carbon stock analysis. In addition, Hino & Ramdani 2013 in Rafli & Buchori,(2022b)shows that oil palm plantations are the cause of increased greenhouse gas emissions.

The expansion of oil palm plantations offers the potential for significant resource consumption and can directly impact environmental change. Palm oil's high economic value drives people into forests and threatens their long-term survival. Encroachment and illegal plantation expansion have created habitat fragmentation, resulting in landscape degradation and reduced wildlife ranges.(Mulawarman et al., 2026).

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Management and the government have actually taken a number of steps to address encroachment and oil palm expansion in the TNTN, including SMART patrol-based forest security patrols, joint operations to regulate and destroy illegal oil palm plantations, the establishment of a Forest Area Regulation Task Force (Satgas PKH), a persuasive approach in the form of outreach and warnings to the community before physical regulation, and an ecosystem restoration program through replanting native vegetation. However, these steps have not been able to halt the rate of damage to the area as a whole.

The IKK achievement, which exceeded the target by 210.61% in 2023, indicates that the area of illegal construction activities within the TNTN is much larger than initially estimated. Even regulated oil palm plantations are often found to be only about a year old when destroyed, indicating a pattern of encroachment that continues to grow back despite repeated enforcement efforts. The fundamental weakness of the current approach is its partial and reactive nature, focusing on law enforcement and physical land restoration without an economic valuation basis that quantitatively compares the financial benefits of illegal oil palm with the ecological losses caused. As a result, the weak economic argument cannot convince all stakeholders that illegal oil palm expansion is actually net detrimental to the region.

Previous studies have extensively examined the dynamics of oil palm plantation expansion in relation to regional economic growth and the general issue of deforestation. This research offers a novel approach through a Benefit-Cost Analysis (BCA) approach that integrates the economic valuation of illegal palm oil profits with the valuation of specific ecological losses, namely the reduction in carbon stocks and the degradation of forest ecosystem functions in the National Park (TNTN) area. This research not only measures one-sided financial efficiency but also evaluates the burden of ecological losses in a balanced manner to formulate more objective mitigation and conservation area management policies.

The urgency of this research is based on the urgent need to respond to the multidimensional threats resulting from massive land conversion. From an ecological perspective, the National Park (TNTN) faces severe pressures from forest encroachment and the expansion of illegal oil palm plantations. Habitat fragmentation not only degrades environmental quality but also triggers escalating tenure conflicts and undermines ecosystem integrity and the area's protected function. From an economic perspective, oil palm expansion continues to grow because it offers short-term financial gains for those involved, while the real losses due to the loss of forest ecosystem services and the decline in carbon stocks are often overlooked in conventional economic calculations. Therefore, this research is crucial for providing a comprehensive policy evaluation

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instrument through the BCA (Balance Sheet) that balances economic benefits and ecological losses.

Based on these problems, the formulation of the research problem is:

1. How is the estimated value of economic benefits and economic valuation of ecological losses resulting from the expansion of oil palm plantations in the TNTN area, Pelalawan Regency?
2. What is the benefit-cost ratio between the economic and ecological aspects of oil palm plantation expansion in the TNTN area?

This study aims to calculate and analyze the economic benefits and ecological conservation losses of oil palm plantation expansion in the National Park (TNTN) area of Pelalawan Regency. Furthermore, the study analyzes the economic-ecological benefit-cost ratio to evaluate whether oil palm expansion in TNTN has a net positive impact or a comprehensive negative impact on the region.

LITERATURE REVIEW

Economic Benefits and Social Implications of Oil Palm Plantations

In general, previous research shows that oil palm expansion generates economic benefits while also incurring social and ecological costs. On the economic side, Kubitza et al.(2024)found that the adoption of oil palm by smallholders in Indonesia on average led to the expansion of agricultural land at the expense of forests, while requiring lower labor per hectare than alternative crops. Fosch et al.(2023)shows that rejuvenating unproductive oil palm plantations with smallholder oil palms is beneficial for poverty reduction and environmental conservation because it utilizes existing plantations. Hasudungan et al.(2024)also shows that oil palm expansion can improve farmers' cash flow, but at the same time can reduce food diversity. These findings demonstrate that the economic benefits of oil palm do not stand alone but must be considered in conjunction with the consequences of land use.

