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Society Net Benefit from a Carbon-Based Agroforestry Project: Comparing Private Forest and Social Forestry in Garut Regency, Indonesia

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Abstract

Background: Carbon-based agroforestry projects are often assessed in terms of carbon sequestration and financial feasibility, with limited attention given to community net benefits after accounting for land opportunity costs.
Objective: This study compares the modeled 21-year net benefits of agroforestry production at two adjacent sites comprising private forest and social forestry areas in Garut Regency, Indonesia.
Methods: A bottom-up comparative case study estimates non-timber forest product income, deducting production costs, land opportunity costs, and farm tool expenditures, across 133.11 ha of private forest and 133.76 ha of social forestry. Net benefits are discounted at rates of 12% and 7%, with additional sensitivity and switching-value analyses and exploratory, expert-informed risk assessments. Project-related wages are excluded.
Results: At a 12% discount rate, estimated net present benefits amount to IDR 43.77 billion (IDR 328.8 million/ha) for private forest and IDR 80.13 billion (IDR 599.1 million/ha) for social forestry. The per-hectare benefit ratio is 1.82, declining to 1.07 when avocado planting density is equalized in the model. The comparative ratio remains broadly stable under common changes in discount rates and yields.
Conclusion: Avocado planting density accounts for much of the modeled benefit gap between the two sites. However, institutional explanations for this difference remain untested. The estimates represent partial site-level benefits rather than household welfare or benefit distribution and cannot be generalized without further evidence.

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INTRODUCTION

The forestry and other land use sector bears the largest share of Indonesia's emissions reduction target under the Enhanced Nationally Determined Contribution (ENDC), while simultaneously sustaining the livelihoods of millions of people involved in rural economic activities. The carbon economic value framework established under Presidential Regulation of the Republic of Indonesia No. 98 of 2021 opens the way for private financing to enter areas that have long been managed by local communities (Indonesia, 2021; Mulyani & Octalica, 2023). Carbon-based agroforestry projects promise to reconcile these two functions: trees are planted to absorb and store carbon, while fruit- and seed-producing plants cultivated alongside them provide annual income for communities participating in the surrounding project. This promise is

particularly attractive because it appears to resolve what has traditionally been considered an unavoidable trade-off between carbon storage and productive land use. However, this promise becomes meaningful only when it can be substantiated quantitatively, and the necessary evidence is rarely available.

Assessments of forest carbon projects commonly focus on two questions. The first concerns carbon sequestration, namely, how many tons of carbon dioxide equivalent (CO_2e) are successfully removed from the atmosphere or avoided through project activities. The second concerns investment feasibility, namely, whether the project generates adequate returns for the financing party. Both are important, but neither addresses the question that ultimately determines whether a project remains viable on the ground: how much participating communities actually receive and whether these benefits exceed the costs they incur. This question is not merely a matter of distributive fairness. Communities participating in a project may withdraw if they perceive their land to be more valuable under alternative uses, potentially threatening the permanence of the forest stand on which the project's carbon claims depend. Land opportunity cost is therefore not simply an additional consideration but a determinant of project continuity. This argument is systematically demonstrated by Ickowitz et al. (2017) and Pirard et al. (2023) through a comparison of eleven tropical countries, which found that opportunity cost calculations at the project level can be misleading when the livelihood structures of participating communities are overlooked.

Gross income per hectare was estimated using a bottom-up approach based on tree-level parameters (Godoy et al., 1993; Ota et al., 2022), following Equation 1, where N represents stand density per hectare, s represents the percentage of surviving plants, y represents annual yield per tree, l represents post-harvest losses, g represents the proportion of harvested products meeting quality standards, and P represents the farm-gate price. Net income was calculated by subtracting annual production and harvesting costs. Production did not begin simultaneously across the assessment period: no yields were recorded during the first two years, production began in the third year at 15 percent of peak yield, increased gradually, reached peak production in the eighth year, and remained at that level until the end of the assessment horizon. Data provenance and literature-based comparisons were documented in Table 3, together with comparative references for parameters derived from the literature. Interview-derived inputs represented study-site estimates, while planning document figures were cross-checked against the corresponding input schedules. Published studies served as plausibility benchmarks rather than sources of independent validation. The transfer of post-harvest loss estimates from rice to coffee and avocado introduced commodity-specific measurement uncertainty. These assumptions should be validated through harvest records and crop-specific loss observations in future research.

$$\text{Gross income per hectare} = \Sigma\text{commodities}[N \times s \times y \times (1 - l) \times g \times P] \quad (1)$$

Net benefits were calculated using Equation 2 as net income from non-timber forest products minus land opportunity costs and farm tool expenditure. Under the project arrangement described in the available documents, project investment and operational expenditures were financed by the forest carbon project, whereas the community-side calculation included the economic value of foregone alternative land uses and a one-time farm tool expenditure of IDR 20,000,000 per site in the first year. Land opportunity cost was assumed to be IDR 6,000,000 per hectare annually, beginning in the third year, as reported in Table 1. The inclusion of land opportunity costs followed the principles of economic project evaluation discussed by the Asian Development Bank (2017), White and Minang (2011), Pirard et al. (2023) and Boardman et al. (2018), as well as the importance of accounting for smallholder opportunity costs highlighted by Ickowitz et al. (2017). The resulting estimates reflected only the economic components included in the model and were not intended to represent a complete accounting of household income and expenditure.

Net benefit to communities involved in the project, = Net NTFTP income, – Land opportunity cost, – Farm tool expenditure, (2)

Wage income from planting and maintenance activities was excluded from the net-benefit calculation, along with the corresponding labor costs borne by participating communities, to maintain consistency in the treatment of labor-related transactions. The available project documents did not provide sufficient information to establish the distribution of wage payments among participating households or to quantify the associated household labor contributions. Consequently, the reported estimates represented partial net benefits derived from non-timber forest product production after accounting for land opportunity costs and farm tool expenditure. They excluded potential net benefits from project-related employment and were not intended to serve as comprehensive measures of household income or welfare. Because agricultural yields, prices, and other model inputs were also subject to uncertainty, the exclusion of wages alone did not establish the estimates as strict lower bounds of realized community benefits.

