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Cost–Benefit and Profitability Assessment of Land Use Transition from Agriculture to Plantation Forest in Bolosso Sore and Hadero Tunto Districts, Southern Ethiopia

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Abstract: Rapid land-use transitions from crop farming to plantation forestry are reshaping rural economies in Ethiopia, driven by declining agricultural productivity, rising demand for wood products, and farmers' preference for low-risk income alternatives. Eucalyptus dominates due to fast growth and high market value. This study assesses the economic viability of converting cropland to eucalyptus in Boloso Sore and Hadero Tunto by comparing tree- and crop-based systems. Data from 240 households were collected via surveys, interviews, focus groups, and field observations (multistage sampling). Cost–benefit analysis used NPV, BCR, and IRR at an 8% discount rate. Eucalyptus plantations yield higher long-term profits with lower labor: NPV 458,577.05 ETB, BCR 16.25, and IRR 66%. Crops provide short-term food and cash: NPV 388,319.97 ETB, BCR 16.36, IRR 203%. Sensitivity tests show plantation forestry is more robust across price, cost, yield, and discount-rate changes. As discount rates rise from 8% to 14%, NPVs fall for both, but plantations remain higher, converging only around 14.5%–15%, beyond which crops may gain advantage under very high capital costs. Under broader sensitivity scenarios including variations in price, production cost, and yield the plantation system demonstrates greater resilience due to its large periodic revenues, which buffer moderate market and productivity fluctuations. In contrast, crop-based agriculture is more vulnerable to input cost increment and short-term yield instability, although it is relatively less sensitive to extreme discount rate increases. Overall, within realistic ranges (8–14%), eucalyptus plantations remain economically superior despite food-security and ecological trade-offs.

Keywords: Cost–Benefit analysis, Crop profitability, Ethiopia, Eucalyptus plantation, Land use conversion, Net Present Value, Smallholder economy.

Introduction

Human-driven and naturally induced land use alterations have caused significant declines in native biodiversity and disrupted ecological functions across the globe (Msofe et al., 2019). Ethiopia reflects this global trend, as rapid shifts in land use and land cover (LULC) continue to reshape its rural economies and ecosystems. Agriculture historically the mainstay of rural livelihoods and a major pillar of national GDP faces increasing pressure from population growth, shrinking landholdings, soil degradation, and climate variability (World Bank, 2022). These challenges have accelerated the movement away from conventional farming systems toward alternative land-based enterprises; fast-growing plantation forestry dominated by exotic species such as *Eucalyptus globulus* and *Acacia decurrens* (Forrester et al., 2004; Zerga et al., 2021; Minotta et al., 2025).

In Ethiopia, the combination of increasing population, reduced soil productivity, and rising demand for wood products has intensified the shift toward tree-based land use, particularly short-rotation plantations (Alemayehu et al., 2024). Comparable land-use transitions have occurred elsewhere, where monoculture plantations of exotic species have been promoted for economic growth, such as in Chile, where commercial plantations of *Pinus radiata* and *Eucalyptus* have been central to national development policy (Carte et al., 2021). Within Ethiopia, formerly cultivated areas are increasingly converted to *Eucalyptus* woodlots in response to declining crop yields and growing demand for construction timber and fuelwood (Birru et al., 2013; Molla et al., 2023; Zeleke et al., 2024). Rather than merely reflecting a land-cover change, this transition represents a fundamental economic decision by smallholders seeking to optimize land productivity under increasing resource constraints.

The expansion of plantation forestry is also linked to global market forces. Rising economic activity and population growth have sharply increased worldwide demand for wood products (FAO, 2014), and the European Union alone recorded more than a tenfold rise in wood imports between 2000 and 2010 (Lamers et al., 2013). To meet this surge, short-rotation tree plantations are widely promoted as cost-efficient sources of bioenergy, industrial raw materials, and household fuelwood (Ronald et al., 2008). *Eucalyptus*, in particular, has become one of the most commercially valuable plantation species globally due to its rapid growth, coppicing ability, and high biomass yield (Bayle, 2019; Zerga et al., 2021). These attributes have positioned plantation forestry as a financially attractive alternative to annual crop production in many smallholder settings.

In the Ethiopian context, the degradation of native tree species with comparable short-term economic returns has further encouraged farmers to convert croplands into *Eucalyptus* stands (Abebe & Tadesse, 2006; Jagger & Pender, 2003). These plantations provide marketable biomass within four to five years and can be harvested repeatedly over multiple rotations (Allen et al., 2013), offering relatively stable income with lower long-term labor and input requirements. Plantation forestry is also aligned with national policy objectives, including the Climate Resilient Green Economy (CRGE) strategy, which frames tree planting as both an economic and ecological intervention (Tesfaye et al., 2015). However, while policy narratives emphasize the economic potential of plantation forestry, empirical evidence comparing its profitability with conventional agriculture remains limited. Thus, the expansion of plantation forests has raised substantive questions regarding their economic, social, and ecological consequences. Studies indicate that converting cropland to *Eucalyptus* may reduce the area available for food production, alter household food systems, and introduce livelihood trade-offs (Belay et al., 2025). Similar patterns have been observed in India and Brazil, where large-scale plantation expansion has affected rural labor dynamics and ecosystem services (Smith et al., 2024). In Ethiopia, concerns persist regarding groundwater depletion, soil nutrient decline, erosion, and allelopathic effects associated with *Eucalyptus* cultivation (Sasikumar et al., 2002; Mengistu et al., 2020; Bayle, 2019). Large-scale plantings have also been linked to invasive behavior and reduced biodiversity (Teketay, 2000; Lopez, 2015; Forstmaier et al., 2020). These documented trade-offs highlight the importance of evaluating plantation expansion not only from an environmental perspective but also through a rigorous economic lens.