2.2 Land Cover Changes and Pressure on Conservation Areas

In terms of changes in land cover and pressure on conservation areas, Juniyanti et al.(2021)A systematic review showed that land use change in Sumatra and Kalimantan is driven by various forestry and agricultural activities, including oil palm plantations. Dwiyahreni et al.(2021)found that human activity pressure is increasing in most Indonesian national parks and is related to population growth and increased access to the area. In the context of TNTN, Tua & Sundari.(2021) shows that population migration, accessibility, and palm oil and rubber plantation activities are related to encroachment and the reduction of natural forests. Prayoga & Imron(2022)also shows that fires worsen habitat conditions in TNTN which is already facing pressure from illegal conversion.

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2.3 Environmental Services Valuation and Benefit-Cost Analysis Framework

At the Riau Province level, Rafli & Buchori(2022a)showed that oil palm expansion is associated with changes in environmental services, including loss of carbon stocks and changes in surface temperature. Pertiwi et al.(2022a)used Benefit-Cost Analysis to compare peatland conservation with its use for oil palm and rubber in Riau. The results showed that when ecosystem services are more fully accounted for, the economic value of conservation becomes more apparent. Sari et al.(2022)also shows that forests have a broader economic value than timber products because they provide provisioning, regulating, supporting, and cultural services. Therefore, the economic benefits of oil palm need to be weighed against the value of ecosystem services lost due to changes in forest cover. This aligns with the findings of Sumarga & Hein.(2016)in Central Kalimantan that in a scenario without policy changes, the social costs of carbon emissions and the loss of other ecosystem services far outweigh the benefits of increased palm oil production.

2.4 Theoretical Basis of Economic Valuation and Benefit-Cost Analysis

From the perspective of valuation and Benefit-Cost Analysis, Aldy et al.(2021)explains the importance of the social discount rate, carbon valuation, and environmental benefit valuation in environmental benefit-cost analysis. OECD (2018)placing discounting, uncertainty, biodiversity valuation, and ecosystem services as important parts of environmental CBA. This view is emphasized by Thomas & Chindarkar(2019)that CBA systematically compares social benefits and costs, including benefits or costs that are not always reflected in market prices. Meanwhile, Arimura & Hibiki(2024)emphasizes the importance of incorporating the economic value of ecosystems and biodiversity into decision-making because many natural services are non-market in nature, and places market failures, externalities, natural resources, and policy instruments as the basis for environmental economic analysis.

Ecological Impacts and Social Costs of Oil Palm Plantations

The ecological aspect is also reinforced by Rennert et al.(2022), which shows that the social cost of carbon is used to monetize the social damage caused by additional CO2 emissions and is an important component in benefit-cost analysis. Zemp et al.(2023)shows that increasing the number of trees in oil palm landscapes can improve biodiversity and ecosystem function compared to conventional oil palm management. Santosa & Purnamasari(2023)shows that oil palm plantations have consequences for mammal and bird conservation, making landscape management important. Xin et al.(2022)projected that if expansion follows historical patterns, approximately 8–22% of secondary forest and 21–54% of peatland would be lost by 2050, and shifting expansion to degraded land could reduce CO2 emissions. These findings are in line with the thinking

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of Qaim et al.(2020)that ecological and social costs cannot be separated from the economic benefits of plantations.

Research Novelty Framework and Study Positioning

Based on this overall research, there is scope for research on combining direct economic benefits and ecological losses into a single Benefit-Cost Ratio measure in the TNTN conservation area. Previous research has largely focused on one aspect, such as land use change, conflict and regional pressures, economic benefits, ecosystem services, carbon, or biodiversity. Pertiwi et al.(2022a)has implemented BCA in the Riau region, but the context is peatland management options and not illegal palm oil expansion within national parks, whereas Sumarga & Hein(2016)comparing the benefits and costs of oil palm expansion at the provincial scale in Central Kalimantan, rather than in conservation areas in Riau. This study fills this gap by comparing the economic benefits of oil palm expansion with the ecological losses, primarily resulting from the loss of carbon stocks and forest ecosystem functions in the National Park (TNTN). Conceptually, this approach is supported by Thomas & Chindarkar.(2019), Qaim et al.(2020), and Arimura & Hibiki(2024).

RESEARCH METHODOLOGY

This study uses a quantitative approach with a descriptive-quantitative design and an ex-post Benefit-Cost Analysis (BCA) method, assessing the expansion of oil palm plantations that has occurred in the TNTN area, Pelalawan Regency. BCA was chosen because it allows for both market-valued and environmentally valuable benefits and costs to be compared within a single economic framework, including land use options that consider ecosystem services.(Pertiwi et al., 2022a). The analytical perspective is a regional social perspective.