Results were reported using two discount rates, each addressing a different analytical question, rather than relying on a single rate. The 12 percent rate was the financial discount rate used in project planning PT Astra International Tbk, (2024) and reflected the cost of capital of the forest carbon project. This rate was retained as the base case to allow comparisons with the project's own assessment. The 7 percent rate was based on the social discount rate specified by the Office of Management and Budget (1992) and Liscow (2025) as the real rate for cost-benefit analysis of public programs, on the grounds that it approximated the pretax return on average private-sector investment. World Bank (2016) and Africa (2025) guidance set the social discount rate at twice the rate of per capita consumption growth, with a reference value of 6 percent and a range of 2 to 10 percent. For institutional comparison, the Asian Development Bank (2017) and Alrbai et al. (2026) specified a minimum economic rate of return of 9 percent, which could be reduced to 6 percent for projects primarily generating environmental benefits. Thus, the selected 7 percent rate fell within the range supported by these institutional references. The analysis focused on whether the conclusions changed between the two discount rates.

Sensitivity was tested by reducing income parameters by 10 percent and increasing land opportunity costs by 50 and 100 percent. The switching value was defined as the percentage change in costs or benefits required for the project result to fall below the minimum acceptability threshold, namely, a net present value (NPV) of zero (IFAD, 2016; Kafle et al., 2022). Its deviation from the base-case value was expressed as a percentage. Risk assessment was structured according to the ISO 31000:2018 framework and the assessment techniques outlined in IEC 31010:2019, using a likelihood scale ranging from 1 to 5 and an impact scale ranging from 1 to 10, anchored to project feasibility indicators, with category thresholds of 8, 16, and 28. Because the impact scale was anchored to project feasibility indicators, the implications of each risk for participating communities were assessed qualitatively based on the affected benefit channels rather than inferred directly from the numerical scores. Assessments from five experts provided an exploratory appraisal of project risks rather than a statistically representative survey. The original documentation did not specify purposive eligibility criteria or the mathematical aggregation rule applied to individual likelihood and impact responses. Consequently, the reported scores could not be independently reproduced as measures of expert consensus. Future reporting should identify expert roles, document individual ratings, and specify whether the scores are based on medians, means, or deliberative agreement.

Previous research has addressed important aspects of carbon project economics and agroforestry-based livelihoods, although these perspectives have not always been examined within a common analytical framework. Studies of carbon projects typically emphasize carbon sequestration, investment feasibility, and benefit-sharing arrangements, whereas agroforestry research focuses on agricultural profitability and contributions to rural livelihoods. Ciptaningtyas et al. (2025) examined the financial feasibility of monoculture coffee and agroforestry farming in Garut Regency; Manurung et al. (2025) investigated the contribution of agroforestry to the income of community forest farmers in Lampung; and Duffy et al. (2021) explored the contribution of agroforestry to smallholder food security in Indonesia. Building on these perspectives, the present study integrates non-timber forest product income, land opportunity costs, and a 21-year assessment period to compare the modeled net benefits of private forest and social forestry at two adjacent sites. Although their broadly similar biophysical settings provide a useful basis for comparison, the two-site design cannot isolate the causal effects of land management institutions

from differences in planting density, project design, or other unobserved factors.

This study addresses this gap through three objectives. First, it measures the net benefits accruing to participating communities over a 21-year period at two adjacent sites managed under different schemes, namely, private forest and social forestry, within the same carbon-based agroforestry project. Second, it identifies the sources and timing of these benefits, as both their magnitude and the timing of their realization have different implications for participating communities, particularly those without financial reserves. Third, it tests the robustness of the results to changes in key parameters, alternative discount rates, and identified project risks. Importantly, wage income earned by participating communities through planting and maintenance activities is excluded from the benefit calculations. The rationale for this exclusion is explained in the Methods section. Consequently, the reported figures exclude this income stream and should be interpreted as partial net-benefit estimates rather than comprehensive measures of community welfare.

This study advances previous research on agroforestry and forest carbon in three ways. First, it estimates net benefits accruing to communities rather than relying on gross crop revenue, explicitly deducting the opportunity cost of land over a 21-year assessment horizon. Second, it compares adjacent sites using consistent production and valuation assumptions, thereby identifying the contributions of crop composition and planting density to the observed difference in modeled net benefits. Third, it examines whether the ratio of net benefits between the two sites remains consistent under common changes in prices, yields, and discount rates, as well as under an avocado-density counterfactual scenario. This decomposition distinguishes between a quantifiable accounting mechanism and an institutional hypothesis that cannot be causally verified using evidence from only two sites.

METHOD

The study was conducted at two adjacent sites in Garut Regency, West Java Province, within a broader carbon-based agroforestry project. The private forest site covered 133.11 hectares of community-owned land planted with coffee, avocado, and durian, whereas the social forestry site covered 133.76 hectares of state-owned land managed by local communities under a management permit and planted with coffee and avocado. Both sites were located within the same landscape and were characterized by broadly similar altitude, rainfall, and soil conditions. These similarities provided a relevant context for comparing their modeled economic outcomes, although they did not eliminate potential differences in site conditions, planting decisions, or management practices. The analysis covered a 21-year period corresponding to the cooperation agreement and adopted a comparative case study design. Accordingly, the findings described differences between the two selected sites rather than causal effects attributable to their respective land management schemes.

Primary data were collected through structured interviews with 30 worker respondents at each site to obtain information on daily wages, working days, commodity prices at the farm-gate level, and fertilizer and pesticide costs. These data were supplemented by interviews with landowners regarding land tenure status and planting patterns. Risk assessment data were collected from five expert respondents. Secondary data, comprising planning documents and budget plans for the forest carbon project, were used to determine stand density, species composition, and activity schedules. Carbon sequestration volume was not included in any calculation; carbon was mentioned solely to establish the institutional context of the sites because the associated carbon benefits did not accrue to participating communities under the applicable project arrangement.

RESULTS AND DISCUSSION

Results

Site characteristics and analysis parameters

The two sites have almost the same area, namely 133.11 hectares of private forest and 133.76 hectares of social forestry, with a difference of less than one percent. This similarity facilitates comparison because the per-hectare and site-level results move almost in parallel. The most striking difference lies in plant composition and density. The private forest is planted with

three commodities at densities of 800 coffee trees, 161 avocado trees, and 23 durian trees per hectare, whereas the social forestry site is planted with two commodities at densities of 1,000 coffee trees and 300 avocado trees per hectare. Avocado density in social forestry is therefore 1.86 times that in private forest. Table 1 summarizes the characteristics of both sites, along with the analytical parameters used.

