



Addis Ababa University
College of Development Studies
Center for Environment and Development Studies

**ECONOMIC IMPACT AND ECOLOGICAL IMPLICATIONS
OF *EUCALYPTUS* PLANTATIONS IN THE
NORTHWESTERN HIGHLANDS OF ETHIOPIA**

A PhD Dissertation
Submitted to Center for Environment & Development Studies

PhD Program in Environment and Development

Amare Tesfaw

November 2022
Addis Ababa, Ethiopia

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OF *EUCALYPTUS* PLANTATIONS IN THE
NORTHWESTERN HIGHLANDS OF ETHIOPIA**

**A Dissertation Submitted to the Center for Environment and
Development at Addis Ababa University in Partial Fulfilment of
the Requirements for the Degree of Doctor of Philosophy in
Environment and Development**

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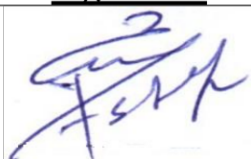


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**November 2022
Addis Ababa, Ethiopia**

APPROVAL SHEET

This is to certify that the dissertation prepared and submitted by Amare Tesfaw entitled “*Economic Impact and Ecological Implications of Eucalyptus Plantations in the Northwestern Highlands of Ethiopia*” has been submitted for the fulfilment of the requirements of the Degree of Doctor of Philosophy (Environment and Development Studies) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

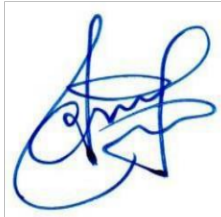
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The current dissertation has been submitted to Addis Ababa University, College of Development studies, Center for Environment and Development for the requirements for Doctor of Philosophy. It is now deposited at the University's library to be archived as the university's resource. I declare that this original work is not submitted to any other institution anywhere for the award of any academic requirement.

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DECLARATION

I, the undersigned, declare that this dissertation is my original work and has never been submitted at any university for any degree or other purpose. All references used have been fully acknowledged and cited in the text.

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Date: **05/12/2022**.

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DEDICATION

To my beloved wife **Rahel Zegeye** and my lovely boys.

&

To my father **Tesfaw Hunegnaw** and my mother **Yalganesh Alemu**
(Their special nursing and classic advice remain immortal)

List of Papers

This PhD dissertation is organized based on four independent papers emanated from four distinct objectives. These include:

1. *The Spatial Distribution and Expansion of Eucalyptus globulus in its Hotspots: Implications on Agricultural Landscapes. Elsevier-Heliyon* 9(3) <https://doi.org/10.1016/j.heliyon.2023.e14393>
2. *Eucalyptus Succession on Croplands in the Highlands of Northwestern Ethiopia: Economic Impact Analysis using Farm Household Model. Resources*, 11(8),71; <https://doi.org/10.3390/resources11080071>
3. *Value Chain Analysis of Eucalyptus Wood Products in the Blue Nile Highlands of Northwestern Ethiopia. Sustainability*, 13(22), 12819; <https://doi.org/10.3390/su132212819>
4. *Estimating the Economic Values of Restricted Monoculture Eucalyptus Plantations: A Choice Modeling Approach. International Journal of Environmental Research and Public Health*, 19(15), 9073; <https://doi.org/10.3390/ijerph19159073>

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Economic Impact and Ecological Implications of *Eucalyptus* Plantations in the Northwestern Highlands of Ethiopia

ABSTRACT

Eucalyptus is the most economically important tree grown in the highlands of East Gojjam. This study examines the spatial expansion, economic value and ecological impact of *Eucalyptus globulus* (onwards called *Eucalyptus*) in the major *Eucalyptus* growing highlands of East Gojjam. Data were generated from 388 smallholder *Eucalyptus* growers of three districts using household survey, focus group discussion and key informant interviews. *Eucalyptus* distribution maps were developed using GIS techniques and the economic and ecological impact of *Eucalyptus* were examined employing farm household model, which is provided in the Generalized Algebraic Model of Systems (GAMS) platform and choice experiment (CE) models respectively. The study also assessed the status of the *Eucalyptus* wood value chain in the study locations. The results revealed that *Eucalyptus* is succeeding croplands alarmingly during the periods from 1999 to 2021. Result of the farm household model gave optimal gross margins of 54,131.10ETB, 60,538.44ETB and 58,101.41ETB in three agroecology zones (onwards called farm typologies) respectively. The results revealed that households' gross margin increases with increasing conversion of crop lands to *Eucalyptus* woodlots. Though *Eucalyptus* is the main source of cash earning, contributing about 46% to the total annual income, the *Eucalyptus* wood value chain is characterized by absence of sectoral integration. Results also showed significant ($P < 0.01$) differences in residents' preferences towards the proposed ecological improvement attributes and their Willingness to pay (WTP) for ecological improvement schemes. Accordingly, the marginal willingness to pay of residents was ETB6,569.02/person/year for the respective ecological improvement programs. The study concluded that an increase in *Eucalyptus* plantation pays off given implementation of proper land resource management and the apparent impacts of *Eucalyptus* on biodiversity and cultural landscape are managed with sustainability perspectives. In order to have optimal use of crop-plantation farm portfolios trade-offs, adopting a land use policy is quite rationale for such *Eucalyptus* growing areas.

Keywords: *Eucalyptus globulus*; smallholder growers; sustainable value chain; Farm portfolio; Farm household model; Succession

CHAPTER 1: GENERAL INTRODUCTION

1.1. Background

Eucalyptus globulus is a widely planted and most important tree species for industrial raw materials (Hafeil, *et al.*, 2020). It is grown in many countries as an alternative tree for fulfilling the demand for construction wood and fiber (Yudego, 2010; Baum, 2009). The tree is innate to Tasmania and belongs to the Myrtaceae family with the existence of about 900 species, subspecies and hybrids of *Eucalyptus* globally (Boland *et al.*, 2006).

Eucalyptus species were familiarized to many parts of the world (Teketay, 2000) and has expanded from 0.7 million ha in 1955 to more than 20 million ha in 2009; and is grown in over 100 countries in tropics, sub tropics and some temperate regions and accounting for 0.5 percent of the global forest area (Dniel *et al.*, 2016). The introduction of *Eucalyptus* to European countries started 200 years ago and late distributed to other parts of the world in the late 19th century and the beginning of 20th century when the demand for fuel and energy were intensified in Europe, South America, Asia and Africa (Bennett, 2011).

Even though *Eucalyptus* is now widely distributed globally, it has confirmed to be mainly grows in humid and sub-humid areas (Staturf *et al.*, 2013). For good weather situations, *Eucalyptus* performs best in African countries. This is because it prefers humid and climatic situations for its physiological growth (Cerasol *et al.*, 2016). It grows best in new areas where it is introduced than its native source. The reason is that pest and disease that gradually evolve are not adapted well in the new areas (Proeca *et al.*, 2010).

Eucalyptus globulus was introduced to African countries such as Ethiopia, Rwanda, Uganda, Kenya, and Sudan in the second half of the 19th century for emerging demands for forest products such as construction and fuel (Teketay, 2001; Turnbull, 1999). During this time, the largest share was taken by Ethiopia and Rwanda accounting about 42,300 and 23,000 hectares respectively (Turnbul 1999; FAO, 2009). *Eucalyptus* was particularly introduced to Ethiopia in 1895 for substituting the declining indigenous alternative tree species with comparable economic contributions like that of *Eucalyptus* remained the main prominent reason for the expansion of *Eucalyptus* in Ethiopia (Jaggere and Pendere, 2003). Indigenous species in Ethiopia have sluggish growth, weak capacity of regeneration and little productivity when compared with *Eucalyptus* (Abebe and Tadese, 2006). For this, the expansion of *Eucalyptus* has been incentivized and taken as part of a national growth strategy by different countries (Carte *et al.*, 2021).

Because of its good attributes like fast growing tendency, quick regeneration capacity, huge potential of yield in quick time, and the provision of wood and non-wood products, farmers are showing increasing tendency of plantation (Mekonen *et al.*, 2007; Biru *et al.*, 2013; Zalsny *et al.*, 2011). In addition, it has positive characteristics like lesser labor demand and high water use efficiency (Albugh, *et al.*, 2013; Toldo *et al.*, 2019; Mai *et al.*, 2017) that help it to be the best bioenergy tree (Gonzalz *et al.*, 2011).

Eucalyptus globulus in Ethiopia is usually being planted as private forest. The Ethiopian Forest Development, Conservation and Utilization No. 1065/2018 allows private forest owners to have afforested land and to transfer possession rights. The proclamation has impersonated obligations to the private forest owners to be under the laws of environmental safety, watershed and biodiversity conservation. On the other hand, the revised Amhara National Regional State Rural Land Administration and Use Proclamation No. 133/2006 advocates creating a favorable state to farmers to get and use land freely. These proclamations have practically contributed for the rapid conversion of arable lands to *Eucalyptus* plantations.

The inceasing plantation was promotted by govenmental and non-govenmental institutes for its rewarding economic potential in short periods (Doghty *et al.*, 2000). It was noted that the tree can provide high yield throughout its life with harvesting of every 3 to 4 years (AFF, 2011).

Although the tree has excellent contributions economically, it is usually complained for its undesirable environmental effects (Muere, 2010 and Burgel). Sutdies such as Forstmaier *et al.*, (2020), Mengstu *et al.* (2020) and Sazikumar (2002) have presented the undesirable attributes of the tree on environment and ecology. Studies by Biru *et al.* (2013), Ragheu *et al.* (2006) and Teketay (2001) have indicated that the attributes of the tree which make it economical tree might have contributed to its latent invasive behavior.

Eucalyptus globulus is the commonly planted and well-suited short rotation tree in Ethiopian highlands including the study areas. By their very nature, newly introduced plants have the capacity to determine the mix, layer, and functioning of the ecology where they are adapted (Money; 2006; Becera; 2006). Several findings including Foresyth *et al.* (2004) and Larcobe *et al.* (2013) indicated that *Eucalyptus* species have strong capacity of invading the ecosystem (Becerra *et al.*, 2018).

The tree can cause ecological challenges such as the impact on soil property, the decrement of water table and the dominance of understory. Forstmaier *et al.* (2020) reported the aggressive behavior of large-scale plantations of *Eucalyptus* as a main environmental problem. Buildup of *Eucalyptus* shades has also been reported to have impacts around roots of food crops and shading problems to the neighboring crops (Mengstu *et al.*, 2020; Saskumar *et al.*, 2002).

Eucalyptus provides economical and social advantages whicha are mainly arising from its ability of provision of good yield from limited area of land (Vaance *et al.*, 2015). Studies by Schiberina and Borvics (2021) evidenced the yielding attributed of poplar short-rotation coppice forest covers in wider areas. A study by Tsegaye (2015) also indicated that *Eucalyptus* is highly preferred tree species in terms of supplying vaneer and sown products with a high hardness index.

Today, expanding economies and increasing population are causing a rise in demand for wood resources. Lamerse (2012) reported that there was more than ten-fold incerment in the need for wood products in the last decades. Such products are proned to continuous needs of the people

which highly calls for proper usage of forest resources for harmonizing the existing supply and demand gap (Schulze *et al.*, 2016).

In Ethiopia, there are various policies and strategies tied with the unplanned expansion of *Eucalyptus*. As the Ethiopian Forest Development, Conservation and Utilization No. 1065/2018 stated there were four categories of forest ownership. These were private, community, association and state-owned forests. This proclamation allows private forest owners to acquire land that has been identified for forest development and to develop that forest, obtain a certificate of title deed for developing forests on the identified land and have the right to transfer possession rights. On the other hand, the Forest Development, Conservation and Utilization Proclamation No. 1065/2018 have posed obligations to the private forest owners to obey the laws issued in respect of environmental safety, watershed and biodiversity conservation. However, despite these obligations, people are replacing arable lands with *Eucalyptus*.

The revised Amhara National Regional State Rural Land Administration and Use Proclamation No. 133/2006 favor creating a favorable situation in the region to fully make practical the rights of farmers to get and use land freely. Because of this, farmers are using their arable lands for crop or *Eucalyptus* on the basis of individual decisions and as their regional land administration regulations doesn't prohibit plantations even on fertile arable lands.

Eucalyptus potential areas of East Gojjam are featured by high level of land resource degradation and compromised agricultural productivity which became a threat smallholders' livelihoods which live on production of food crops. Recently, farmers have begun planting *Eucalyptus* intensively on their cultivable lands for different reasons such as a reduction in productivity of land and plot size, quick elimination of forest lands and the ensuing need for wood products (Kbebew and Ayale, 2010). Therefore, *Eucalyptus globulus* is among the best economic source for growing farmers and has become the best chosen tree. This demands a deeper focus to the main challenges of the *Eucalyptus* growing highland areas of East Gojjam in the arena of the existing land use systems, land cover dynamics and the contribution of *Eucalyptus* to households' livelihoods.

1.2. Problem Justification

For natural and human-driven factors, land use changes has resulted in elimination of natural bio-diversity and change in environmental services (Mosife *et al.*, 2019). The study region (East Gojjam) have a changing ecology where there is rigorous and exploitative farming practices which involves food crop production and *Eucalyptus* plantation (Leweyehu *et al.*, 2020). The decline in productivity of crop lands has aggravated the rapid conversion of crop lands and pushed farmers to shift to tree plantations in recent years including *Eucalyptus* (Jembere *et al.*, 2012).

It was noted that natural forest covers were being replaced with cultivable lands in former times. But, today, *Eucalyptus* is replacing arable lands and because of this, smallholder farmers are focusing towards *Eucalyptus* plantations (Teferi *et al.*, 2013; Jouquet *et al.*, 2007; Biru *et*

al., 2013). Alefred *et al.* (2020) showed that the world market for *Eucalyptus* wood-products and the need for a wide-scale planting for the production of for wood products are the major pushing factors for the expansion of *Eucalyptus*. After all, the rapidly rising population, increasing revalry for resources, and decrement in land productivity have increased the demand for focsing towards the fast growing tree (Alemineh *et al.*, 2009; Hureni *et al.*, 2005). This ulitimately requires research interests that mainly focus on the economic contribution and ecological impact of *Eucalyptus* in the highlands of East Gojjam Zone of the Amhara Natioanl Regional State where this study was undertaken.

In spite of all the above concerns, the majority of researches done so far focus on the environmental effects of *Eucalyptus*. Studies by Mosfe *et al.* (2019), Jouquet *et al.* (2007), Kebebew and Ayele (2010) and Mengistu *et al.* (2020) intensively assessed the environmental effects of the tree and its socioeconomic contributions. Other studies (Bewket and Abebe, 2013; Teketay, 2001) examined the impact of the tree on biodiversity. They reported that *Eucalyptus* plantations exhibit low herbacious species richness than native forests. A similar by Lopeze (2015) reported that there were changes in native ecological processes and decrement in biodiversity and native species and migration of wild animals following the succeeding of the area by *Eucalyptus*.

Given growers' preference to the tree and its economic contribution to income, the trend of succession and spatial expansion of *Eucalyptus globulus*, the crop-plantation farm portfolio choices, nature of the *Eucalyptus* wood value chain and ecological implications of the tree need to be examined. The current study is therefore envisioned to bridge the aforementioned gaps with indepth investigation of the land cover changes and trade-offs of the *Eucalyptus-crop* farm portfolios together with the socioeconomic and ecological implications of *Eucalyptus* expansion. The study presents policy suggestions which can help address the underlying challenges in the study area.

1.3. Objectives

The overall objective of the study was to analyze the spatial expansion, economic impact and ecological implications of smallholder *Eucalyptus* plannations/wood lots and its trend of expansion in East Gojjam Zone of the Amhara National Regional State. The specific objectives include:

1. To map the spatial distribution and expansion of *Eucalyptus* in the highlands of East Gojjam
2. To analyze the economic impacts of *Eucalyptus* plantations in relation to cultivation of food crops
3. To analyze value chains of *Eucalyptus* wood products together with the actors involved and market margins taken by value chain actors
4. To analysis willingness to pay of *Eucalyptus* growers to offset its impacts

1.4. Research Questions

The central research questions answered by this study are the following:

1. Taking 1999 as a reference period, what seem the spatial distribution and expansion trend of *Eucalyptus* plantations up to 2021?
 - ✓ Which land classes are being intensively succeeded with *Eucalyptus*?
 - ✓ What implications does such succession have on the agricultural landscape?
2. What is the economic impact of *Eucalyptus* plantation for smallholder growers in relation to choices of farm portfolios?
 - ✓ What is the economic impact of *Eucalyptus* expansion on households' gross margin?
 - ✓ What seems the cost-benefit comparison of crop-*Eucalyptus* investment comparison?
3. What is the status of value chain development of the *Eucalyptus* wood sector and type of actors involved in the chain?
 - ✓ What interventions are there which favor development of the wood sector value chain in the study area?
 - ✓ What are the major challenges and opportunities for the *Eucalyptus* wood value chain in the study area?
 - ✓ Which actors are governing the wood sector value chain?
4. What is concern and willingness of *Eucalyptus* growers to the restricted plantation of *Eucalyptus* towards contributing to ecological improvement programs?
 - ✓ Are growers willing to accept ecological improvement programs that restrict plantation of *Eucalyptus*?
 - ✓ How much are growers willing to pay for the proposed ecological improvement programs?

1.5. Significance

The current study provides empirical evidence that connecting the people's interest for the expansion of *Eucalyptus*, value chains, ecological implications and the spatial distribution of *Eucalyptus* for suggesting scientific policy directions for future planning. The study provides evidences for future land use plans and land use policy options thereby contributing for the sustainable improvement of local as well as national economies. The study can be taken as a bench mark for the proper understanding of the underlying linkages between economic and ecological arguments with regard to the expansion of *Eucalyptus* and research interests in the study area.

The findings presented in this study provide imperative policy directions that are aimed at enlightening the land use system and improving livelihoods of the study area. The study mainly suggested important government sectors including the Ethiopian Environment, Forest and Climate Change, the Ministry of Agriculture and the regional land administration bureau for policy rectification in the sense of sustainable land management and public interests.

1.6. Scope

This study focused on the *Eucalyptus* growing areas East Gojjam Zone of the Amhara National Regional State. In terms of time coverage, a cross-sectional data was used which was taken in January 2020. However, satellite data required for mapping the spatial distribution of *Eucalyptus* covered from 1999 to 2021. The study is limited to analyzing the economic contribution, environmental values and spatial distribution of *Eucalyptus* in the study area. The study is set in the perspective of socioeconomic and ecological viewpoints seeing the trends of *Eucalyptus* expansion, its economic/market contributions to smallholder growers, ecological implications and driving factor of *Eucalyptus* expansion in the study area employing different approaches for the respective objectives. Thus, the study aimed at presenting the socioeconomic and ecological impacts of *Eucalyptus* together with mapping monoculture plantation of *Eucalyptus*. The study employed different models for addressing the respective objectives.

1.7. Limitation of the Study

Though this study profoundly examines the spatial expansion, economic impact and ecological implications of *Eucalyptus*, it is however not without limitations. Due to spectral similarity of color bands of Landsat images of 1999 to 2010, we faced inseparability of land classes. The images acquired were also a 30x30m resolution while recent images of 5mx5m resolutions are available which can give more accurate classifications. The hypothetical bias which confronted our respondents for which there were no real transactions and due to this the probabilities of over estimations that may happen are acknowledged as study limitations.

1.8. Theoretical and Conceptual Framework

This study was framed in view of the theoretical foundation of the Driving Forces-Pressures-State-Impacts-Responses (DPSIR) framework. This theoretical framework was adopted as a good tool for linking the interactions of socioeconomic, environmental and underlying policies together in the arena of sustainable development. The framework has also been widely used as a communication tool among policy makers, scientists and the public for its ability to simplify in five steps the complex topic of social-ecological system interactions. .

In view of the underlying theoretical framework, the drivers in this study can be viewed from social and economic viewpoints. The social aspects are choices of crop-plantation farm portfolio choices while the environmental drivers include percapita land holding, land productivity, land ownership, cost of cultivation of and diversity of income sources. The economic sectors are considered as the main driving factors while social factors that influence the structure, characteristics and functioning of the economic sectors are given a lesser attention. However, social factors also have a strong influence on human wellbeing and in DPSIR framework; the driving factors have been divided into two categories as economic and social forces (Maxim, *et al.*, 2009). In the current study, decreased percapita landholding, land productivity, land ownership issues and land tenure system are considered as economic

drivers. On the other hand, making of farm portfolio choices (crop versus *Eucalyptus*) are social driving factors.

Pressures are alterations in the ecological landscape as a result of monoculture *Eucalyptus* plantations, which is solely a human-driven effect. As Maxim *et al.* (2009), pressures was defined as human activities that are derived from the functioning of social and economic driving forces that induce changes in the environment or human behaviors that can ultimately influence human wellbeing. Land use changes resulting from alterations of the natural landscape due to the associated population growth are typically environmental pressures. Such landscape changes are common in the study area as happening as a result of development of new *Eucalyptus* plantation stands on new habitats, usually crop and grazing lands. Accordingly, the environment, land use systems, ecosystem services and land fertility are experiencing the pressure in the study area.

The states are the existing conditions such as the natural and built environment and humans (Yee *et al.*, 2012; Gabrielsen and Bosch, 2003). The state can be of environmental that constitute the biotic and abiotic components of the physical, chemical and biological components of the natural environment. They can be viewed as economic or environmental conditions. In the study area, the existing land type, topography, weather/climatic condition, land size dynamics, land use classes and plantation/tree areas are viewed as economic states. On the other hand, the existing wood markets, income, profits, business cycle, land size and income options are economic states.

The impacts are changes in the quality and functioning of the ecosystem which have a direct influence on human welfare like production of ecosystem goods and services and ultimately on human well-being (Gabrielsen and Bosch, 2003). In this regard, growers in the study area are highly influenced by the changing soil condition (acidity problem) and productivity of the area. The impacts act on the ecosystem (ecology and ecosystem services, water sources, air and climate) and on social wellbeing (economy employment, market opportunity and prosperity).

Responses are action components that can be taken at any level of the causal network for preventing, compensating, ameliorating or adapting changes in the state of the environment and for modifying human behavior or compensating social or economic impacts of human condition towards social well-being (Yee *et al.*, 2012). The right choice of farm portfolios (crop versus *Eucalyptus*), proper land management and usage and designing of land use policy are the inherent responses.

As the current study examines the integration of livelihood activities (cultivation of food crops, livestock rearing and plantation of *Eucalyptus*) and the governing policies, the DPSIR framework is considered as a valuable tool for understanding the inter-linkage of activities and policies, organizing and communicating complex socioeconomic and environmental issues.

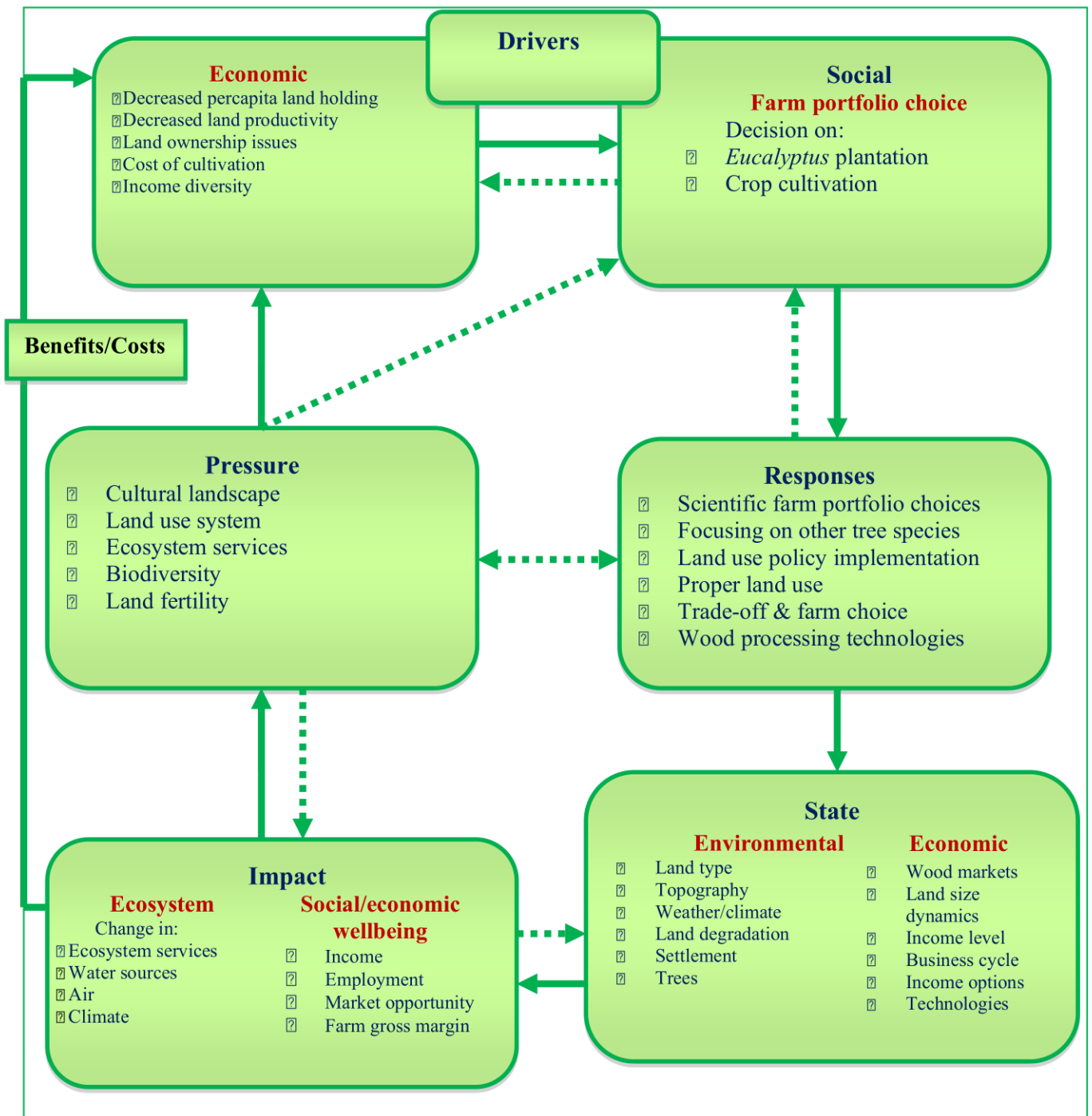


Figure 1. The DPSIR framework

Adapted from Jabareen, 2008

In the current study, the framework can be used to analyze growers’ portfolio choice between crop production and plantation and the impact of activities on ecology and human wellbeing. The expansion of *Eucalyptus* in the study area can be seen in two perspectives. On one hand, given proper land management options are used and plantations are not at the expenses of other land classes, *Eucalyptus* has immense economic contribution to smallholder growers. The current state of plantation of *Eucalyptus* in the study area is highly threatening the ecosystem and the natural landscape of the area. In order to optimize this with a win-win scenario, the use of DPSIR framework can logically integrate all the above stated factors. The

framework also can be used to integrate social, cultural, and economic aspects of environmental and human health into a single framework and usually, the framework has most commonly been used in the context of environmental management to link ecological and socioeconomic factors (Murphy, 2012; Jabareen, 2008).

The succession of *Eucalyptus* over crop lands in the study area is apparently posing a burden on the ecological wellbeing and biodiversity of the area. The framework can be used to adequately capture inter-relationship between variables and tries to optimize the impacts of *Eucalyptus* expansion posed on household's wellbeing, ecology and biodiversity. Thus the framework has been found to be a very good tool for planning the rational farm options, land use systems in view of healthy ecosystem and biodiversity (Maxim *et al.*, 2009).

CHAPTER 2: THE SPATIAL DISTRIBUTION AND EXPANSION OF *EUCALYPTUS* IN THE *EUCALYPTUS* GROWING HIGHLANDS OF EAST GOJJAM: IMPLICATIONS ON AGRICULTURAL LANDSCAPE

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Abstract

Fast coppicing plantations like Eucalyptus are becoming an ever increasingly important land use system globally, including the Eucalyptus hotspot highlands of Northwestern Ethiopia. However, comprehensive information regarding species composition is essential for proper planning and policy decisions. The current study mapped the spatial distribution of Eucalyptus globulus (hereafter referred to as Eucalyptus) and identified the key push factors for its expansion. The study used a mapping procedure that uses Landsat imagery together with ground truth data based on supervised training of a pixel-by-pixel classification algorithm within image regions to distinguish areas of Eucalyptus plantations from other classes. High-resolution multispectral and multi-temporal remote-sensing images were combined with ground truth data to produce robust features of Eucalyptus plantation distribution maps. Heckman's Two-Stage econometric model was also employed for determining the major driving factors of Eucalyptus expansion. The results of the mapping algorithm were Eucalyptus plantation distribution maps of 30x30m resolution that showed temporal changes from 1999 to 2021. The findings revealed that Eucalyptus coverage increased by 55% during the period from 1999 to 2010 and the change expressively increased to 69% in 2021 with respect to the reference period. The study also found that a number of push factors influenced the size of land planted with Eucalyptus. The developed maps will help policymakers make scientific planning which can ensure proper management of the ecosystems and agricultural landscapes of Eucalyptus growing areas.