The analysis follows the with-without principle. The “with expansion” condition is an oil palm plantation on land that was previously forested. The “without expansion” condition (baseline) is the same land remaining forested with the cover condition before conversion. This baseline determines the carbon stocks and ecosystem services that are considered lost. The analysis is conducted in four stages: (1) calculating the net economic benefits of oil palm cultivation; (2) estimating the value of ecological losses in the form of lost carbon stocks and non-carbon ecosystem services; (3) comparing the two through the Benefit-Cost Ratio (BCR) and the social Net Present Value (NPV); and (4) testing the sensitivity of the results. Economic valuation is necessary because the value of forests comes not only from direct benefits, but also from indirect benefits and environmental services that are often not reflected in market prices.(Harini et al., 2024; Sari et al., 2022)

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Research Location and Data

The research location is TNTN in Pelalawan Regency, Riau Province, which is located at coordinates 0°05′40″–0°20′47″ S and 101°35′21″–102°03′57″ E(Rizki et al., 2023)(Figure 1). This area was selected because it faces land cover changes and oil palm expansion within the conservation area. The study used secondary data collected and processed from August to October 2026 from government publications, official reports, news reports from official government statements, and scientific articles. Sources were selected based on three criteria: (a) published by government agencies, scientific journals, or searchable media; (b) relevant to the TNTN or oil palm plantations in Riau; and (c) containing parameter values along with the year and units. Searches were conducted through Google Scholar and official portals using the keywords "Tesso Nilo," "oil palm plantations," "forest carbon stocks," "Riau FFB prices," and "oil palm production costs."

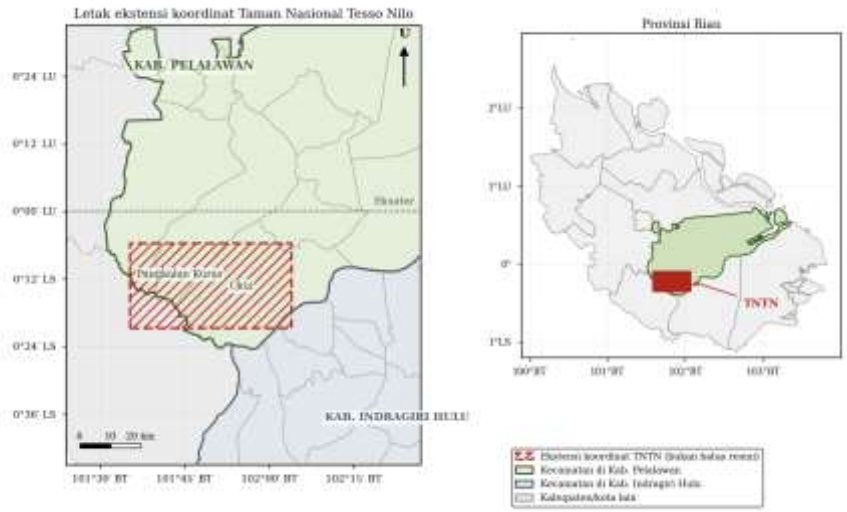


Figure 1. Geographical Location of Tesso Nilo National Park, Pelalawan Regency, Riau Province

Source: Administrative boundaries from the Central Statistics Agency (BPS, 2020) via the Humanitarian Data Exchange; area coordinates from Rizki et al. (2023); processed by the author. The red box indicates the extension of the area coordinates, not the official boundaries of TNTN.

All monetary values are expressed in 2026 prices. The economic benefit parameters use 2025–2026 price and cost data and are therefore not further converted. The US dollar values are converted using Bank Indonesia's JISDOR exchange rate on September 30, 2026, of Rp17,877 per US$1. The social cost of carbon is converted using this exchange rate without additional inflation adjustment, so the carbon loss estimate is conservative. Data processing and calculations were performed using Microsoft Excel.

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The analysis components and data sources for each parameter are detailed in Tables 1 and 2.