Table 1
Site characteristics and analysis parameters

Description	People Forest	Social Forestry
Site area (ha)	133,11	133,76
Land tenure status	Community-owned	State land, management permit
Commodities	Coffee, avocado, durian	Coffee, avocado
Coffee density (trees/ha)	800	1.000
Avocado density (trees/ha)	161	300
Durian density (trees/ha)	23	–
Analysis horizon (years)	21	21
Base discount rate	12%	12%
Comparison discount rate	7%	7%
Land opportunity cost (IDR/ha/yr)	6,000,000	6,000,000
Year opportunity cost begins	Year 3	Year 3
Farm tool expenditure (IDR per site)	20,000,000	20,000,000

Source: Forest carbon project planning document and author's field survey

Decomposition of non-timber forest product income

Table 2 presents the six parameters used to calculate gross income per hectare for each commodity at both sites. Plant survival is set at 80 percent for all commodities, post-harvest loss at 10 percent for coffee and avocado, and the proportion meeting quality standards at 92 percent for coffee and 88 percent for avocado. Gross income per hectare per year at peak production reaches IDR 87.17 million in private forest and IDR 144.55 million in social forestry. After deducting production and harvesting costs of IDR 11.00 million and IDR 12.50 million, respectively, net income at peak production amounts to IDR 76.17 million and IDR 132.05 million per hectare per year.

The composition of this income is highly uneven. As shown in Figure 1, avocado contributes IDR 58.91 million, or 67.6 percent, of gross income in private forest and IDR 109.77 million, or 75.9 percent, in social forestry. Coffee contributes 31.9 percent and 24.1 percent, respectively, while durian is present only in private forest, where it contributes 0.5 percent. The entire difference in gross income between the sites, amounting to IDR 57.37 million per hectare per year, comes from two sources: IDR 50.86 million from avocado and IDR 6.96 million from coffee, offset by IDR 0.44 million because durian is absent from social forestry.

Table 2
Parameters composing gross non-timber forest product income per hectare at peak production

Commodity	N (trees/ha)	s	y (kg/tree)	l	g	P (IDR/kg)	Gross income (IDR/ha/yr)
Private Forest							
Robusta coffee	800	0.80	3.5	0.10	0.92	15,000	27,820,800
Avocado	161	0.80	55.0	0.10	0.88	10,500	58,910,544
Durian	23	0.80	1.0	0.00	1.00	24,000	441,600
Total gross							87,172,944
Production and harvest costs							(11,000,000)
Net income at peak							76,172,944
Social Forestry							
Robusta coffee	1,000	0.80	3.5	0.10	0.92	15,000	34,776,000
Avocado	300	0.80	55.0	0.10	0.88	10,500	109,771,200
Total gross							144,547,200

Commodity	N (trees/ha)	s	y (kg/tree)	l	g	P (IDR/kg)	Gross income (IDR/ha/yr)
Production and harvest costs							(12,500,000)
Net income at peak							132,047,200

N = stand density; s = plant survival percentage; y = yield per tree per year; l = post-harvest loss; g = proportion passing quality standards; P = price at garden level. Source: author's field survey and forest carbon project planning document.

Origin and status of parameters

Table 3 reports the origin of each parameter and its corresponding status. Of the fourteen parameters used in the calculations, seven are derived from the author's primary data, collected through interviews with 30 respondents at each site; four are obtained from the forest carbon project planning document; and three can be traced to published references, although not all of these references concern the same commodities.

Four points require explicit clarification. First, stand density at both sites is derived from the forest carbon project planning document. The densities of 300 and 161 trees per hectare are indeed higher than the recommended monoculture planting density of approximately 92 trees per hectare (Kartikasari, 2023; Sadwiyanti et al., 2009). However, these densities reflect the agroforestry systems established at the study sites, in which avocado is cultivated alongside coffee beneath the tree canopy.

Second, the coffee yield of 3.5 kilograms of cherries per tree is above the range of 1.5–3 kilograms reported in Indonesian studies. However, the coffee densities used in this study are also substantially lower than those reported in those studies. Consequently, the assumed yield per hectare is actually lower than the published yields (Fiqhry et al., 2024; Ratnawati et al., 2024; Supriadi & Pranowo, 2015)

Third, the assumed post-harvest loss rate of 10 percent is close to the national post-harvest loss figure of 10.82 percent Sawit (2023) Pusat Sosial Ekonomi dan Kebijakan Pertanian, (2018) and below the 12.7 percent measured at the farmer level (Hidayat et al., 2021; Suryana et al., 2024). It should be emphasized that these figures concern paddy, not coffee or fruit. Their application in this study therefore represents a transfer of benchmarks across commodities rather than a direct measurement of post-harvest losses in the commodities examined. The only farmer-level measurement of tropical fruit losses identified in the literature reports a lower figure, namely 5.6 percent for Siamese orange (Fauzi et al., 2024; Purba & Purwoko, 2019). Thus, the assumed rate of 10 percent can be considered a conservative benchmark, although its applicability to coffee and avocado remains uncertain.

Fourth, the assumed proportion of coffee meeting quality standards, at 92 percent, falls between two published figures: 70 percent red fruit relative to total fresh cherries in one harvest Aklimawati et al. (2014) and Fauzan and Pratama (2026) 93.63 percent red cherries in a spot check. For avocado, the available marketing-mapping study reports a quality distribution of 67.8 percent Class A and 32.2 percent Class B, without identifying a rejection category (Fajriyanti et al., 2024). This suggests that avocado quality grading may operate through price differentiation rather than outright rejection of produce. The methodological implications of this finding are discussed in the Discussion section.

Annual production and harvesting costs are set at IDR 12.50 million per hectare in social forestry (IDR 10.00 million for fertilizer and IDR 2.50 million for pesticides) and IDR 11.00 million per hectare in private forest. At the private forest site, recorded fertilizer expenditure is IDR 4.80 million, while pesticide expenditure ranges from IDR 1.50 million to IDR 2.50 million. Using the upper pesticide expenditure figure, the residual is IDR 3.70 million per hectare (11.00 − 4.80 − 2.50); using the lower figure, the residual is IDR 4.70 million. The available itemization does not allow this residual to be verified as wage expenditure. It therefore remains classified as an unallocated production and harvesting cost rather than an empirically measured labor payment. Both sites are treated consistently as having aggregate annual cost inputs, although their differing cost breakdowns limit comparability.