Keywords: *Eucalyptus*, Landsat imagery, Remote sensing, Species-level mapping, Supervised classification

2.1. Introduction

Ecological changes due to land management dynamics is thought to be responsible for the conversion of different land covers to plantation stands of *Eucalyptus globulus* (hereafter referred to as *Eucalyptus*) in Northwestern Ethiopia. Originated from Australia, several species of the genus *Eucalyptus* were introduced to different parts of the world in the late 18th century (Luzar, 2007). Later, large-scale plantations of *Eucalyptus* were intensified due to the increasing demand for wood processing industries and the construction sector (Doughty *et al.*, 2000). In Ethiopia, *Eucalyptus globulus* /also named as the *Tasmanian blue gum*, was introduced in 1895 by Emperor Menelik II (Abebe and Tadesse, 2006). For its fast-growing behavior and high economic contribution, the expansion of *Eucalyptus* was supported by

government policies and international organizations (Doughty *et al.*, 2000). Given the industrial contributions of *Eucalyptus*, many studies have shown the apparent undesirable effects of the tree on the environment and ecosystems (Becerra *et al.*, 2017; Ferreira *et al.*, 2006).

Today, extensive areas are being converted to *Eucalyptus* woodlots and ultimately resulting in alteration of the cultural landscape and the natural ecosystem. As a quick growing species, *Eucalyptus* can disturb the natural composition of habitats and biodiversity and thus monitoring and managing such species should be given much emphasis (Teferi *et al.*, 2013; Guth and Kucera, 2005). Mapping is very important for designing management plans especial for plant species of invasive behavior that are serious threats to biodiversity. In order to map and monitor forest areas at a wider spatial and temporal scales, remote sensing is a commonly applied technique. These days, (employing machine learning approaches) Landsat images are considered as the fundamental approaches for producing wider scale land cover change maps and environmental management.

Following the advancement of observatory sciences, many regional or global land cover maps have been produced (Gong *et al.*, 2019; Bartholome and Belward, 2005). Mapping vegetation at the species level can help monitor their size and spatial distributions and design specific modeling for the inhabiting tree species (Liang *et al.*, 2019). In order to map species of certain vegetation, remote-sensing data have been commonly used for their wide availability and palatability for analysis (Xie *et al.*, 2008). Tracking such land cover changes at a regional scale is of critical importance to analyze the transformation of the cultural landscape of an area and the impacts of such changes on environmental policies. Land cover maps are usually produced from the classification of remote sensing data (Triedl *et al.*, 2010). There are different types of classification algorithms that include supervised decision trees, unsupervised classification followed by post-classification refinement, and unsupervised and clustered supervised classifications (Loveland *et al.*, 2000). However, maps developed using such classification algorithms have coarse spatial resolution and have limited importance for monitoring specific vegetation maps.

The intriguing question of how specific tree species are spatially distributed has inspired many scholars within plant ecology (Elith and Leathwick, 2009). Mapping vegetation at the species level is however quite difficult because of spectral mimic nature of bands and within-class variation arising from species diversity, environmental conditions, and other factors like farming activities (Zhong *et al.*, 2014; Wardlow *et al.* 2007). Because of this, supervised classification algorithm was employed for mapping *Eucalyptus* plantations in the study area. Various studies employed the method for mapping individual species in different parts of the world. Recent advances in remote sensing enable the mapping of actual species distributions, yet previous studies remain at a local scale (Fassnacht *et al.*, 2016; Karlson *et al.*, 2004). Hesketh and Sanchez-Azofeifa (2012) observed inter-seasonal spectral variation that allowed the accurate discernment of species of trees using automated classification methods. Following the launch of many satellites like Landsat, Sentinel, and Moderate Resolution Imaging

Spectroradiometer having different temporal and spatial resolutions, numerous studies were carried out. Images obtained from such satellites have different resolutions ranging from less than 1m to greater than 100m (Jia *et al.*, 2014). The resolution feature of the images determines the type of map to be developed. Today, images of lower resolutions are required for mapping vegetations while plots lower than 0.0256 km² are difficult to map as they appear as mixed pixels of different species (Fritz *et al.*, 2015).

Satellite imagery was widely used in crop-type mapping with 30 m spatial resolution (Foerster *et al.*, 2012). The launch of a 10m Sentinel-2 satellites with high temporal resolution resulted in further improvements in crop-type mapping and marking of regional or field borders (Dong *et al.*, 2020). A study by Mazarire *et al.* (2020) showed the conveniences of mapping different crop types in different landscapes using Sentinel-2 imagery and machine learning algorithms. Another study by Plakman *et al.* (2020) mapped individual tree species in the temperate forest using Sentinel -2 images.

Supervised image classification methods utilize the spatial information of pixels for reducing the effect of stippled noise in classified maps. However, many automated classification techniques fail to map specific vegetation and are characterized by a high tendency of misclassification. The rapid expansion of *Eucalyptus* in the study area has drawn ecological and social attentions from two perspectives. On one hand, fertile lands that are suitable for crop production are considerably diminishing and on the other hand, the conversion of cultivable lands to *Eucalyptus* plantations is changing the ecology. This calls for proper management and monitoring of the current land use system and predictions for the future. *Eucalyptus* with such an expansion trend can change the ecosystem, especially the species composition of the habitat, there should be a mechanism for monitoring such changing species. Employing remote sensing approaches and field surveys can help monitor such alarmingly expanding species (Andrew *et al.*, 2008). Though there are previous studies carried out in the study area including Bewket and Abebe (2013) and Teferi (2013) their main focus is on land use land cover changes for the whole set of classes. Studies that specifically focus on mapping *Eucalyptus* vegetation at the species level are lacking in the study area.

The main goal of the current study is therefore to map the spatial distribution of *Eucalyptus* in the study area and examine the major driving factors of its expansion. The study explicitly shows the temporal and spatial trends at the expense of other land classes which can help design future management policy options. Temporally, *Eucalyptus* expansion maps covered from 1999 to 2021 and showed how remotely sensed high-resolution, multi-temporal information of plantation covers can help policymakers and environmentalists and ecologists make proper ecological planning. Unique to this study is that it is the first to address species-level mapping for showing the trend of *Eucalyptus* plantation expansion in the study regions.

2.2. Materials and Methods

The structure of the current study constitutes of selection of study regions, choice of data sets, identification of appropriate algorithm for mapping monoculture *Eucalyptus* plantation.

2.2.1. Study site

The current study was undertaken in the *Eucalyptus* hotspot areas of Northwestern Ethiopia with a geographic coverage of 10°21'23.59'' to 10°37'28.05''N and 37°53'09.02'' to 37°40'25.95''E. This region covers the major *Eucalyptus* growing districts namely, Senan, Gozamin and Machakel covering about 241,129 ha. This location featured by varying topography and altitude (2,500 masl- 3900 masl). Rainfall in the area is unimodal with average annual of 1,300 mm usually occurring in the months of May to September with a yearly average temperature of 18 °C.

In terms of agro-ecological setup, the area is characterized by distinct landscape features with slope ranging from nearly plain to very steep (greater than 45%) slopes. The majority of land is used for the cultivation of food crops while monoculture *Eucalyptus* plantations take the next highest share. Commonly grown food crops in the area include maize, *teff* (*Eragrostis tef*), wheat, potato, barley and beans. *Eucalyptus globulus* is the vastly planted monoculture plantation in the study area (Simane, 2013). Map of the study area is located in Figure 2.

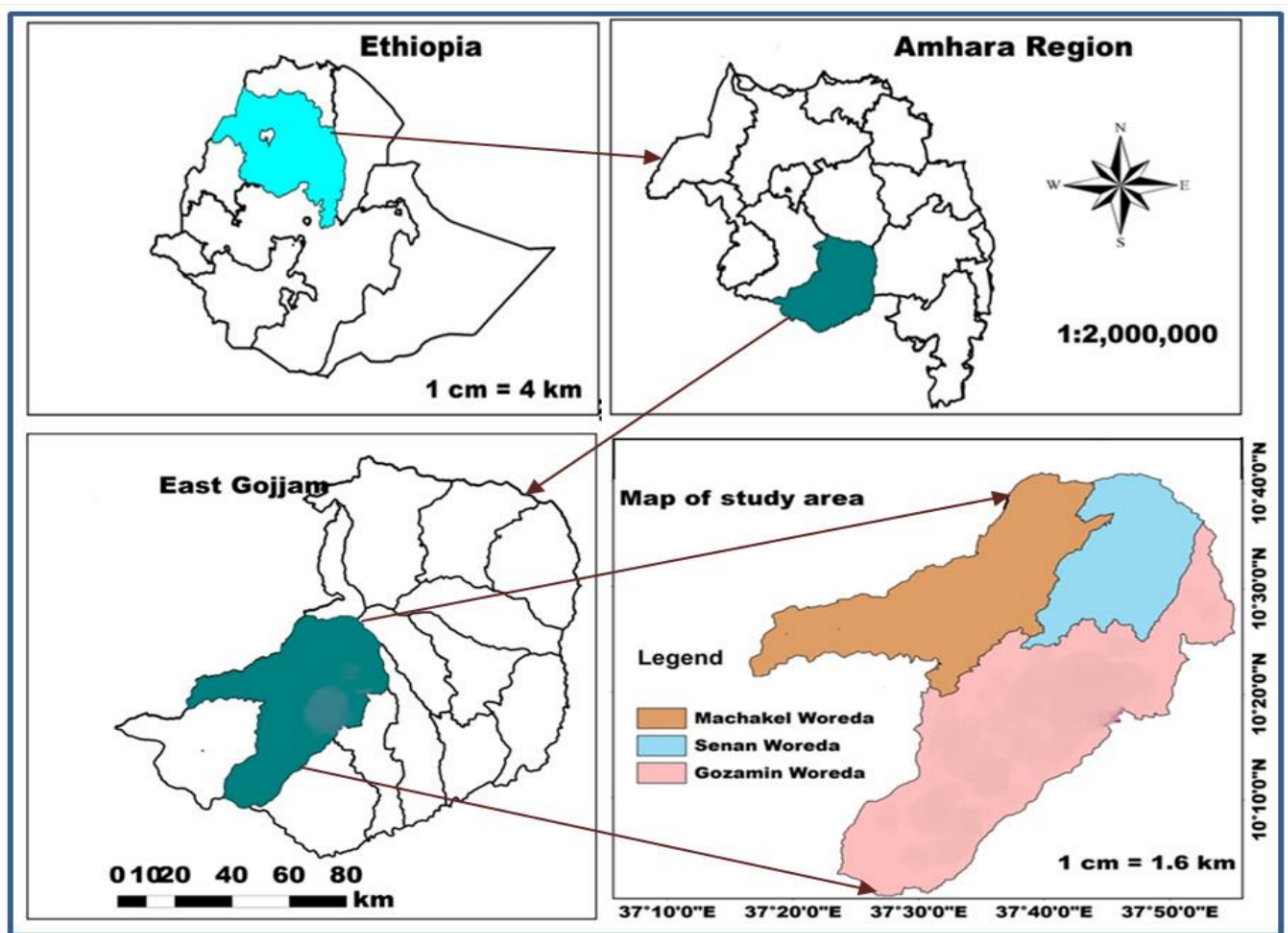


Figure 2. Map of the study area

2.2.2. Satellite data

2.2.2.1. Data acquisition and preparation

Multi-temporal high-resolution data from Landsat4-5 (C2L2) and Landsat8 C2L2 satellite images of the years 1999, 2009 and 2021 were downloaded from USGS official site. Images were then processed and made ready for interactive supervised classification method. Using ground truth data, *Eucalyptus* maps developed were validated across the study regions. The base year was considered as land re-allocation which initiated significant land cover changes was done in 1997 and dramatic expansion of *Eucalyptus* plantations were seen referencing this period. After about 11 years, there have been social conflicts of interest associated with afforested lands including shading and allelopathic problems to the neighboring plots. In 2021, additional areas been succeeded with *Eucalyptus* plantation. In order to have a clear sky season, cloud free images (0 ground cloud cover) were acquired. Surface features were identified with interpretation of true and false color composites. With integration of existing topographic maps and administrative data (secondary), land cover changes were classified and mapped with the help of Arc GIS (10.3).

2.2.2.2. Land use classification and change detection

In order to categorize each of the Landsat images digitally, a hybrid classification technique was employed as this technique better enables for identifying the spectral variability of individual cover types (Mas, 1999). Adopting hybrid classification method is preferred over unsupervised or supervised classification and it has been suggested by various researchers (Twisa and Buchroithner, 2019; Xiao and Wendg, 2007; Garica and Alvarez, 1994).

Assessing land use patterns for scientific utilization of the given area and existing natural resources has become predominantly important. Recently, alarmingly increasing population has led to severe resource completion and decline in use value of natural resources. Analysis of land use land cover changes with wider spatial and temporal dimensions can lead to optimized utilization of the existing natural resources.

Land use mapping helps examine the best possible optimal utilization of resources and scientific management of a given area with its natural resources (Lillesand *et al.*, 2008). The application of recent methods of GIS and remote sensing is vital for capturing spatiotemporal land cover changes the major focus being tracking change succession of arable lands with *Eucalyptus* plantation as hot spots.

In order examine changes in *Eucalyptus* plantation cover for the last 22 years, expansion rate and succession of arable lands with *Eucalyptus* plantation were estimated through land cover changes using GIS. High resolution successive Landsat images (with resolution of 30 meter) of the years from 1999 to 2021 were taken for the analysis. According to Cohen and Goward (2004), the multispectral character and spatial resolution of Landsat imagery is much preferred for studies focusing on environmental monitoring and agricultural sciences. The land use classes considered in this study are shown in Table 1.

Table 1. Land use classes of the study area

S. No	Land Use Class	Description
1.	<i>Eucalyptus</i>	Monoculture plantation of <i>Eucalyptus</i> stands
2.	Other forests	Forest stands which are both native and indigenous located in various landscapes of the study region
3.	Crop lands	Cultivable lands that are assigned for the production of food crops
4.	Grazing lands	Communal lands which are let for free grazing
5.	Bush lands	Lands featured with short vegetation cover
6.	Built ups	Residential and non-residential buildings
7.	Water bodies	Rivers, open water sources and ponds

2.2.2.3. Image Processing

Satellite images of (Landsat4-5 and Landsat8) respective periods (1999 to 2021) were obtained from the official site of the USG (United States Geographical Survey) agency. Then, images were georeferenced together with the appropriate image interpretation. In recent years, researchers have proposed many vegetation mapping methods. In comparison with various novel classifiers, the conventional interactive supervised classification method has generally been used because of its ease in application, simple operation and good performance. For this study, we employed supervised classification (Lillesand *et al.*, 2008). Supervised classification has been widely used in the literature (Richards and Jia, 2006). After we identified land use classes with visual observation of the Landsat images, identified classes were crosschecked with recent Google Earth images and true ground data.

2.2.2.4. Accuracy assessment

Then, using the required number of points, the accuracy of the classification was assessed for recent Landsat images. About 50% of the points were taken from *Eucalyptus* plantation covered areas and the other 50% from non-forest areas. A classification data to be useful in change detection, accuracy assessment is very essential (Owojori and Xie, 2005). Following the Jensen (1996) standard procedure, the accuracy of the different maps produced from the classifiers was done based on the computation of the error matrix statistics. Then, we calculated the producer's accuracy, user's accuracy and overall accuracy and our accuracy levels were 81.13%, 78.09% and 72.20% respectively. The spatial distribution of *Eucalyptus* was compared to the one obtained by the overlay of the common areas classified as *Eucalyptus*. In order to assess the accuracy of the classified maps, we created a set of random points from the ground truth data and compared them with the classified using a confusion matrix.

2.2.3. Driving Factors of *Eucalyptus* Expansion

In order to identify the drivers influencing households' decision in intensive plantation of *Eucalyptus* and the size of land covered with *Eucalyptus* in the study area, we employed the Heckman Two-Stages econometric model (Gujarati, 2004; Heckman, 1979). The model is preferred as it help know households' decision to involve in plantation of *Eucalyptus* and the size of land planted with *Eucalyptus* (Heckman, 1979). The model has also advantages in

terms of its ability to eliminate selectivity bias. In this study, involvement in intensive plantation of *Eucalyptus* for five years and above was taken as a selection criterion.

With the Heckman Two-stage model, where a Probit model (selection equation) and a regression model (with correction for selectivity bias) was specified. The first stage of the model is the equation that catches the involvement in *Eucalyptus* plantation. The second stage of the model is the fitted Ordinary Least Squares regression which helps identify the drivers that influence the size of land planted with *Eucalyptus*. It is estimated with the Probit estimate of the Invers Mill's ratio (λ).

The first stage of the model (Probit equation), can be specified as:

$$Y_i = \beta_i x_i + \varepsilon_i \quad (1)$$

Where, $\varepsilon_i \sim N(0,1)$

$i = 1, 2, \dots, n$

Y_i = a dummy variable indicating decision on intensive *Eucalyptus* plantation as

$Y_i = 1$ if $Y_i >$; Otherwise, $Y_i = 0$.

β_i = unknown parameters to be estimated in the Probit equation

χ_i = are explanatory variables that determine the decision in intensive plantation of *Eucalyptus*

ε_i = Random term which is assumed to be bivariate and normally distributed with correlation coefficient, ρ).

Then, with the inclusion of the Inverse Mill's Ratio (λ), the second stage of the model can be expressed as:

$$Y_i = \beta_i x_i + \mu \lambda_i + \varepsilon_i \quad (2)$$

where, $\varepsilon_i \sim N(0, \delta^2)$

$i = 1, 2, \dots, n$

Y_i = size of land planted with *Eucalyptus* (ha) (which is only observed if a household's decision to involve in intensive plantation of *Eucalyptus* is yes.

β_i = Unknown parameters

χ_i = Explanatory variables influencing size of land planted with *Eucalyptus*

μ = Parameter indicating the impact of households' plantation decision on the size of land planted with *Eucalyptus*

λ = Inverse Mills ratio (correction factor for selection bias)

ε_i = Random term (assumed to be bivariate and normally distributed with correlation coefficient, δ^2)

Table 2. Variables and their hypothesized effect on size of land planted with *Eucalyptus*

Variables	Description	Hypothesized effect
Number of oxen	Continuous	+
Management cost of <i>Eucalyptus</i>	Continuous	+
Experience (years)	Continuous	+
Sources of income	Continuous	-
Slope	1=plain; 2=gentle slope; 3=steep slope	+
Fertility of plots (%)	Continuous	-
Neighborhood effect	0= <i>Eucalyptus</i> has effect) on adjoining plots; 1= <i>Eucalyptus</i> has not effect)	+
Tenure security	0 = Plantation doesn't ensure tenure security 1= Plantation ensures tenure security	+
Total size of land (ha)	Continues	+
Income sources	Continues variable (1,2,3, etc.)	+
Number of other trees owned	Continuous	-
Age	Continuous	+
Sex of household head	Dummy (0=female; 1=male)	+

2.3. Results

2.3.1. Spatial Distribution and Expansion of *Eucalyptus*

The total area of land in the study regions is estimated to be about 241,129 ha and the majority of the land is suited for the plantation of *Eucalyptus*. Whilst the dominant farming system in the study area is cultivation of food crops, *Eucalyptus* is succeeding and replacing crop and other land covers at an alarming rate (Figure 3 and 4). Based on our classification, the estimated area of land covered by *Eucalyptus* plantation in 1999 was about 832 ha (3.71% of the area land potentially suitable for the plantation of *Eucalyptus*). The figure quickly grew to 1,837 ha (8.20%) in 2010 (Table 3).

We observed different levels of spectral separability of bands between the study periods. The quality of spectral separability increased in the order 1999, 2010 and 2021 for the different land cover categories. There was a spectral confusion between the categories *Eucalyptus* and other forests covers for the 1999 Landsat 4-5 imagery and thus we faced difficulty in separating the seven classes visibly. From 2010 to 2021, a tremendous area of land has been covered with *Eucalyptus* which roughly figured about 2,692 ha with an increase in area of *Eucalyptus* coverage from the reference period by 69.01%. These changes are visibly observed in Figure 4.

We noticed that the distribution of *Eucalyptus* in 1999 was confined mainly near to settlement areas (especially towns), river banks and near water bodies and the majority of arable lands

were devoid of *Eucalyptus* plantations (Figure 2). Since 1999, however, a significant proportion of arable lands were planted with *Eucalyptus*. Growers confirmed that they began to convert their arable lands to *Eucalyptus* stands following the land redistribution program which was taken place in the Amhara region. People assume that plots with plantation stands will secure land ownership and this has initiated the majority to focus on conversion of their plots to *Eucalyptus* stands. The rising demand for construction and fuel wood and its major contribution as source of cash to smallholder growers pushed growers to extensively plant *Eucalyptus*.

Table 3. Estimated proportion of area with *Eucalyptus* plantation

Year	1999	2010	2021
Total estimated area covered by <i>Eucalyptus</i> (ha)	832	1,837	2,692
Proportion of area covered by <i>Eucalyptus</i> (%)	3.71	8.20	12.01
Change in area of plantation from the reference period (%)	—	54.71	69.10

Prior to 1999, indigenous alternative tree species were not totally eliminated and people had the option to use those indigenous species to fulfill their wood demand for construction and fuel. During this time, *Eucalyptus* has been planted mainly as homestead plantations and at borders of plots. Later, the roles of all indigenous tree species were totally substituted by *Eucalyptus* and growers began plantation stands on cultivable plots. In this regard, the period was taken as a benchmark for the expansion of *Eucalyptus* in the study area. Growers begin converting significant portions of their crop lands for many socioeconomic and policy related factors which will be discussed in Section 2.3.2.

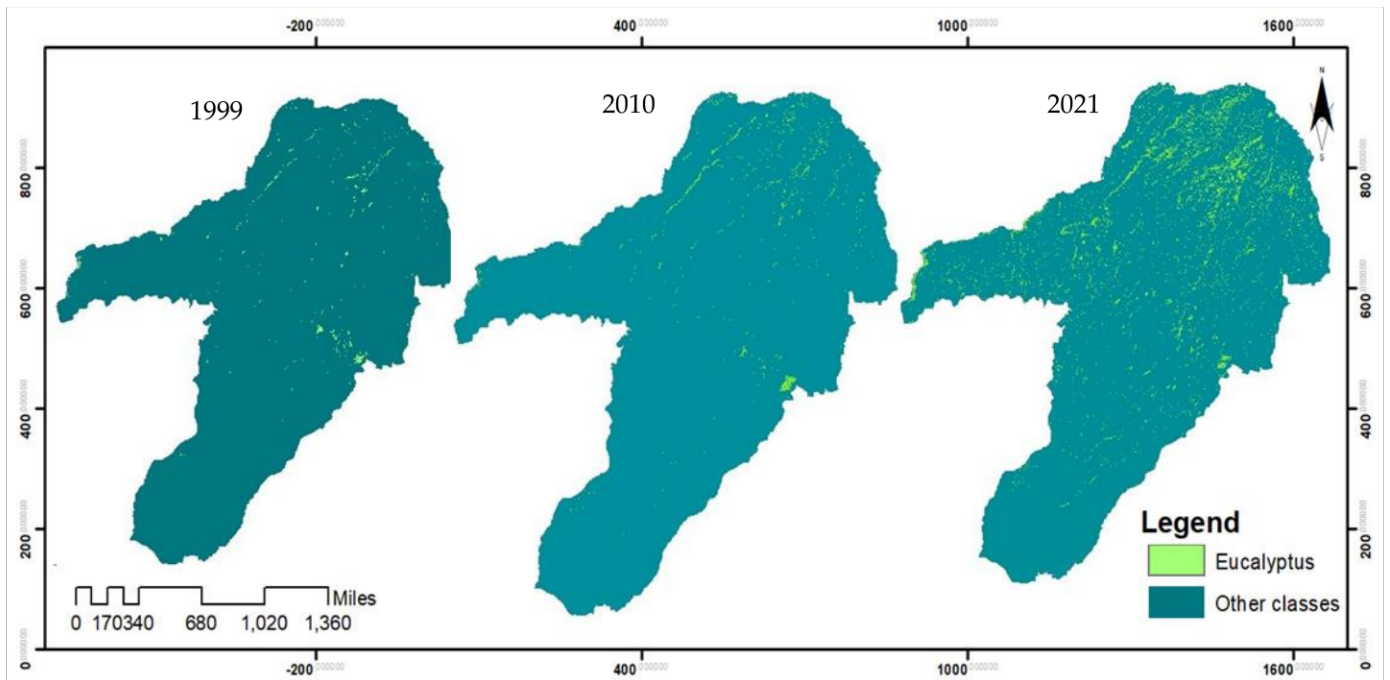


Figure 3. The distribution of *Eucalyptus* from 1999, 2010 and 2021

In 2010, growers observed the returns and became initiated to expand *Eucalyptus* more as a trickle-down effect. During this time, urban areas previously planted with *Eucalyptus* were partly converted to built-up areas but intensive land cover classes were converted to *Eucalyptus* stands. From 2010 to 2021, the changes were so rapid due to the rising interests of people for planting fast growing wood products. We noticed that the expansion of *Eucalyptus* in the higher altitude areas of steep slopes and terrain features is mainly driven by continues degradation and decline in productivity of cultivable lands. Such lands are characterized by high level of acidity and low fertility which however are still suitable for the plantation of *Eucalyptus*.

Figure 4 below shows the different land use classes (*Eucalyptus*, other forests, crop lands, grazing lands, bush lands, built up areas and water bodies). We observed that *Eucalyptus* is extensively succeeding arable lands mainly in the mid and highland altitude areas. The intensity of conversion was much higher for food crop lands followed by grazing and bush lands.

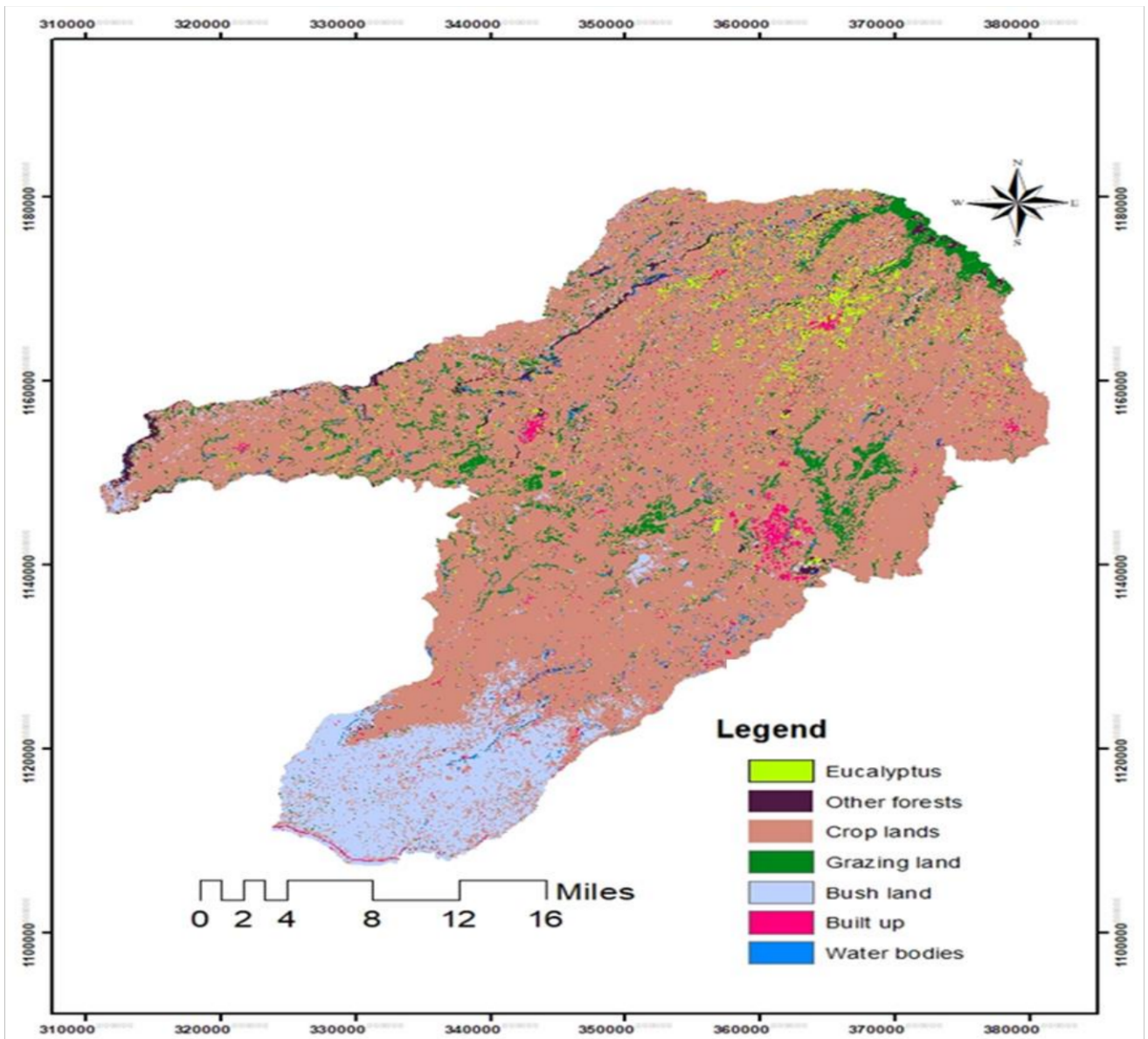


Figure 4. The distribution of *Eucalyptus* and other land cover classes in 2021

2.3.2. The trend of *Eucalyptus* Succession and its drivers

Because of high population density, rugged topography (up to 45% slope) and intensive agricultural practices, the study area is characterized by serious degradation and decline in productivity. Growers confirmed that they prefer replacing their crop lands with *Eucalyptus* for many reasons. In the first instance, they argue that *Eucalyptus* has higher profit and quick returns as compared to returns from crops. *Eucalyptus* requires lesser cultural management than crops.