Table 1. Analysis Components

Code	Component	Definition	Calculation
ME	Clean economic benefits of palm oil	Present value of palm oil revenue minus production costs on converted land	PV(R) − PV(BP), equations (1)–(3)
TO	Ecological losses	Present value of lost carbon stocks (and non-carbon ecosystem services where available)	KC + JEnk, equations (4)–(6)
BCR	*Benefit-cost ratio*	The ratio of the present value of benefits to the present value of all costs, including ecological losses	PV(R) / [PV(BP) + KE], equation (7)
NPV	social NPV	The difference between net economic benefits and ecological losses	ME − KE, equation (8)

Source: Author, 2026

Table 2. Parameters and Data Sources

Parameter	Symbol	Core values	Data source
Area of palm oil expansion	L	40,000 ha (alternative 27,000 ha)	Ministry of Forestry (2025) in Kompas.com(2025); data from the Pelalawan Regency Government in Mongabay Indonesia(2025)
FFB Productivity	Pt	14 tons/ha/year at maturity (midpoint range 12–16); zero in years 1–3; 45%, 70%, 85% in years 4–6; 100% in years 7–20; 85% in years 21–25	The range of productivity of Riau smallholder oil palms from the Ministry of Agriculture; age patterns are the author's assumptions.

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Parameter	Symbol	Core values	Data source
Fresh Fruit Bunch Price	H	Rp3,884,840 per ton (independent farmers, age 9 years, 2–8 September 2026), considered constant	Riau Province Plantation Service in BCA Securities/ANTARA(2026).
Production cost	BPt	t = 0: Rp60 million/ha; years 4–25: Rp1,648.40 per kg of fresh fruit bunches	BPDP community oil palm rejuvenation fund(IDX Channel, 2026), cost of production of Mustofa & Bakce(2024).
Loss of carbon stock	ΔC	(182.2 − 63) tC/ha × 44/12 = 437.07 tCO2e/ha	Carbon stocks of secondary dryland forests and plantations in TNTN Rizki et al(2023), sourced from KLHK, 2020).
Carbon price	HC	US$185/tCO2 = Rp. 3,307,245/tCO2e; comparison of US$5 and US$10	Rennert et al.(2022); carbon market price Djaenudin (2014) in Rizki et al.(2023).
Non-carbon ecosystem services	jet	Not monetized in the base scenario; counts as a threshold value	See subsections 3.2 and 4.5
Discount and horizon		8% (tested 4% and 12%); 25 years	Research assumptions, because there is no single official provision for social analysis in Indonesia.

Source: Author, 2026

Data Analysis Techniques

The entire area L is treated as a single cohort converted and planted at t = 0, and analyzed over one cropping cycle T = 25 years. Land clearing costs and carbon losses occur at t = 0 and are therefore not discounted. This simplification is discussed as a limitation.

A. Estimation of the economic benefits of oil palm plantations

Cultivation revenues and costs are discounted to present value:

$$PV(R) = \Sigma [L \times Pt \times H] / (1 + r)t, \text{ for } t = 1 \text{ to } T \quad (1)$$

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$$PV(BP) = \Sigma [L \times BPt] / (1 + r)t, \text{ for } t = 0 \text{ to } T \quad (2)$$

$$ME = PV(R) - PV(BP) \quad (3)$$

with PV(R) = present value of gross palm oil revenue (Rp); PV(BP) = present value of production costs (Rp); ME = present value of net economic benefits (Rp); L = expansion area (ha); Pt = productivity in year t according to plant age (ton/ha/year); H = FFB price (Rp/ton); BPt = production costs per hectare in year t (Rp/ha); r = discount rate; and T = analysis horizon.

B. Estimation of ecological losses

Ecological losses conceptually consist of the loss of carbon stocks and non-carbon ecosystem services which include provisioning, regulating, supporting and cultural services.(Sari et al., 2022):

$$KE = KC + JEnk \quad (4)$$

$$KC = L \times \Delta C \times HC \quad (5)$$

$$JEnk = \Sigma [L \times jet] / (1 + r)t, \text{ for } t = 1 \text{ to } T \quad (6)$$

where KE = total ecological loss (Rp, present value); KC = value of carbon stock loss at t = 0 (Rp); JEnk = present value of lost non-carbon ecosystem services (Rp); ΔC = net loss of carbon stock per hectare (ton CO2e/ha; stock in tons C multiplied by 44/12); HC = carbon price (Rp/tCO2e); and jet = value of non-carbon ecosystem services per hectare per year (Rp/ha/year).

The basic carbon price uses the social cost of carbon(Rennert et al., 2022), which is approximately US$185 per ton of CO2 (2020 prices, 2% discount), converted to rupiah. Carbon market prices of US$5 and US$10 per ton were used as comparison scenarios. The difference in discount rates inherent in these values and those used in the ME is discussed as a limitation.