Table 3
Origin and status of each parameter used in the calculation

Parameter	Value used	Origin	Status
Site area	133.11 and 133.76 ha	Forest carbon project planning document	Secondary data
Stand density (N)	Coffee 800 and 1,000; avocado 161 and 300; durian 23 per ha	Forest carbon project planning document	Secondary data
Plant survival percentage (s)	0.80	Forest carbon project carbon calculation document; same as the 80 percent survival rate in Ota et al. (2022); above the minimum growth success criterion of 75 percent Peraturan Menteri Lingkungan Hidup Dan Kehutanan Nomor 23 Tahun 2021 Tentang Pelaksanaan Rehabilitasi Hutan Dan Lahan (2021).	Secondary data; consistent with reference
Coffee yield per tree (y)	3.5 kg cherries	Author's field survey; comparison Ratnawati et al. (2024), Fiqhry et al. (2024) and Supriadi & Pranowo (2015)	Primary data; conservative at hectare level
Avocado yield per tree (y)	55 kg	Author's field survey; comparison Sadwiyanti et al., (2009), Setiawan & Djelantik (2025) and Hortikultura (2024)	Primary data; within the published range of 30–80 kg
Durian yield per tree (y)	1.0 kg	Author's field survey	Primary data; share of income 0.5 percent
Post-harvest loss (l)	0.10 for coffee and avocado; 0.00 for durian	National post-harvest loss benchmark 10.82 percent Sawit (2023) PSEKP, 2018); farmer-level comparison 12.7 percent Hidayat et al. (2021), Suryana et al. (2024) and 5.6 percent for Siamese orange Purba & Purwoko (2019)	Consistent with reference; within the published range of 5.6–12.7 percent
Proportion passing quality standards (g)	0.92 coffee; 0.88 avocado; 1.00 durian	Coffee: between 70 percent Aklimawati et al. (2014) and 93.63 percent Fauzan & Pratama (2026). Avocado: field grading 67.8 percent class A and 32.2 percent class B without rejection Fajriyanti et al. (2024)	Consistent with reference; within the published range of 70–93.63 percent, the same range used for avocado
Coffee cherry price (P)	IDR 15,000/kg	Interviews with 30 respondents per site, garden-level price	Primary data
Avocado price (P)	IDR 10,500/kg	Interviews with 30 respondents per site, garden-level price	Primary data
Durian price (P)	IDR 24,000/kg	Interviews with 30 respondents per site, garden-level price	Primary data

Parameter	Value used	Origin	Status
Production and harvesting costs	Rp11.00 million and Rp12.50 million per ha per year	Interviews: fertilizer Rp4.80 and Rp10.00 million; pesticides Rp1.50–2.50 and Rp2.50–5.00 million per ha per year	Primary data; for community forests, an amount of approx. Rp3.70 million was not itemized
Production increase schedule	Starts Year 3; peaks Year 8	Carbon forest project planning documents	Secondary Data
Land opportunity cost	Rp6.00 million per ha per year starting Year 3	Local rental value and seasonal crop yields; landowner interviews	Data primer
Farm equipment expenditure	Rp20.00 million per area, one-off in Year 1	Carbon forest project budget plan	Secondary Data
Discount rate	12 percent and 7 percent	Project planning PT Astra International Tbk (2024), for 12 percent; World Bank (2016), Asian Development Bank (2017), and Office of Management and Budget (1992) for 7 percent	Secondary data; per references
Risk score	Likelihood 1–5; impact 1–10	Assessment by 5 expert respondents; ISO 31000:2018 Standardization (2018) and IEC 31010:2019 Commission (2019) frameworks	Data primer

Note: Status "primary data" means the figure comes from the author's data collection; "secondary data" means it comes from the forest carbon project document; "consistent with reference" means the figure was set by the author and is at or within the value or range reported by the stated published reference.
Source: author's compilation

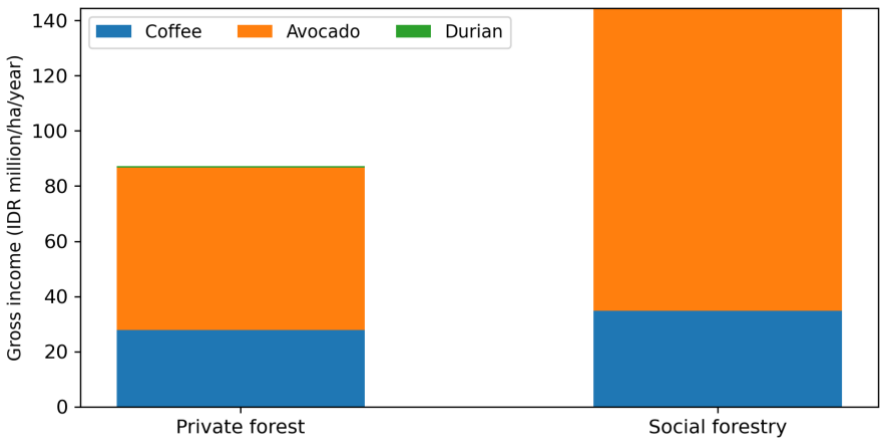


Figure 1. Composition of gross non-timber forest product income per hectare per year at peak production, by commodity and site

Production schedule and net cash flow of communities involved in the project

Production is not available from the outset. No production is obtained during the first two years. Production begins in the third year at 15 percent of peak production, then increases to 30, 50, 70, and 85 percent in Years 4–7, respectively, before reaching peak production in Year 8. Meanwhile, participating communities begin to bear land opportunity costs in the third year, while farm tool expenditure occurs in the first year.

Figure 2 presents the net cash flows of participating communities at both sites over a 21-year period. In the first year, both sites record negative cash flows of IDR 20.0 million due to farm tool expenditure, followed by zero cash flow in the second year. From the third year onward, cash flows become positive, reaching IDR 9,341 million in private forest and IDR 16,860 million in social forestry at peak production. The cumulative discounted cash flow becomes positive in the third year at both sites, reflecting the relatively small initial expenditure on farm tools compared with the income generated from agricultural production.