We observed that cultivable lands are decreasing each year because of the rising interest of people to plantations over crop production. *Eucalyptus* is also being planted on grazing and bush lands pushing borders of communal areas. This has caused a displacement of grazing lands to new areas which consequently led to degradation of lands. This can be viewed as a serious impact on crop and livestock in the study area.



Figure 5. Google earth partial view of the area in Senan disttict (Image trimmed on 16 April 2022)

Table 4 below shows result of the Heckman Two-Stage model that depict the major driving factors of *Eucalyptus* expansion in the study area. We found that grower households in the study area are focussing on plantation of *Eucalyptus* for a number of socioeconomic reasons. In order to identify major driving factors for *Eucalyptus* plantations, we run the Tobit regression model. The model was highly significant ($\text{prob} > \chi^2 = 0.0000$) showing its high capacity of prediction.

Table 4. Result of the Heckman Two-stage model

Involvement in plantation for ≥5 years	Number of obs = 388 Censored obs = 29 Uncensored obs = 359			
	Coefficient	Standard Error	Z	P > Z
Number of oxen	0.0074	0.0043	1.70	0.089
Cost of management	-0.0323	0.0275	-1.18	0.240
Experience	0.0077	0.0023	3.32	0.001
Sources of income	0.1190	0.0312	3.81	0.000
Slope	0.0980	0.0258	3.79	0.000
Fertility of plots	-0.0581	0.0243	-2.39	0.017
Neighborhood effect	0.0248	0.0164	1.51	0.132
Tenure security	0.0886	0.0534	1.66	0.097
Total size of land	0.0721	0.0251	2.87	0.004
Number of other trees owned	0.0743	0.0302	2.46	0.014
Sex	0.0424	0.0308	1.38	0.169
Age of households	0.2104	0.1336	1.58	0.115
Constant	-0.4041	0.2291	-1.76	0.078
Land planted with <i>Eucalyptus</i> (ha)				
Number of oxen	0.0197	0.0404	0.49	0.627
Cost of management	-0.0559	0.2024	-0.28	0.781
Experience	0.0289	0.0225	1.28	0.199
Sources of income	0.0057	0.2788	0.02	0.984
Slope	0.4429	0.2044	2.17	0.030
Fertility of plots	0.0739	0.1807	0.41	0.682
Neighborhood effect	0.5241	0.1801	2.91	0.002
Tenure security	0.7556	0.2702	2.80	0.005
Total size of land	0.2308	0.2115	1.09	0.275
Number of other trees owned	0.0156	0.0226	0.69	0.491
Age of households	2.0192	0.3380	5.97	0.000
Constant	-2.8271	0.9270	-3.05	0.002
Lambda (λ)	0.2828	0.1770	1.60	0.110
rho = 1.0000		Sigma = 0.2828		

Our findings indicate that a number of pushing factors were found to significantly influence both growers' tendency of involvement in *Eucalyptus* plantation and size of land planted with *Eucalyptus*. Accordingly, we identified the major driving factors for the conversion of different land uses to *Eucalyptus* plantations. Number of oxen owned influenced (positively and significantly at $P < 0.1$) households' involvement in *Eucalyptus* plantation. Experience of households, number of income sources, slope and total size of land holding were potential factors that significantly and positively ($P < 0.01$) influenced households' decision to involve in *Eucalyptus* plantation. On the other hand, the amount of land planted with *Eucalyptus* was significantly and positively influenced by slope of plots ($P < 0.05$). This is because sloppy areas are characterized by high degree of marginality and lower fertility. Such plots are preferred for plantations than cultivation of crops. Another most prominent reason factor for

the expansion of *Eucalyptus* in the study area was the trickle-down effect of plantation of *Eucalyptus* (i.e., effect on the neighborhood farms). Neighborhood effect was significant at 1% probability. Newly planted *Eucalyptus* stands will apparently have shading and allelopathic effects on adjoining plots which in turn obliges other growers to convert their arable lands to *Eucalyptus* plantation.

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We also found households engage in intensive plantation of *Eucalyptus* as they believe that plots planted with *Eucalyptus* will be more secured than arable lands. Tenure security significantly ($P < 0.01$) and positively influenced the size of land planted with *Eucalyptus*.

Age of households significantly and positively ($P < 0.01$) determined the size of land planted with *Eucalyptus*. This is because aged households experience shortage of labor in the family and want to focus on plantations which require lesser management cost as compared to cultivation of food crops.

2.4. Discussion

The findings presented in this study show the expansion of *Eucalyptus* at the expense of cultivable lands and other land classes such as grazing lands, other forest lands, bush lands and water bodies. The succession of different land covers with *Eucalyptus* plantation stands poses a risk on the ecology and natural biodiversity and therefore the detection of such alterations of the natural landscape is essential for sustainable management of existing land and other natural resources. During the periods from 1999 to 2021, *Eucalyptus* has been expanding rapidly. The result apparently indicates that *Eucalyptus* is changing the natural ecosystem and biodiversity as an exotic species and its implications can be viewed differently.

2.4.1. Implication on Food Crop Production

Eucalyptus as an invasive short rotation tree species highly impedes the growth of neighboring plants by hindering light, aggressively competing for nutrients and causing allelopathic effects on adjoining plots (Sasikumar *et al.* (2002); Mengistu, *et al.* (2020); Bayle (2019). In the study area, arable lands are getting diminished and being converted to monoculture *Eucalyptus* plantation from year-to-year. Because of the alarmingly increasing market demand of construction and fuel wood and for other socioeconomic reasons, there will be a shift in growers' attention from cultivation of food crops to plantation of *Eucalyptus*. This indicates that food crop production in the study area may diminish and pose a threat on food security. Forstmaier *et al.* (2020) indicated the invasive behavior of large scale plantations of *Eucalyptus* and its negative impact on the ecological wellbeing.

Eucalyptus as an exotic and alien species can pose a burden on the ecosystem and negatively affect biodiversity. Studies by Bewket and Abebe (2013) and Teketay (2001) also showed low herbaceous species richness in *Eucalyptus* plantations than native forests. A similar finding was concluded by Lopez (2015) who witnessed a change in native Californian ecosystem processes and reduction in biological diversity and indigenous plant species and displacement of wild habitats following the invasion by *Eucalyptus globulus*.

Many factors significantly influenced the preferences of farmers to convert their lands to *Eucalyptus* plantations. The cumulative effect of this trend was seen a push on cultivable lands to be succeeded with *Eucalyptus* (a change from 54.71% in 2010 to 69.10% in 2021). This apparently have serious impact on cultivation of food crops.

Information obtained from key informants discussion revealed that the rising wood demand and absence of land use policy have increased growers' tendency to convert their cultivable plots to *Eucalyptus* stands. Worku *et al.* (2017) studied that the rising demand for wood products initiated farmes to focus on tree plantations. Informal land transactions and permission of land rents up to 25 years remained other driving factors for the expansion of *Eucalyptus*. Group discussion held with growers also indicated that households who lack family labor and reside in towns rent out their plots up to 25 years to farmers with better financial capacity. This has contributed for the conversion of tremendous are of land to *Eucalyptus* stands.

2.4.2. Implication on agricultural landscape

The conversion of different land covers to monoculture plantations of *Eucalyptus* can bring a general alteration of the natural landscape and scene of an area. We found that during the period from 1999 to 2021, the proportion of land covered with *Eucalyptus* quadrupled (changed from 3.71% to 12.01%). This trend has ultimately changed the agricultural landscape of the area (mainly conversion of crop lands to plantation of *Eucalyptus*). *Eucalyptus* is genrally thought to cause changes in landscape and scenery of the area and can be viewed from positive and negative perspectives (Flaten, 2011).

Afforestation of other land classes with *Eucalyptus* can result in soil physicochemical property and organic matter dynamics. This change in turn affects the growing potential of the area because of change in. Different scholars including Birru *et al.* (2013), Mekonnen *et al.* (2007), Abebe and Tadesse (2006) and Jagger and Pender (2003) presented that *Eucalyptus* is vastly planted by smallholder growers for its positive attributes such as better yield, coppicing and quick growing ability in a variety of environments. Such intensive conversion of cultivable lands to *Eucalyptus* planation aparently poses a threat on future cultivation of food crops and food security in the area.

2.4.3. Socioeconomic concerns

There are a number of social issues related with the expansion of *Eucalyptus*. We found that experience of growers in *Eucalpytus* production, the number of income sources of households and slope of plots were the major driving factors that positively and significantly influenced involvement of growers in *Eucalyptus* plantatioln for more than five years. Similarly, slope of plots, neighborhood effect, tenure security and age of households affected the size of land planted with *Eucalyptus*.

Neighborhood effect of plantation of *Eucalyptus* was one of the driving factors for the expansion of *Eucalyptus* in the study area. Social tension and conflicts as a result of different effects of *Eucalyptus* plantations on neighboring plots like shading, litter fall, blockage of

scene and allelopathic effects of the tree in the root zones of neighboring plots are among the main social effects of the plant.

Different studies including Sasikumar *et al.* (2002), Mengistu *et al.* (2020) and Forstmaier *et al.* (2020) reported the negative impacts of the tree especially the allelopathic effects around the root zone and its shading effect under the tree canopy. Forstmaier *et al.* (2020) stated that large scale plantations of *Eucalyptus* have negative impact and invasive behavior to the environment. All these effects of the tree can apparently trigger social tensions and conflicts.

As plantations are mainly carried out in rural communities, a significant number of manpower is involved in nursery operations, silvicultural activities, plantations and overall management of the tree stands. This confirms the contributions of plantation in creating employment opportunities to the rural community. Studies of Hamid and Abdalla (2015) and Alemu (2016) indicated the role of the sector to employment in rural areas.

It was found that the minimal cost of management and its better income contribution was one of the driving factors for *Eucalyptus* plantations. *Eucalyptus* also has a significant contribution to income of smallholder farmers *Eucalyptus* contributed significantly to the forestry in terms of economic income. This conclusion is in line with Zerga and Woldetsadik (2016) who reported the income contribution of the tree and its role to be considered as a measure of insurance for smallholder growers.

The contribution of *Eucalyptus* is not only limited to the above list but includes its contribution to infrastructure (poles, posts and construction) and making of farm tools. A study by Feyera *et al.* (2010) reported a similar conclusion. It can be concluded that various factors are driving the expansion of *Eucalyptus* and smallholder growers are found to rely on plantation of *Eucalyptus* to support their livelihoods (due to the rising market opportunity for the wood products) especially in the aspect of food security. However, it demands proper land use management and optimal benefit and in the sense of sustainability.

2.5. Conclusions

The current study stresses on mapping the spatial distribution of *Eucalyptus* using supervised classification algorithm in the main *Eucalyptus* growing highlands of Northwestern Ethiopia over a period of 21 years for assessing the major driving factors and land covered with *Eucalyptus* employing the Heckman Two-stage econometric model. The study suggested appropriate policy measures for proper management of land in especially in areas where the dominant population supports their livelihood with cultivation of food crops.

Given the overall strength of the study in classifying the land classes successfully and proper identification of the spatial distribution of *Eucalyptus* in the study regions, the study is not without limitations. Due to inseparability of classes for the spectral mimicry of bands of different land covers, we faced in exactly identifying the specific *Eucalyptus* species vegetation for the Landsat images taken 1999.

Based on the findings of this study, it is concluded that land cover transformation was driven by a combination of many pushing factors. Our findings showed that many areas are being rapidly converted to *Eucalyptus* stands and call for proper land use and management. Whilst *Eucalyptus* has socioeconomic contributions, plantations are at the expense of arable lands leading to dramatic land conversions.

The study provided valuable insights to policy makers and researchers as it provides useful information for foreseeing and monitoring the socioeconomic and ecological impacts arising from the expansion of *Eucalyptus* at the expense of other land classes. Predicting and monitoring environmental changes as a result of human-induced factors and exactly identifying conditions that allow such ecological transformations over time are vitally important for future land use planning. Based on our findings, we suggest further researches that will emphasize on the socioeconomic and ecological impact of *Eucalyptus* especially in countries with extensive *Eucalyptus* plantations in the perspectives of sustainability.

CHAPTER 3: *EUCALYPTUS* SUCCESSION ON CROP LANDS: ECONOMIC IMAPCT ANALYSIS USING FAMRM HOUSEHOLD MODEL

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Abstract

The northwestern highlands of Ethiopia are characterized by severe land degradation and apparently low agricultural productivity. This situation is continuously threatening the livelihoods of smallholder farmers who mainly sustain their living from the cultivation of annual crops. In recent years, however, smallholder farmers have started converting their croplands to plantations of *Eucalyptus globulus*, a non-native tree species to Africa, for its rewarding economic contributions. In this study, we aggregated data from 388 smallholder *Eucalyptus* growers located in three agroecology zones (onwards called farm typologies). We measured the economic impact of *Eucalyptus* succession on croplands using a farm household model which is provided in the GAMS (General Algebraic Modeling System) platform. The results of the model varied between farm typologies and showed that households' gross margins increased with a corresponding increase in the conversion of croplands. Results also showed that gross margins from plantations of *Eucalyptus* were higher than that of cultivation of food crops. Furthermore, evaluation of farm portfolios indicated a higher benefit-cost ratio (BCR) for the plantation of *Eucalyptus*. We concluded that the conversion of croplands in the study area is an incentive-driven process in a dynamic farming system, which strongly demands bringing policy-emanated livelihood alternatives. With this arena, the expansion of *Eucalyptus* is recommended for lands of terrain features, high marginality and low suitability for the cultivation of food crops and setting aside fertile arable lands. We generalized that an increase in *Eucalyptus* plantation pays off given the implementation of proper land resource management and the apparent impacts of *Eucalyptus* on biodiversity and cultural landscape is managed with sustainability perspectives. However, it demands collaborative policy efforts that can ensure proper usage of land and especially meet socioeconomic, environmental and public interests.

Keywords: *Eucalyptus*; *Farm portfolio*; *Farm household model*; *GAMS*, *Succession*;
Trade-off

3.1. Introduction

Land use changes driven by human activities and natural factors has resulted in the global loss of native biodiversity and the alteration of ecological processes and services across different ecosystems (Mosfe *et al.*, 2019). Dramatic land use changes and intensive utilization of the natural resource base were taking place in Ethiopia, which were driven by rapid population growth, increase in land degradation and decline in productivity that in turn derive the need for investing on plantation of fast growing trees like *Eucalyptus* (Alemneh *et al.*, 2009; Hurni *et al.*, 2005; Teketay, 2001). The expansion of monoculture forest plantations of exotic species like *Eucalyptus* has been incentivised and taken as part of a development strategy (Carte *et al.*, 2021).

Land use change dynamics in the study area indicate that fertile and marginal lands are being converted to *Eucalyptus* plantations and crop lands were succeeding natural forest areas

decades before. Nevertheless, due to the elimination of natural forest stands, declining crop productivity and the rising demand for wood products, crop lands are now in turn succeeded by *Eucalyptus* plantations (Teferi *et al.*, 2013; Jouquet *et al.*, 2007; Birru *et al.*, 2013). The global market for *Eucalyptus* wood products and the interest of wide-scale planting for the production of biofuels are among the main factors for the expansion of *Eucalyptus* as woodlots (Alfred *et al.*, 2020).

Wood is a limited bio-based resource that serves as a source of raw materials for wood industries, power and heat. Economic growth and demographic change are causing increase in the global wood demand which is a limited resource that serves as material provision, energy and fuel (WF, 2014). A study by Lamers (2012) showed that between 2000 and 2010, there was more than tenfold increase in the European Union demand for wood products. Forest products are however limited resources which are exposed to a continuously growing global demand which requires a sustainable approach for balancing the increasing wood demand through plantation of short rotation plantation trees (Schulze *et al.*, 2016).

Eucalyptus is one of the most economically important short rotation plantation grown in various countries as an option tree for the production of biomass energy and fiber (Baum, 2009). *Eucalyptus* was introduced to African countries including Ethiopia in the second half of the 19th century for emerging demands for forest products for construction and fuel from Australia (Teketay, 2001; Turnbull, 1999). The absence of indigenous alternative tree species with comparable economic contributions like that of *Eucalyptus* remained the main prominent reason for the expansion of *Eucalyptus* in Ethiopia. Native forests species have slow growth, limited regeneration capacity and low yield in as compared to *Eucalyptus* (Abebe and Tadesse, 2006). *Eucalyptus* species have quick growing tendency and high yielding potential in short rotations and vastly planted by smallholder growers for its wide range of economic and social benefits (Birru *et al.*, 2013; Forest, 2012; Jagger and Pender, 2003). The positive attributes of short rotation plantation trees like the ability to quickly coppice after harvest, fast growing tendency, minimum care requirement and ability to grow in a wide range of ecological zones and land types are the main pushing factors for their expansion (Mekonnen *et al.*, 2007).

Owing to these positive attributes, recently smallholder farmers have engaged in conversion of crop lands to *Eucalyptus* stands in Ethiopia. Short rotation coppice plantations can provide woody biomass within the first four years of the plantation's life cycle and every three or four years thereafter for up to seven rotations. They also provide environmental and other benefits including offsetting greenhouse gas emissions, improving ground water and soil quality and expanding some forms of wildlife habitat and revitalizing rural economies. *Eucalyptus* has economic and environmental benefits stemming from its capability of supplying fiber on a reduced land base (Vance *et al.*, 2015). Schiberna and Borovics (2021) studied the potential yield and return characteristics of poplar short rotation coppice plantations in a range of sites in Hungary and stated their advantages in supplying bioenergy and other possible bio-products.

Aside from the economic and social benefits, there are scientific debates with regard to the expansion of *Eucalyptus* and its negative ecological impacts. *Eucalyptus* can drain water resources, aggravate soil erosion, suppress under growth, deplete soil nutrients and induce allelopathic effects (FAO, 2012). Studies by Sasikumar *et al.* (2002), Mengistu *et al.* (2020) and Bayle (2019) reported the negative ecological impacts of the tree especially the allelopathic effects around the root zone and its shading effect under the tree canopy. A study by Forstmaier *et al.* (2020) stated that large scale plantations of *Eucalyptus* have negative ecological impact and invasive behavior to the environment. The introduction of *Eucalyptus*, as an alien species to a new area, has serious invasion risks on biodiversity and ecosystem. A study by Lopez (2015) indicated change of native Californian ecosystem processes as a result of invasion by *Eucalyptus* globulus which reduced biological diversity as native plants and wildlife habitat are displaced. A similarly conclusion was reported by Teketay (2001) who reported low herbaceous species richness in *Eucalyptus* plantations than native forests.

Decline in land productivity and percapita landholding, rapid loss of forest stands and the subsequent escalating demand of wood products, farmers were forced to look for farm portfolio choices and focus on plantation of *Eucalyptus* as potential coping strategy in Ethiopia (Kebebew and Ayele, 2010). Thus, *Eucalyptus* is one of the major sources of income for smallholder growers and became the most preferred tree for its intended provision of wood products.

With this in mind, it is important to examine the economic impact of conversion of crop lands to *Eucalyptus* plantations with different trade-off scenarios. There are a number of methods for measuring an economic impact which can be used to measure gains or improvement in the economic wellbeing (Measurign econ.imp., 2021; Adam, 2000; Dervis *et al.*, 1982).

The study estimated the impact of land succeeded with *Eucalyptus* on households' average annual revenue using a farm household model of the GAMS platform (Yan *et al.*, 2021; Islam *et al.*, 2021). GAMS has been exhaustively applied by many scholars worldwide for measuring economic and policy impacts (Agropol, 2021), analyzing technology options and policy incentives (Bidogeza *et al.*, 2015) and for evaluating farm types and scenarios (Boere, 2010). In order to analyze farm portfolio choices, we made BCR taking in to account the returns from food crop production and *Eucalyptus* plantations. Studies including Tafa *et al.* (2020) used similar approach to compare conservation and conventional agriculture in South Africa.

Though there are different studies carried out employing farm household model (Minot, 2009; Boere, 2010; Bidogeza *et al.*, 2015), studies that explicitly evaluate the crop-plantation farm portfolio choices are absent. The over all objective of this study was to develop a farm optimization model that involves cultivation of major food crops and plantation of *Eucalyptus*. The study was also intended to analyze the new farm dynamics by creating trade-off scenarios with a hypothetical increase of land allocated for *Eucalyptus* and observing how sensitive will households' average annual revenue will be to the respective changes in land

allocated for *Eucalyptus*. The outcomes of the study can provide vital information regarding farm households that can make choice of farm portfolios. The study also highlights how future studies can address gaps in similar studies.

3.2. Materials and Methods

3.2.1. The Study Area

This study was carried out in potential *Eucalyptus* growing areas of Northwestern Ethiopia that geographically extends from 10°21'23.59''-10°37'28.05''N to 37°40'25.95''-37°53'09.02''E. The study area includes three of the major *Eucalyptus* growing districts including Senan, Gozamin and Machakel which covers about 128,000 square kilometers. The area is characterized by plain to terrain features with altitude ranging from 2,500 masl to 3900 masl. The area is highly degraded especially during the last two decades and recently arable lands are being converted to *Eucalyptus* plantations. The area receives a unimodal average annual rainfall of 1,350 mm that dominantly showers from May to September with cool humid (Dega) and cool sub-humid (Woinadega) climatic zonations and average annual temperature of 18°C (Simane, 2013).

A variety of crops including maize, sorghum and teff (*Eragrostis tef*), barley, wheat, faba bean, pea and lentil are cultivated in diverse topographic features with slopes ranging from nearly plain to very steep (>45°) landscapes. Though intensive cultivation of food crops is the main farming activity in the study area, households are recently converting their crop lands to plantation of *Eucalyptus globulus*. Map of the study area is indicated in Figure 2 of the previous chapter .

3.2.2. Sampling

In order to draw the required sample from the study population, we followed a multi-step sampling procedure. Considering East Gojjam zone on the basis of its *Eucalyptus* growing potential, we considered three districts namely, Senan, Gozamin and Machakel.

Three farm types were created each constituting four villages which were selected on the basis of *Eucalyptus* coverage and type of agro-ecosystem. The farm types created were Farm typology I (semi-plain midlands), Farm typology II (sloping midlands), Farm typology III (lands with terrain features) (Table 5). In order to see the trade-offs of *Eucalyptus* plantation versus cultivation of food crops, we also considered fertility status of lands (fertile versus marginal) which is based on production potentials. Marginal lands are degraded plots which are usually assigner the cultivation of *avena* (*Avena fatua*) and lupin (*Lupinus albus*).

As farm households in the three farm typologies differ in making farm choices, we made a record of data to the three farm types including endowments like land holdings, fixed assets, crops cultivated, livestock owned, household characteristics, family labor, farm inputs such as seed and fertilizer and the yield obtained during the 2019/2020 calendar. On the basis of

willingness, we chose a representative farm household from each farm type for running the farm household model.

Table 5. Classifications of farm typologies and samples taken

Farm typology	Dominant farming system	Soils	Elevation	Actual number of farm households fulfilling the selection criteria	Sample taken
I. Semi-plain lands	Intensive wheat , <i>teff</i> and maize - based farming with plantation of <i>Eucalyptus</i>	Alisols, Leptosols, and Nitosols	2500-2900	2,977	127
II. Sloping lands	Wheat, barley, potato, beans-based farming together with <i>Eucalyptus</i> plantation	Mixture of Leptisols and Nitosols	2900-3400	3,593	151
III. Lands with terrain features	Abundant plantation of <i>Eucalyptus</i> with wheat, barley, avena and potato-based farming	Marginal lands with shallow soils of luvisols and leptosols exist dominantly	3400-3800	3,004	128
Total				9,574	406

At each farm typology, we drew respective samples following Yamane’s (1967) sample size formula. A total of 406 questionnaires were dispatched for data collection but 18 were improperly filled and rejected and finally 388 sample (with 95.6% response rate) respondents were used for analysis. In addition to the formal questionnaire, three consecutive focus group discussions were carried out which involved members of 8, 7 and 10 individuals respectively.

3.2.3. Specification of the farm household model

A farm household model of the GAMS platform was designed in order to reproduce the behavior of farm households (Christophe *et al.*, 2000) that have to select a set of farm choices under resource constraints with respect to available production factors and technical opportunities. The farm household model depends on production decisions that contribute to income through farm profits (Switek *et al.*, 2013; Liu *et al.*, 2018). The primary motivation for constructing household models is to analyze the impact of resource use, production and consumption decisions on farm household welfare (Ouadi *et al.*, 2014; Malak-Rawlikowska, 2019). We employed a farm household model to estimate households’ gross margins

assuming a discretionary income assuming that farm households want to maximize their expected utility (Xiong *et al.*, 2018; Louhichi *et al.*, 2020).

This model is proposed for capturing the behavior of farm households that have to select a set of farm portfolios (crop/*Eucalyptus* and off-farm activities) under existing constraints (Bidogeza *et al.*, 2015). The proposed optimization model incorporates essential characteristics of each representative household (Frija *et al.*, 2021). A linear programming model for making decisions in farm planning is stated by Rehman (1984).

$$MaxZ = c'x - \phi\delta \quad (3)$$

Subject to $Ax \leq b$ and $X \geq 0$

Where,

Z = Gross margin (ETB/ha)

c = Vector of gross farm income per unit of activity

x = Vector of activities

ϕ = Risk aversion coefficient ($\phi > 0$)

δ = Standard deviation of total gross margin

A = Matrix of technical coefficients

b = Vector of resource availabilities

The first objective of the farm household model is the maximization of gross margin. With this objective, it is assumed that farmers can reach their highest possible welfare (from the sale of farm activities). A record was made for household incomes (gross margin from farm products and off-farm activities) and expenses such as farm inputs and wages paid for hired labor.

The specified equation for maximization of the gross farm income is:

$$c'x = \sum[(Y_c * P_c) + (Y_E * P_E)] - \sum[(S_c * P_s) + (F_c * P_F) + (E_s * P_{ES})] - \sum[(L^{Hired} * W) + (L^{Off} * W)] \quad (4)$$

Where,

Y_c = Yield of crop c (kg/ha)

P_c = Selling price of crop c (ETB/kg)

Y_E = Yield of *Eucalyptus* (m³)
 P_E = Price of *Eucalyptus* (ETB/m³)
 S_c = Seed used for crop c (kg)
 P_s = Price of seed (ETB/kg)
 F_c = Fertilizer used for crop c (kg)
 P_F = Price of fertilizer (ETB/ha)
 E_s = Number of *Eucalyptus* seedlings
 P_{Es} = Price of *Eucalyptus* seedlings (ETB/ha)
 L^{Hired} = Number of hired labor (man labor hours)
 W = Wage rate per hour for man labor (ETB/hr)

Then, using the variance/covariance matrix of gross margins for production of crops and *Eucalyptus*, the standard deviation for total gross margin is specified as:

$$\delta = \sqrt{[\text{var}(L_c) + \text{var}(L_E) + 2 \text{cov}(L_c, L_E)]} \quad (5)$$

Where

$\text{var}L_c$ = variance of gross margin from crops

L_c = Land allocated for crops

$\text{var}L_E$ = Variance of gross margin from *Eucalyptus*

L_E = Land allocated for *Eucalyptus*

$\text{Cov}(L_c, L_E)$ = covariance of gross margins from crop and *Eucalyptus*

The equation for summation productions from cultivation of crops and plantation of *Eucalyptus* per input per farm typology is:

$$\sum (I_c + I_E) \geq 0 \quad (6)$$

Where, I_c and I_E are income from crops and *Eucalyptus* respectively. Labor involved in different farm/off-farm activities can be expressed using the labor balance equation as:

$$\sum L_{c,E,L} + L^{Off} \leq L^{Farm} + L^{Hired} \quad (7)$$

Where $L_{c,E,L}$ are labor involved in cultivation of crops, *Eucalyptus* plantation and livestock rearing, L^{off} is labor went out in search of off-farm works, L^{farm} is labor involved in farm activities and L^{Hired} is hired labor.