Jet values were not included in the baseline scenario because no non-carbon ecosystem service values were found for lowland forests in the study area that could be reliably transferred. Therefore, the baseline EC only includes the KC and is conservative for conservation reasons. Instead, a jet threshold value was calculated, which is the value of non-carbon ecosystem services per hectare per year that makes the BCR equal to 1 in the carbon market price scenario.

C. Social Benefit-Cost Ratio and NPV Analysis

$$BCR = PV(R) / [\, PV(BP) + KE \,] \quad (7)$$

$$NPVsocial = PV(R) - PV(BP) - KE = ME - KE \quad (8)$$

A BCR > 1 and a social NPV > 0 means that the benefits of oil palm exceed all monetized costs and ecological losses. A BCR < 1 and a social NPV < 0 mean that the expansion is net detrimental. A BCR = 1 means break-even. As a complementary

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measure, the ME/KE ratio is reported, which is in the same direction as the social NPV (ME/KE > 1 if and only if the social NPV > 0). The results apply only to monetizable components.

D. Sensitivity analysis

Since ME and KE are both proportional to L, changes in L do not change the BCR, only the magnitude of the social NPV. Therefore, L is tested by reporting results on two estimated areas, namely 40,000 ha and 27,000 ha. The sensitivity of the BCR is tested on per-hectare parameters, namely FFB price, productivity, production costs, ΔC, and HC, each ±20%. Discount rates are tested at 4%, 8%, and 12%. Additional scenarios include carbon market prices of US$5 and US$10, low production costs based on the cost of independent farming in Bengkalis of Rp4,947,098 per ha per year.(Trio Cahyono, 2022), and the plantation carbon baseline is 98 tC/ha(Rizki et al., 2023). For each scenario, ME, KE, and BCR are recalculated, and the switching value that makes BCR equal to 1 is determined. Pertiwi et al.(2022a)shows that the results of land use comparisons are influenced by economic assumptions and the inclusion of ecosystem services.

Analysis Assumptions

1. Discounting and horizon. The baseline discount rate of 8% was tested at 4% and 12%, with T = 25 years, which approximates the economic life of the oil palm. The 8% discount rate is used as a baseline analysis assumption, not as a single official provision for all social analyses in Indonesia. High discount rates tend to underestimate long-term ecological losses, making the 4% test important.
2. Profits from unlicensed activities. All net profits from cultivation are counted as benefits, without separating out the portion enjoyed by actors outside the region. This treatment is conservative in light of conservation arguments.
3. Production parameters. Productivity is taken from the range of smallholder plantations and the price of fresh fruit bunches (FFB) at the independent farmer level. The price used is the price for the 9-year-old age group, the highest price, and is assumed to be constant. Unlicensed plantations can have lower productivity and lower prices, so adjustments were tested in a sensitivity analysis.
4. *Baseline*carbon. The entire area of L is assumed to have originally been secondary dryland forest (182.2 tC/ha). This assumption is an upper limit because some of the plantation may have originated from plantation forests or open land, so it is tested against the plantation forest baseline (98 tC/ha).

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5. Restoration and enforcement costs are not included, as they are alternative measures of damage equal to the value of lost ecosystem services, and adding them together risks double-counting. Fines and administrative transfers are also not included.
6. Scope. Only monetizable components are counted. Non-carbon ecosystem services, biodiversity, and the distribution of benefits between groups are discussed qualitatively.

RESULTS AND DISCUSSION

Overview of Palm Oil Expansion Areas and Areas

TNTN was established in 2004 and now has an area of approximately 81,793 hectares.(Kompas.com, 2025). Spatial analysis of Rizki et al.(2023)The data shows that between 2014 and 2021, the area of plantations within the area increased from 24,999 hectares to 40,405 hectares, while secondary dryland forest decreased from 23,406 hectares to 20,904 hectares (Figure 2). Gross deforestation during this period reached 11,554 hectares, or 14.15% of the area. By 2025, only about 24% of the area will remain.(Kompas.com, 2025).