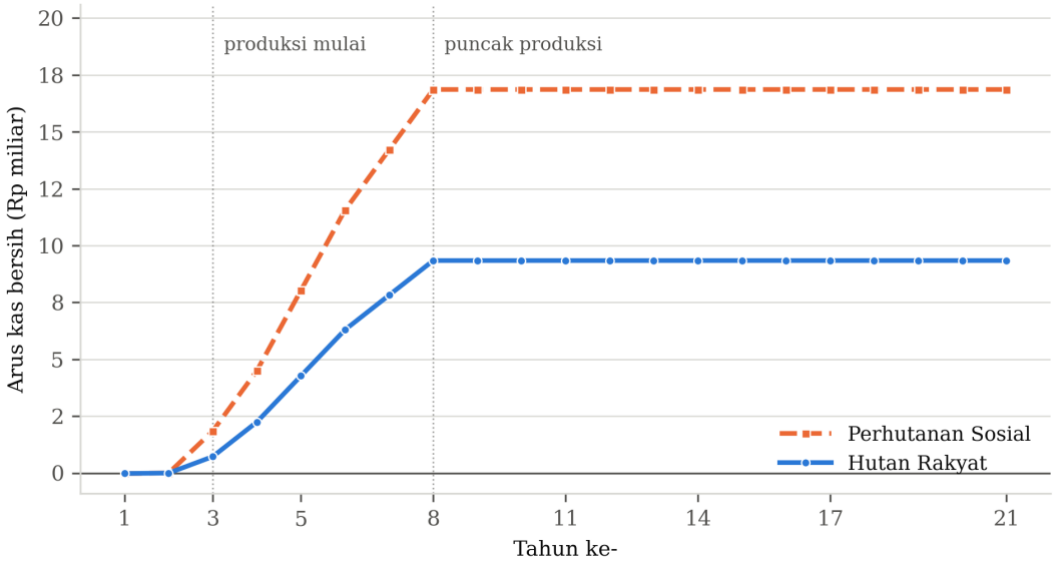


Figure 2. Annual net cash flow of communities involved in the project at both sites, Years 1 to 21

Present value of net benefit to communities involved in the project

At a 12 percent discount rate, the present value of non-timber forest product income reaches IDR 49.04 billion in private forest and IDR 85.43 billion in social forestry. The present value of land opportunity costs and farm tool expenditure reaches IDR 5.27 billion and IDR 5.30 billion, respectively. These figures are almost identical at both sites because their areas are nearly the same and the applicable rates are identical. The resulting net benefits to participating communities are therefore IDR 43.77 billion in private forest and IDR 80.13 billion in social forestry, equivalent to IDR 328.8 million and IDR 599.1 million per hectare, respectively, over the 21-year period. The ratio of net benefits per hectare between the sites is 1.82. The benefit-to-cost ratios from the perspective of participating communities are 9.30 in private forest and 16.12 in social forestry.

Table 4 presents the results at both discount rates. The absolute values change considerably: net benefits per hectare increase from IDR 328.8 million at 12 percent to IDR 524.6 million at 7 percent in private forest, and from IDR 599.1 million to IDR 952.1 million in social forestry, representing increases of approximately 59 percent at both sites. The absolute magnitude of the benefits is therefore sensitive to the choice of discount rate. However, the ratio between the sites changes very little, from 1.822 at 12 percent to 1.815 at 7 percent. The benefit-to-cost ratios also shift only slightly, from 9.30 to 10.03 in private forest and from 16.12 to 17.39 in social forestry.

The distribution of benefits over time warrants separate consideration. Without discounting, the total net benefits over 21 years reach IDR 152.1 billion in private forest and IDR 276.2 billion in social forestry, with the first ten years contributing only 32.4 percent and 32.8 percent of these totals, respectively. After discounting at 12 percent, the pattern reverses: the first

ten years contribute 54.3 percent and 54.9 percent of the present values, respectively, and half of the present value is reached in the tenth year at both sites. At 7 percent, the shares attributable to the first ten years fall to 45.4 percent and 46.0 percent. The difference between these two patterns results entirely from discounting, and its implications are discussed in the Discussion section.

Table 4

Present value of net benefit to communities involved in the project at two discount rates

Description	12% (financial)	7% (social)	Change
Private Forest			
Present value of NTFTP income (IDR billion)	49.04	77.57	+58.2%
Present value of community costs in the project (IDR billion)	(5.27)	(7.73)	+46.8%
Net benefit (IDR billion)	43.77	69.83	+59.5%
Net benefit per hectare (IDR million)	328.8	524.6	+59.5%
Benefit-to-cost ratio	9.30	10.03	+7.8%
Social Forestry			
Present value of NTFTP income (IDR billion)	85.43	135.12	+58.2%
Present value of community costs in the project (IDR billion)	(5.30)	(7.77)	+46.7%
Net benefit (IDR billion)	80.13	127.35	+58.9%
Net benefit per hectare (IDR million)	599.1	952.1	+58.9%
Benefit-to-cost ratio	16.12	17.39	+7.9%
Ratio per hectare, SF to PF	1.822	1.815	−0.4%

Note: Community costs in the project include land opportunity cost and farm tool expenditure. Figures in parentheses are deductions. The 12 percent rate is the financial discount rate used in project planning (Tbk, 2024); 7 percent is the social discount rate according to World Bank (2016), Africa (2025) Asian Development Bank (2017), and Office of Management and Budget (1992). Source: author's calculations

Sensitivity and switching value

Table 5 presents the results of the sensitivity analysis. A 10 percent decrease in avocado price or yield reduces net benefits by 8.7 percent in private forest and 8.9 percent in social forestry. A decrease of the same magnitude in coffee-related parameters reduces net benefits by only 4.1 percent and 2.8 percent, respectively. Increasing land opportunity costs from IDR 6 million to IDR 12 million per hectare per year reduces net benefits by 12.0 percent in private forest and 6.6 percent in social forestry.