Land required for different farm activities is constrained by the available land of farm households per farm typology:

$$\sum (X_c + X_E) \leq A_{C,E} \quad (8)$$

Where X_C and X_E are lands allocated for crops and *Eucalyptus*, respectively, and $A_{C,E}$ is the total available land owned by a household. The hypothesized constraints for the model were land (both fertile and marginal), labor, fertilizer and seed, and the model activities were the purchase of farm inputs (seeds, fertilizers and *Eucalyptus* seedlings), hiring of labor and selling harvested crop of *Eucalyptus* wood.

3.2.4. Evaluation of Farm Portfolios

In addition to optimization of gross margins, we also used Benefit Cost Ratio (BCR) as an indicator of farm performance as proposed by studies including Wainaina *et al.* (2020), Furtner *et al.* (2022) and Sebastian and Michael (2020). Such indicators have been used by different projects to evaluate activities that can be useful in public and governmental decision-making (Henke *et al.*, 2020). The BCR is calculated as:

$$BCR = \frac{\sum_{i=0}^n \frac{B^i}{(1+r)^i}}{\sum_{i=0}^n \frac{C_i}{(1+r)^i}} \quad (9)$$

Where B = net benefits, C = Cost and r = discount rate and i = investment period.

A farm portfolio (farm choice between plantations of *Eucalyptus* versus cultivation of wheat) with a BCR above 1 provides a net economic gain and can be considered economically feasible.

3.2.5. Farm Typology and Household Characteristics

In order to measure farm incomes of households, we constructed typologies of different farm households within the main *Eucalyptus* growing areas. We classified the areas into three farm typologies based on the existing agroecology and land suitability for the production of food crops and plantation of *Eucalyptus*.

Farm typology I (semi-plain lands) is demarked at altitude ranges between 2500–2900 masl which are dominated by alisols, leptosols, and nitosols that are suited for the cultivation of wheat, *teff* and maize together with plantation of *Eucalyptus*. Agroecologies within the altitude range between 2900–3400 masl are categorized as Farm typology II (sloping lands) where the dominant soil types are a mixture of leptisols and nitosols that mainly allow the cultivation of wheat, barley, potato, beans and *Eucalyptus* plantation. Farm typology III (lands with terrain features) that lie within the altitude ranges from 3400–3800 masl is characterized by shallow soils of luvisols and leptosols where there is abundant planting of *Eucalyptus* with wheat, barley, avena and potato-based farming.

In all of the farm types, households engage in the planting of *Eucalyptus* and cultivation of the major types of crops together with livestock rearing. The result showed that households are characterized by more or less similar socioeconomic setups and farming systems across farm types. In all farm typologies, the cultivation of crops is accompanied by the planting of *Eucalyptus* as a potential short rotation species.

3.3. Results

3.3.1. Technical Findings

Table 6 below presents the optimal level of land allocated for the planting of *Eucalyptus* and different food crops (wheat, potato, barley, *teff*, maize and faba bean) for the 2020 cropping season across the different farm typologies. Wheat is the major crop intensively grown in all farm typologies. In Farm typology I, households allocated the highest portion of their plots to wheat followed by the production of *teff* and the planting of *Eucalyptus*. In Farm typology II, land allocated for potatoes was highest next to wheat. In Farm typology III, households allocated the highest proportion of their plots to planting *Eucalyptus*, next to wheat. This is because Farm typology III is characterized by relatively rugged topographic features with less fertile and shallow soils which are unsuitable for the cultivation of food crops. However,

Eucalyptus potentially thrives in such marginal plots as it does not demand intensive care and high levels of soil fertility.

Table 6. Farm households' land allocation plan for the 2020 cropping season

Optimal Land Size (ha)	Farm Typology		
	Typology I	Typology II	Typology III
<i>Eucalyptus</i>	0.41	0.43	0.51
Wheat	0.65	0.86	0.52
Potato	0.38	0.60	0.23
Barley	0.20	0.29	0.26
Teff	0.41	0.34	0.19
Maize	0.25	0.24	0.21
Faba bean	0.20	0.27	0.23
Average	0.357	0.433	0.307

Results of the farm household model show the shadow prices and slack values of utilized resources. Table 7 depicts the optimal level of available resources together with the respective shadow prices and slack values of the farm household model results. The shadow price indicates the rate of improvement in the optimal objective function value that shows the possibility of increasing the value of gross margin by a unit increase of the limiting resource given all other factors held constant.

Accordingly, the land had positive shadow prices in all farm typologies as land scarcity is apparent and decreasing per capita with landholding in general. Conversely, the shadow prices of labor were zero in all farm typologies. It was observed that labor supply was in excess, particularly during the production season. Seed and fertilizer had positive shadow prices in Farm typologies I and II. The result indicated that there was a surplus of labor, seed and fertilizer resources for the fertile land scenario. The result indicated that there were 65 idle labor in Farm typology I, 82 in Farm typology II and 72 in Farm typology III.

Table 7. Optimal level of resource use, shadow prices and slack values

Resources	Farm Typology I			Farm Typology II			Farm Typology III		
	Optimal Value	Slack Value	Shadow Price (ETB)	Optimal Value	Slack Value	Shadow Price (ETB)	Optimal value	Slack Value	Shadow Price (ETB)
Land (ha)	0.357	0	836	0.433	0	1352	0.307	0	918
Labor	222	65	0	410	82	0	316	72	0
Seed (kg/ha)	89.7	0	0.12	0.24	0	231	101	52.4	0
Seedling/ha	4800	245	0	4800	211	0	5315	0	1268
Fertilizer (kg/ha)	101.57	0	42	111.6	0	92	86	14	0

Shadow prices of *Eucalyptus* seedlings are positive only in Farm typology III. This was because seedling nurseries and other seedling supply sources are not sufficiently available in this farm typology and thus seedling is a binding constraint.

3.3.2. Succession of Croplands by *Eucalyptus*

Information obtained during focus group discussion revealed that a number of socioeconomic and environmental factors have contributed to the rapid expansion of *Eucalyptus* in the study area. According to growers' information, native tree species that are of equivalent socioeconomic importance as *Eucalyptus* are absent in the study area. There is also a growing market demand for *Eucalyptus* wood products as *Eucalyptus* is becoming the main wood resource for construction, fuel and raw materials for small-and medium-scale wood industries. In addition, *Eucalyptus* has fast-growing potential in a wide range of soil types with little management.

Analyzing the costs of production and the returns, farmers who have additional off-farm income sources prefer conversion of their croplands to *Eucalyptus* plantations. Respondents confirmed that crop yields in the adjoining plots are significantly decreased due to the negative effects of the tree such as shading and competition for nutrients and water. All these facts contributed to the conversion of croplands to plantations of *Eucalyptus* and the trickle-down effect continues year to year. Figure 6 below shows *Eucalyptus* planted on croplands bordering a *teff* field. In this figure, the *teff* and lupin plots are more likely to be planted with *Eucalyptus* in a year or two.



Figure 6. A year-old *Eucalyptus* plantation established bordering teff (left) and lupin (right) lands. Photo by researcher (2020).

In the study area, there is a wide-scale degraded land that is unsuitable for the cultivation of food crops. Such aggravated land degradations are mainly attributed to the long-term intensive farming and overgrazing practiced in the area. Increasing levels of soil acidity, especially in areas with steep slopes and terrain features, are another major factor in the decline of land productivity. In such areas, farmers cultivate species such as *avena* (*Avena fatua*), lupin (*Lupinus albus*) and *Eucalyptus*. These species can perform best in such marginal lands. Lupin is mainly sown for its land reclaiming potential for the next season's crop (Figure 7).



Figure 7. Lupin (*Lupinus albus*) and avena (*Avena fatua*) (sown for land reclaiming purpose) and *Eucalyptus* planted on marginal land. Photo by researcher (2020).

Discussion with key informants indicated that *Eucalyptus* supports the livelihoods of smallholder growers through the provision of various types of services including construction, energy sources, making of plowing tools and making of rope from its bark. Because of its multipurpose uses, growers tend to convert their cultivable lands to the planting of *Eucalyptus* at a year-to-year increasing rate.

Once produced, *Eucalyptus* wood products are supplied to the market in different forms including roofing wood, poles, walling wood, logs, rods and fuel wood with prices that vary on the basis of type and season. Prices are usually set depending on the size/ dimensions (such as with roofing wood) or volume of the product (such as with stacked wood). Of all wood types, roofing wood is the most expensive one costing about ETB 162. The product usually has a length of about 12 m and a base diameter of about 21.2 cm. Wood products are transacted through various channels by different market actors such as construction wood retailers, wood processing enterprises, fuel wood retailers and individual house builders. These actors integrate and transact *Eucalyptus* wood to form the value chain. However, due to a lack of sectoral integration and policy focus, the *Eucalyptus* wood sector value chain is found to be undeveloped.

3.4. Economic Results of the Farm Household Model

3.4.1. Impact of Land Succeeded by *Eucalyptus* on Households' Gross Margins

Farm households are not able to separate their resource use and production decisions as they experience direct trade-offs and will continue to produce up to the level where the shadow value of producing one more unit of product is equal to the opportunity cost of producing the product. When farm households make a decision on production, labor allocation and consumption, they will have decisions that are dependent upon each other.

In order to see the impact of land succeeded with *Eucalyptus* on households' gross margins and to realize whether involvement in intensive plantation of *Eucalyptus* can affect the level and distribution of farm households' gross margin, a farm household model was employed by integrating major food crops (wheat and barley, which are commonly grown in the three farm typologies) and *Eucalyptus*, that are subjected to resource constraints (land, labor, seed and fertilizer). For a better representation and estimation of farm outputs, we considered production both at fertile and marginal lands and integrated the respective prices of farm resources such as labor (16.99 ETB/hour for summer labor and 16.95 ETB/hour for the season from September to December). The prices of wheat and barley were 26.01 ETB and 27.39 ETB/kg, respectively. The price of *Eucalyptus* was 1,787.08 ETB/ton. Using these resources, the farm household model gave optimal gross margins for each farm typology (Figure 8).

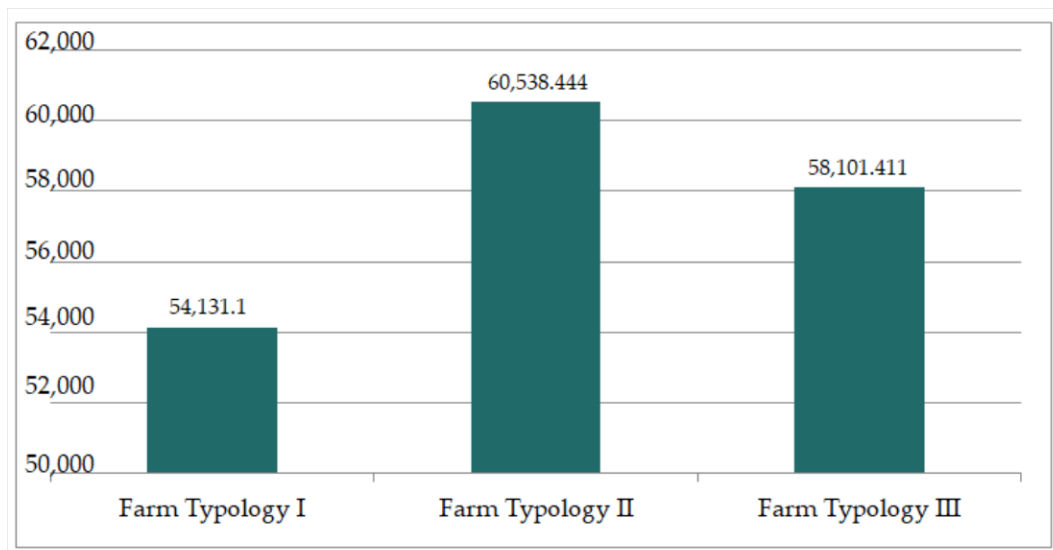


Figure 8. Farm households' gross margin by farm typology (ETB)

Results show that gross margins varied across farm typologies. The farm household model output showed that the optimal gross margins for Farm typologies I, II and III were 54,131.10 ETB, 60,538.44 ETB and 58,101.41 ETB respectively (Figure 4). It was observed that gross margin was relatively lower in Farm typology I and highest in Farm typology II. This was mainly attributed to variations in farm activities in the three farm typologies. Growers in Farm typology I mainly engage in the cultivation of food crops. In Farm typology II, intensive plantation and production of crops are practiced simultaneously. In Farm typology III, lands are highly degraded for sole cultivation of food crops; they grow *Eucalyptus* well and are still surplus for the plantation of *Eucalyptus*. The main focus of this study was to see the economic impact of the succession of *Eucalyptus* on household gross margins.

3.4.2. Trade-Off Scenarios

In order to see the trade-offs of conversion of croplands to *Eucalyptus* plantations, we considered the three farm typologies of households where we assumed a hypothetical increase of land allocated for *Eucalyptus* and a proportional decrease in cropland and observed how sensitive households' gross margins were for the respective percentage changes in the land. Three scenarios were created by increasing land allocated for *Eucalyptus* by from 30 to 50%. With these land conversion scenarios, the actual changes in gross margins from the status were 13,937.71 ETB, 8367.80 ETB and 8,542.72 ETB in Farm typologies I, II and III, respectively (Table 8).

Table 8. The trade-off scenarios and change in households' gross margins (ETB)

	Typology I	Typology II	Typology III	Average
Model output of gross margin for the status quo (ETB)	54,131.10	60,538.44	58,101.41	57,590.32
Gross margin value when <i>Eucalyptus</i> land is increased by:				
Scenario I (30%)	56,802.60	62,623.94	61,139.62	60,188.72
Scenario II (40%)	64,980.34	65,917.74	63,605.93	64,834.67
Scenario III (50%)	68,068.81	68,906.24	66,644.13	67,873.06
Actual change in gross margin from the status quo (ETB)	13,937.71	8367.80	8542.72	10,282.74

With the available resources, households' gross margins increased for every percentage increase in land allocated for *Eucalyptus*, depicting that the conversion of cultivable plots to *Eucalyptus* plantation is a rational choice to bring about improvement in farm gross margins.

3.4.3. Farm Portfolio Evaluation

Plantation trees have a longer gestation period as compared to food crops and thus, estimations of their returns at a point in time may not provide reliable estimates as prices are subjected to dynamism over ten years. In order to handle such price dynamics, we estimated gross margins from plantations of *Eucalyptus* and the cultivation of wheat by discounting future benefits using Benefit Cost Ratio (BCR) as an appraisal indicator. Gross margins calculated for the two cases showed that the highest margin value of 42,890.96 ETB was obtained from plantations of *Eucalyptus* (Table 9).

Table 9. Evaluation of *Eucalyptus* versus food crops portfolio choice

Cost of Production	Wheat (ha)			<i>Eucalyptus</i> (ha)		
	Amount	Price (ETB/Unit)	Cost (ETB)	Amount	Price (ETB/Unit)	Cost (ETB)
Seed(ton)/seedling	0.327	9,358.29	3,060.16	3,200.00	0.50	1,600.00
Fertilize(ton)	0.295	14,450.00	4262.19	4.30	75.00	322.50
Herbicide (lt)	1.321	165.00	218.43	—	—	—
Labor (hour)	101.00	16.09	1625.09	244.62	15.00	3,669.23
Total cost (A)			9165.87			5591.73
Income	Amount (ton)	Price	Product value	Amount	Price	Product value
Revenue (B)	1.717	28,550.00	49,020.35	27.17	1,787.08	48,554.96
Gross margin (B-A)			39,854.48			42,890.96

Note: Fertilizer used for *Eucalyptus* is locally available manure. Source: Researcher, 2022.

Our main purpose of undertaking these analyses is for quantifying the net financial gains from using a given plot of land for the production of wheat and planting of *Eucalyptus* for ten years at a 12% discount rate, a discount rate which is the current lending interest rate of the Commercial Bank of Ethiopia.

The ten-year projections indicate that both the cultivation of wheat and plantation of *Eucalyptus* are feasible in the existing states. However, the BCR value for *Eucalyptus* indicates a greater worthiness, 2.15 for *Eucalyptus*, while that of wheat is 1.08 (Table 10).

Table 10. Cost-benefit analysis for the two farm portfolios

Year	Wheat						<i>Eucalyptus</i>							
	Cash Outflows	Cash Inflows	Net Cash Flows	Discounted Factor (r = 12%) 1/(1+r) ⁿ	Net Present Value	Discounted Cash Outflows	Discounted Net Cash Inflows	Cash Outflows	Cash Inflows	Net Cash Inflows	Discounted Factor (r = 12%) 1/(1+r) ⁿ	Net Present Value	Discounted cash Outflows	Discounted Net Cash Inflows
2020	9165.87	39,854.48	30,688.61	1	30,688.61	9165.87	39,854.48	5591.73	42,890.96	37,299.23	1	37,299.23	5591.73	42,890.96
2021	9165.87	39,854.48	30,688.61	0.893	27,400.54	8183.81	35,584.36	5591.73	42,890.96	37,299.23	0.893	33,308.21	4992.62	38301.63
2022	9165.87	39,854.48	30,688.61	0.797	24,464.77	7306.97	31,771.75	5591.73	42,890.96	37,299.23	0.797	29,727.49	4457.69	34184.10
2023	9165.87	39,854.48	30,688.61	0.712	21,843.55	6524.08	28,367.63	5591.73	42,890.96	37,299.23	0.712	26,557.05	3980.08	30538.36
2024	9165.87	39,854.48	30,688.61	0.636	19,503.17	5825.08	25,328.24	5591.73	42,890.96	37,299.23	0.635	23,685.01	3553.64	27235.76
2025	9165.87	39,854.48	30,688.61	0.567	17,413.54	5200.96	22,614.50	5591.73	42,890.96	37,299.23	0.567	21,148.66	3172.90	24319.17
2026	9165.87	39,854.48	30,688.61	0.507	15,547.80	4643.71	20,191.52	5591.73	42,890.96	37,299.23	0.507	18,910.71	2832.94	21745.72
2027	9165.87	39,854.48	30,688.61	0.452	13,881.97	4146.17	18,028.14	5591.73	42,890.96	37,299.23	0.452	16,859.25	2529.41	19386.71
2028	9165.87	39,854.48	30,688.61	0.404	12,394.61	3701.94	16,096.56	5591.73	42,890.96	37,299.23	0.404	15,068.89	2258.41	17327.95
2029	9165.87	39,854.48	30,688.61	0.361	11,066.62	3305.30	14,371.92	5591.73	42,890.96	37,299.23	0.361	13,465.02	2016.43	15483.64
2030	9165.87	39,854.48	30,688.61	0.322	9880.91	2951.16	12,832.08	5591.73	42,890.96	37,299.23	0.322	12,010.35	1800.39	13810.89
Total					204,086.09	56,808.88	265,041.18					248,039.9	37,186.24	285,224.89
BCR						1.08						2.15		

Note: The uniform cash inflows and outflows are considered in discounting.

3.4. Discussion

Land use changes in the study area have undergone a typical conversion from crops to plantations of *Eucalyptus* at an increasing rate. This was mainly driven by an increasing population that supports their livelihoods with subsistence farming, putting pressure on the natural resource base. The current study measured the economic impact of the conversion of croplands to *Eucalyptus* plantations on households' gross margins using a farm household model where we incorporated important characteristics of each representative farmer that are grouped according to type and the agroecology in which they operate. In order to see the economic impact of *Eucalyptus* expansion on households' annual average revenue, we ran

the farm household model as employed by (Wainaina *et al.*, 2022; Elouadi *et al.*, 2017). We also made comparisons of farm returns from two farm portfolios using BCR.

The increasing demand for wood products, socioeconomic forces and the land use regulation that allows right-of-use to farmers have significantly contributed to this land conversion trajectory. This finding is in line with the studies by Karttunen *et al.* (2018) which examined the impacts of intensive forest management arising from increased demand for wood biomass with major emphasis on intensive forest management on the regional gross domestic product, private consumption and employment. Land use regulation in the study area which permits land rental and right-of-use is among the driving factors for the expansion of *Eucalyptus*. In Ethiopia, the land belongs to the state and the people and it is the major impeding factor of production. However, the government allows use rights to the people to use their plots for different investment options (Jouquet *et al.*, 2007; Samuel, 2006; Hailemichael, 2012). Because of this, growers are converting their cultivable lands to *Eucalyptus* plantation stands.

Currently, the *Eucalyptus* wood products have a potential market share and the demand for the products is spectacularly hiking following the growing market opportunities, particularly in the construction sector (Vance *et al.*, 2014). The increasing number of small- and medium-scale wood processing enterprises is another opportunity for the development of the wood sector value chain and thereby supports the livelihoods of smallholders. A similar conclusion was drawn by Ullah *et al.* (2021) who studied the economic roles of fuelwood and timber smallholders' livelihoods in Pakistan.

This rapid expansion of *Eucalyptus* has bilateral implications for the study area's socio-economic setup. On one hand, with the existing increase in population and declining productivity of croplands, *Eucalyptus* can be taken as an opportunity that guarantees smallholder growers an alternative income. A study by Simo (2020) witnessed the economic contribution of the tree to smallholder growers, especially in areas where the productivity of lands is declining. On the other hand, the alarming expansion rate of *Eucalyptus* over croplands may pose a threat to food crops, diminishing the quantity of production, the types of food crops and biodiversity in the future.

The results revealed that households plant *Eucalyptus* at the expense of croplands for a multitude of reasons, including the growing demand for construction wood and subsequent increase in the price of *Eucalyptus* wood, its ability to thrive best with minimal management, its multiple roles and its ability to provide better profitability from a given parcel of land. This has become a threat to fertile arable lands by diminishing food crops in the study area (Birru *et al.*, 2013). Cultivation of food crops and livestock rearing complemented with *Eucalyptus* plantation are the main farming activities in the study area. Apart from the cultivation of food crops such as wheat, *teff*, maize, potato, barley and faba bean, farmers are showing a tendency of converting their plots to plantations of *Eucalyptus*. Labor is the main factor of production and factor source of difference in household endowments. In the study area, farm households mainly use family labor. In peak times (sowing, weeding and

harvesting), hired labor and labor sharing arrangements (locally called *debo*) are commonly used.

Aside from all the above, the expansion of *Eucalyptus* has been reported to have a negative impact on ecology and biodiversity. There is significant, supporting evidence regarding the negative impacts of *Eucalyptus* on ecology and biodiversity. The impact of *Eucalyptus* on wood-decaying fungi and saproxylic beetles has been studied by Hopkins *et al.* (Hopkins *et al.*, 2005). A study by Bonham *et al.* (2002) in Tasmania found that native land snails and millipedes were less diverse in *Eucalyptus* plantations than in native forests. Studies by Riffell *et al.* (2011) and Teketay (2001) found low diversity and abundance of birds and browsing animals in *Eucalyptus* plantations than in native forests. Because of its morphology, mainly, limited availability of large stems, *Eucalyptus* is not convenient for cavity-nesting bird species and thus, it has a moderate capacity to harbor species of fauna, leading to migration and decreased species richness. A similar study by Proenca *et al.* (2010) reported lower plant and animal diversity in *Eucalyptus* plantations relative to native forests. In Brazil, Rocha *et al.* (2012) found fewer species of lizards and selected invertebrates in *Eucalyptus* plantations than in primary Atlantic forests. Generally, *Eucalyptus* in its niches of plantations apparently negatively impacts species richness and consequently causes increased biodiversity erosion.

If the rate of expansion continues at the same pace the entire area will be covered with *Eucalyptus* within a few years. Understanding such land conversions is central to the proper management of land resources, especially in areas where the majority of the people support their livelihood using a base of natural resources. These conclusions are consistent with the study that indicated the importance of knowledge of the land use dynamics for land resource management (Wood *et al.*, 2004).

We employed the farm household model to examine the behavior of farm households that have to make choices about farm portfolios with respect to available factors of production and resource constraints. In the study area where land resources are limited and per capita land holding is declining, maximizing the economic return per unit area is essential for increasing households' income. The model gave varying values of gross margins for different farm typologies that are in line with the findings of scholars who analyzed different policy impacts and farm alternatives (Liu *et al.*, 2018; Bidogeza *et al.*, 2018; Rosenthal, 2007). Our results are also in line with Alvarez-Lopez *et al.* (2008) who studied the typology, classification and characterization of farms for agricultural production planning in Northwest Spain. In the farm household model, we assumed that the household budget is endogenous and depends on production decisions that contribute to income through farm profits (Rosenthal, 2007; Liu *et al.*, 2018).

Similar results were reported by Elouadi *et al.* (2017) who examined the socioeconomic impact of climate change on agriculture activities, taking into account the agricultural, socio-economic and hydrology systems in Eastern Morocco and found that climate change tremendously impacted the income and living standards of farmers. In all farm typologies,

households are converting their croplands to plantations of *Eucalyptus*. This is in line with the study by Worku *et al.* (2017) who noted that an increase in demand for wood motivated people to have privately planted trees. This suggests that farmers still have the advantage of obtaining additional benefits from the increases in conversion of croplands to *Eucalyptus* leaving other factors constant. Studies by Singh *et al.* (1986) and (Minot, 2021) drew similar conclusions about how farmers make rational choices concerning farm portfolios.

Scenarios created by increasing land allocated for *Eucalyptus* showed corresponding increases in households' gross margin. The result implies that farm returns obtained from increases in land allocated for *Eucalyptus* cannot be compensated for with a proportional level of increase in land allocated for the cultivation of food crops. This further suggests that farmers still have the advantage of obtaining additional benefits from the increases in conversion of croplands to *Eucalyptus* leaving other factors constant. Studies of Boere (2010) and Bojnec and Knific (2021) drew similar conclusions about how farmers make rational choices concerning farm portfolios.

Gross margins and BCR analysis results gave higher values for the plantation of *Eucalyptus* than for the cultivation of food crops. This implies that *Eucalyptus* contributes better to households' income as compared with food crops cultivated using the same plot of land. This result is consistent with the study which indicated that plantations support local economies and rural livelihoods in many mountainous regions, where poverty and a fragile environment are often interlinked (Bidogeza *et al.*, 2015). The result is in line with the findings of Tafa *et al.* (2020) who investigated farm-level cost-benefit analysis for evaluating the economics of conservation agriculture in Kwa-Zulu Natal Province of South Africa.

The likeness of the findings of this study with other previous studies undertaken worldwide has policy implications in that it is possible to make generalizations to other areas with similar environmental and socioeconomic setups. The results presented in this study, however, differed from another study by Rondhi *et al.* (2018) which measured the economic value of land in rural and peri-urban areas in East Java, Indonesia in the sense of making economic comparisons. To the best of our knowledge, this study is the first of its kind in Ethiopia which maximized households' gross margins from similar farm alternatives using the farm household model. An exception to this study is that we were able to measure the optimal level of households' gross margin for each of the farm types and made farm portfolio evaluations with hypothetical land conversion scenarios. The findings are useful for guiding the proper and sustainable management of future land resources.

5. Conclusion

The succession of croplands in the study area is an incentive-driven process in a dynamic farming system in need of policy attention. In this study, we analyzed the interlinkage between the land converted to *Eucalyptus* plantation and the respective change in the level of gross margin. We measured the economic impact of the conversion of croplands to

Eucalyptus plantations on households' gross margins in major *Eucalyptus* growing areas of Northwestern Ethiopia using a farm household.

Due to rapid land degradation, a decline in soil fertility and a subsequent decrease in crop productivity, farmers in the study area are shifting their cultivable lands to *Eucalyptus* plantations with a yearly expansion rate irrespective of the fertility status of their plots. In the current study, we characterized farm households in three typologies that showed diversity in endowment and farming system where there is a general increase in conversion of croplands to *Eucalyptus* plantation year to year. The expansion of *Eucalyptus* over croplands has created a two-dimensional ongoing debate. On one hand, the expansion of *Eucalyptus* can be viewed as a major source of income and livelihood supporting strategy for farm households that exercise dynamic income alternatives and coping strategies. On the other hand, the alarmingly increasing population may be threatened by a shortage of food as *Eucalyptus* is expanding at the expense of croplands which will ultimately lead to a decline in food crop production.