Given the competing demands for land between food production and plantation forestry, assessing the economic implications of land-use conversion is essential. Land is a finite production factor, and reallocating it from crops to trees entails opportunity costs that must be justified through comparative financial returns (Lambin & Meyfroidt, 2011; Lubowski et al., 2006). Although previous studies in Ethiopia have examined the economics of agroforestry systems, mixed tree crop arrangements, and selected plantation models (Ayana & Lejissa, 2018), most analyses stop short of evaluating complete land-use conversion from agriculture to plantation forestry using standardized financial indicators over full production cycles, particularly in densely populated areas of sub-Saharan African countries. Accordingly, this study explicitly addresses this gap by conducting a cost–benefit and profitability assessment of agricultural land conversion to plantation forestry in Bolosso Sore and Hadero Tunto districts of southern Ethiopia. By applying Net Present Value (NPV), Benefit–Cost Ratio (BCR) and Internal Rate of Return (IRR), the study provides a direct, empirical comparison of the long-term financial performance of plantation forestry versus continued agricultural cultivation under local production and market conditions. The study is guided by a set of focused analytical questions: (i) whether plantation forestry generates higher long-term financial returns than conventional crop production under smallholder conditions; (ii) how sensitive these returns are to changes in prices, labor costs, yields, and discount rates; and (iii) whether the observed profitability differences are sufficient to justify the opportunity costs associated with withdrawing land from food production.

Methodology

Study Area Description

The study was conducted in Bolosso Sore and Hadero Tunto districts in Southern Ethiopia, which were purposively selected due to the rapid conversion of farmlands into smallholder eucalyptus plantations and the coexistence of agricultural and plantation-based livelihoods (Alemu, 2016; Chinasho et al., 2022). Bolosso Sore lies between 7°40′ N and 7°10′ N and 37°40′ N to 37°50′E, at an altitude of 750–1820 m above sea level, while Hadero Tunto is located between 7°10′ and 7°20′ N and 37°39′30″ E and 37°50′0″E (Fig 1). Both districts experience a mid-altitude subtropical climate with bimodal rainfall distribution, annual rainfall ranging from 1200–1500 mm, and average temperatures between 14.48°C (minimum) and 25.6°C (maximum). Agricultural activities are concentrated during the spring (March–May) and summer (June–September) rainy seasons. The districts’ increasing land pressure has encouraged farmers to adopt fast-growing eucalyptus plantations as an alternative or complementary livelihood strategy, making them highly suitable for a comparative economic assessment of agriculture and plantation forestry.