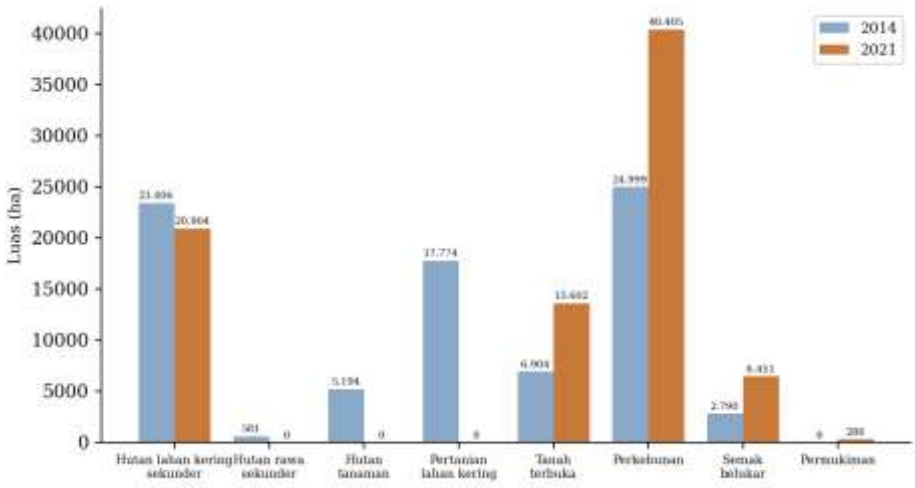


Figure 2. Changes in Land Cover of TNTN in 2014 and 2021

Source: Adapted from Rizki et al. (2023)

The area of illegal oil palm plantations in the TNTN analyzed (L) is 40,000 hectares, according to the Ministry of Forestry's records regarding TNTN land that has been cleared and planted with oil palm illegally.(kompas.com, 2025). As an alternative estimate, 27,000 hectares are used, namely the ownership of community gardens recorded by the Pelalawan Regency Government.(Mongabay, 2025). The pressure on this area is in line with the findings of Tua & Sundari(2021)that population migration, accessibility, and palm oil and rubber plantation activities are related to the encroachment of TNTN's natural forests.

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Estimation of the Economic Benefits of Palm Oil

Based on equations (1) to (3), with a FFB price of IDR 3,884,840 per ton, mature productivity of 14 tons per hectare per year, clearing and planting costs of IDR 60 million per hectare, and production costs of IDR 1,648.40 per kg of FFB, the present value of gross income PV(R) is IDR 15.81 trillion and the present value of production costs PV(BP) is IDR 9.11 trillion. Thus, the net economic benefit (ME) is IDR 6.70 trillion, or IDR 167.5 million per hectare for 25 years at an 8% discount rate. These results indicate that oil palm does offer financial benefits to its actors, as shown by Hasudungan et al.(2024)that oil palm expansion increases farmers' cash flow. However, Kubitza et al.(2024)reminding that these benefits are achieved at the expense of forests.

Ecological Loss Estimation

The carbon stock of secondary dryland forests in TNTN is 182.2 tC/ha, while plantations are only 63 tC/ha.(Rizki et al., 2023)The difference is 119.2 tC/ha, equivalent to 437.07 tCO2e/ha, bringing the total emissions from the conversion of 40,000 hectares to 17.48 million tCO2e. The social cost of carbon is US$185 per ton of CO2.(Rennert et al., 2022)equivalent to Rp3,307,245 per ton at an exchange rate of Rp17,877 per US$1. Using equation (5), the value of carbon stock loss (KC) is Rp57.82 trillion, or Rp1.45 billion per hectare. Because non-carbon ecosystem services are not monetized in the baseline scenario, the total ecological loss (KE) is equal to KC, namely Rp57.82 trillion. This figure does not include the loss of water management services, biodiversity, and cultural services, which Sari et al.(2022)categorized as the economic value of forests outside of wood products.

***Benefit-Cost Ratio*and Social NPV**

Table 3. Summary of Benefit-Cost Analysis Results (L = 40,000 ha, r = 8%, T = 25 years)

Component	Symbol	Value (Rp trillion)
Present value of gross palm oil revenues	PV(R)	15.81
Present value of production costs	PV(BP)	9.11
Clean economic benefits	ME	6.70
Loss of carbon stock	KC	57.82
Lost non-carbon ecosystem services	JEnk	not monetized
Total ecological loss	TO	57.82

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Component	Symbol	Value (Rp trillion)
Benefit-cost ratio	BCR	0.24
social NPV	ME − KE	−51.12
ME/KE ratio	ME/TO	0.12