Switching values cannot be meaningfully established within plausible ranges for all income-side parameters. For net benefits to reach zero, avocado and coffee prices or yields would have to decline by more than 100 percent, which is not economically meaningful. Switching values are therefore meaningful only for two cost-side parameters: production and harvesting costs, which would have to increase by 618 percent in private forest and 991 percent in social forestry, and land opportunity costs, which would have to increase by 833 percent and 1,518 percent, respectively, reaching approximately IDR 56 million and IDR 97 million per hectare per year. This pattern is consistent with the concept of switching values formulated by IFAD (2016) and Kafle et al. (2022), namely, the percentage change required for a result to fall below the minimum acceptability threshold. The methodological explanation is provided in the Discussion section.

Because the main finding of this study concerns the ratio of net benefits between the sites, its robustness was tested separately. Reducing avocado yield from 55 to 30 kilograms per tree at both sites simultaneously reduces net benefits per hectare to IDR 199.3 million and IDR 357.7 million, respectively, but the ratio changes only from 1.822 to 1.795. Conversely, equalizing avocado density in social forestry with that in private forest, namely, reducing it from 300 to 161 trees per hectare, reduces the ratio to 1.074. The complete results are presented in Table 6.

Tabel 5

Sensitivity of the net societal benefits associated with the project to changes in parameters

Change scenario	Private Forest	Social Forestry	Ratio per ha
Base case	-	-	1.822
Avocado price down 10%	-8.7%	-8.9%	1.818
Avocado yield down 10%	-8.7%	-8.9%	1.818
Coffee price down 10%	-4.1%	-2.8%	1.846
Coffee yield down 10%	-4.1%	-2.8%	1.846
Land opportunity cost up 50%	-6.0%	-3.3%	1.874
Land opportunity cost up 100%	-12.0%	-6.6%	1.934

Note: Percentages indicate the change in present value of net benefit relative to the base case at a 12 percent discount rate.
Source: author's calculations

Table 6

Robustness test of the benefit ratio per hectare between sites

Treatment	Private Forest (IDR Million/Ha)	Social Forestry (IDR Million/Ha)	Ratio
Base Case (Avocado Yield 55 Kg/Tree)	328.8	599.1	1.822
Avocado Yield 45 Kg/Tree At Both Sites	277.0	502.5	1.814
Avocado Yield 35 Kg/Tree At Both Sites	225.2	406.0	1.803
Avocado Yield 30 Kg/Tree At Both Sites	199.3	357.7	1.795
Avocado Density In Sf Reduced To 240 Trees/Ha	328.8	492.9	1.499
Avocado Density In Sf Reduced To 180 Trees/Ha	328.8	386.7	1.176
Avocado Density In Sf Equalised (161 Trees/Ha)	328.8	353.1	1.074

Note: Discount rate 12%. SF = social forestry. Source: author's calculations

Risk profile for the benefit of communities involved in the project

Table 7 presents the ten identified risks, together with their likelihood and impact scores at both sites and the community benefit channels affected. In private forest, no risk reaches the high category; the highest scores are plant mortality at 23.0 and validation failure at 18.9. In social forestry, two risks fall into the high category: a carbon price decline below the break-even level, at 35.7, and plant mortality, at 34.4. These are followed by changes in permit regulations, at 24.6.

When risks are classified according to their effects on community benefit channels, the ranking differs. The risks that directly affect community income are plant mortality, fire and natural disasters, land conflict, withdrawal of partner farmers, and changes in social forestry permit regulations, because all five reduce the productive stand or restrict access to it. Conversely, carbon price declines and validation failures do not directly affect community income under the applicable arrangement, because all non-timber forest product yields belong to the community and are not contingent on the issuance of carbon credits.

When the ten risks are grouped according to the final column of Table 7, five directly affect community income: plant mortality, fire and natural disasters, land conflict, withdrawal of partner farmers, and changes in permit regulations. The remaining five do not directly affect community income. The combined scores of the five direct risks reach 76.4 in private forest and 124.5 in social forestry, whereas those of the five indirect risks reach 71.2 and 110.5, respectively. The most striking difference between the sites concerns the risk of changes in permit regulations, which scores 7.0 in private forest and 24.6 in social forestry, representing the largest difference among all assessed risks.

Table 7
Risk profile of both sites and community benefit channels involved in the affected project

Risk	Category	HR P	HR D	HR Score	PS P	PS D	PS Score	Community benefit channel
Carbon price decline	Market	1.8	8.4	15.1	3.8	9.4	35.7	Indirect; NTFTP remains community right
Plant mortality	Technical-biophysical	3.6	6.4	23.0	4.0	8.6	34.4	Direct; coffee and avocado production falls
Fire and disaster	Force majeure	2.2	8.4	18.5	2.6	8.8	22.9	Direct; loss of productive stand
Land or social conflict	Social-institutional	1.8	7.2	13.0	2.8	8.0	22.4	Direct; management and harvest access threatened
MRV validation failure	MRV/certification	2.2	8.6	18.9	2.6	9.0	23.4	Indirect; NTFTP continues
Partner farmers withdraw	Social-institutional	2.4	6.2	14.9	2.8	7.2	20.2	Direct; loss of seedlings and assistance
Forest carbon project cost efficiency	Operational	2.8	3.8	10.6	3.0	6.6	19.8	Indirect; suppresses assistance
Corporate target change	Strategic	1.8	6.4	11.5	2.0	6.8	13.6	Indirect; assistance stops
Change in SF permit regulation	Regulation	2.2	3.2	7.0	3.0	8.2	24.6	Direct in SF; land access threatened
Excess sequestration claim	Integrity/MRV	1.8	8.4	15.1	2.0	9.0	18.0	Indirect; erosion of trust

P = likelihood (scale 1–5); D = impact (scale 1–10); score = P × D. Category thresholds: low ≤ 8, medium > 8–16, medium-high > 16–28, high > 28. HR = private forest; PS = social forestry. Scores are the average of five expert respondents' assessments and are anchored to project feasibility indicators; the last column is the author's qualitative assessment of the affected community benefit channel.
Source: respondent assessment and author's analysis

Discussion

Annual harvests, not carbon revenue, sustain participating communities

The first finding is that the benefits modeled for participating communities arise primarily from annual agroforestry harvests rather than carbon revenue. Under the applicable arrangement, the right to monetize carbon rests with the forest carbon project as a return on investment, whereas all non-timber forest product yields belong to the community. This structure explains why a carbon price decline, which represents the largest risk to the forest carbon project at the social forestry site, has little direct effect on participating communities.