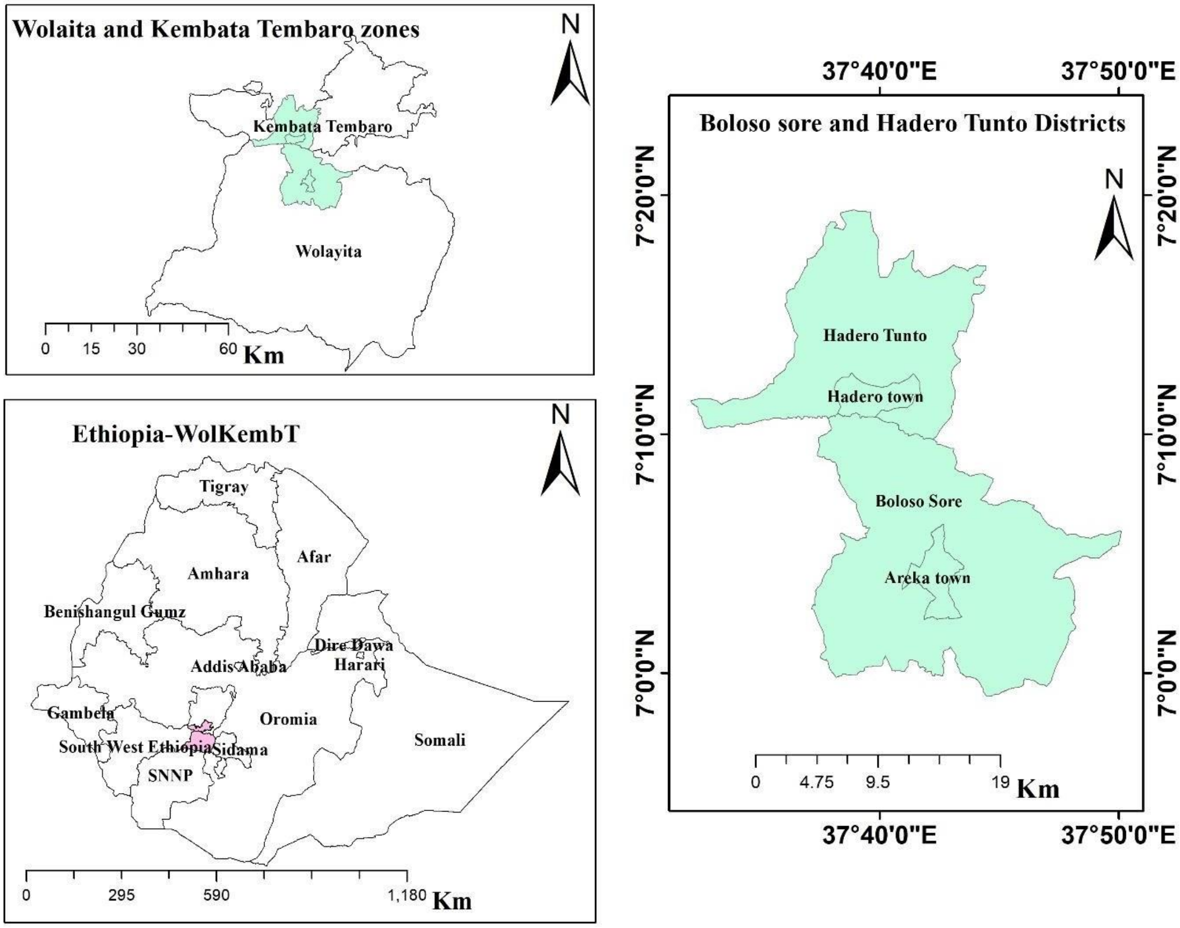

Figure 1: Map of the study areas

Hadero Tunto, which falls under a slightly warmer agro-ecological zone, is dominated by cash crop cultivation including enset, coffee, and ginger, but has similarly witnessed a substantial rise in eucalyptus plantations over the past two decades. The selection of Bolosso Sore and Hadero Tunto was guided by three main criteria: (1) documented land use transition from food crop production to eucalyptus plantations over the last 15–20 years, (2) active participation of smallholder farmers in both agricultural and plantation-based land use systems, and (3) agro-ecological representativeness, reflecting landscapes where land scarcity, market access, and ecological change strongly shape livelihood decisions. The key demographic and spatial characteristics of Bolosso Sore District and Hadero Tunto District, providing important contextual information for understanding population pressure, land availability, and potential drivers of land-use change is indicated below (Table 1). By focusing exclusively on these two districts, the study provides a context-specific evaluation of the financial feasibility and economic implications of shifting land from agriculture to plantation forestry under real smallholder production conditions in southern Ethiopia.

Table 1. Demographic and Spatial Characteristics of the Study Districts

DESCRIPTION	BOLOSSO SORE DISTRICT	HADERO TUNTO DISTRICT
Total Population (2007)	98,375	197,973
Projected Population (2022)	160,660	301,147
Area (km²)	190.3	303.1
Population Density (per km², 2022)	844.2	993.7
Annual Population Growth Rate	3.3%	2.8%

Sampling Technique and Sample Size Determination

A multistage sampling technique was employed, concentrating on the two districts in Southern Ethiopia; Bolosso Sore (Wolaita Zone) and Hadero Tunto (Kembata Tembaro Zone); where significant land use transitions from crop cultivation to plantation forestry have recently occurred. The sampling approach was designed to ensure that the selected households and key actors accurately represent the economic and land management dynamics associated with this land use change. A multistage sampling technique was adopted to balance representativeness with feasibility, allowing the study to capture both spatial variation in land-use conversion and household-level economic behavior**.** In the first stage, the districts were purposively selected based on official records from zonal agriculture and forestry offices, which confirmed substantial expansion of *Eucalyptus* plantations at the expense of cropland. Consultations with district experts and key informants were used to validate the intensity and economic relevance of the conversion trend in both areas. In the second stage, kebeles (villages) within each district were identified. A complete list of kebeles was compiled in both districts, and those with the highest proportion of former croplands converted to *Eucalyptus* plantations were categorized as high-conversion areas. From this list, two kebeles per district were randomly selected, prioritizing those with the largest plantation coverage and commercial production activities. In the third stage, a list of farming households practicing both crop cultivation and plantation forestry was obtained from the respective district Land Administration Offices. Using systematic random sampling, a total of 240 households (60 households per kebele) were selected for the household survey. The sample size was considered adequate to support comparative financial analysis while remaining consistent with similar household-level cost–benefit studies in agricultural and forestry economics. The sampling interval was calculated by dividing the total number of eligible households by the assigned sample size per kebele. This ensured proportional representation of different household types and management strategies.

Data Collection Methods

Both primary and secondary data sources were used to ensure comprehensive and reliable findings. Primary data were collected through household surveys; key informant interviews (KIIs), focus group discussions (FGDs), and field observations. The combination of household surveys, KIIs, FGDs, and field observations was employed to triangulate economic data and reduce recall and reporting bias, particularly for long-rotation plantation investments. Structured questionnaires were administered to randomly selected farmers who had fully transitioned part or all of their land from crop production to *Eucalyptus* plantations. The survey captured socio-economic characteristics of households, land use types and sizes, land quality, yields of crops and trees per hectare, production costs, and revenue generated over defined periods. Additional information included intermediate and supplementary benefits such as fuelwood, farm implements, construction poles, and household energy sources. Farmers were also asked about labor use, the opportunity cost of family labor, expected rotation period, price variability, and perceived risks affecting plantation-based incomes.

Key informants were selected using a snowball sampling technique (Nader far, et al. 2017; Pahwa et al., 2023), resulting in 16 individuals (four per kebele), including forestry officers, experienced tree growers, and community leaders. These informants were selected for their knowledge of land use history, plantation expansion, and economic outcomes in their locality. Additionally, four FGDs (two per district) were conducted after the household survey, each consisting of eight participants (men and women) with direct experience in both crop and tree-based production. FGDs were used to explore community-level perceptions on economic drivers, social implications, environmental impacts, and challenges associated with the expansion of *Eucalyptus* plantations. We used the qualitative methods to supplement the quantitative analysis by contextualizing cost and revenue estimates, price formation, labor allocation, and perceived risk, which are critical for interpreting profitability results. Field observations were conducted across the two districts to validate the quantitative and qualitative information gathered. Secondary data were obtained from district and zonal agriculture and forestry offices, the Central Statistical Agency (CSA), and published and unpublished documents. These data provided supplementary trends on crop production, plantation expansion, input and output prices, and interest rates (Ministry of Finance), used to support and triangulate primary findings.

Data Analysis

Both quantitative and qualitative data were analyzed to assess the economic viability and motivations behind land use transitions from crops to plantation forestry. Quantitative data were processed using SPSS v26 and Microsoft Excel. Descriptive statistics were used to summarize household characteristics, land allocation, yields, and costs. Financial computations were applied to compare economic returns from crop-based and tree-based systems. Qualitative data from FGDs and KIIs were analyzed through thematic coding to interpret perceptions of economic incentives, environmental effects, institutional factors, and socio-cultural implications. The analytical sequence moved from descriptive characterization of land-use systems to comparative financial evaluation, ensuring that observed profitability differences were grounded in observed production and cost structures.