In Farm typology I, where lands are relatively plain, fertile and preferred for the cultivation of food crops such as wheat and *teff*, policies must restrict the expansion of *Eucalyptus* over croplands and only marginal lands should be reserved for *Eucalyptus* plantations. In Farm typology II, where lands are relatively sloped with mixed soils of Leptisols and Nitisols, farming systems are mainly based on the cultivation of major crops such as wheat, barley, potato and beans together with *Eucalyptus* plantation. Lands in this farm typology are less fertile and have a high percentage of marginal area coverage compared to those in Farm typology I. For this farm typology, a hand-in-hand increase in *Eucalyptus* expansion with the level of marginal area coverage is recommended as it can give optimal farm income from the crop-plantation farm portfolios.

Farm typology III is characterized by lands with steep slopes, highly erodible terrain features and a high degree of marginality. In this farm type, plots are less productive which lead to the election of plantations as a compensatory option for the farm household in light of ecological considerations, especially with regard to slope stabilization.

In Ethiopia, as a developing country with high demographic and economic transition, the need for land (for cultivation, plantation or housing) is becoming significantly higher. In the same arena, conservation of the cultivable land is vitally important for meeting the mounting food demand of the growing population.

Scenarios created by percentage increases in land allocated for *Eucalyptus* were accompanied by corresponding increases in households' gross margins implying that *Eucalyptus* is the most economically important tree that pays off as compared to the returns from food crops cultivated using the same area of land.

Results reported in this study indicate that there is still a potential of improving households' gross margin with optimal allocation and proper management of land resources for the two farm portfolios. The ten-year projections of farm portfolios from a hectare of land at a 12% discount rate showed a higher BCR for plantation of *Eucalyptus*. Following these conclusions, we drew the following policy suggestions:

1. *Eucalyptus* plantations can be taken as important resources which can contribute to a number of high-priority policy objectives of the country including contributing raw materials for the industrialization of the forest sector. However, this is only valid if there is proper utilization of land resources.
2. There is a need to design and implement a land use policy for the country which concisely states the proper usage of land considering *Eucalyptus* as a farm portfolio choice beyond the conventional criteria for land use, which is based only on suitability. Efforts should be made to encourage and incentivize farmers to use their land with pre-specified characteristics (focusing plantations on marginal lands and setting aside fertile lands for food crops).
3. There should be evidence-based land choice and prioritization while allocating lands for *Eucalyptus* plantations; ensuring the wellbeing of water reserve areas and fertile croplands and reserving marginal lands for the planting of *Eucalyptus*.
4. To ensure proper usage of land resources in a Pareto-efficient and optimal way, collaborative policy efforts of the Ministry of Environment, Forest and Climate Change and the Ministry of Agriculture are vitally important. Such efforts can help promote the optimal choice of farm portfolios in different farm typologies with a trade-off with a win-win economic and environmental scenario.

CHAPTER 4: VALUE CHAIN ANALYSIS OF *EUCALYPTUS* WOOD PRODUCTS IN THE BLUE NILE HIGHLANDS OF NORTHWESTERN ETHIOPIA

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Abstract

Eucalyptus wood products contribute significantly to the income of smallholder growers in many parts of Ethiopia. This has incentivized smallholders to convert arable lands to *Eucalyptus* plantation. Given the limited attention and availability of empirical evidence, this study examined the *Eucalyptus* wood products value chain in terms of the actors engaged, the type and importance of channels, margins analysis and the overall value chain governance in the main *Eucalyptus* growing areas of the Blue Nile highlands of Northwestern Ethiopia in 2019/2020. Sources of data were randomly selected 388 *Eucalyptus* grower households and 166 *Eucalyptus* wood traders, complemented by an interview with key informants, group discussions and direct observations. The results reveal that large volume of *Eucalyptus* wood products was produced in the study area. Many actors involved handle a large volume of different types of wood in eight main channels with a high disparity in the shares of the margins. We found that *Eucalyptus* is the main source of cash earning, contributing about 45.76% to the total annual income of smallholder growers. Little policy attention, a lack of sectoral integration, missing infrastructure and absence of modern wood processing factories are among the key challenges impeding the performance of the wood sector value chain. There are however existing opportunities for the development of the wood sector value chain such as favorable growing conditions and the spectacular growing demand for wood products. The study provides valuable insights about the wood sector value chain and actions towards ensuring sustainable value chains and the commercialization of the sector.

Keywords: *Eucalyptus globulus*; *Eucalyptus* wood products; governance; smallholder growers; sustainable value chain; wood processors

4.1. Introduction

Eucalyptus is one of the most planted short rotation tree genera in the world next to *Pinus* and *Cunninghamia* and it is among the most important forest tree species for industrial raw materials (Haifeil, *et al.*, 2020, Dessie *et al.*, 2019). For their economic importance and especially for energy production, short rotation tree plantations are attracting the attention of many countries in the world (Mola-Yudego, 2010). Short rotation plantation trees

including *Eucalyptus*, *willow*, *poplar* and *Robinia* have a quick growing habit grown closely together and are harvested within 2 to 20 years (Lindegaard *et al.*, 2016). They have been cultivated in various countries and have been considered as an option in modern agriculture for biomass energy and fiber production for more than 40 years (Baum *et al.*, 2009). Constituting a genus of more than five hundred species, such short rotation plantation trees provide multiple economic advantages and social benefits including employment, income from sale of forest products, watershed management and climate change mitigation (Teketa, 2000). Forest products also make an enormous contribution to the success of industrialization as they provide the raw materials required for downstream activities including pulp milling, paper manufacturing, saw milling and furniture manufacturing which could be considered as the value chain activities of the wood sector (Ullah, *et al.*, 2021).

The growing deficit of wood and wood products in the world has forced policy rectifications for the establishment of fast-growing plantations and recently, there has been a rapid large-scale shift from conventional food crop production to short rotation plantations which will certainly have positive and negative implications on a range of environmental issues (Boruszewski *et al.*, 2021; Baum *et al.*, 2009).

Eucalyptus is largely planted by smallholder growers with a yearly expansion trend (Birru *et al.*, 2013; Jagger and Pender, 2003). Due to its fast-growing tendency and quick return potential, *Eucalyptus* is preferred as the most advantageous tree in terms of employment creation, provision of goods and services and its overall contributions to livelihoods (Joel and Kpwa, 2020; Hailemichael, 2012; Feyera *et al.*, 2010).

In recent years, owing to the escalating demands of *Eucalyptus* wood products for different purposes, growers have converted crop lands to *Eucalyptus* plantation regardless of the fertility status and productivity of the plots in many parts of Ethiopia (Kebebew and Ayele, 2010). There are different reasons for such land use changes. At a large scale, the global market for *Eucalyptus* wood products and the interest in wide-scale planting for the production of biofuels are the driving factors for the expansion of *Eucalyptus* as woodlots (Alfred *et al.*, 2020).

The prevailing soil degradation in the highlands of the country related to soil acidity is causing disarray among food crop growers. In addition, soil fertility is also declining year to year as a result of rapid population growth and changes in agricultural activities (Lewoyehu *et al.*, 2020; FAO, 2011). Along with this, poor households cannot afford to manage the escalating price of fertilizers, seeds, lime and other agrochemical inputs. So, they opt to plant their land with *Eucalyptus* and move to urban areas in search of off-farm income. In addition, *Eucalyptus* plantation does not require as much input as crop production does. Its vigorous growing habit and quick return, high potential of coppicing, reduced labor requirements, the increasing demand for its multipurpose wood products and the emerging wood market opportunities are the main driving factors for the expansion of *Eucalyptus* over crop lands as woodlots (Birru *et al.*, 2013; Jenbere *et al.*, 2012).

Given the positive economic attributes of the tree, there has also been criticism regarding ecological challenges such as the impact on soil health, the depletion of ground water and the suppression of undergrowth. A study by Forstmaier *et al.* (2020) reported the invasive behavior of large-scale plantations of *Eucalyptus* as a major ecological challenge. *Eucalyptus* leaf litter accumulation has also been reported to have allelopathic effects in the root zones of cultivated crops and *Eucalyptus* planted on fertile crop lands creates shading effects on adjoining plots which lead to a significant reduction in productivity (Mengistu *et al.*, 2020; Sasikumar *et al.*, 2002). *Eucalyptus* also depletes ground water which aggravates watershed degradation (Bayle, 2019).

On the other hand, several ecological advantages of short rotation coppices of such fast-growing plantations on arable soils have also been reported, including a long-term non-tillage management with increased litter content which can change the abundance and diversity of the soil fauna (Baum, 2009). Structured plantations of short rotation trees have also been reported to have a positive impact on ecological conservation and biodiversity (Baum, 2009). With these arenas, a rapid increase in population and the subsequent rise in the wood market and grazing and cultivation land coupled with declining crop productivity has become a threat to the ecosystem (Alemneh *et al.*, 2019). The growing demand for wood for construction and fuel on the demand side and its high adaptive capacity in a wide range of soil types on the supply side together with the aforementioned reasons have fostered the rapid expansion of *Eucalyptus* (Vance *et al.*, 2014). Of the total of 972,000ha

of forest land in Ethiopia, *Eucalyptus* accounts for about 90% of the available forests covers, ranking first (Tadesse *et al.*, 2019).

Eucalyptus is the main cash generating and livelihood supporting investment in the study area (Alfred *et al.*, 2020). This requires ensuring sustainable product markets to growers and other actors to increase their competitiveness in the business. In order to empower smallholder growers and other actors and to improve their performance and commercialize the sector, it is important to examine the nature of the *Eucalyptus* wood value chain by examining the entire series of activities that are needed to bring a product from production to the ultimate consumers (Strakova *et al.*, 2020).

Porter (Porter, 1985) coined the term value chain as a representation of a firm's value-adding activities, based on its pricing strategy and cost structure. Value chains represent the full range of activities that are required to bring a product or service from the beginning, via the intermediary production phases and delivery to final consumers (Kaplinsky and Morrie, 2001).

Analysis of value chains provides a rational and systematic framework to describe and evaluate the roles and interrelationship of the actors in the chain (Sutarmin and Jatmiko, 2016). Globally, the wood value chain adds more than double of the direct economic product contribution to GDP through the impact on value additions, income and employment in other economic sectors and strongly sustains about 75% of micro and small enterprises (FAO, 2011). Even though many value chain studies (Strakova *et al.*, 2020; Ljiljana and Phil, 2016; Global Wood Furniture, 2009) have been carried out in the wood sector in different countries, most of them have given emphasis to the processed wood products and studies that explicitly deal with the value chain development of *Eucalyptus* wood products are absent. A study by Teischinger (2009) examined the forest-based sector value chain in Austria and quantified the gross value additions of the sector. Another study by Johansen (2017) explored the balance between regional policy interests and the industrial sector by optimizing the wood sector value chain in northern Norway taking into account national and regional economic trade-offs.

To the best of our knowledge, this study is the first of its kind in analyzing the value chains of the specific *Eucalyptus* wood products in Northwestern Ethiopia. Despite the

choice of smallholder growers' of *Eucalyptus* as a strategic income option, the actors engaged in the sector, the nature of the market, the product type and the values that are added at each segment of the chain together with the shares of each actor need to be studied. In this study, we analyzed the value chains of *Eucalyptus* wood products targeting the identification of key challenges and opportunities in promoting well developed value chains and the sustainable management of *Eucalyptus* wood and wood products that can bring about the improved commercialization of the wood sector in the study area.

4.2. Materials and Methods

4.2.1. The Study Area

This study was conducted in the Blue Nile highlands of Northwestern Ethiopia covering the three major *Eucalyptus* growing districts, namely Gozamin, Sinan and Machakel in the East Gojjam zone (Figure 1). The study covered an area of 128,000 square kilometers with altitude ranges between 2500 and 3900masl. The area has cool humid (Dega) and cool sub-humid (Woinadega) climatic zonation and experiences a unimodal rainfall type with average annual rainfall ranging from 1000 to 1700mm and an average annual temperature of 18 °C. The area had a total population of 2.45 million in 2014 with an average population density of 89 persons per square kilometer. The vast majority of the population in the zone (86.5%) lives in rural areas where agriculture is the predominant economic activity (EIAR, 2021).

East Gojjam is characterized by diverse topographic features with slopes ranging from nearly plain to very steep (greater than 45%) slopes. The area permits the growth of a variety of agricultural crops. The lower altitude areas support maize, sorghum and *teff* (*Eragrostis tef*) while mid-altitudes are suited for the cultivation of *teff*, wheat, maize and other crops. In the highland places, barley, wheat, faba bean, pea and lentil are dominantly grown. White *Eucalyptus* (*Eucalyptus globulus*) is widely grown across this study area (Simane *et al.*, 2013). Map of the study location is indicted in Figure 2.

4.2.2. Sampling and Sample Size

Multi-stage sampling procedures were followed for generating primary data from grower households. In the first stage, the East Gojjam Zone was selected purposively for the prevalence of large *Eucalyptus* stands. Secondly, three districts within East Gojjam were chosen on the basis of *Eucalyptus* coverage. Information obtained from the report

indicated that Sinan, Gozamin and Machakel districts took the first, second and third rank in terms of *Eucalyptus* percentage cover, respectively (East Gojjam Agr. Office, 2020). From each district, 4 *kebeles* (micro level formal administrations) were chosen based on their *Eucalyptus* coverage. From each *kebele*, respondents were randomly chosen. The sample size was determined using the Yamane (1967) sample size formula. The actual number of *Eucalyptus* growing households and the respective samples taken are shown in Table 9.

A total of 406 questionnaires were dispatched for data collection but 18 were improperly filled and rejected. Finally, 388 sample (with a response rate of 95.6%) respondents were used for analysis (Table 11).

Table 11. *Eucalyptus* growing households and samples by kebele

Districts	Kebele	Number of <i>Eucalyptus</i> Growing Households Fulfilling the Criteria	Sample Size
Senan (17 kebeles)	Wolekie	632	27
	Gedamawit	854	36
	Yeted	1393	40
	Chabi	714	30
Gozamin (25 kebeles)	Gedemala	618	26
	Kegn Abu	671	29
	Giraram	852	36
	Enerata	836	36
Machakel (25 kebeles)	Shafogalat	989	42
	Degasegnin	751	32
	Debre Kelemo	710	30
	Temamagn	554	24
Total		9574	388

Because of the diverse and complex nature of viewing the economic and ecological impacts of *Eucalyptus* in smallholder growers' perspective, we employed a mixed method of data collection for obtaining adequate and reliable data that would be enhanced through triangulation and crosschecks as recommended by Greene *et al.* (1989).

Focus group discussion: People tend to share a common interest and eagerness to ideas when they are let to discuss in groups. Bringing participants of similar backgrounds together for a common issue is a convenient and easy way for obtaining their views, opinions and reflections (Chambers, 1992). In this regard, three consecutive focus group discussions were carried out and each group had 9 members. In each group discussion, issues including the beginning of

plantation of *Eucalyptus*, their choice for plantation of *Eucalyptus* over crop production, economic contributions of the tree and ecological impacts were discussed.

Key informant interview: In order to obtain information that requires longer periods and experiences, in-depth interviews are very imperative. The key informants group includes community elders, priests, *kebele* administration leaders, school directors who had long experiences in the area. A total of 3 key informant interviews each having 8 members were carried out. In this interview, informal conversation interviews were carried out for addressing the topics including the trend of *Eucalyptus* succession, periods of afforestation and plantation plot dynamics.

Then, the actual number of licensed value chain actors was identified in each market center. Legal registration/license ownership was a criterion for considering traders as sampling units. As the actual number of traders was limited, we used census sampling (*i.e.*, almost the entire population) with the exclusion of participants who were unwilling to participate in the survey and thus 166 out of 188 registered traders were taken as the final sample (Table 12). Two successive key informant discussions (having 5 members each) were also carried out with traders to complement the data obtained using a questionnaire. Data including the type and volume of wood product traded, taxation and legality were requested and obtained from traders. The study period was the 2019/2020 production year.

Table 12. Number of actors sampled per market center

Value Chain Actors	Market Centers				Total
	Dega Segnin	Amanuel	Debre Markos	Rebu Gebeya	
Construction wood retailers	9 (16)	12 (13)	33	9 (12)	63
Fuel wood retailers	8 (11)	8	4 (7)	6 (9)	26
Wood processors	4	6	19	6	35
Collectors	2 (4)	-	4	2 (5)	8
Walling wood splitters	4 (9)	6 (8)	8	2 (6)	20
Wood trading growers	0	6	4	4 (7)	14
Total	27	38	72	29	166

Note: Parenthesized figures are number of licensed traders that fulfill the selection criteria. Dega Segnin and Amanuel market centers are found in Machakel district while Debre Markos and Rebu Gebeya are located in the Gozamin and Senan districts, respectively.

4.2.3. Data Analysis and Value Chain Mapping

Data related to the volume of wood produced and the products handled, the costs incurred and the gross margins obtained by each actor were analyzed. Then, key value chain actors together with enablers were identified. Value chain actors included growers, construction wood retailers, fuel wood retailers, wood processors, collectors, walling wood splitters and wood trading growers. These value chain actors are explained in detail in Section 4.3.3.

By using data from formal interviews and discussions with key informants, potential market routes of *Eucalyptus* wood products were identified and the actual value chain map was traced with industry or product case studies value chain analytical approaches (Jones *et al.*, 2019). Using the gross margin model, marketing margins were calculated for each actor along the chain (Wohlgenant, 2001).

The gross margin was calculated as:

$$GMM = \frac{\text{Consumer Price} - \text{Marketing Gross Margin}}{\text{Consumer Price}} \times 100 \quad (10)$$

Similarly, we calculated the net margin using the following formula:

$$NMM = \frac{\text{Gross Margin} - \text{Marketing Costs}}{\text{Consumer Price}} \times 100 \quad (11)$$

Where, *GMM* is the gross marketing margin and *NMM* is the net marketing margin. For each actor along the value chains, gross margins were calculated using a one-season price (January 2020). This is because the price of *Eucalyptus* wood products significantly varies with time.

4.2.4. Selection and Prioritization of *Eucalyptus* Wood Products

Three consecutive meetings were carried out with *Eucalyptus* value chain actors to prioritize the major *Eucalyptus* forest products. Then, by setting the prioritization criteria and developing a ranking matrix, major forest products were identified. Farmers were able to prioritize the *Eucalyptus* forest products on the basis of their needs. Accordingly, the ranking matrices indicated that fuel wood, split wood, rod/*atana* and log were ranked in descending order. Accordingly, the analysis considered these products.

4.2.5. Wood Volume Estimation

Note that in order to estimate the amount of wood produced and transacted, the volumetric wood measurement method was used. There are different formulae for measuring wood volume which include the Smalian, Huber, Newton, centroid and two-end conic methods, each of which has its strengths and weaknesses depending on the dimensions of logs and forms of stem (FAO, 2012). We also employed the sectional volumetric method for quantifying the volume of stacked wood as explained in a study on manual and automatic volume measuring methods for industrial timber (Pasztory *et al.*, 2018).

4.3. Results

4.3.1. Characteristics of Growing Households

Table 13 below presents the characteristics of grower households. From the entire sample of *Eucalyptus* growers, 90% were male and 9.5% were female heads of household. The majority of respondents (89.9%) were found to be within the working age of 31 to 65 years, about 5.4% were under 31 years and only 4.6% were above 65 years. The average size of families was about six persons, which is a larger than the national average. Similarly, 48.5% of respondents could not read and write, 41% could read and write, 4.1% followed their education in religious schools, 5.2% were grade 1 to 6 and only 1.3% followed formal schooling of grade 7 to 12.

The findings reveal that the average land holding of growers was 1.51ha which is utilized for the production of food crops, the plantation of *Eucalyptus* and homestead gardening. The average annual income of households from *Eucalyptus* alone was found to be 28,237.17ETB, covering about 46% of the total annual income. The annual income from crop production was 16,117.35ETB, which constitutes about 26% of the total income. Income from non-farm activities (off-farm and remittance) and livestock rearing were found to be 10,576.92ETB and 6,775.19ETB, taking shares of about 17% and 11% of the total annual income of households respectively.

Table 13. Characteristics of the sample growing households

	Indicator	Value (N = 388)
Demography	Family size	6
	Dependency ratio (%)	64
	Age	48
	Gender (%)	
	Female	10
Male	90	
Literacy status	Can not read and write	7.42
	Read and write	40.98
	Religious school	4.12
	Grade 1–6	5.15
	Grade 7–12	1.29
	Land size (ha)	1.51
Farm resource and income	Average annual income (ETB) from:	
	Crop	16,117.35
	<i>Eucalyptus</i>	28,237.17
	Livestock	10,576.92
	Non-farm sources	6775.19

4.3.2. *Eucalyptus* Wood Production and Marketing

In the study area, *Eucalyptus* is the major source of cash earning. It is extensively planted by smallholder growers with a yearly expansion rate for various socioeconomic and environmental reasons and overall comparative advantage. Its fast-growing habit and quick return potential, its minimal management requirement and land administration regulation which permit the renting out land for up to 25 years are among the major driving factors for the expansion of *Eucalyptus* over crop lands.

The meaningful expansion trend of *Eucalyptus* plantations shows the existence of a surplus supply of wood in the study area. The top prioritized *Eucalyptus* wood products include construction wood/post, rod/atana, fuel wood, log and split wood. Table 14 below shows the mean production of *Eucalyptus* wood in the study area during the 2019/2020 production year.

Table 14. Average *Eucalyptus* wood production of growers (2019/2020) (m³)

Product Type	Average	St. Dev.
Pole/post	5155.97	2101.81
Rod (<i>Atana</i>)	5578.10	4136.82
Fuel wood	3999.93	1768.40
Log	4663.17	1693.27
Split wood	3546.46	584.64

Note: Rod/*Atana* = Entire thin wood from base to terminal with base circumference of 12 cm. Log = A large volume of *Eucalyptus* wood cut in a manageable size with average base circumference of 190 cm.

In the *Eucalyptus* wood market, there are no collective marketing decisions involved. As per the information obtained from key informants, self-initiative marketing decisions are made by growers and there is no collaborative market planning and price determination. *Eucalyptus* growers set prices to their wood lots and felled trees on the bases of type of trees and location (accessibility). Growers sell *Eucalyptus* wood at different stages of growth depending on its intended purpose (starting from thin rod wood to big size logs).

The results show that for rod/*atana*, the average time of the harvest is approximately 4–5 years (when it is harvested from the first stand the production will be halved when it is from coppice). For roofing, wall or fuel, it takes about 10 years. Production of logs however needs longer periods (about 15–25 years) in primary stands. Respondents confirmed that the time of harvest diminishes by half if the harvest is from coppicing. This is one of the reasons that made *Eucalyptus* the most preferred tree in the study area.

4.3.3. Characteristics and Roles of *Eucalyptus* Wood Value-Chain Actors

The *Eucalyptus* wood value chain actors can be identified along the chain, as shown in Table 15. They include input suppliers, growers, construction wood retailers, wood processors, fuel wood retailers, wood collectors, walling wood splitters, wood trading growers and final consumers. The results show that there were no significance differences among the traders' characteristics such as family size and age. Significant ($P < 0.01$) differences were observed in the volume of wood handled by actors.

Table 15. Summary of the characteristics and roles of *Eucalyptus* wood value chain actors

Value Chain Actor	Average Family Size	Average Age	Male/Female (%)	Volume of Wood Traded (M ³)	Supply Source	Market Destination	Main Activities of Actors	Total Cost Incurred (ETB/M ³)	Profit (ETB/m ³)
Construction wood retailers	4	34	100 (0)	1,025,557.10	Growers	Construction sector Wood trading growers	Collecting Sorting Retailing	128.89	409.22
Wood processors	5	43	100 (0)	4,663.17	Growers	Construction sector Furniture enterprises	Felling and log collection Lumbering Processing Selling	155.72	11,594.62
Fuel wood retailers	4	40	86 (14)	328,178.47	Growers	Fuel wood consumers	Splitting, arranging in bundles and retailing of fuel wood	120.32	2373.27
Wood collectors	5	39	66 (34)	40,236.23	Growers	Walling wood splitters Furniture enterprises	Felling Collection Splitting Selling	98.23	84.38
Walling wood splitters	6	44	100 (0)	123,067.31	Growers Wood collectors	House builders	Felling, Splitting, Retailing	163.03	2120.46
Wood trading growers	4	42	100 (0)	123,067	Own production and other growers	Construction sector	Sorting wood, resizing logs, splitting and arranging wood splits in bundles	37.77	17.26
F-value	6.01	4.13	—	18.66 ***					

*** indicate level of significance at 1% probability.

4.3.3.1. Input Suppliers

Public nurseries owned by the Ethiopian Ministry of Agriculture (district level agriculture offices) and private nurseries are the main supply sources of the white *Eucalyptus* (*Eucalyptus globulus*) seedlings in the study area. *Eucalyptus* seeds are collected from local sources (matured *Eucalyptus* trees) for both public and private nurseries. There are 4 public and 32 private nurseries in the sampled kebeles. However, public nurseries focus on the raising of fruit and other indigenous tree seedlings and private ones mainly engage in the raising of *Eucalyptus* seedlings.

Agricultural offices are responsible for providing expertise for nursery management and the raising of *Eucalyptus* and other tree seedlings. Both public and private nurseries sell their seedlings at spot markets with no pre-arranged contracts. *Eucalyptus* seedlings are usually distributed to growers at optimum prices with an average price of 0.50 ETB (Ethiopian Birr) with a lump sum cost of 5717.08ETB/ha. However, 32.0% of respondents confirmed that they utilize seedlings raised at their own nurseries while 66.2% obtain seedlings from public nurseries and only 1.8% was found to use seedlings from both nurseries. This is mainly because raising *Eucalyptus* seedlings requires little nursery management.

The majority of private nursery owners had access to nearby potential water sources and they were aware of raising seedlings in pots. For the simplicity of purchase process, farmers prefer privately grown seedlings over public ones. The main challenge with private nurseries is that seedlings from private nurseries exhibit a lower survival status in the field compared to public nurseries that raise

seedlings in pots. The challenge related to the public nurseries is that growers cannot obtain the number of seedlings they need as distribution is on the basis of a quota system.

4.3.3.2. *Eucalyptus* Growers

Cultivation of food crops complemented with livestock rearing is the dominant economic activity of growers in the study area. However, growers have shown a tendency to focus on plantations of *Eucalyptus* as wood lots. Focus group discussions held with respondent farmers indicated that this is mainly due to diminishing land productivity, the accelerating rise in demand for wood, the rapid vanishing of other natural wood sources, the depletion of livestock feed sources, reduced cultural/management requirements, a rapid growing tendency and existing land administration regulations. In addition, respondent growers confirmed that *Eucalyptus* has excellent area adaptability, a fast-growing tendency and multiple uses. *Eucalyptus* is becoming the most important livelihood supporting tree species in the study area.

4.3.3.3. Construction Wood Retailers

All of these actors could read and write and about 67% of them had followed formal schooling. They have a good communication with growers and consumers (especially construction companies and agents). They maintain smooth market information with phone communications. Discussions with key informants indicated that more than half of them have their own houses in towns and own about one hectare of land in rural areas. *Eucalyptus* wood trading is the main source of income for these actors. Information obtained during discussions with key informants showed that they owned an estimated initial capital ranging from 100,000 to 245,000 ETB.

Construction wood retailers are special actors who handle a large volume of *Eucalyptus* wood transacted in 2020/2021. The product they handle is for construction purposes that include roofing wood, construction poles, rod/*atana* and wood for structural frameworks and supports. The total volume of construction (roofing wood, walling wood and rod/*atana*) handled by these actors were estimated at 314,514m³ and 301,2017.20 m³, respectively. The majority of the wood transacted by these actors was consumed by the construction sector. Product destinations include construction sites (large building structural supports and frameworks, roofing frameworks).

For these actors, value addition begins with debranching which is practiced just following the felling of the forest stands. This will be followed by sorting the wood according to size and use such as roofing, poles, *atana*, etc. Sorting helps traders easily set prices depending on the type of product. Roofing wood is the most expensive of all wood product types in the study area. A single roofing wood (with a length of about 12 m and base diameter of about 21.2 cm) costs about 162 ETB. These products are highly preferred for their straightness and fitness to the proposed construction purpose, usually for commonly made non-concrete houses. Peeling/debarking is one of the most important value addition activities carried out by construction wood retailers. Peeling is usually performed immediately after felling the trees as it takes much labor to peel as the wood becomes drier. Poles dried without peeling have significantly lower prices than peeled ones.