Source: Author's processed results, 2026

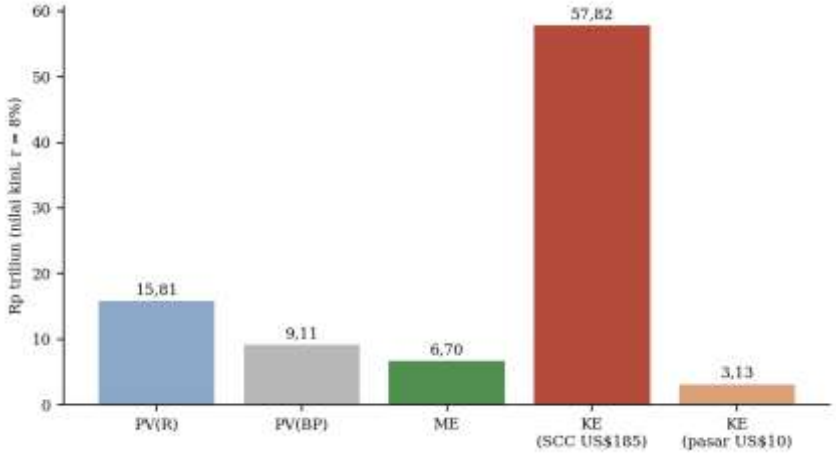


Figure 3. Comparison of Economic Benefits and Ecological Losses
Source: Author's processed results, 2026

The BCR value of 0.24 and the social NPV of -Rp51.12 trillion indicate that the economic benefits of palm oil far outweigh the monetized costs and ecological losses. This means that every Rp1 spent and sacrificed socially generates only Rp0.24 in benefits, making palm oil expansion in the TNNP a net loss for the region. The ME/KE ratio of 0.12 aligns with these results. This result only includes monetizable components, so biodiversity losses and the distribution of benefits between groups are not fully reflected.

Sensitivity Analysis

The sensitivity test results are presented in Table 4. In all scenarios using the social cost of carbon, the BCR remains below 1, ranging between 0.16 and 0.61. A ±20% change in the per hectare parameter only shifts the BCR to within the range of 0.19–0.29. A 4% discount rate increases the BCR to 0.36, and a 12% discount rate decreases it to 0.16, as the lower discount rate increases the present value of oil palm benefits in productive years. The plantation carbon baseline (98 tC/ha) yields a BCR of 0.61 and a social NPV of -Rp10.28 trillion, so the conclusion does not rely on the assumption that all

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land was originally secondary natural forest. In line with Aldy et al.(2021), the results are strongly influenced by the choice of carbon value and discount rate.

Table 4. Sensitivity Analysis Results

Scenario	ME (Rp trillion)	KE (Rp trillion)	BCR
Basic (r = 8%, SCC US$185)	6.70	57.82	0.24
4% discount	12.26	57.82	0.36
12% discount	3.60	57.82	0.16
TBS Price +20% / −20%	9.86 / 3.54	57.82	0.28 / 0.19
Productivity +20% / −20%	8.52 / 4.88	57.82	0.28 / 0.19
Production costs +20% / −20%	4.88 / 8.52	57.82	0.23 / 0.24
ΔC +20% / −20%	6.70	69.38 / 46.26	0.20 / 0.29
HC +20% / −20%	6.70	69.38 / 46.26	0.20 / 0.29
Low production costs (Bengkalis)	11.81	57.82	0.26
*Baseline*plantation forest (98 tC/ha)	6.70	16.98	0.61
Carbon market price US$10	6.70	3.13	1.29
Carbon market price US$5	6.70	1.56	1.48
L = 27,000 ha	4.52	39.03	0.24

Source: Author's processed results, 2026

The most important result is the sensitivity to carbon prices. At a carbon market price of US$5–10 per ton, the BCR exceeds 1 (1.48 and 1.29) as the value of carbon losses drops to Rp1.56–3.13 trillion. The threshold value of HC that makes the BCR equal to 1 is Rp383,251 per tCO2e, or approximately US$21.4, or 11.6% of the social cost of carbon. In other words, oil palm expansion appears profitable only if climate damage is valued at less than one-eighth of its social value. In terms of carbon losses, the BCR is 1 if the ΔC is only 50.6 tCO2e/ha, far below the baseline estimate of 437.07 tCO2e/ha. Meanwhile, the price of fresh fruit bunches (FFB) would need to rise to around IDR 16.45 million per ton, or 4.2 times the current price, for the BCR to reach 1. Under carbon market price scenarios of US$10 and US$5, the jet limit values are IDR 8.37 million and IDR 12.03 million per hectare per year, respectively. These values serve as a benchmark for

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further research into whether non-carbon ecosystem services in TNNP, such as water management and wildlife habitat, are worth that much.