Economic Analysis

A Cost–Benefit Analysis (CBA) framework was used to evaluate and compare the economic performance of agricultural and plantation-based land uses. The analysis employed standard investment indicators: Net Present Value (NPV): discounted net return of each land use across its lifespan. Benefit–Cost Ratio (BCR): ratio of discounted benefits to discounted costs (BCR > 1 indicates profitability). Internal Rate of Return (IRR): discount rate where NPV = 0, used to compare profitability across land uses. Return on Investment (ROI): profitability expressed relative to total cost. NPV, BCR, IRR, and ROI were used together to

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capture absolute profitability, efficiency of capital use, and comparative investment performance across land uses with different time horizons.

A discount rate of 8% was applied, approaching Ethiopian standards for agricultural investment appraisal which was 7% (Chipeta et al., 2015). For land uses such as *Eucalyptus* plantations that involve recurring returns per rotation, the Faustmann model was applied to evaluate long-term forest investment returns. We used Faustmann model to appropriately account *Eucalyptus* plantations for infinite rotation cycles and land expectation value, which is not captured by single-rotation profit measures**.**

All future benefits and costs were discounted to present value, following Harvey, (1995) to account for the time value of money. Opportunity cost of labor was calculated separately for men and women due to seasonal wage variation. Land returns were expressed in NPV terms, based on Evison, 2006, to allow economic comparison of alternative land uses over time.

$$\text{NPV} = \sum_{t=0}^{n} \frac{(Bt - Ct)}{(1+r)^t} > 0 \qquad \text{...(1)}$$

Where; NPV= Net Present Value, Bt= Benefit flows at time t, Ct= Cost of production at time t, r= discount rate and t= time. The Benefit–Cost Ratio (BCR) compares the present value of benefits with the present value of costs. The land use option with the higher BCR is considered more profitable. It is calculated below using Formula (2).

$$\text{BCR} = \frac{\sum_{t=0}^{n} \frac{\text{Bt}}{(1+r)^t}}{\sum_{t=0}^{n} \frac{\text{Ct}}{(1+r)^t}} > 1 \qquad \text{...(2)}$$

The profitability of an investment is measured by how much return it generates compared to the cost of the resources used. In this study, all calculations are based on current input and output prices, which are assumed to remain the same throughout the analysis period. A 7% discount rate was applied, which is the official rate used for agricultural investments in Ethiopia. This rate represents the opportunity cost of capital meaning the income that could have been earned if the money had been invested elsewhere (Gollier & Hammitt, 2014). Return on Investment (ROI) is used to measure how efficiently money is being invested. It is calculated by dividing the net return (benefit minus cost) by the total cost, and the result is given as a percentage or ratio (Investopedia).

The types of crops grown in each kebele were identified through FGDs. Total income from these crops was estimated based on recorded yields and local market prices. Total variable costs such as seeds, fertilizers, chemicals, ploughing, harvesting, and labor were calculated using local price data. Net returns were assessed assuming that both costs and benefits stay the same over the study period.

Financial Analysis

The financial analysis was carried out to compare the economic performance of shifting land use from annual crop production to plantation forestry specifically eucalyptus in Bolosso Sore and Hadero Tunto districts. A discount rate of 8% was applied to all projected costs and benefits over a 15-year rotation period, reflecting the long-term nature of tree-based investments in the study area. Key investment indicators used in the analysis include Net Present Value (NPV), Benefit–Cost Ratio (BCR), and Internal Rate of Return (IRR). The assessment focused on two scenarios:

- P1 – Crop farming system (Agriculture)
- P2 – Plantation forestry (eucalyptus)

These indicators were calculated based on district-level cost and revenue data, enabling a direct comparison of profitability between tree plantations and agricultural land use.

Cost and Revenue Structure

Eucalyptus plantations in both districts are characterized by high establishment costs in the initial year primarily for seedlings, land preparation, and fencing followed by relatively low maintenance costs in subsequent years. Revenues are generated periodically through pole harvests, with major income peaks recorded in years 5, 10, and 15. In contrast, the crop farming system shows small but regular annual cash inflows and outflows, reflecting the seasonal nature of production. While annual crops generate frequent returns, they do not accumulate into large harvest-cycle revenues like eucalyptus. This difference in cash flow timing is central to the profitability gap between plantation forestry and cropping systems.

Sensitivity Analysis

A sensitivity analysis was carried out to make the economic results more reliable. This analysis examined how changes in important factors such as product prices, labor costs, discount rates, and yields could affect the profitability of land use options. The study tested what would happen if these values increased or decreased by 50%, based on methods used by Tortorelli & Michaleris (1994), Saltelli, A. (1999), and Christopher & Patil, (2002). The ±10% variation range was selected to reflect realistic fluctuations observed in local markets and climatic conditions, providing a conservative assessment of investment robustness.

This helped show how risks like climate change, pests, or market price changes could influence farmers' decisions. Sensitivity analysis is important in cost–benefit studies, especially in agriculture and forestry where many factors are uncertain. It helps investors and policymakers understand how stable or risky an investment might be if conditions change in the future. While constant prices were assumed to establish a baseline comparison, this limitation was explicitly addressed through sensitivity analysis. This is particularly valuable in countries like Ethiopia, where land use decisions are closely linked to improving livelihoods while coping with environmental challenges.

Results and Discussion

Socio-demographic Characteristics

Table 2 presents the descriptive statistics of the socio-economic characteristics of the sampled households (n = 240) across the four kebeles: Chema Embecho, Wormuma, Hachacho, and Tunto One. The variables include age, education level, family size, total landholding, farmland size, and woodlot size. These characteristics are essential for understanding the demographic structure, human capital endowment, and resource base of households, which may significantly influence land-use decisions and livelihood strategies in the study area.