4.3.3.4. Wood Processors

The entire sample of respondents could read and write and 65% confirmed that they followed formal schooling. These value chain actors started their business as small-scale enterprises and became medium level enterprises after 5–10 years of experience. Wood processors own wood processing machines. They transacted 4663.17m³ of logs on average and processed 1543.09m³ of lumber annually on average. Their products are designed for making lumber for construction, roofing structures, frame works, beds, office and home furniture and others. In addition to the primary products, about 363,463kg of sawdust is produced by wood processors on average as a byproduct which is consumed as a fuel source by traditional bakers and local drink processors.

These enterprises make different furniture products and produce lumber for construction inputs such as concrete frameworks. Previously, furniture products were made from indigenous tree species such as large-leaved cordia (*Cordia Africana*) and ebony (*Diospyros ebenum*). However, due to the successive degradation of natural resources in the study area, *Eucalyptus* is becoming the most popular and abundantly used raw material for wood processing enterprises. Large *Eucalyptus* trees with large volumes of wood (log) are in high demand from wood processing enterprises. The annual log consumption of wood processing enterprises in different towns is depicted in Table 16. Sawdust is an intermediary product in wood processing which is in high demand from *injera* (Ethiopian common dish) bakers and *araki* (locally made alcohol) processors. Of all the actors in the chain, log processors add the highest value to the products.

Table 16. Average log consumption and production of lumber and sawdust per processor per annum

Product Type	Quantity	Standard Deviation
Log consumed (m ³)	4663.17	1693.27
Lumber produced (m ³)	1543.09	917.23
Sawdust (kg)	363,462.90	101,267.01

Despite the emerging wood industries in the country, none of them are built around the study area. However, one push factor is that farmers are being informed about the huge wood demand of these factories in the future. This is another factor which initiated growers to expand *Eucalyptus* plantation beyond the needs of medium scale wood processing enterprises. For these actors, the value addition begins from cutting the logs into manageable sizes at the growers' site. The logs are then transported for debarking and stocking where they lose moisture to the desired level. In order to reduce the size of logs to a manageable size for machines, primary processing/partial removal of the external wood is performed manually at stock though it requires intensive labor. Logs are then processed to produce lumber by the required type and size.

Depending on the product type, packing may be important as is the case for the stacking of small size lumber for roofing and frameworks. Processed lumber is then ready for marketing which will be used for a variety of purposes including construction and furniture works. In terms of value addition, wood processors add the highest value to the product and incur the highest processing costs as compared with the rest value chain actors.

4.3.3.5. Fuel Wood Retailers

These actors play an important role in the fuel wood value chain in that they maintain a continuous supply of fuel wood to consumers, bridging the gap between the producers and fuel wood consumers. They handle approximately 328,178m³ of fuel wood annually.

As per the information obtained from group discussion, fuel wood retailers purchase *Eucalyptus* wood from two sources, *i.e.*, directly from growers and from wood collectors. When a purchase is made from the growers, an agreement is made between the grower and the trader by setting the prices of trees at stands. Then, felling, debranching, cutting to manageable sizes and sorting are the primary value addition activities performed by these actors. Sorted wood and branches are then stocked for retailing. Then, splitting is performed immediately after felling before the wood is dried. Wood splits for fuel purposes are cut into lengths of about 0.9m and stacked for retailing in large quantities (with trucks) or in small quantities using pack animals. When a purchase is to be made from wood collectors, value addition will start at the splitting of the wood which will be further packed in bundles (about 20 pieces of each 0.9m long).

4.3.3.6. Wood Collectors

Wood collectors are special actors who assemble various types of *Eucalyptus* wood for the purpose of retailing to different customers. They supply the collected wood to different consumers who utilize the product for the intended purposes (construction and fuel). The total volume of wood collected by these actors is estimated to be 40,236.23 m³. Wood collectors play a role in the smoothening supply of fuel wood sources especially. Trading and farming are the major income sources of wood collectors. Sorting, resizing and splitting are the main value addition activities of these actors.

4.3.3.7. Walling Wood Splitters

Walling wood splitters are urban dwellers who are specialized in selling split wood for walling and fencing purposes. These actors usually hire special labor for splitting the large volume of *Eucalyptus* logs. Their main role in the chain is supplying split wood which is mainly used for walling and fencing purposes. The estimated volume of wood handled by these actors is about 123,067.31m³ per annum. These actors purchase trees in the farmers' fields by selecting trees appropriate for splitting.

Once trees of the required age are purchased at farmers' fields, the felling, debranching and cutting of logs at the required sizes (usually 3.2 m) are the primary activities. Then, shortened logs will be split at the farmers' fields or after transportation depending on convenience. Walling wood is prepared by splitting logs at a length of about 3 m. Group discussions with *Eucalyptus* wood traders indicated that the price of a log on average doubles when it is made ready as split wood for walling and fencing. Split/walling wood is in high demand for the construction of house walls and fences. On average, a single piece of split/walling wood costs 30ETB.

4.3.3.8. Wood Trading Growers

These value chain actors are basically farmers with similar sociodemographic set ups as other growers but they support their livelihood with *Eucalyptus* trading. These actors purchase various types of *Eucalyptus* wood products from other growers at farm gate price for stacking and further retailing. Fuel wood and roofing wood are the main products transacted by these actors with an annual transaction volume of 123,067.31m³.

Wood trading growers play two major roles in the transaction process. On one hand, they have a role of linking growers to alternative market options year-round though their purchases are relatively little as compared to other traders. On the other hand, with their supply stocks, they make wood supplies available to consumers at any season. Value addition activities carried out by wood trading growers vary depending on the type of wood transacted. Sorting wood, resizing logs, splitting and arranging wood splits in bundles are the main value addition activities.

4.3.4. Governance and Business Enabling Environment

In general, government bodies are responsible for controlling the overall production and marketing systems with regulatory legislation such as regional land administration regulations (on the production side) and the Ethiopian Revenue and Custom Authority. We found that *Eucalyptus* growers have a limited voice and have little participation in the governance of the *Eucalyptus* value chain while construction wood retailers have the maximum control of activities, especially price determination, among the rest of the actors. This is because the time of tree felling depends on the needs of individual farmers who are forced to sell to buyers with less bargaining power. In order to minimize their marketing costs, construction wood retailers have the power to coordinate activities on the supply side, make choices about suppliers and claim about prices set by the growers.

Public nurseries are solely managed by extension agents who are employees of the Ethiopian Ministry of Agriculture until the distribution of seedlings to farmers, whereas extension agents provide expert advice to private nursery owners. On the industry side, small and medium scale enterprises and wood factories encourage the development of *Eucalyptus* forest resources as input for wood processing enterprises.

Growers obtain agro-chemicals both from government and private sources. From the government side, agriculture offices are responsible for distributing inputs such as fertilizers, seeds, herbicides and pesticides at predetermined prices. On the other hand, private agricultural input suppliers provide seeds, pesticides, herbicides and other inputs. Private agricultural inputs suppliers are usually preferred over public ones in terms of timeliness and ease of procurement.

As a regulatory system, taxes are formally levied from legal traders as per the formal tax laws on annual basis. In addition, the Ethiopian Revenue and Custom Authority is responsible for controlling trades transporting wood from place to place by levying fixed payments/taxes per volume of loaded truck at selected gateways. Land administration proclamation is another regulatory organ determining the performance the wood sector value chain.

Transportation is another important service for the best performance of the value chain. Product transportation from growers' point to consumers is carried out by private transport providers. Car (truck) transport is the main means of wood transportation in the study area. The most common vehicles providing transportation services are small and big trucks with a transport tariff of about 7ETB/22m³ wood/km. However, as potential growing areas are characterized by sloppy topographic features, they are not accessible for vehicles.

4.3.5. Mapping the Value Chain

In order to develop the final value chain map of *Eucalyptus* wood products, a two-phased process of developing the value chain map was carried out. Primarily, the basic initial mapping was carried out after discussions made with value chain actors during the first reconnaissance survey. Then, the final value chain map was completed by revising the initial map, considering ideas from group discussions and the interview with key informants.

In the value chain of *Eucalyptus* wood products, the interlinkage of activities of different types of actors was noticed. These include input suppliers, growers, construction wood retailers, wood processors, fuel wood retailers, wood collectors, walling wood splitters and wood trading growers. Along the value chain, each actor adds value for the respective product except growing farmers. From the entire product of *Eucalyptus* supplied by growers, the maximum share (50%) was taken by construction wood retailers followed by wood processors (22%) (Figure 9).

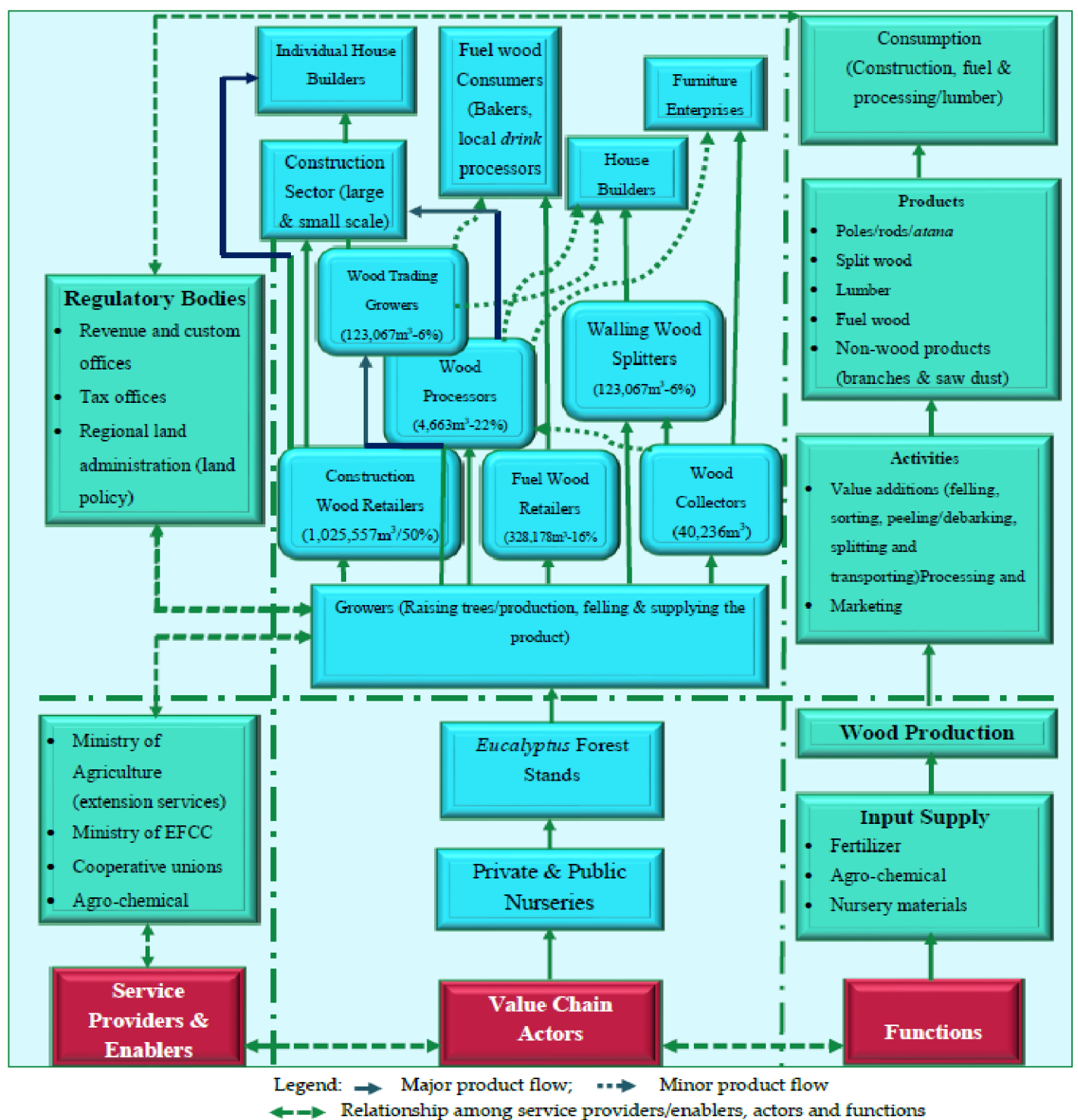


Figure 9. Value chain map of *Eucalyptus* wood products

Market channels were traced based on the direction of flow and volume of *Eucalyptus* wood transacted. *Eucalyptus* forest products were found to pass through seven channels. During the 2019/2020 production year, about 2,051,114.753m³ of *Eucalyptus* wood was produced in the study area and transacted through eight main market routes as depicted below.

From Figure 9 above, many market channels (flow directions) can be traced but eight main channels were developed depending on the intensity of volume of wood transacted.

- (1) Growers → Construction wood retailers → Construction companies
- (2) Growers → Construction wood retailers → Individual house builders
- (3) Growers → Fuel wood retailers → Bakers and local drink processors
- (4) Growers → Walling wood splitters → Wooden house builders
- (5) Growers → Wood collectors → Walling wood splitters → Wooden house builders
- (6) Growers → Wood processors → Construction companies
- (7) Growers → Wood collectors → Wood processors → Furniture enterprises
- (8) Growers → Wood trading growers → Individual house builders

In terms of the intensity of the volume of wood transaction, the highest volume of wood (about 50% of the total wood volume) is transacted through Channel 1 followed by Channel 6, which about 22% of the total volume of wood passed through.

On the basis of the volume of wood handled by actors, the largest volume of construction wood (314,514m³) was channeled from the growers' point to construction companies via construction wood retailers and this route was the leading channel of *Eucalyptus* wood transaction in the study area. Another product type of the construction wood, walling wood, had the second leading volume of 301,217.20m³ and was transacted in Channel 4. As seen in Figure 3, about 50% the total volume of wood transacted in the study area is construction wood.

Similarly, Channel 6 was the third leading route through which about 141,627.48m³ of wood/logs was transacted. In this channel, wood processors process logs to an intermediate wood product/lumber and supply them to construction companies and individual house builders. In this channel, an estimated volume of 47,835m³ of processed lumber was supplied to construction companies and other consumers. Fuel wood retailers are other dominant actors who transacted about 103,998m³ of fuel wood in Channel 3. The greatest volume of wood product handled by these actors directly purchased from growers and directly sold to bakers and local drink processors. Wood collectors transacted about 440,236m³ of wood in Channel 5. Wood collectors are special wood traders who purchase different types of wood products for stocking and retailing. Likewise, about 15,694.69m³ of wood was handled by wood trading growers. Wood trading growers are

basically farmers but specialize in marketing of different types of *Eucalyptus* wood products in relatively small quantities.

4.3.6. Marketing Costs, Profit and Profit Margins

Because of the variation in product types, the direction of product flow and the corresponding costs and margins are highly variable. Construction wood (roofing and walling), fuel wood, log and rods/*atana* are the primary *Eucalyptus* wood products considered in this study.

Due to significant temporal variation in the price of *Eucalyptus* wood products, one season (January 2020) was considered for each of the product types transacted along the chain. The price setting strategy for construction wood is carried out in two main ways. The first way estimates the number and size of *Eucalyptus* stands in farmers' fields. In this method of price setting, *Eucalyptus* stands with an estimated age of eight to ten years covering a quarter of a hectare with uniform spacing costs of about 52,000ETB.

In terms of volume, this is approximately as much as one and half of the volume of a fully loaded truck which has an estimated external volume of about 23m³. Therefore, the estimated volume of a *Eucalyptus* stand covering a quarter of a hectare is about 34.5m³. This implies that the unit price construction (roofing) wood is about 1,507.25 ETB/m³. On the other hand, when tree stands are sparsely populated with irregularities in size, the price is set by estimating the volume of the product. In the study area, a fully loaded truck (*Sino truck*) costs about 40,000ETB or 1,739.13ETB/m³. Then, by taking the average, the price of construction wood is 1,623.19ETB/m³. Similarly, the respondents confirmed that the average farm gate price of construction wood is 1,343.64ETB/m³.

In the process of transaction, each value chain actor incurs costs which are attributed to labor, transportation, processing, brokerage and electricity. The costs incurred by each actor are depicted in Table 17. Among the value chain actors, walling wood splitters incur the highest cost (163.03ETB/m³) followed by wood processors (155.72ETB/m³). The reason for the former was the utilization of tiresome manual labor for the splitting of logs for walling purposes and the reason for the latter was the processing cost of sawmills.

Wood trading growers incurred the minimum marketing costs (37.77ETB/m³). This is because these actors play the role of transferring the product from the grower to the consumer (usually to fuel wood consumers) with minimal contributions to value addition of the product.

Table 17. Average marketing costs of *Eucalyptus* wood value chain actors (ETB/m³)

Cost Item	Labor (Cutting, Peeling, Sorting, Piling, Processing)	Loading and Unloading	Transport (ETB/Km)	Brokerage	Electricity	Total (ETB)
Construction wood retailers	5.39	13.93	8.89	100.68	-	128.89
Fuel wood retailers	4.60	14.49	9.61	91.62	-	120.32
Wood processors	28.52	25	9.23	85.68	7.29	155.72
Walling wood splitters	55	14.24	11.29	82.50	-	163.03
Wood collectors	9.47	23.73	18.78	46.25	-	98.23
Wood trading growers	8.36	2.09	7.32	-	-	37.77

Profits were then calculated by deducting the total cost incurred by each actor along the value chain from the selling price. The results showed that producers took the highest profit of all value chain actors. The maximum (2373.27ETB/m³) profit was taken by fuel wood retailers in Channel III followed by walling wood splitters (2120.46ETB/m³) in Channel IV. On the contrary, wood trading growers were found to take the least (17.26ETB/m³) gross profit in Channel VIII. The extent of variation in profit might be attributed to the degree of values added to the wood product and cost associated with the process of value additions within the chain (Table 18).

Table 18. Profit obtained by actors (ETB/m3)

Value Chain Actors		Market Channels							
		I	II	III	IV	V	VI	VII	VIII
Construction wood retailers	Purchase price	1343.64	1343.64						
	Marketing cost	128.89	128.89						
	Selling price	1815.59	1881.75						
	Gross profit	343.09	409.22						
Wood collectors	Purchase price					1343.64		1343.64	
	Marketing cost					98.23		98.23	
	Selling price					1486.45		1526.25	
	Gross profit					44.58		84.38	
Wood processors	Purchase price						1343.64	1486.45	
	Marketing cost						155.72	155.72	
	Selling price						13,236.79	13,236.79	
	Gross profit						11,737.43	11,594.62	
Walling wood splitters	Purchase price				1424.22	1486.45			
	Marketing cost				163.03	163.03			
	Selling price				3707.71	3707.71			
	Gross profit				2120.46	2058.23			
Fuel wood retailers	Purchase price			1343.64					
	Marketing cost			120.32					
	Selling price			3837.23					
	Gross profit			2373.27					
Wood trading growers	Purchase price								1176.26
	Marketing cost								37.77
	Selling price								1231.29
	Gross profit								17.26

The gross profit margins were calculated to see the share of each value chain actor from the profit earned. As depicted in Table 19, wood processors take the highest gross margin (88.67%) in Channel VI followed by the same actors in Channel VII (87.59%). The variation in gross margins is attributed to the values added at each segment of the chain. Among the different actors along the chain, we found that wood processors add significant values for the product. This indicates that the addition of value to *Eucalyptus* wood products significantly increases the share of return, calling a serious look for the emergence of wood processing enterprise, which can create good job opportunities for the increasing number of unemployed youth in the area.

Table 19. Marketing margins of value chain actors (%)

Marketing Margin	Market Channels							
	I	II	III	IV	V	VI	VII	VIII
Gross margins								
Construction wood retailers	18.90	21.75						
Wood collectors					3.00		5.53	
Wood processors						88.67	87.59	
Walling wood splitters				57.19	55.51			
Fuel wood retailers			61.85					
Wood trading growers								1.40
Producers' share	25.99	28.60	64.98	61.59	59.91	89.85	88.77	4.47
Net marketing margin								
Net margins								
Construction wood retailers	11.80	14.89						
Wood collectors					3.61		0.91	
Wood processors						87.49	86.42	
Walling wood splitters				52.79	51.11			
Fuel wood retailers			58.71					
Wood trading growers								1.67

4.3.7. Challenges and Opportunities

4.3.7.1. Challenges

Eucalyptus plantation sites in the study area are mainly characterized by rugged topographic features. Because of this, many of the potential *Eucalyptus* growing locations are not accessible by all-weather roads which are among the major challenges for growers. Growers' feedback revealed that *Eucalyptus* products from inaccessible locations are subjected to significantly increasing labor costs for cutting and transporting to accessible locations. In the study area, *Eucalyptus* lots are being sold during the dry season (usually from December to April) as the dry season allows the movement of trucks by cultivable lands.

Despite the growing potential of the area in robust production of *Eucalyptus* wood, the majority of products are mainly consumed with little value additions due to absence of large-scale wood processing factories in the area. The only available wood processing enterprises are small-scale sawmills that focus on the production of lumber and related products. The absence of large-scale timber processing industries and wood impregnating machines (to overcome termite susceptibility of construction wood) impede the development of the wood sector value chain. The findings of our study show that these actors took the highest net marketing margin as they are the only ones who add the highest value for the product. This shows that the more the values added in the transaction process, the higher will be the profit margin that is obtained by the respective value chain actors.

When a farmer plants *Eucalyptus* on his plots, farmers owning neighboring plots claim shade effect of the forest and diminishing fertility status of the plot in the vicinity of the forest which lead

leads to land use conflicts. This condition has resulted in the expansion of *Eucalyptus* forests each year. Such challenges are usually seen to trigger social crises and disagreement among growing farmers, who are different in two scenario choices, *i.e.*, the plantation of *Eucalyptus* versus crop production (Figure 10).



Figure 10. Newly planted/5 months old (left) and a week old (right) *Eucalyptus* stands in the middle of teff and wheat lands, respectively. Photo by researcher (2020).

Discussions with key informants also indicated that households with non-farm income sources (those residing in towns) plant *Eucalyptus* in rented lands using the current land use policy (that allows land rent for up to 25 years) as an opportunity. According to the revised Amhara National Regional State Rural Land Administration and Use Proclamation (133/2006), any land holder may transfer his/her use right in rent to any person. Because of the prevailing challenges, farmers in the neighborhood will be obliged to change their crop lands to *Eucalyptus* stands.

The current land administration proclamation permits land ownership transfers by rent up to 25 years. This was favored especially by landless farmers to rent land as much as they can and plant *Eucalyptus*. In addition, even though this policy allows the utilization of arable land for proper utilization only, farmers intensively plant *Eucalyptus* regardless of the fertility status of their plots. The trend of succession of arable lands with *Eucalyptus* may result in a crop production deficit.

Focus group discussions with growers revealed that households with insufficient family labor and alternative non-farm incomes convert their fertile crop lands to *Eucalyptus* and possess larger plots of *Eucalyptus*. This is because *Eucalyptus* requires relatively less labor for cultural management. We found that *Eucalyptus* in the study area is expanding over crop lands at a rate of 102.35 ha per year which is now becoming a threat for fertile crop lands. Information obtained from key

informants indicated that there is lack of coordination to work towards commercializing the *Eucalyptus* wood value chain. The sector's value chain is characterized by asymmetric market information among all stakeholders (input providers, enablers, controlling organizations) and actors. The *Eucalyptus* wood value chain is also characterized by a lack of sectoral integration among actors, especially between growers and wood processing firms. Because prices vary across locations, we found a high disparity in marketing margin shares among actors.

We found that a number of unlicensed wood traders were involved in the *Eucalyptus* wood value chain. Unlicensed traders purchase at different towns for resale. As the information obtained from key informants, there are no control mechanisms that restrict individual unlicensed wood traders. These traders handle *Eucalyptus* wood in small quantities and sell at relatively lower prices than licensed ones and create price distortions. We found that unlike cash commodities such as horticultural and oil seed crops, institutional programs that support the *Eucalyptus* wood value chain development are absent in the study area.

4.3.7.2. Opportunities

One of the aims of the second Ethiopian Growth and Transformation plan was to make the country a middle-income category. To assist this, there is a strategy to support small and medium-scale enterprises to involve in the industry sector. This favors the emergence of wood processing factories which in turn increases the demand for *Eucalyptus* wood in the area.

In the study area, natural forest cover areas have been reduced significantly owing to deforestation and *Eucalyptus* plantation is the only option to meet the rising wood demand of consumers. The existing natural forests have already been vanished and *Eucalyptus* is the most economical forest that fulfills the demand for construction wood, firewood, log, and split wood. Following the rapid emergence of wood processing companies, raw wood materials became increasingly important and farmers focused on the massive production of *Eucalyptus*. Currently, *Eucalyptus* is used as a major means of cash earning including its leaves and branches.

The costs of transport in transacting *Eucalyptus* forest products are mainly posed on the buyer side. Retailers buy *Eucalyptus* stands at farm gate price and ship the entire products to their points of destiny. This has favored growers as it reduces the cost of cutting, sorting and shipping the product to the targeted market centers. However, growers could sell their product with added value.

Because of the spectacular rise of the construction sector in the country, demand for the respective construction inputs (*Eucalyptus* wood) is rising. Currently, *Eucalyptus* wood is used by both wooden and concrete house builders as a direct construction material and as support structures, respectively. This has ensured sustainable *Eucalyptus* wood products market opportunities that assimilate the product throughout the country.

In Ethiopia, fuel wood consumption is by far higher than the consumption of electricity. The immense fuel wood requirement by both rural and urban people is one of the main reasons for the rapid expansion of *Eucalyptus* as wood lots. Today, it is a common practice for every farmer in the study area to transport and sell fuel wood every market day. This has immense contribution to growers in terms of supporting their livelihoods.

Eucalyptus favorably grows both in highland land mid-altitude areas. As the study area has a suitable highland ecology, the white *Eucalyptus* (*Eucalyptus globulus*) grows well. On average, *Eucalyptus* takes about 5 years from seedling to nursery and 4 years from coppicing to become an economically important product (mainly for construction wood). In spite of environmental variations, this is a very quick time of return compared to other types of trees.

4.4. Discussion

The results presented in this study highlight contemporary value chain perspectives towards improving the performance of the wood sector value chain as stated in the standard approach of Porter (28) for creating market competitiveness and values in business enterprises. The methods were also devised in different studies (Stakova *et al.*, 2020; Kaplinsky and Morris, 2001; Bocken *et al.*, 2015). *Eucalyptus*, an economically important multipurpose plantation tree, is now extensively planted by smallholder growers. It is the major source of income for smallholder growers next to food crops in the study area where there is an increasing population, diminishing percapita landholdings and a subsequent decline in the productivity of food crop lands (Hailemichael, 2012; Alemneh *et al.*, 2019).

For its comparative economic advantage, farmers are converting their crop lands to plantation of *Eucalyptus* stands. As the result indicates, the reasons are diminishing land productivity, the accelerating rise in demand for wood products, rapid elimination of other natural wood sources,

depletion of livestock feed sources, lesser cultural/management requirement, rapid growing tendency and existing land administration regulations which has no land use restrictions for *Eucalyptus*. Respondent growers also confirmed that *Eucalyptus* has excellent area adaptability, a fast-growing tendency and multiple uses which incentivized them to focus on its plantation. These conclusions are in line with the studies (Hailemichael, 2012; Zerga and Berta, 2016; Getaneh, 2010).

Like that of the supply side, demand for *Eucalyptus* wood products is significantly increasing due to increasing market opportunities. The construction sector which utilizes an ample amount of *Eucalyptus* wood products is growing rapidly (Vance *et al.*, 2014). On the other hand, there are increasing numbers of small-scale enterprises that are engaged in the furniture industry which positively contribute to the growth of the sector. The study found that *Eucalyptus* provides a huge amount of biomass-based energy sources to grower households in the study area to support their daily lives. This is in line with the findings of Ullah *et al.* (2021) who examined the impacts of fuelwood and timber consumption on the livelihood of households in Pakistan. Situation analysis of report of the National Forest Sector Development Program of Ethiopia (2018) indicated that fuel wood is the largest source of wood-based production and consumption.

Generally, sustained production of *Eucalyptus* wood from the supply side and the growing market opportunities for wood products on the demand side can be taken as enabling opportunities for the development of the wood sector value chain in the study area. Given the production and market opportunities for *Eucalyptus* wood, little attention is given to the development of the wood sector value chain and systems that empower growers and other actors for increasing competitiveness are absent in the study area while the issues are call for thoughtful policy attentions.

Grower households are the ultimate suppliers of all the wood products transacted along the value chain. Unique to this study is that it forecasted the yearly expansion rate of *Eucalyptus* lands in major *Eucalyptus* growing areas as a means of identifying sustainable supply in the study area. The results show that *Eucalyptus* is succeeding crop lands at an alarming rate depicting a steady supply of *Eucalyptus* wood in the potential growing areas. As indicated in a study by Semane *et al.* (2013), the white *Eucalyptus* grows well in the area while the fertility status and productivity of crop lands are declining. This implies that growers suffering from decline in productivity of food crops can support their livelihood with *Eucalyptus* as an alternative income source provided that

there are good market opportunities for the product. The study also quantified the estimated volume of different types of wood products that were channeled from production to ultimate consumption and quantified the estimated volume of wood handled by each actor.