DISCUSSION

The results of this study are in line with Sumarga & Hein(2016)in Central Kalimantan, which found that in a scenario without policy changes, the social costs of carbon emissions and loss of ecosystem services far outweighed the benefits of increased palm oil production. This finding is also consistent with Pertiwi et al.(2022a), which shows that the economic value of conservation becomes more visible when ecosystem services are fully accounted for. The difference in context is worth noting: Pertiwi et al.(2022b)studied peatlands, and Sumarga & Hein studied at the provincial scale, while this study assessed oil palm expansion within conservation areas.

Conceptually, these results confirm the argument of Thomas & Chindarkar(2019)and Arimura & Hibiki(2024)Decisions based solely on market prices ignore social costs not reflected in the market. Palm oil profits for stakeholders are private and measurable, amounting to IDR 167.5 million per hectare, while carbon losses of IDR 1.45 billion per hectare are shared and not included in the stakeholders' calculations. Rennert et al.(2022)explains that the social cost of carbon is intended to monetize the social damage caused by additional CO2 emissions. This distinction between private and social values explains why expansion continues despite repeated enforcement. Dwiyahreni et al.(2021)and Tua & Sundari(2021)shows that this pressure is related to population growth, migration, and increased access to the area, so that the law enforcement approach needs to be equipped with an economic valuation basis.

The results also show that conclusions depend on the carbon price used. At low carbon market prices, palm oil expansion appears economically viable. These market prices reflect current transaction values, not the social damage caused by emissions, making the social cost of carbon more appropriate for a regional social perspective, as explained by Aldy et al.(2021)and OECD(2018)However, readers should note that BCR 1 was achieved at a price of approximately US$21.4, so this result should not be interpreted as a guarantee of losses in all price scenarios.

The unmonetized ecological impacts reinforce caution in reading these results. Santosa & Purnamasari(2023)shows that oil palm plantations impact the conservation of mammals and birds, andPrayoga & Imron(2022) This indicates that the fires worsened the condition of the TNTN habitat. These biodiversity and habitat losses were not included in the KE, so the KE value tends to be conservative.

Several policy implications can be formulated. First, carbon valuation needs to form the basis of economic arguments in area management and restoration. Second, Xin et al.(2022)showed that moving expansion to degraded land can reduce CO2 emissions,

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and Fosch et al.(2023)demonstrated that rejuvenating unproductive smallholder oil palm plantations can reduce poverty and protect the environment without clearing new forests. Both approaches could offer alternatives for communities dependent on oil palm. Third, Zemp et al.(2023)shows that increasing the number of trees in oil palm landscapes can increase biodiversity, so landscape management around the area needs to be considered.

This study has several limitations. First, the entire area is treated as a single cohort planted at t = 0 and all of it was originally forested. Second, the social cost of carbon calculated at a 2% discount rate differs from the 8% discount rate in the ME. Third, productivity, cost, and price parameters are derived from data on smallholder plantations in Riau, not from plantations within the TNTN. Fourth, non-carbon ecosystem services, biodiversity, and intergroup benefit distribution have not been monetized. Future research could utilize primary valuation, planting year data per plot, and stakeholder distribution analysis.

CONCLUSION

The net economic benefit of oil palm expansion across 40,000 hectares in the National Park (TNTN) is estimated at IDR 6.70 trillion, while the ecological loss from carbon stock loss is estimated at IDR 57.82 trillion. Comparing the two yields a BCR of 0.24 and a social NPV of -IDR 51.12 trillion, resulting in a net loss for the region. This conclusion holds true in sensitivity tests using discount rates, FFB prices, productivity, costs, and carbon baselines, as long as the social cost of carbon is used. The BCR only exceeds 1 if the carbon price is below approximately US$21.4 per tCO2, for example, at a carbon market price of US$5–10.

Based on these results, it is recommended that managers and the government use carbon economic valuation as a basis for area management and restoration, and provide alternatives for communities in the form of rejuvenating existing plantations and directing expansion into degraded lands. Further research is recommended using plantation data within the TNTN, primary valuation of non-carbon ecosystem services, and incorporating biodiversity and the distribution of benefits between groups.

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