Table 2. Descriptive Statistics of Socio-Economic Characteristics of Sample Households (n = 240)

Kebeles	Socio-economic Variables	Obs.	Mean	SD	Min	Max
Chema Embecho	Age (years)	60	45.10	11.20	22	78
	Education (years)	60	4.80	4.90	0	16
	Family size	60	6.70	2.10	2	14
	Total land size (ha)	60	0.80	0.60	0.13	4.50
	Farm land size (ha)	60	0.48	0.35	0.00	2.50
	Woodlot size (ha)	60	0.18	0.14	0.00	0.90
Wormuma	Age (years)	60	46.00	10.80	20	76
	Education (years)	60	4.60	4.50	0	15
	Family size	60	6.90	2.20	2	12
	Total land size (ha)	60	0.79	0.65	0.10	4.00
	Farm land size (ha)	60	0.50	0.32	0.10	2.00
	Woodlot size (ha)	60	0.17	0.13	0.00	0.80
Hachacho	Age (years)	60	47.20	11.30	26	80
	Education (years)	60	5.00	3.90	0	15
	Family size	60	7.40	2.10	2	12
	Total land size (ha)	60	0.87	0.45	0.25	2.30
	Farm land size (ha)	60	0.62	0.35	0.20	2.00
	Woodlot size (ha)	60	0.16	0.11	0.00	0.50
Tunto One	Age (years)	60	46.60	13.00	22	85
	Education (years)	60	5.10	4.60	0	15
	Family size	60	8.00	2.30	3	15
	Total land size (ha)	60	0.83	0.45	0.25	2.50
	Farm land size (ha)	60	0.56	0.30	0.12	1.30
	Woodlot size (ha)	60	0.19	0.18	0.00	1.00

The mean age of household heads ranges from 45.10 years in Chema Embecho to 47.20 years in Hachacho, indicating that the majority of respondents are within the economically active age group. The relatively moderate standard deviations (10.80–13.00 years) suggest a fairly balanced age distribution across the kebeles. The minimum and maximum values (20 to 85 years) reveal the presence of both young and elderly household heads, implying potential intergenerational differences in farming experience, risk perception, and adoption of land-use changes. Educational attainment remains generally low across all kebeles, with mean years of schooling ranging from 4.60 in Wormuma to 5.10 in Tunto One. The relatively high standard deviations (3.90–4.90) indicate considerable variation in educational levels among households. Notably, the minimum value of zero years in all kebeles shows that a substantial proportion of household heads lack formal education, which may affect access to information, technological adoption, and responsiveness to institutional interventions related to land-use transformation. The average family size varies from 6.70 persons in Chema Embecho to 8.00 persons in Tunto One, reflecting relatively large household structures. The presence of large families (maximum values ranging from 12 to 15 members) suggests high dependency ratios and labor availability within households. Larger family sizes may simultaneously provide labor for agricultural and plantation activities while also increasing consumption pressure on limited land resources.

The mean total landholding size is relatively small across all kebeles, ranging from 0.79 ha in Wormuma to 0.87 ha in Hachacho. This indicates that households operate under conditions of land scarcity, which is a critical factor influencing land-use decisions. Despite small average holdings, the maximum values (up to 4.50 ha in Chema Embecho) reveal disparities in land distribution among households. The moderate standard deviations suggest some heterogeneity in land access within each kebele. Farmland constitutes the major portion of total landholdings. The mean farmland size ranges from 0.48 ha in Chema Embecho to 0.62 ha in Hachacho. The relatively small minimum values, including zero farmland in Chema Embecho, indicate that some households may rely partially or entirely on alternative land uses such as woodlots or non-farm activities. The variation in farmland size highlights differences in production capacity and potential vulnerability to land-use conversion. Woodlot holdings are comparatively small, with mean values ranging from 0.16 ha in Hachacho to 0.19 ha in Tunto One. Although the average size is limited, the maximum values (up to 1.00 ha in Tunto One) demonstrate that certain households allocate a substantial portion of their land to woodlot production. This may reflect increasing engagement in plantation-based livelihoods or strategic diversification in response to economic and environmental pressures.

Benefits and Costs of Crop and Plantation Forest Production

The table presents a comparative overview of crop production returns in Boloso Sore and Hadero Tunto districts. In both districts, Godera records the highest mean returns, amounting to ETB 60,802 in Boloso Sore and ETB 55,888 in Hadero Tunto. The standard deviations are ETB 71,957 and ETB 107,601, respectively. The maximum recorded return for Godera reaches ETB 800,000 in Hadero Tunto (Table 3).

Maize and teff show lower mean returns in both districts. In Boloso Sore, maize generates a mean return of ETB 31,875, while in Hadero Tunto the mean return is ETB 25,747. Teff records mean returns ranging from ETB 43,015 to ETB 48,720 across the two districts. The standard deviations for maize and teff are smaller than those observed for Godera. The total mean return per household is ETB 43,616 in Boloso Sore and ETB 40,511 in Hadero Tunto. In both districts, wide differences are observed between minimum and maximum returns, accompanied by relatively large standard deviations.

Table 3. Summary on Benefits and Costs of Crop and Plantation

Region	Zone	District	Crop	Mean	Min	Max	Std. Dev
South Ethiopia	Wolaita	Boloso Sore	Godera	60,802	3,733	533,333	71,957
			Maize	31,875	2,200	232,000	37,812
			Potato	26,190	8,333	50,000	9,357
			Teff	48,720	8,500	74,000	24,480
			Total	43,616	2,200	533,333	53,886
South Ethiopia	Kembata-Tambaro	Hadero Tunto	Godera	55,888	2,000	800,000	107,601
			Maize	25,747	680	90,000	19,296
			Zinger	43,786	8,095	136,780	56,093
			Teff	43,015	7,091	112,500	40,198
			Total	40,511	680	800,000	76,753

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Costs Involved in Crop Production

Godera exhibits the highest mean production costs in both districts, with ETB 55,439 in Boloso Sore and ETB 52,133 in Hadero Tunto. Maximum costs reach ETB 258,333 and ETB 160,000, respectively. Maize and teff show lower mean production costs. Maize costs average ETB 19,829 in Boloso Sore and ETB 23,286 in Hadero Tunto, while teff ranges from ETB 14,508 to ETB 19,063 (Table 4). Potato in Boloso Sore records a mean cost of ETB 31,171. Standard deviations are relatively high across crops, particularly for Godera. The total mean production cost per household is ETB 33,792 in Boloso Sore and ETB 36,803 in Hadero Tunto.