Input suppliers such as agricultural offices and cooperative unions, farm centers and pesticide/herbicide retailers are limited to only supplying seedlings and agro chemicals to nursery owners and other growers. Unlike food crops, production incentives from the enablers and input providers side is so weak to the wood sector and because of this plantation programs are usually based on the farmers' own initiatives.

The study also identified the main actors involved in *Eucalyptus* wood value chain together with their main activities. The study also traced eight important channels of the wood market and mapped the *Eucalyptus* wood value chain. Of all actors involved, construction wood retailers handled the largest volume wood and exhibited trade dominance in the value chain. Relative to other actors, construction wood retailers have a good supplier–buyer relationship and have better market opportunities due to the spectacular rise in the construction sector and the increase in the price of metal structures for construction which has created increased demand.

A similar finding was reported by Iqbal (2021) who presented the increasing need for tall wood buildings in the world following population growth and urbanization. Sawdust is an important byproduct produced during wood processing which can also be taken as a good opportunity for the production of particle boards. A study by Boruszewski *et al.* (2021) indicated the significant market share and economic contribution of the wood-based panel production in Poland. In Ethiopia, the demand for furniture products is increasing and this has subsequently resulted in the emergence of small-scale wood processing enterprises. The furniture industry is one of the large businesses in the world. By 2000, it was recorded as the largest low-tech sector with total global trade contributing about 57.4 billion dollars (Sutarmin and Jatmiko, 2016).

Margins calculated for each actor were found to be distributed unequally. The result showed that the highest margin shares were taken by wood processors and margin values corresponded to the values added to the commodity which indicates a need for incentivizing actors to engage in addition of values employing better wood processing technologies. In the *Eucalyptus* wood value chain; there is a relational type of governance with a general control system from the government

bodies, mainly the Ethiopian Revenue and Custom Authority which have the power of control of the product's formal transactions and the land administration proclamation that has the autonomy on the land for production. The interrelationship between enablers and actors however was not harmonious while collaboration is very important strategy for business performance (Strakova *et al.*, 2020). The study shows that the interrelationship among enablers, actors and service providers in the *Eucalyptus* wood value chain is characterized by a lack of horizontal and vertical integration which can be taken as an indicator of the sector's weak performance that demands a strong focus (Bedeley *et al.*, 2018; Krykavskyy *et al.*, 2015).

The study identified the key challenges of the wood sector value chain such as the lack of all-weather road networks, the involvement of unlicensed traders, the negative externalities of the *Eucalyptus* plantation (Mengistu *et al.*, 2020; Sasikumar *et al.*, 2002) and good growing opportunities such as the ability of the tree to thrive on marginal lands. This calls for attention for changing the land use proclamation for advocating plantation of *Eucalyptus* on marginal lands for ensuring optimal land use at a win-win scheme in the absence of socio-economic crisis. A similar rationalization was given by Boruszewski *et al.* (2021) which determined the potential of land for fast growing tree plantations in Poland considering marginal agricultural lands.

The study presents the status of *Eucalyptus* wood value chain which needs to be promoted for the inherent transformation of the wood sector in main *Eucalyptus* growing areas based on empirical evidence and actual data. Despite the plantation/production and market opportunities, the wood sector has unexploited potential for assimilating the immense labor force with a paramount economic contribution (Lazaridou *et al.*, 2021). By its very nature, the sector demands the introduction of large scale wood processing industries and thus prevailing conventional wood production and timber processing system in the study areas need to be strengthened and replaced with better wood processing technologies that ensure high value additions to the product and commercialization of the sector. Authors of this study are however, aware that the findings of the study are not without limitations, which include the unavailability of empirical evidence that deal with the specific *Eucalyptus* wood value chain and the very vast nature of the sector. The authors believe that this study paves the way for future research directions in the wood sector value chain.

4.5. Conclusions

This study provides important insights into the performance of the *Eucalyptus* wood value chain in potential *Eucalyptus* growing areas of the Blue Nile highlands of Northwestern Ethiopia. In a subsistence economy where the livelihoods of farming communities rely on the cultivation of food crops, *Eucalyptus* is an economically important short rotation tree which can improve the competitive performance of smallholder growers. The development of the wood sector value chain makes an immense contribution to the improvement of business performance and thus the empowerment of value chain actors deserves serious program attention as its ripple effects on the economy are apparent.

The study found that the *Eucalyptus* wood value chain is challenged by a lack of policy focus, a lack of sectoral integration, missing infrastructure in the vicinity of growers, the absence of growing industries in the wood sector and a high disparity in the margin shares of actors from the final product price featuring weak performance of the sector. The study showed that *Eucalyptus* accounts for the highest proportion of households' income next to food crops. Due to the decline in the food crop productivity of cultivable lands, growers are intensively planting *Eucalyptus* as a primary economic tree with the surplus production of multipurpose wood. The steadily expanding rate of *Eucalyptus* over crop lands is an indicator for the presence of sustainable wood supply in the area which needs to be commercialized. A large volume of *Eucalyptus* wood is harvested and transacted annually which was conveyed in eight main channels. The highest share of the total volume of wood transacted was consumed by the construction sector with little value addition and only a small portion by small scale wood processors.

To the other end, the wood sector value chain has attracted little interest and is characterized by the lack of multi-sectoral coordination. Enabling growers and other actors by creating market coordination with large scale wood processing factories and wood value addition technologies (such as wood impregnating) can improve the *Eucalyptus* wood value chain, thereby ensuring sustainable product markets and the improved livelihood of growers.

Product surplus and rising market opportunities for the wood products indicate that the sector has the potential of assimilating the qualified and immense workforce in the country. Despite the tremendous production and existence of continuous supply of *Eucalyptus* wood products in the study area, product destinations are only limited to construction and fuel wood consumers. Modern

wood processing factories that can convey the products through substantial value additions are absent. The only wood processors are small scale sawmills that mainly process timber for construction purposes. The investment policy of Ethiopia shall give priority to the development of the sector through integrating small and medium scale enterprises and large-scale wood processing industries with *Eucalyptus* growers and encourage investors to launch large scale wood processing industries such as chip wood, plywood, and paper factories which can improve value creations and market opportunities in the study area.

The existing traditional wood production and timber processing system in the region should be augmented with better wood processing technologies that ensure high value additions to the product and help commercialization of the sector thereby contributing to substitution of huge lumber imports in the country. For this, there should be a policy initiative from the government that encourage investment options which focus on processing of *Eucalyptus* forest products such as wood processing factories with significant value additions.

The rising demand for construction and fuel wood, permitting land policies and the decline in crop productivity of arable lands have contributed to the rapid expansion of *Eucalyptus* in the study area. This poses a threat in the future as crop lands may significantly diminish, resulting in the enormous decrement of crop produce in the region. This demands a land policy permitting plantation of *Eucalyptus* and crop production at *Pareto-optimum conditions* (i.e., plantation of *Eucalyptus* on marginal lands and without compromising the benefits of plot owners in the neighborhood and the public).

In terms of trade benefits, construction wood retailers who handle the largest volume of wood were found to have the highest bargaining power among the rest actors. On the other hand, the highest marketing margins were taken by wood processors depicting that the more the values added at each segment of the chain, the more will be the margin obtained by the respective actor. However, the *Eucalyptus* wood products market is characterized by the involvement of unlicensed traders who entertain at the expense of growers and licensed traders. Thus, the Revenue and Custom Authority should pose restrictions on product transportation and handling on those who have no legal trade licenses.

Land use conflicts arising due shading effects of trees rapid succession of crop lands and revising existing land policies and land use system, encouraging emergence of wood processing enterprises and posing regulatory measure on unlicensed traders are exemplary measures for promoting well developed *Eucalyptus* wood value chain in the study area and thereby sustaining livelihood of smallholder farmers that are dependent on *Eucalyptus* wood products.

Growers have a limited voice and participation in the value chain governance structure of *Eucalyptus* wood products. In addition, the absence of control mechanisms and institutional programs supporting the development of the sector's value chain are also prevailing challenges which demand the entrustment of responsibility to governmental and non-governmental institutions that will ensure sustainable wood production, good integration among enablers, growers and actors, commercialization of the wood sector and development of sustainable wood value chain.

CHAPTER 5: ESTIMATING THE ECONOMIC VALUES OF RESTRICTED MONOCULTURE *EUCALYPTUS* PLANTATIONS: A CHOICE MODELLING APPROACH

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Abstract

Today, evaluating ecological wellbeing and ecosystem services is becoming a great concern towards conserving the natural resource base. Healthy functioning ecosystems have fundamental roles for aiding humankind to lead a healthy life and ensure an improved social welfare. Estimating the non-market benefits of ecosystem services can help experts and the public to frame policy directions for landscape development. The ecosystem of the Eucalyptus growing highlands of northwestern Ethiopia, where this study was carried out, provides services that are essential to changes in the life of the society and biodiversity. In recent years, however, the ecosystem is facing a serious threat from intensive monoculture plantations of Eucalyptus which resulted in transformation of the cultural landscapes and a loss of biodiversity. Thus, the current study examined the preferences of residents and estimated their willingness to pay (WTP) for the proposed ecosystem improvement programs using a Choice Experiment approach. Data were aggregated from 388 residents using a questionnaire survey in January 2020. The survey contained ecological improvement schemes and a hypothetical event by which respondents expressed their willingness to pay a yearly utility fee as a compensation for the improvement programs. Results showed significant differences in resident preferences towards the proposed ecological improvement attributes. The findings also indicated that the socioeconomic backgrounds of residents such as income, family labor and age contributed for the heterogeneity in their WTP for ecological improvement schemes. Accordingly, the marginal willingness to pay of residents was USD 205/ha/person/year for the respective ecological improvement attributes. The findings suggest that policy makers should consider such attribute-based public preferences while planning landscape development and conservation programs. This study can provide vital policy implications and contribute to knowledge as it presents how the non-market valuations of ecosystems help maximize social welfare. Accordingly, the Ministry of Agriculture and Environment, Forest and Climate Change should focus on increasing plantations of other tree species and reducing Eucalyptus plantation areas.

Keywords: *choice experiment; Eucalyptus; monoculture plantations; non-market benefit; marginal willingness to pay*

5.1. Introduction

The northwestern highlands of Ethiopia have a dynamic ecosystem, which experiences intensive farming practices involving cultivation of food crops and plantations of *Eucalyptus* that sustain the livelihood of smallholder growers. Increasing population together with intensive traditional

farming has resulted in degradation of the natural environment. The decline in productivity of crop lands has aggravated the rapid conversion of crop lands and pushed farmers to shift to plantation growing of the most rewarding tree genera, *Eucalyptus*. Today, *Eucalyptus* is among the most economically important for short rotation plantations as an option tree for biomass and fiber production (Baum *et al.*, 2009; Bayle, 2019). *Eucalyptus* was introduced to Ethiopia in the second half of the 19th century for the rising demands of forest products for construction and fuel (Teketay, 2001).

There are different reasons for the expansion of *Eucalyptus* in Ethiopia. The first and most prominent reason is the absence of native tree species that can be grown alternatively with equivalent economic contributions similar to *Eucalyptus*. Indigenous and other exotic forest stands, such as *Cordia africana*, *Juniperus procera*, *Podocarpus falcatus*, *Olea europaea*, *Acacia decurrens*, and *Cupressus* species, have limited growth and production capacity compared to *Eucalyptus* (Abebe and Tadesse, 2006). Another positive attribute of the tree that drive the expansion of *Eucalyptus* use, is its vigorous growing habit, high potential for coppicing, high yielding potential in short rotations, and the provision of fiber and energy sources suitable for a variety of uses (Mekonnen *et al.*, 2007; Birru *et al.*, 2013; Zalesny *et al.*, 2011; Jagger and Pender, 2003). The tree exhibits important traits, such as a lesser labor requirement (9,10) and higher water use efficiency (Albaugh, *et al.*, 2013; Toledo *et al.*, 2019; Maie *et al.*, 2017) that help make it an excellent biofuel crop (Gonzalez *et al.*, 2011).

Despite its economic and social benefits, there is a growing concern regarding the negative ecological attributes and invasive nature of the tree, which can be considered as one of the greatest threats to biodiversity and the provision of valuable ecosystem services (Burgiel and Muer, 2010). Different studies have criticized the tree for its ecological challenges, including for its invasive behavior Forstmaier *et al.* (2020), impact on soil health, depletion of ground water, depletion of nutrients, suppression of undergrowth and subsequent reduction in species in neighboring crops (Mengistu *et al.*, 2020). *Eucalyptus* also depletes ground water, which aggravates watershed degradation (Sazikumar, 2002). Different studies have evidenced that the same traits that make *Eucalyptus* a highly productive crop may contribute to its potential to be an invasive species (Raghu *et al.*, 2006). *Eucalyptus globulus* is the most widely grown and well-adapted non-native tree species in the study area. Non-native species have the potential to influence the composition, structure, and function of ecosystems where they are introduced Mooney (2006) and Becerra (2006), and numerous reports suggest that species of *Eucalyptus* are capable of invading ecosystems across the world (Forsyth *et al.*, 2004; Larcombe *et al.*, 2013). *Eucalyptus globulus* has been introduced and become established in five different countries with climates ranging from shrub lands to forests and resulted in the understory exhibiting decreased height and species richness (Becerra *et al.*, 2018).

Aside from the economic and social benefits, there are scientific debates regarding the negative ecological impacts of *Eucalyptus* and its expansion as a monoculture plantation. The introduction of *Eucalyptus*, as an alien genus to a new area, has serious invasion risks on biodiversity and ecosystem. Forstmaier *et al.* (2020) reported the negative ecological impact of *Eucalyptus* and its

invasive behavior on the ecological wellbeing. Various studies have also reported the negative impact of *Eucalyptus* on soil and biodiversity, with evidence that *Eucalyptus* can drain water resources, aggravate soil erosion, suppress undergrowth, deplete soil nutrients, and induce allelopathic effects (FAO, 2009). Studies of Bayle (2019), Mengistu *et al.* (2020) and Sasikumar *et al.* (2002) have reported that *Eucalyptus* has allelopathic effects around the root zones of the neighboring crops and ecological impacts due to its shading effect under and near the tree canopy. A study by Lopez (2015) has reported a change in native Californian ecosystem processes following the invasion of the local landscapes by *Eucalyptus globulus*, which resulted in reduction in biological diversity due to the displacement of native plants and wildlife habitats. Teketay (2001) has also reported a similarly conclusion that showed a lower herbaceous species richness in *Eucalyptus* plantations than in indigenous forest stands.

Given the positive economic attributes and negative ecological impacts of the tree, the natural forests in these areas have been eliminated and replaced with a monoculture of *Eucalyptus* plantations exposing ecosystem vulnerability and challenges to the long-term ecological sustainability. Ongoing land degradation, climate change, ocean acidification, and land cover changes are reducing the quantity and quality of ecosystem services being provided globally (Costanza *et al.*, 2011). A study by Ali *et al.* (2021) showed the impact of climate change on many organisms in different ecosystems. He found that annual mean precipitation was a key determinant of suitable habitat for ungulate species. Townhill *et al.* (2022) also indicated that pressure on the Arctic species and the ecosystem was a result of human activities.

Practical evidence shows that the ecosystem of the *Eucalyptus* growing highlands of northwestern Ethiopia has been disturbed. This includes a near to complete replacement of the natural forests, conversion of crop lands to *Eucalyptus* plantations, and the establishment of a monoculture *Eucalyptus* plantation over most of the area. This apparently threatens the existing natural ecosystem that has provisioning, regulating, cultural, and supporting services (MESA, 2005).

To restore the natural ecosystem in the study area with Pareto efficiency land resource management, designing improvement programs for the restricted plantation of *Eucalyptus* would be of paramount importance. Natural resource management interventions by rational land use strategies are very important to control the rapid expansion of *Eucalyptus*, which can pose burdens on ecological wellbeing. In addition, it would be very important to estimate the economic value of restricted plantation areas of *Eucalyptus* and residents' willingness to pay for the designed ecological improvement programs in the study area. It is possible to estimate the non-market benefits of restricting the expansion of *Eucalyptus* in economic terms and to examine the possible directions for supporting the conservation of ecological biodiversity that are preferred by people in the conservation strategy.

We employed a Choice Experiment (CE) method, which was selected as the most suitable technique to analyze people's choice for its wide application for valuing environmental goods and services. The CE method is appropriate for analyzing choice to exploit the *Eucalyptus* growing highlands of the Northwestern Ethiopia and identify values on this basis.

The method has already been successfully applied in many different wetland settings and has the advantage of being able to generate multiple value estimates from a single application. Many scholars including Bennett and Blaney (2001), Hanley *et al.* (2001) and Hensher *et al.* (2005) have applied a CE for analyzing their studies. A CE has been widely used for analyzing people's choice regarding wetland ecosystem improvements and providing policy suggestions including studies in USA and Canada (Smith *et al.*, 2009), in Australia and Tasmania (Kragt and Bennett, 2009) and in Vietnam (Nam Do and Bennett, 2007). Other studies, like Luisetti *et al.* (2008) used the same approach to examine readjustment of coastal policies in England.

The study hypothesized that the expansion of areas of monoculture *Eucalyptus* plantations in the *Eucalyptus* growing highlands of northwestern Ethiopia would impact the ecological wellbeing and that these ecological challenges can be overcome through designing appropriate ecological management programs. Hence, the main aim of this study was to contribute to these ecological improvement programs through estimating the economic value of restricted plantation areas of *Eucalyptus* in the study region. In addition, the study was intended to estimate residents' willingness to pay for the ecological improvement schemes.

The study presents policy suggestions for addressing the challenges to ecology and biodiversity due to the establishment of *Eucalyptus* monoculture plantations. It also provides rational strategies to policy makers for the possibility of ensuring the ecological sustainability and biodiversity conservation in the study area. In contrast to studies including Hanley *et al.* (2001), Hensher *et al.* (2005) and Kragt and Bennett (2009), which mainly utilized CE for the conservation of conserved areas, the current study faced challenges in designing hypothetical attributes and conceptualizing them regarding restricting the expansion of *Eucalyptus*. However, using the same approach as for the restriction of such invasive species was taken as a good opportunity and exception for this study. Good awareness of most of the respondents to the negative impact of *Eucalyptus* is another opportunity. The problem, however, demands continuous policy efforts for ensuring ecological wellbeing and biodiversity conservation.

5.2. Materials and Methods

5.2.1. Study Location

This study was carried out in the *Eucalyptus* growing highlands of northwestern Ethiopia (Figure 1). Geographically, it extends from 10°21'23.59"–10°37'28.05" N, 37°40'25.95"–37°53'09.02" E. The area is characterized by diverse agro-ecology with an altitude ranging from 2500 to 3900 meter above sea level. Generally, a cool humid and sub-humid climatic zonation characterizes the area with unimodal rainfall, average annual rainfall ranging from 1000–1700 mm, and an average annual temperature of 18 °C. The area had a total population of 2.45 million in 2014 with an average population density of 89 persons per square kilometer. The vast majority of the population in the zone (86.5%) lives in rural areas where agriculture is the predominant economic activity (EIAR, 2021).

In terms of ecological setup, the area is characterized by distinct landscape features with slopes ranging from nearly flat to very steep (greater than 45%). Most of the land is used for the

cultivation of food crops, while monoculture *Eucalyptus* plantations make up the next highest share. Commonly grown food crops in the area include maize, teff (*Eragrostis tef*), wheat, potato, barley, and beans. *Eucalyptus globulus* is the widely planted species for monoculture plantations in the study area (Simane, *et al.*, 2013).

5.2.2. Choice Modeling

Choice modeling is a popularly applied technique in various fields for estimating the passive use value of environmental goods. It is a random utility model that can be used to explore the marginal willingness to pay for all the attributes and levels (Shoyama *et al.*, 2013). The technique was originally developed from conjoint analysis and differs from it in that instead of rating or ranking, it asks respondents to choose one alternative from each of the alternative choice sets, and in this way, it differs from contingent valuation, which focuses on valuation of a specific trade-off.

McFadden (1974) defined different choices in a situation as alternative choices, or simply alternatives and every choice is made from a set of alternatives. The environment of the decision maker determines the universal set of alternatives, but single decision makers do not consider all alternatives. In a choice experiment (CE) method, respondents are presented with a series of alternatives, differing in terms of attributes and levels, and are asked to choose the most preferred one. A baseline alternative, corresponding to the 'status quo' or 'do nothing' situation, is usually included in each choice set. This is because one of the options must always be in the respondent's currently feasible choice set to be able to interpret the results in standard welfare economic terms.

A CE has many advantages over the contingent valuation method. It is easier to estimate the value of the individual attributes that make up an environmental good. In the contingent valuation method (CVM), the value of individual characteristics of the good will not be estimated and thus estimation is made for the environmental good or services as a whole (Alpinzar *et al.*, 2001; Hanley *et al.*, 2004). A CE provides the opportunity to identify the marginal values of attributes, which may be difficult to identify using revealed preference data because of co-linearity or lack of variation. Because of this, a CE offers advantages over the CVM in terms of benefits transfer if environmental goods can indeed be decomposed into measurable attributes with money values and if socioeconomic variables are included in the CE models.

A CE also avoids the limited choice problem of the dichotomous choice design in the CVM, as respondents are not faced with the stark 'all or nothing' choice. They may choose one of two environmental alternatives. Thus, in a CE design, there are repeated opportunities for them to express their environmental preferences. The use of the choice experiment method is a model of consumer choice following the works of Lancaster (1966) and the econometric model is basically derived from the random utility theory (McFadden, 1974). The governing idea of the model is that consumers derive satisfaction, not from the goods themselves, but rather from the attributes of those goods. According to this theory, consumption decisions are determined by the utility that is derived from the attributes of a good, rather than from the good in isolation. The econometric ground of the CE pivots on the behavioral framework of random utility theory, which describes discrete choices in a utility-maximizing framework.

5.2.3. The Theory of Choice

According to this theory, individuals are assumed to make choices based on the attributes of the alternatives with some degree of randomness (Lancaster, 1966). Random Utility Theory (RUT) states that utility derived by individuals from their choice is not directly observable but as an indirect determination of preferences is possible and thus the utility can be best explained in terms of those attributes. It is also understood that choice is not a static action but has random elements within it (Luce, 1959). With this arena, the utility function can be decomposed into an observed/measurable component and an unobserved/random component. This model currently serves as the foundation for modeling the choices that individuals make (Hensher *et al.*, 2005; Bateman *et al.*, 2002). The random utility model allows for random (error) influences in addition to identify fixed ones (McFadden, 1974):

$$U_{ij} = V_{ij} + \varepsilon_{ij} \quad (12)$$

Where, u_{ij} represents utility derived for consumer j from option i , v_{ij} is an attribute vector representing the observable component of utility from option i for consumer j . ε_{ij} is the unobservable component of latent utility derived for consumer j from option i (Nam Do and Bennett, 2007).

In CE, where the respondent is asked to choose the most preferred among a set of alternatives, random utility theory can be used to model the choices as a function of attributes and attribute levels. The RUT thus, provides a link between the deterministic model outlined above and a statistical model (McFadden, 1974).

Assuming a linear additive form for v_{ij} attribute vector, Equation 1 can be specified as:

$$V_{ij} = \beta_{1i} f_1(S_{1ij}) + \dots + \beta_{ki} f_k(S_{kij}) + \varepsilon_{ij} \quad (13)$$

Where S_{ij} represent 1 to k different attributes with different levels and β_{ki} are utility parameters for option i . Then, by expanding Equation (1), we find:

$$V_{ij} = \beta_{1i} f_1(S_{1ij}) + \dots + \beta_{ki} f_k(S_{kij}) + \varepsilon_{ij} \quad (14)$$

This random utility model is converted into a choice model with the assumption that an individual j will select alternative i if and only if the utility derived from any other alternative in the choice set. Alternative i is preferred to q if

$$P[(v_{ij} + \varepsilon_{ij}) > (v_{iq} + \varepsilon_{iq})]$$

and choice can be predicted by estimating the probability of individual j ranking alternative i higher than any other alternative j in the set of choices available (Nam Do and Bennett, 2007; Louviere, *et al.*, 2000).

The probability of consumer j choosing option i from a choice set may be estimated by means of the maximum likelihood estimation whereby estimates are obtained through the maximization of a probabilistic function with respect to the parameters (Hensher *et al.*, 2005; Nam Do and Bennett, 2007; Louviere *et al.*, 2000).

Then, v_{ij} which is the systematic component, could be specified as a function of the vectors of the restriction strategy attributes which characterizes j alternatives and respondent i 's characteristics.

As absolute prediction of individual choices is impossible, the probability of choice can be expressed as:

$$P(i) = P(V_{ij} + e_{ij} > V_{iq} + e_{iq}) \quad (15)$$

Given the random terms are distributed identically and independently, the probability that option I will be selected can be estimated using a multinomial logit model (MNL) Greene and Hansher (2003) as follows:

$$P(i) = \frac{\exp(V_{ij})}{\sum_{j \in C} \exp(V_{ij})} \quad (16)$$

To improve the fitness of the model, violation of irrelevant alternatives need to be avoided using different techniques. In this study, we analyzed the socioeconomic alternatives using a multinomial logit model including non-attribute variables with minimum bias and more accuracy by employing the STATA14 and SAS 9.4 programs (the later used for observing the interaction effects between attribute and non-attribute variables).

In this model, coefficients can be used for estimating the rate at which respondents are willing to choose one attribute for another. The trade-off estimated is known as the marginal willingness to pay or part-worth or an implicit price. This expresses the amounts of money respondents are willing to pay to receive more of the non-marketed environmental attribute (Jo *et al.*, 2021).

$$\text{Marginal Willingness to Pay} = - \frac{\beta_{\text{Non-marketed Output}}}{\beta_{\text{Monetary attribute}}} \quad (12)$$

To analyze welfare, the willingness to pay WTP of farmers for a change in attribute levels was estimated by taking the ratio between the coefficients of individual attributes and the price attribute (Oh *et al.*, 2021).

$$WTP_i = \frac{dx_i}{dx_c} = - \frac{\beta_i}{\delta_c} \quad (13)$$

where, WTP_i = Willingness to pay for a given attribute, β_i = Marginal utility of an attribute i , and δ_c = Estimated parameter of costs associated to the alternatives.

5.2.4. Design of the Survey Questionnaire

Identification of attributes and their levels is the first and essential step in designing a questionnaire for a choice experiment. In this paper, management scenarios for restricting *Eucalyptus* expansion with their attributes were determined in consultation with respondents in the study area. The identification of an appropriate experimental design is the most important precondition for undertaking a CE analysis. Using the right experimental design, it is possible to create choice sets in the most efficient way that combines attribute levels to alternatives and alternatives to the choice sets (Alpinzar *et al.*, 2001). Before administering the choice experiment questionnaire, a focus group discussion and pilot survey of 35 respondents was undertaken to agree on the final version of the questionnaire and attributes and levels. Table 20 shows the final attributes and levels for the choice model.

Table 20. Conceptual attributes and levels

Attribute	Description/Assumptions	Levels
Intended land use plan (scale of <i>Eucalyptus</i> plantation, %)	Plots devoid of <i>Eucalyptus</i> plantations are rich in biodiversity	25
		50
		75
Fertility of land ¹	Plantations focusing mainly on marginal lands will have reduced impact ecosystem	Not fertile
		Fertile
		Highly fertile
Number of other tree species to be grown	The more the number of other tree species, the better will be the ecological wellbeing	2
		3
		4
Payment for change in attribute (USD)	How much are households willing to pay as a compensation for restriction of <i>Eucalyptus</i> plantation	31.21
		62.41
		93.62

The 'numeraire' used throughout this paper are in USD using the 21 January 2020 exchange rate (\$1 USD = ETB 32.044. ¹ Land fertility is a relative term, which is based on farmers' ratings. Marginal lands that are not used for the cultivation of food crops, except avena and lupin, are categorized as "not fertile". Lands that support the cultivation of wheat, barley, flax, etc. are categorized as "fertile". "Highly fertile" lands exceptionally permit the cultivation of maize, potato, bean and teff.

Our assumption was that conservation plans that restrict the expansion of *Eucalyptus* over crop lands would create positive environmental impacts, which were used as attributes of the choice experiment. Complete factorial designs allow the estimation of the full effects of the attributes upon choices that include the effects of each of the individual attributes presented (main effects) and the extent to which behavior relates to variations in the combination of different attributes offered (interactions). As these designs often give an impractically large number of combinations to be evaluated, we reduced the number of scenarios of combinations to an optimum manageable size of nine different choice sets using orthogonality analysis using SPSS software (IBM Corporation, Armonk, NY, USA) (Louvirrie *et al.*, 2000). To make the questionnaires manageable for respondents, we further limited these choice sets to three blocks.