The implications for project design are considerable. A carbon project designed solely as a planting activity with wage payments provides participating communities with an income stream that ends when planting is completed. In contrast, a project that allows sustainable productive land use provides an income stream that strengthens over time and persists throughout the project horizon. This finding is consistent with Indonesian agroforestry literature demonstrating the contribution of agroforestry systems to the income and food security of farming communities (Duffy et al., 2021; Manurung et al., 2025). It also adds an insight that has received less attention in the literature: this contribution remains substantial even after land

opportunity costs are deducted.

It should be noted that the high benefit-to-cost ratios of 9.30 and 16.12 should not be interpreted as indicators of investment attractiveness. These relatively high ratios reflect the limited costs borne by participating communities, as investment and operational expenditures are financed by the forest carbon project, leaving forgone land income and relatively minor farm tool expenditures as the primary community costs. This cost structure also explains why switching values cannot be meaningfully determined for income-related parameters, as reductions in commodity prices or productivity within plausible ranges would not reduce net benefits to zero. Therefore, the primary consideration is not merely whether participating communities generate positive net benefits, but also the magnitude and timing of these benefits and the factors contributing to differences between the two forest management arrangements.

Comparisons of the magnitude of these benefits with Indonesian agroforestry literature require caution because the units of analysis differ. Most studies report agroforestry contributions as annual income per farming household or as a percentage of total household income, whereas this study reports present values per hectare over 21 years. These units cannot be compared directly without information on the number of cultivating households and the average cultivated area at each site. Establishing such equivalence represents a reasonable direction for further research. Until that information becomes available, the figures in this manuscript should be interpreted as measures of land productivity for participating communities, rather than as direct measures of their welfare. The estimates represent aggregate site-level net present values and area-normalized values, not average household income or welfare effects. Because information on the number of participating households, benefit allocation rules, and distributional outcomes is unavailable, no conclusions about household-level poverty reduction or equity are warranted.

Sources of the modeled benefit gap: differences in crop density and composition

The modeled net benefit per hectare at the social forestry site is approximately 1.82 times that at the private forest site under the baseline assumptions. Although the two sites are adjacent and share broadly similar reported biophysical characteristics, the comparison does not entirely exclude the influence of unmeasured environmental or management differences. The robustness analysis in Table 6 shows that reducing avocado yield from 55 to 30 kilograms per tree at both sites changes the benefit ratio from 1.822 to 1.795. Similarly, Table 4 indicates that changing the discount rate from 12 percent to 7 percent produces only a small change in the ratio, from 1.822 to 1.815. These findings suggest that the comparative result is relatively stable under the common parameter changes examined. However, this stability should not be interpreted as immunity to all measurement errors or untested differences between the two sites.

Conversely, when avocado density in social forestry is reduced from 300 to 161 trees per hectare to match that of private forest, the ratio declines to 1.074. Thus, the difference in benefits between the two arrangements is primarily associated with differences in planting density and composition, particularly avocado density. This statement is arithmetic and can be verified directly from Table 6. Precisely because it is supported by a numerical decomposition, it is stronger than an institutional explanation presented without such analysis. Equalizing avocado density is an accounting counterfactual, not a causal test of tenure arrangements or institutional decision-making. Differences in project design, implementation, site management, or unmeasured conditions may also explain planting choices; institutional mechanisms therefore require comparative evidence from additional sites.

The remaining question is why plant densities differ between the two arrangements. This is where institutions enter as a potential explanation rather than as a substitute for the arithmetic. Several plausible mechanisms warrant further investigation. Private forest land is individually owned, meaning that planting decisions are made independently by participating landowners according to their own risk considerations and cash requirements, while some land may already have been planted before the project began. Social forestry land, by contrast, is managed collectively through permits and jointly prepared work plans, allowing planting designs to be established more uniformly and at higher densities. The certainty of permit duration may also influence the willingness of participating communities to accept the eight-year period required to reach peak production. These explanations are consistent with the available data, but this study

does not test them directly. They are therefore presented as hypotheses.

These hypotheses can be tested in further research without necessarily requiring expensive data collection. If planting density is genuinely determined by the land management arrangement, comparisons of additional pairs of sites within the same project should reveal a consistent density pattern rather than a random distribution. The project examined in this study covers several locations, making such a test feasible. Conversely, if density varies independently of the management arrangement, the more plausible explanation may be land-use history before the project began. In that case, the findings in this manuscript should be interpreted as characteristics of these two sites only.

Land opportunity costs and the problem of time

The present value of land opportunity costs reaches approximately IDR 5.3 billion at both sites, equivalent to approximately 12 percent and 6.6 percent of net benefits, respectively. Their relative magnitude does not threaten the main conclusion, but their timing makes them important. These costs begin to be borne by participating communities in the third year, whereas production reaches its peak only in the eighth year. During the intervening five years, participating communities bear the opportunity costs while receiving only partial agricultural income.

The timing of agricultural benefits and land opportunity costs may have important implications for participating communities, particularly those with limited financial reserves. Although the modeled annual net cash flows become positive in the third year, production does not reach its assumed peak until the eighth year. Consequently, the magnitude of early benefits remains lower than that achieved during the subsequent production period. This temporal pattern may create financial constraints for households that depend on more immediate income, although the present study does not directly measure household liquidity, consumption requirements, or decisions to withdraw from the project. The findings therefore support the importance of considering the timing of net benefits alongside their aggregate present value, consistent with the broader relevance of household-level opportunity costs discussed by Ickowitz et al. (2017) and Pirard et al. (2023).

This timing issue explains why the choice of discount rate warrants consideration in community-level analysis. Without discounting, more than two-thirds of the benefits accrue during the final 11 years. At a 12 percent discount rate, more than half of the present value accrues during the first ten years, whereas at 7 percent, its share falls to approximately 46 percent. The 12 percent discount rate used in this study comes from project planning and reflects corporate capital costs rather than the time preferences of rural communities, which several studies have shown may be higher. Using a higher discount rate suppresses the value of benefits received in later years and accentuates the timing-related issue described above, but it does not change the ratio between the sites, as shown in Table 4. The comparative conclusion of this study therefore does not depend on this debate, whereas the absolute magnitude of the benefits does. The approximately 59 percent difference between the estimates obtained using the two discount rates illustrates the extent of this sensitivity.