Table 4- Average Production Costs (ETB) by Crop and District

REGION	DISTRCIT	CROPS	MEAN	MINIMUM	MAXIMUM	STD. DEV
South Ethiopia	Bolososore	Godera	55439	6000	258333	43754
		Maize	19829	2367	54792	11283
		Potato	31171	5000	73400	22242
		Teff	14508	5200	30600	6852
		Total	33792	2367	258333	33459
	Hadero Tunto	Godera	52133	3900	160000	32807
		Maize	23286	410	95652	15663
		Zinger	21368	7400	57380	17213
		Teff	19063	6909	51058	16421
		Total	36803	410	160000	29098

Return and Costs from Plantation Forests of Boloso Sore and Hadero Tunto

Eucalyptus plantation forestry in Boloso Sore and Hadero Tunto districts presents a viable economic alternative to annual crop farming, offering steady financial returns for households that allocate land to tree-based production. Although the level of profitability varies among farmers, eucalyptus plantations in both districts generate meaningful cash income, particularly at harvest cycles when mature stands are sold for construction poles, fuelwood, or charcoal. The scale of return is influenced by factors such as plantation size, rotation length, market access, and management practices, but overall, eucalyptus remains an important source of medium- to long-term income in both districts. The cost of establishing and managing eucalyptus plantations in Boloso Sore and Hadero Tunto remains relatively modest compared to other commercial farming activities. Total production costs per hectare generally fall within the range of ETB 29,774 to ETB 45,060, reflecting a production system that relies more on family labor and low external input use. The largest share of expenditure occurs during the establishment phase, where households invest in seedling purchase, land preparation, fencing, and initial planting. After this phase, management and maintenance costs decrease significantly, making eucalyptus a low-input and labor-saving land use option, especially suitable for households facing labor shortages or prioritizing off-farm activities.

The relatively low cost structure, combined with the ability of eucalyptus to grow on degraded or marginal lands, has encouraged farmers in both districts to continue expanding plantation areas. Unlike annual crops that require recurrent input purchases and seasonal labor, eucalyptus offers a more predictable production cycle with reduced annual cash outflow. As a result, many farmers in Boloso Sore and Hadero Tunto view eucalyptus as both a financial safety net and a strategic investment one that provides lump-sum income at harvest while reducing exposure to climate-related risks and market fluctuations associated with crop production.

Comparative Financial Performance

Three financial indicators were considered in evaluating the comparative financial performance of agriculture and eucalyptus plantations: Net Present Value (NPV), Benefit–Cost Ratio (B/C), and Internal Rate of Return (IRR). The NPV is a crucial measure indicating the value added by the project. The B/C ratio compares the benefits to the costs of the project. The IRR measures the rate of return at which the NPV of the project becomes zero. Result revealed that both projects have positive NPVs, suggesting economic viability. Agriculture (P1) will generate a net benefit of 388,319.97 ETB over the 15-year period when discounted at 8%; whereas, plantation (P2) will generate a net benefit of 458,577.05 ETB over the same period. From this result, we found that, comparatively, P2 has a higher NPV than P1, indicating that converting to a plantation provides a greater economic benefit in absolute terms. The positive B/C ratio indicates that for every ETB invested in agriculture, the return is 16.36 ETB, demonstrating a highly favorable benefit relative to cost. Similarly, the B/C ratio of plantation suggests that for every ETB invested in the plantation, the return is 16.25 ETB, which is also highly favorable. Both projects have very high B/C ratios, indicating that they are both highly beneficial compared to their costs. The slight difference between the B/C ratios of P1 and P2 suggests that while both projects are highly profitable, P1 has a marginally higher benefit relative to its cost.

The unusually highest IRR (203%) of P1 suggests that agriculture is highly profitable, with returns far exceeding the discount rate of 8%, whereas; IRR (66%) of P2 still significantly exceeds the 8% discount rate, indicating strong profitability although lower than P1.

The cost–benefit analysis further demonstrates that both agricultural production (P1) and plantation forestry (P2) are economically viable land-use options under the assumed 8% discount rate, as evidenced by their positive NPVs, high IRRs, and exceptionally favorable B/C ratios. Although agriculture exhibits a remarkably high IRR (203%) and a marginally superior B/C ratio (16.36), indicating very strong short-term returns relative to investment, the plantation alternative generates a higher absolute NPV (458,577.05 ETB) over the 15-year period, reflecting greater long-term value addition (Table 5). This divergence suggests that while agriculture may provide faster capital recovery and higher proportional returns, plantation forestry offers stronger aggregate economic gains and sustained financial benefits over time. Furthermore, the results support the economic justification for land-use transition to plantation forestry, particularly when long-term income stability and cumulative profitability are prioritized alongside immediate returns.

Table 5. Discounted Cash Flow and Profitability Comparison of Agriculture (P1) to Plantation (P2)

YEAR	CASH FLOW	CASH FLOW	R=8%	T=15	NPV OF P1	NPV OF P2	IRR OF P1	IRR OF P2	B/C OF P1	B/C OF P2
0	-23729.91	-28212	0.08		388,319.9	458,577.0	203%	66%	(16.36)	(16.25)
1	48139.6	0								
2	48139.6	0								
3	48139.6	0								
4	48139.6	0								
5	48139.6	332422.4								
6	48139.6	0								
7	48139.6	0								
8	48139.6	0								
9	48139.6	0								
10	48139.6	332422.4								
11	48139.6	0								
12	48139.6	0								
13	48139.6	0								
14	48139.6	0								
15	48139.6	338064.8								

Sensitivity and Investment Resilience

The financial advantage of eucalyptus persists even when discount rates increase, demonstrating higher resilience than crops under changing economic conditions. The income structure of eucalyptus, large but less frequent returns allows the investment to remain profitable even when future benefits are discounted heavily. By contrast, crop-based systems are more vulnerable to interest rate fluctuations because of their smaller, short-cycle revenues.

Table 6. Sensitivity of NPV to Discount Rate Variations

DISCOUNT RATE	NPV – P1 (AGRICULTURE)	NPV – P2 (PLANTATION)	HIGHER NPV
8%	388,319.97 ETB	458,577.05 ETB	P2
10%	342,335 ETB	387,175 ETB	P2
12%	304,161 ETB	329,358 ETB	P2
14%	272,061 ETB	282,557 ETB	P2 (very close)

The sensitivity analysis indicates that both project options experience declining NPVs as the discount rate increases from 8% to 14%, consistent with time-value-of-money principles. However, plantation forestry (P2) consistently maintains a higher NPV across all tested discount levels, although the margin steadily narrows. The NPVs approach near equality at approximately 14.5%–15%, which represents the approximate switching point where agriculture may begin to surpass plantation under very high capital costs.

When broader sensitivity dimensions are considered, namely price, cost and yield variations the plantation system demonstrates relatively stronger robustness. Its profitability is primarily driven by large periodic revenues, making it less sensitive to moderate price and yield fluctuations compared to annual crop systems, which depend on continuous seasonal performance. Crop-based agriculture is generally more vulnerable to the rise in input cost and short-term yield variability, while plantation forestry is more sensitive to extreme discount rate increase due to its back-loaded income structure. Overall, under realistic variations in market prices, production costs, yields, and discount rates (within the 8–14% range), eucalyptus plantation remains economically superior.

Household Decision-Making: Comparing Agricultural Land and Plantation Use

Short-Term Benefits of Land Use

In both Boloso Sore and Hadero Tunto, farmers overwhelmingly identify annual crop farming as the primary source of short-term household benefits. Over 78% of respondents in each district reported that agricultural crops provide the fastest and most frequent cash flow, essential for meeting immediate household needs such as food, school expenses, and inputs for the next planting season. In contrast, eucalyptus plantations, while financially superior over the long term, were recognized by a smaller share of farmers for short-term gains. This is due to the longer rotation period and delayed revenue cycle associated with tree production. Overall, the responses illustrate a clear distinction in farmer decision-making: crops are maintained for immediate livelihood needs, while eucalyptus is increasingly adopted as a strategic long-term investment.

Willingness to Continue Plantations

The data show contrasting levels of willingness to continue plantation activities between the two districts when forest product prices decline. In Bolosso Sore, a majority of respondents (58.3%) indicated that they would continue growing plantations despite a price drop, suggesting a relatively stronger long-term commitment to plantation forestry (Table 7). This may reflect greater experience with plantation management, better access to alternative markets, or confidence in future price recovery.

Table 7. Communities willingness to plant eucalyptus

District	Yes (Count)	Yes (%)	No (Count)	No (%)
Bolosso Sore	70	58.3%	50	41.7%
Hadero Tunto	42	35%	78	65%

In contrast, Hadero Tunto shows a much lower willingness, with only 35% of respondents expressing readiness to continue plantations under reduced prices, while 65% would discontinue. This indicates higher sensitivity to market fluctuations, possibly due to stronger dependence on immediate income, lower financial resilience, or limited diversification beyond plantation products. Overall, the comparison highlights that economic behavior toward plantations is not uniform even within similar agro-ecological zones. While Bolosso Sore farmers show relatively higher tolerance to market risk, farmers in Hadero Tunto appear more vulnerable to price changes, which may influence future land-use decisions and plantation sustainability.

Discussion

The profitability advantage of eucalyptus plantations observed in this study is consistent with findings from other plantation-dominated landscapes in Africa, Asia, and Latin America. Studies from India and Brazil report similarly high internal rates of return for short-rotation eucalyptus due to strong market demand and low post-establishment management costs (Smith et al., 2024; Carte et al., 2021). Compared with annual cropping systems, plantation forestry offers superior capital efficiency, particularly where labor scarcity and climate variability constrain agricultural productivity. The financial comparison between eucalyptus plantations and annual crop farming in Boloso Sore and Hadero Tunto demonstrates a clear economic advantage in favor of eucalyptus-based land use. This finding is consistent with a growing body of evidence from Southern Ethiopia, where eucalyptus plantations continue to outperform crop-based systems in terms of long-term profitability and investment resilience (Mekonnen et al., 2007; Gebrehiwot et al., 2022). The consistently strong demand for poles, charcoal, and fuelwood both locally and in regional markets has played a central role in sustaining high returns from eucalyptus plantations (Belay et al., 2024). The results from both districts confirm this market-driven advantage, as eucalyptus generated substantially higher Net Present Value (NPV), Benefit–Cost Ratio (BCR), and Internal Rate of Return (IRR) compared to traditional crops. However, the economic superiority of eucalyptus should not be interpreted as universally risk-free. Several studies caution against overlooking ecological trade-offs, especially in areas already affected by groundwater depletion, soil nutrient decline, and landscape homogenization (Bayle, 2019; Mengistu et al., 2020). The high variability observed in crop profitability in both study districts aligns with the findings of Tadesse et al. (2022), who showed that smallholder crop income remains highly vulnerable to rainfall irregularity, pest infestation, and market price volatility. This vulnerability explains the accelerated shift toward eucalyptus as a financial buffer against agricultural uncertainty. As farmers repeatedly experience climate- and market-related shocks, tree plantations offer a form of “natural savings account,” generating lump-sum income at harvest intervals with far lower annual labor and input requirements. This supports the assertion by Mekonnen (2024) that integrating trees into farming landscapes increases household economic resilience, particularly in regions where rain-fed agriculture is becoming less reliable. A key insight from the financial analysis is the differing response of land uses to discount rate changes. The results from Boloso Sore and Hadero Tunto show that eucalyptus remains profitable even under high discount rates, while the returns from annual crops fall sharply as discount rates increase. This confirms earlier findings by Jagger and Pender (2003), who documented that eucalyptus, remained profitable for smallholders in Tigray despite high informal interest rates, due to its ability to generate high-value outputs over multiple harvest cycles. The same investment behavior is visible in the present study areas, where smallholders view eucalyptus not merely as a land use option but as a long-term wealth accumulation strategy. The differences in willingness to continue plantation investment under price decline between the two districts also reveal contrasting economic behavior. Farmers in Boloso Sore showed greater tolerance to market fluctuation, suggesting a more established plantation culture and confidence in future wood prices, whereas farmers in Hadero Tunto more dependent on short-term crop income were less willing to continue when prices fall. Differences in household responses to price decline between Boloso Sore and Hadero Tunto highlight the role of market access, prior experience, and livelihood diversification in shaping land-use decisions. This highlights the uneven capacity of households to absorb risk and points to the need for differentiated extension support, particularly in regions where plantation adoption remains economically fragile.