Risks from the perspective of participating communities

The risk assessment highlights the importance of distinguishing risks to the forest carbon project from their potential implications for participating communities. As shown in Table 7, carbon price declines and monitoring, reporting, and verification (MRV) validation failures are relevant to project-level financial and certification performance. Under the arrangement examined, however, non-timber forest product yields remain allocated to participating communities and are not directly contingent on the issuance of carbon credits. These risks may nevertheless affect communities indirectly if they influence the continuity of project support or implementation activities. By contrast, plant mortality, fire and natural disasters, land conflict, withdrawal of partner farmers, and changes in social forestry permit regulations are more directly connected to agricultural production or land access. Because community-level consequences were qualitatively interpreted rather than independently measured, these distinctions should be regarded as analytical risk classifications rather than observed differences in household risk perceptions.

This distinction between risk categories has practical consequences for mitigation design. Mitigation efforts prepared solely from the forest carbon project perspective may concentrate resources on carbon sales contracts and methodological compliance, while risks that are more decisive for community livelihoods, such as replanting dead trees, fire prevention, and permit certainty, may receive insufficient attention. The situation at the social forestry site is more urgent because the risk associated with changes in permit regulations scores 24.6, compared with 7.0 in private forest. This difference reflects the potential vulnerability of management rights over state land relative to private ownership rights.

This finding suggests that risk assessments for community-based carbon projects should be prepared using two separate lists from the outset: one from the forest carbon project perspective and another from the community perspective, rather than relying on a single list assumed to represent both. The ISO 31000:2018 framework itself identifies context establishment and stakeholder identification as initial steps. Separating the risk lists is therefore consistent with that framework and does not require a new method. What is needed is simply a willingness to ask the same questions of two different stakeholder groups.

Implications and limitations

The findings offer two practical considerations for carbon-based agroforestry project design and public policy. First, the modeled benefits at both sites are strongly influenced by agricultural production, particularly avocado planting density and the resulting non-timber forest product income. Project designers should therefore consider planting composition, production schedules, land opportunity costs, and the timing of agricultural returns when evaluating benefits to participating communities. Second, land management arrangements and the security of access to productive land may be relevant to long-term participation in agroforestry projects. The higher assessed risk associated with permit regulations at the social forestry site suggests that regulatory certainty warrants attention in project planning. However, the present two-site comparison does not establish that the management arrangement itself caused the observed differences in planting density or quantify the economic value of permit certainty. Further research involving additional sites and household-level information is required before broader institutional or distributional policy conclusions can be drawn.

Several limitations should be considered when interpreting the findings. First, the analysis focuses on two adjacent sites within a larger carbon-based agroforestry project, which limits the generalizability of the results to other geographical and institutional contexts. Second, the estimated benefits depend on assumptions regarding planting density, production schedules, crop yields, and commodity prices, particularly for avocado production. These parameters were derived from interviews, project planning documents, and published benchmarks that may not fully reflect the characteristics of the commodities examined. Third, wage income and associated household labor costs were excluded because of insufficient information on their distribution. Consequently, the estimates represent partial modeled net benefits rather than comprehensive measures of household welfare. Fourth, the exploratory risk assessment involved only five expert respondents, with limited documentation of the procedures used to aggregate their assessments. Finally, the potential institutional factors underlying differences in planting density were not empirically tested through comparative institutional analysis or household-level data.

An additional limitation concerns the provenance and applicability of the production parameters summarized in Table 3. The assumed 10 percent post-harvest loss rate for coffee and avocado was informed by benchmarks from other agricultural commodities, particularly paddy, rather than by direct measurements at the study sites. Moreover, the model applies an 88 percent quality acceptance factor to avocado production, although the cited marketing study by Fajriyanti et al. (2024) reports Class A and Class B quality categories without documenting a corresponding rejection rate. This distinction is important because lower-grade produce may remain marketable at different prices rather than being entirely excluded from sale. Applying separate post-harvest loss and quality acceptance deductions may therefore overstate quantity reductions if quality differences are already reflected in the farm-gate price. The available evidence does not establish the magnitude or direction of the resulting estimation error. Future research should incorporate crop-specific post-harvest loss observations, site-level quality grading, and grade-adjusted prices

to improve the reliability of the modeled net benefit estimates.

CONCLUSION

This study compared the modeled 21-year net benefits of carbon-based agroforestry production at two adjacent sites operating under private forest and social forestry arrangements in Garut Regency, Indonesia. At a 12 percent discount rate, the estimated net present benefits were IDR 43.77 billion for private forest and IDR 80.13 billion for social forestry, equivalent to IDR 328.8 million and IDR 599.1 million per hectare, respectively. The calculations include non-timber forest product income, land opportunity costs, and farm tool expenditure but exclude project-related wage income and associated labor costs. The benefits arise mainly from agroforestry harvests, particularly avocado. Production begins in the third year and reaches its assumed peak in the eighth year, underscoring the importance of considering when benefits become available.

The social forestry site showed approximately 1.82 times the modeled net benefit per hectare of the private forest site under the baseline assumptions. This ratio remained broadly stable under the tested common changes in discount rates and yields but declined to approximately 1.07 when avocado planting density was equalized. This indicates that crop density explains much of the estimated difference within the model, rather than establishing a causal effect of forest management arrangements. Because the analysis covers only two sites and uses partly assumed production parameters, the findings should not be generalized to other projects. Moreover, the figures describe partial aggregate and per-hectare net benefits, not household welfare or the distribution of gains. Further research should examine additional sites, planting decisions, crop-specific assumptions, and household-level outcomes.

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AUTHOR CONTRIBUTION STATEMENT

Bima Krida Pamungkas, Dodik Ridho Nurrochmat, and Perdinan contributed to the preparation of this manuscript. Bima Krida Pamungkas was responsible for the research conception, methodology, data collection, formal analysis, interpretation of findings, and preparation of the original manuscript. Dodik Ridho Nurrochmat and Perdinan contributed to the research methodology, supervision, and manuscript revision. All authors approved the final version of the manuscript.

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