The evidence supports the economic rationale for expanding eucalyptus-based land use in southern Ethiopia, but this must be accompanied by policy safeguards. Without regulation, the rapid conversion of cropland to plantations could accelerate food system disruptions, deepen land-use conflicts, and intensify environmental degradation. Therefore, land-use planning must balance economic return with social and ecological sustainability, ensuring that eucalyptus expansion complements rather than replaces food production. From a policy perspective, the results suggest that while eucalyptus plantations offer strong economic incentives, unregulated expansion may intensify competition between food production and commercial forestry. Economic signals alone may therefore drive excessive land conversion unless supported by land-use planning frameworks that explicitly safeguard food security and ecological functions.

Conclusion

This study provides empirical evidence that full conversion from annual crop production to eucalyptus plantation forestry yields significantly higher long-term financial returns for smallholder households under current market and production conditions in southern Ethiopia. By applying standardized investment indicators across competing land-use systems, the study demonstrates that eucalyptus plantations outperform crop farming in terms of profitability, capital efficiency, and resilience to discount rate changes. The main contribution of this study lies in its direct, plot-level comparison of complete land-use conversion, rather than partial or integrated systems, using a consistent cost–benefit framework. The findings clarify why smallholders increasingly allocate land to plantations despite continued reliance on crops for short-term subsistence. At the same time, the results highlight the need for balanced land-use strategies that reconcile economic incentives with food security and environmental sustainability. Future research should integrate ecological indicators, food system impacts, and long-term landscape dynamics to support more comprehensive land-use policy decisions in plantation-expanding regions.

Recommendations

Policymakers should promote balanced land-use planning that enables households to sustain food crop production while allocating part of their land to profitable plantation forestry. Specifically, district land-use plans should introduce indicative zoning guidelines that prevent complete conversion of food-crop land into eucalyptus plantations, particularly in high-density areas. The expansion of eucalyptus plantations must be regulated through clear ecological safeguards. Local administrations should enforce buffer zones along rivers and wetlands (e.g., minimum setback distances), promote mixed-species plantation models, and require soil fertility management practices in areas experiencing continuous eucalyptus rotations. Since the results show that farmers in Hadero Tunto are more sensitive to wood price decline, mechanisms to reduce market uncertainty are needed. Establishing district-level wood marketing cooperatives and introducing transparent price information systems would help reduce information asymmetry and improve farmers' bargaining power. Given that eucalyptus remains profitable under high discount rates, but requires initial establishment capital, strengthening extension and financial services is essential. Targeted credit schemes with repayment schedules aligned to eucalyptus rotation periods (rather than annual repayment cycles) should be introduced through rural financial institutions. In addition, extension services should provide technical guidance on optimal spacing, rotation management, and integrated tree–crop systems, particularly in districts with less established plantation experience. Finally, as the study highlights potential long-term ecological risks, district-level environmental monitoring programs should be institutionalized, with periodic assessment of groundwater levels, soil nutrient status, and biodiversity indicators in plantation-dominated kebeles. This will ensure that the economic benefits of eucalyptus expansion are evaluated alongside measurable environmental thresholds.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

DB: Conceptualization, Data collection, Data curation, Investigation, Methodology, Writing draft, review & editing, writing final paper. GF: Conceptualization, Data collection, Data curation, Investigation, Methodology, Supervision, review & editing. GS: Data curation, Investigation, Methodology, review & editing. TA: Conceptualization, Data collection, Data curation, Investigation, Methodology, review & editing.

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Annex I

Table 8. Summary of Returns from Eucalyptus Plantations (ETB/ha)

Study Area		Income from Wood Sale/ha	Stumpage Price/ha	Income from Thinning/ha	Total Return/ha
Bolososore	N	96	96	96	96
	Minimum	0.00	8,000.00	0.00	12,000.00
	Maximum	20,000.00	866,666.67	300,000.00	875,666.67
	Mean	2,910.05	152,055.56	13,446.88	154,965.61
	Std. Dev	3,970.04	169,360.89	35,938.97	170,232.46
Hadero Tunto	N	103	103	103	103
	Minimum	0.00	16,666.67	0.00	27,466.67
	Maximum	56,400.00	2,400,000.00	150,000.00	2,400,800.00
	Mean	3,226.80	234,392.28	14,355.79	237,619.08
	Std. Dev	6,611.05	351,291.95	22,664.45	351,730.11

NB: The sample size N is considered only for those who have the plantation area 0.25 ha and more.

Annex II

Table 9. Summary of Costs for Eucalyptus Production (ETB/ha)

District		Establishment Cost/ha	Management Cost/ha	Harvesting Cost/ha
Bolososore	N	96	96	96
	Minimum	960.00	0.00	0.00
	Maximum	112,000.00	40,000.00	500,000.00
	Mean	16,402.65	4,157.94	9,212.78
	Std. Dev	19,429.52	6,127.48	51,378.16
Hadero Tunto	N	103	103	103
	Minimum	440.00	0.00	0.00
	Maximum	104,000.00	32,000.00	150,000.00
	Mean	15,744.64	4,598.22	10,717.16
	Std. Dev	16,463.29	5,800.40	23,726.93