With the four attributes, each with three labels, we applied an experimental design technique of 3⁴ combinations for a total of 81 alternatives with main effects, which generated nine orthogonal combinations, which were blocked into three different questionnaire versions, each constituting three choice sets (Kang *et al.*, 2021).

5.2.5. Data Sources and Sampling

The sample design strategy entails four distinct steps: selecting the target (sample) population, determining who to sample (the sample frame), determining the appropriate sample size, and choosing the method of respondent selection and elicitation of response technique. Relevant stakeholders were identified through a brainstorming session with respondents with the help of local experts following stakeholder analysis (Louvirrie *et al.*, 2000).

We considered a final sample of 388 respondents for the final data collection. Then, before administering the choice modeling questions on the respondents, we induced informative

discussion about the current situation of *Eucalyptus* expansion and its impact on biodiversity together with elicitation of response techniques (Nam Do and Bennett, 2007; Birol *et al.*, 2006).

Each respondent was provided with three choice sets and left to choose among three alternative scenarios, which showed various options for the restriction of areas of *Eucalyptus* plantation over crop lands and biodiversity conservation strategies in the study area (Figure 11). The alternatives involved the options from minimal to higher conservation strategies with inclusion of payment as annual utility fee.

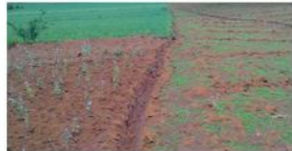








Attributes	Alternative A	Alternative B	Alternative C
Intended land use plan (% of own holdings planted covered with <i>Eucalyptus</i> plantation)	 25%	 75%	 50%
Fertility of land	 Not fertile (25%) Grows <i>Avena fatua</i>	 Highly fertile (100%) Grows potato	 Fertile (75%) Grows wheat
Number of other tree species to be grown	 2 species	 4 species	 3 species
Payment for change in attribute (USD/household/year)	62.41	93.62	31.21
Choice (please tick one)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Figure 11. Sample profile of choice sets

The payment vehicle was used as a voluntary continuous donation contributed through a yearly land use fee for 3 years, which could catch the present value of preferences for *Eucalyptus* restriction for ecological wellbeing. The payment levels of USD 31.21, 62.41 and 93.62 were determined based on the focus group and pilot survey. Non-attribute variables, which were supposed to have high predictor capacity, were also prioritized for their inclusion in the multinomial logit model (Table 21).

Table 21. Summary of variables used in the choice model

Variable	Description
Attribute variables	
Intended land use plan (scale of <i>Eucalyptus</i> plantation, %)	Plots devoid of <i>Eucalyptus</i> plantations are rich in biodiversity
Fertility of land planned for <i>Eucalyptus</i> plantation (%)	Plantations of <i>Eucalyptus</i> on marginal lands will have reduced impact on biodiversity
Number of other tree species to be grown	The more the number of other tree species, the better will be the ecological wellbeing
Payment (Birr)	Charge incurred as a compensation for restriction of <i>Eucalyptus</i> expansion per hectare year
Non-attribute variable	
Income source	Sources of income from crop, livestock, trading, rentals, etc.
Age	Age of household head
Sex	Sex of the household head
Family Labor	Number of family labor available (continuous)
Total land size (ha)	Size of total land holdings of households (ha)
Slope (%)	Slope of cultivable plots (%)
Number of oxen	Number of oxen owned by a household

5.3. Results

5.3.1. Characteristics of Respondent Residents

The demographic and socioeconomic characteristics of the respondent households are presented in Table 22. For head of the household, about 90% of sample respondents were male and only 10% were female. Regarding marital status, 80.9% of residents were married, 5% not married, 4% divorced and 3% were widowed. Age is an important demographic factor that determines household involvement in different activities. Considering their age, most respondents (90%) were found to be within the age range of 31 to 65 years, about 5% were under 31 years, and only 5% were above 65 years. On average, families had about six individuals, which was relatively higher than the national average family size. Likewise, 8.93% of respondents could not read and write, 80.51% could read and write, 4% followed their education in religious schools, 5% were grade 1 to 6, and only 1% followed formal schooling of grade 7 to 12.

All farm households involved in this study possessed varying sizes of plots. The average land holding of respondent households was 1.37 ha, which was utilized for the cultivation of food crops, *Eucalyptus* plantations and homestead plantations. We found that farming practices of residents were not limited only to their own plots but they also cultivated a sizable area of land for production of food crops and plantations of *Eucalyptus* on a rental basis. Considering the annual income of residents from different sources, income from *Eucalyptus* was found to be the highest (USD 881.20), accounting for about 46% of their total annual income. Similarly, the average annual income obtained from cultivation of food crops was USD 502.98. Income from non-farm activities (off-farm and remittance) and livestock rearing were found to be UDSD 330.07 and USD 211.43, respectively.

Table 22. Sociodemographic characteristics of respondents

Characteristics	Variable	Value
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	Average family size	6
	Dependency ratio (%)	64
Demography	Age	48
	Gender (%)	
	Female	10
	Male	90
	Marital status (%)	
	Married	80.9
	Not Married	5.2
Literacy status (%)	Divorced	7.7
	Widowed	6.2
	Cannot read and write	8.93
	Read and write	80.51
	Religious school	4.12
Farm resource and income	Grade 1–6	5.15
	Grade 7–12	1.29
	Average land size (ha)	1.37
	Average annual income (USD) from	
	Crop	502.98
	<i>Eucalyptus</i>	881.20
	Livestock	330.07
	Non-farm sources	211.43

5.3.2. The Multinomial Logit Model

A multinomial logit model was used to analyze the preferences of respondents and their WTP for the ecological improvement schemes (Table 23). The model fulfilled the test of goodness of fit ($\text{Prob} > \text{Chi}^2 = 0.0000$) criteria implying that the predictor attributes under consideration had strong determination and explanatory power. In Models 2 and 3, we introduced socioeconomic variables to the indirect utility function and observed that presence variable as additive forms and interaction with selected variables respectively.

The first model presented in Table 4 represents the basic attribute variables that were specified for the ecological improvement program. In this model, all coefficients were found to be significantly ($p < 0.01$) different from zero. The signs of attribute variables were found as expected. Accordingly, the land use plan, to use a small portion of their plots for plantation increased the probability that an option would be chosen by 42%. Similarly, all the rest of the attribute variables increased the probability. Most of the predicted variables significantly ($p < 0.01$) and positively influenced the preferences of residents for each improvement scheme. In Model 1, the highest (48.95%) probability increase in choice of options was brought by the program for increasing the number of other tree species to be planted.

Table 23. Result of the multinomial logit model

Attribute Variables	Model 1	Model 2	Model 3
	Coefficient	Coefficient	Coefficient
Land use plan	0.42199 (0.05109) ***	0.42128 (0.05139) ***	0.41006 (0.05142) ***
Fertility	0.23473 (0.05459) ***	0.23437 (0.05493) ***	0.22117 (0.06120) **
Other trees	0.48953 (0.05362) ***	0.49173 (0.05393) ***	0.50125 (0.05421) ***
Payment	0.00031(0.00003) ***	0.00031 (0.00003) ***	0.00033 (0.00004) **
Constant	-3.32501(0.19608) ***		
Income		0.10495 (0.04776) ***	0.12136 (0.04991) ***
Age		0.01499 (0.00498) ***	0.01501 (0.00611)
Sex		-0.15990 (0.13622)	-0.16030 (0.14501)
Family labor		0.16043 (0.03937) ***	0.16171 (0.04015) ***
Land size (ha)		-0.00366 (0.06307)	-0.00386 (0.08821)
Slope (%)		0.11086 (0.08254)	0.11104 (0.08715)
Number of oxen		-0.11045 (0.05235)	-0.11630 (0.06104)
Constant		-4.90173 (0.41072) ***	
Income *Land use plan			0.31090 (0.03281) **
Income *Fertility			0.03931 (0.01410)
Income *Other trees			0.21095 (0.09142) ***
Age *Land use plan			0.02657 (0.03120) ***
Age *Fertility			-0.03531 (0.02381) **
Age *Other trees			0.31140 (0.00201)
Family labor *Land use			0.07142 (0.03224) ***
Family labor *Fertility			0.21705 (0.03496) **
Family labor *Other trees			0.362510 (0.04184)
Constant			-6.03272 (0.49035) ***
Log likelihood	-3406.2996	-3382.7425	-3391.5241
Pseudo R ²	0.0458	0.0528	0.0762

Number of obs = 3492; Prob > Chi² = 0.0000; Parenthesized figures are standard deviations; ** and *** indicate level of significance at 5% and 1% probability. * in between two variables indicate interaction.

In Model 2, all the attribute variables and three of the non-attribute variables were found to be significantly ($p < 0.001$) different from zero. Variables including sex (0 = female; 1 = male), land size and the number of oxen owned were found to influence respondent choice negatively, showing that a unit increase in the respective variables causes a decrease in the probability of households' preferences for the improvement program. For this model, the highest (about 49%) increase in the probability that an improvement option would be chosen was observed for the number of other tree species grown. For the non-attribute variables, the number of family laborers had a positive and significant ($p < 0.01$) effect on respondents' preferences for improved ecological wellbeing. Results in this model also showed that households with higher income, older in age and with higher number of family laborers had an increased option choice.

Results of Model 3 presented how socioeconomic variables that were significant in Model 2 affected option choices in interactions. In this model, attribute variables were found to significantly ($p < 0.001$ and $p < 0.05$) influence respondents' choice for the improvement program. Among the attribute variables, the number of other tree species to be planted increased respondents' choice by 50.13%. The interaction of variables that were significant in Model 2 with attribute variables also showed significant influence on respondents' preferences except for the interactions of income *land fertility, age*number of other tree species to be grown and family labor *number of other tree species to be grown.

To obtain a better representation and understanding of the effect of attribute and non-attribute variables beyond the individual effects, we also examined their interaction effects on residents' preferences. Signs of the coefficients of non-attribute variables including sex, size of holdings and the number of oxen owned were found to be negative, but these were non-significant influences on residents' choice for the ecological improvement program.

5.3.3. Estimation of Marginal WTP Values

We calculated the inherent value of marginal attribute changes by observing the marginal rate of substitution between the price attribute and the respective attribute, i.e., by taking the ratio of the attribute under consideration to the payment coefficient. The marginal willingness to pay (MWTP) measure the amount of money respondents are willing to pay to trade off for a unit improvement in an environmental attribute, or the amount they are willing to pay to prevent the expected welfare losses. For the improvement of the ecological scheme in the study area, the MWTP values represent a change in size of land allocated for *Eucalyptus* (75 to 25% or less), planting *Eucalyptus* on fertile plots to planting on marginal lands, and a change from planting small numbers of other tree species to more diverse tree species for ecological conservation in the study area.

Accordingly, the results showed that residents were willing to trade off a USD 54.83 increase in household annual utility cost for the contribution of the land use plan attribute for the ecological improvement programs. As seen in Table 24, the compensation variation for improving households' intended plan of planting *Eucalyptus* on 75% of their plots to 25% was USD 54.83/person/year. Similarly, to change the households' need for planting *Eucalyptus* on fertile plots to planting on more marginal ones, the corresponding compensation variation was USD 24.35/person/year. The compensation variation for enhancing the number of other tree species to be grown, which is the highest value of all, was USD 125.82/person/year.

Table 24. MWTP for a change in attributes

Change in Attribute	MWTP (USD/Person/Year)
Intended land use plan (scale of <i>Eucalyptus</i> plantation, from 75–25% or less)	54.83 (26.75%)
Shift of plantation from fertile to non-fertile plots	24.35 (11.88%)
Increasing plantation of other tree species from minimal to more	125.82 (61.38%)
Total	205.00 (100%)

Note: MWTP values are converted to USD after running the multinomial logit model.

This study estimated the amount residents of the study area can willingly pay for a policy relevant to ecological improvement schemes. Overall, residents were WTP USD 205.00 or ETB 6,569.02/person/year on average as a yearly utility fee in support of the ecological improvement schemes in the study area. The WTP estimates for the ecological improvement programs suggest that residents of the study area were diverse in terms of their views regarding ecological wellbeing.

5.4. Discussion

The ecosystem in the *Eucalyptus* growing highlands of northwestern Ethiopia is influenced by intensive human activities, land cover changes, and subsequent climate change and loss of biodiversity. This situation will get worse and may result in ecological deterioration unless certain improvements and conservation schemes are not enforced. Recently, rapid land cover changes have been observed in the study area, where *Eucalyptus* was alarmingly replacing arable land in monoculture plantations, which has impacted the ecosystem and brought transformation of the cultural landscapes in the area.

Though the majority of the land in the study area is primarily used for the cultivation of food crops, livestock rearing and plantations, it also provides services including biofuel, fiber, opportunities to store carbon, biodiversity, and recreational and aesthetic values (Swinton *et al.*, 2007; Sandhu *et al.*, 2016). Nevertheless, monoculture plantations of *Eucalyptus* can result in disturbance of the natural ecosystem and loss of ecosystem services (Zhao *et al.*, 2022). This infers that the conservation of biodiversity and ecosystems is quite important for ensuring the improved livelihood and social welfare of the population (De Castro-Pardo, *et al.*, 2021).

In the study area, the area in which *Eucalyptus* is grown is expanding rapidly. Studies by Rejmanek and Richardson (2011) showed that *Eucalyptus* has reached an estimated coverage of about 2.3 million hectares globally since its introduction from its center of origin. In Portugal, for instance, where the species seems to find particularly favorable conditions for successful reproduction, an estimated area of 845,000 ha, which accounts about 26% of the Portuguese forest, is covered with *Eucalyptus* plantations (Aguas *et al.*, 2014). Despite its spread worldwide, *Eucalyptus* has proven to be particularly successful in tropical and sub-tropical regions like Portugal and Spain, more than elsewhere (Stanturf *et al.*, 2013). Because of suitable climatic conditions, *Eucalyptus* grows well and is well-adapted to conditions in Africa, including Ethiopia.

The replacement of crop lands by *Eucalyptus* can also apparently alter the ecological make-up of the area by changing the scene and population dynamics of flora and fauna. As a non-native species, the expansion of *Eucalyptus* can result in the transformation of the landscape and a change in the natural ecosystem. This finding is also in line with Toledo *et al.* (2020), who assessed the potential spread and invasive nature of *Eucalyptus*, which could impact ecosystem properties and functions.

To limit the expansion of *Eucalyptus* and improve the disturbed natural ecosystem in the study area, endorsing ecological improvement schemes towards sustainability of the ecosystem and biodiversity would be essential. Residents of the study area are aware of that *Eucalyptus*, as a non-native tree species, has a potentially invasive behavior. This conclusion is in line with the study by Vance *et al.* (2014), which showed the negative impacts of the tree on biodiversity can lead to long-term transformation of cultural landscape of an area. Large-scale *Eucalyptus* plantations have caused various problems including reduced species diversity and loss of soil

nutrients, which threaten ecological security regionally and worldwide (Wen, *et al.*, 2005; Zhu, *et al.*, 2019). In addition, it would also be rather necessary to estimate the non-market benefits of the ecosystem to ensure sustainable functioning of the agricultural and non-agricultural landscape though examining residents' preferences and attitudes to the conservation of the ecosystem and biodiversity. However, residents' preferences and WTP for the ecological improvement schemes have not been studied. To this end, the development of attributes that can help improve the ecological wellbeing would be important.

Results presented in this study showed that residents of the *Eucalyptus* growing highlands of northwestern Ethiopia had diverse preferences to ecological improvement and WTP for the same programs. Multinomial logit results indicated that all attribute variables significantly and positively influenced residents' willingness to pay for the improvement programs. This conclusion is in line with the studies by Yang, *et al.* (2021), Anderson, *et al.* (2017) and Sutton (2014) that reported significant variations in preferences of residents and tourists regarding the Green Island environmental resources in Taiwan.

Changes in personal attitudes of residents towards accepting proposed ecological improvement schemes are quite important for sustainable biodiversity conservation. Residents considered in this study differed in terms of demographic variables (such as age, sex, and family labor) and socioeconomic variables (like size of land holdings and average annual income). The changes in residents' preferences for the ecological improvement programs were attributed to these variations. However, there was limited information regarding residents' preferences and their WTP for the acceptance of ecological improvement schemes focused towards improving the ecological and biodiversity wellbeing.

Results of separate model runs showed different effects of attribute and non-attribute variables. The significance of all attribute variables in the first and second run showed that the explanatory powers of the attributes were as expected. Among the socioeconomic variables that were included in the second model, income source, age, and number of family laborers were found to significantly influence residents' choice. The findings also suggest that residents who better made choices of improved ecological conservation were those who had more income (including off-farm) sources, were older in age and had more family laborers of working age. This finding is consistent with the study by Kubak, *et al.* (2020) who reported that income level and age of respondents had significant impact on WTP for the conservation of the natural heritage in Tatra National Park. Sex, size of land holding, and the number of oxen owned appeared with negative coefficients, implying that residents owning a greater number of oxen involved in cultivation of food crops preferred assigning a larger share of their plots to cultivation of food crops, than to plantation of *Eucalyptus*.

For all the improvement schemes, residents showed varying levels of preferences. The schemes were designed for improving the level of ecological security and were comprised of three attributes and their levels including reduction of total area of *Eucalyptus* plantations, excluding for *Eucalyptus* plantations, and increasing the number of other tree species to be grown.

The MWTP of respondents was estimated by taking the implicit value of marginal attribute changes with respect to the payment coefficient (Juutinen *et al.*, 2011). It measures the amount of money respondents are willing to pay to trade off for a unit improvement in an environmental attribute, or the amount they are willing to pay to prevent the expected welfare losses. Residents (smallholder growers) were WTP on average more for increasing other tree species (third attribute) and were WTP less for the attribute encouraging plantation of *Eucalyptus* on less fertile lands for the improvement program (second attribute). Accordingly, there was a 26.75% change in MWTP of respondents for the first attribute (*i.e.*, intended land use plan or scale of *Eucalyptus* plantation, from 75–25% or less). The highest attribute change (61.38%) was observed for the third attribute (involving increasing plantation of other tree species from minimal to more). The findings are in line with a study by Kim *et al.* (2021) which assessed the non-market environmental values of biodiversity conservation in Vietnam and indicated that residents were WTP a monthly payment of VND 913 for a % increase in healthy vegetation.

The contribution of a reduction of plantation area of *Eucalyptus* was estimated to be USD 54.83/person/year. Similarly, the benefits from the exclusion of fertile plots from plantations and increasing the number of other tree species were USD 24.35/person/year and USD 125.82/person/year, respectively; the overall value being USD 205. Differences in attribute values have also been reported by Kibak *et al.* (2020). It was found that respondents' preference for the ecological improvement programs can be improved if land allocated for *Eucalyptus* was significantly reduced, fertile lands were set aside from *Eucalyptus* plantation and the number of other tree species was increased.

Our study showed that the socioeconomic backgrounds of the respondents contributed to the heterogeneity in residents' preferences and their WTP for ecological improvement schemes. This outcome is in line with the study by Qiao and Randrupm (2022). Our findings are similar to the results of the study by Pakalniete *et al.* (2021), which used a similar approach to evaluate the attitudes and WTP values of local residents for deep-sea ecosystem conservation in England. The proposed attribute and non-attribute variables were identified by considering previous works including those by Kragt and Bennett (2009) and Luisetti (2008) and the views of residents who participated in the proposed ecological improvement program. The study is in line with the finding of Townhill *et al.* (2022) who reported the burden on the Arctic species and the ecosystem resulting from human activity and Luisetti (2008) who drew similar conclusions while examining the readjustment of coastal policies in England using a CE approach.

This study is a first attempt to evaluate the economic value of restricting areas of monoculture *Eucalyptus* plantation. Our findings can be utilized for instructing residents and the provision of information regarding conservation plans for ecosystems and biodiversity. Nonetheless, we acknowledge the uncertainties with our approach. For instance, our study participants were confronted with a hypothetical bias in which there were no real transactions and thus there might be over estimations.

5.5. Conclusions

This study presents economic estimation of restricting the area of plantations of *Eucalyptus* in the *Eucalyptus* growing highlands of northwestern Ethiopia from the perspective of ecological economics using a CE method and devised attributes that are important for ecological improvement and biodiversity conservation. The study indicated that policy-targeting management advice is essential for the development of a sustainable ecosystem, especially in areas that are fragile in terms of hosting biotic and abiotic components that are essential to healthy functioning of the ecosystem. The findings of this study revealed that the expansion of areas of monoculture *Eucalyptus* plantation is a big threat for ecological wellbeing and biodiversity in the area.

In this study, a choice experiment approach was validated for constructing a random utility model and examining the preferences of residents to possible ecological improvement options. It is believed that this study presents a splendid prospect for employing a choice modeling approach for addressing real policy-impacting environmental challenges involving passive use values and a plausible payment vehicle. The results showed high heterogeneity in preference and WTP of residents for the proposed ecological improvement schemes.

The ecosystem of the *Eucalyptus* growing highlands of northwestern Ethiopia is highly disturbed due to the undergoing dramatic land use changes due to human activity. Absence of land policy initiatives that work for proper land use and limited management options have contributed to the unprecedented expansion of areas of monoculture *Eucalyptus* plantations and ecological deterioration. Validation of the CE approach showed that respondents are willing to pay for the proposed ecological improvement programs.

We believe that this study yields important findings that can provide trustworthy information to policymakers and researchers and creates public awareness regarding ecological wellbeing and biodiversity conservation. Our findings can address similar areas that demand immediate policy interventions regarding management of development strategies for a given ecosystem and biodiversity.

The findings can provide important implications about relevant attributes for ecological improvement. Based on our findings, the following key policy suggestions are forwarded for the ecologically sensitive *Eucalyptus* growing areas of the highlands of northwestern Ethiopia. (1) Policies should incentivize farmers with compensation to restrict areas of further *Eucalyptus* plantations. (2) Emphasis should be given to land types for the plantation of *Eucalyptus* setting aside cultivable lands for crops. (3) Focusing on increasing plantation areas of other tree species. (4) Creating awareness on residents regarding the conservation of the ecosystem through restricted plantation areas of *Eucalyptus* and advocating plantation of other tree species. Finally, it is suggested that further research shall be carried out as extension of this study.

CHAPTER 6: SYNTHESIS

This synthesis presents the entire work linking plantation of *Eucalyptus* with socioeconomic impact, land conversion dynamics and the implications of land conversions on agricultural landscape. Furthermore, the rising debates over *Eucalyptus* expansion and how policy changes can enable interventions for proper land utilization are discussed. The study addressed the increasing need for land conversions, analysis of the crop-plantation portfolio, the status of the *Eucalyptus* wood value chain and the ecological implications of conversion of cultivable lands to *Eucalyptus* stands. It also presents the implications of the study findings and future research directions.

6.1. *Eucalyptus* and Smallholder's Income

Driven by various pushing factors, land use changes in the study area have been typical, with an increasing conversion from crop lands to *Eucalyptus* plantation. Rising demand for wood products, regional land use regulation, and socioeconomic pushes have all contributed significantly to the study area's land conversion trajectory, *Eucalyptus* becoming the primary economic tree choice intensively planted by smallholder farmers. Despite the fact that farm households differ in demographic, socioeconomic and farm characteristics across farm typologies, it was discovered that *Eucalyptus* accounts about 46% of smallholder growers' annual income. The study examined that farming is practiced in the study area by three types of farm households, each with a unique land use and farm endowment. Households in all farm typologies are converting their crop lands to *Eucalyptus* plantation, regardless of fertility status.

Analysis of economic impact is undertaken for assessing a given project usually, through appropriate econometric techniques for addressing the various benefits of choices of farm portfolios. Advantages of interventions of a certain investment are usually studied using economic and environmental impact analysis. In doing so, the study employed a farm household model. It was found that an increase in land allocated for *Eucalyptus* has resulted in a proportional increase in households' gross margin indicating that farm returns obtained from increases in land allocated for *Eucalyptus* can't be compensated with a proportional level of increase in land allocated for the cultivation of food crops. This suggests that farmers still have advantage of obtaining additional benefit from the increases in conversion of crop lands to *Eucalyptus* leaving other factors constant. However, this is so long as it is viewed from the perspective of the financial return.

Assessing land use patterns for scientific utilization of the given area and existing resources has become predominantly important. Recently, alarmingly increasing population has led to severe resource completion and decline in use value of natural resources. Analysis of land use land cover changes with wider spatial and temporal dimensions can lead to optimized utilization of the existing resources. The study shows that plantation of *Eucalyptus* is worth paying whilst using proper utilization of land. A higher benefit cost ratio per hectare was observed for plantation of *Eucalyptus* as compared with the relatively lower value per hectare for cultivation of wheat. This implies that *Eucalyptus* has better contribution to households' income as compared with food crops cultivated using the same plot of land.

6.2. *Eucalyptus* and Land Conversions

Crop production together with rearing of livestock is the predominant farming activity in the study area. Recently, growers are showing great tendency of changing their arable lands to eucalyptus stands which resulted in dramatic land use land cover changes during the period from 1999 to 2021. Though plantation of this short rotation tree is being highly preferred by smallholder growers, its expansion as a monoculture plantation is creating a threat to cultivation of food crops and ecological wellbeing and biodiversity.

The findings of this study revealed that crop lands are being converted to *Eucalyptus* plantations very rapidly. This hasty expansion of *Eucalyptus* has consensual implications. On one hand, with the existing increase in population and declining per capital landholding and productivity of crop lands, *Eucalyptus* can be taken as an opportunity that ensures smallholder growers to have a risk free income source in comparison with food crops. On the other hand, the alarmingly expansion rate of *Eucalyptus* over crop lands may pose a threat for diminishing in quantity and variety of food crops in the future.

In the *Eucalyptus* growing highlands of East Gojjam, keeping other factors constant and if the rate of expansion continues at the same pace, a subsequent decline in crop lands is expected which apparently will result in decline in production of food crops. Understanding such land conversion dynamics is central for proper management of land resource especially in areas where the majority of the people who support their livelihood on the natural resource base. In a nutshell, the rapid expansion of *Eucalyptus* is causing dramatic transformation of the agricultural and natural land covers in the study area.

Land use conflicts arising due shading effects of trees rapid succession of crop lands and revising existing land policies and land use system, encouraging emergence of wood processing enterprises and posing regulatory measure on unlicensed traders are exemplary measures for promoting well developed *Eucalyptus* wood value chain in the study area and thereby sustaining livelihood of smallholder farmers that are dependent on *Eucalyptus* wood products.

6.3. Policy Implications

1. We found that *Eucalyptus* has immense contribution figuring about 46% of households' annual income. Large volume of *Eucalyptus* wood is harvested and transacted annually in different market channels. However, the wood sector value chain has attracted little policy interest and is characterized by the lack of multi-sectoral coordination. Enabling growers and other actors by creating market coordination with large scale wood processing factories can improve the *Eucalyptus* wood value chain thereby ensuring sustainable product markets and improved livelihood of growers.
2. Though land is a public property in Ethiopia and the major impeding factor of production, the existing land regulations and use right need rectification and land use plans are very important for maximizing the economic return per unit area. In line with this, the Ministry of Agriculture should focus on encouraging farmers for the plantation of other potential tree species such as *Acacia decurrens* and *Grevillea robusta*.
3. The different farm typologies presented in this study need special policy attentions. In the first typology, farming system is highly intensive that involves cultivation of major crops like wheat, *teff* and maize together with plantation of *Eucalyptus*. In this farm typology, lands are relatively better in terms of fertility and productivity potentials. We noted that further plantations of *Eucalyptus* can lead to complete succession of crop lands and ultimately threatening fate of food crop production. Thus, there should be a land policy that can aware household regarding proper land use through incentives plantation of *Eucalyptus* in this farm typology.
4. As one moves from Farm typology I to III, soil fertility declines in the move along. Farm typology II is thus characterized by a mix of fertile and marginal lands together land with steep features. In such lands, plantation of *Eucalyptus* should be permitted only to marginal lands. In Farm typology III, the farming system is a combination of abundant plantation of *Eucalyptus* with crops such as wheat, barley, *avena* and potato. In this farm typology, the land is characterized by steep slopes with altitude ranges between 3400-3800m, high slope

(>45°) features and abundant coverage of marginal lands which is not suitable for the cultivation of food crops as compared with Farm type I and II, but, ideal for the expansion of *Eucalyptus*. Focusing plantation of *Eucalyptus* in Farm typology III will be a rationale choice at least in the short term as it relieves future threats of the expansion of *Eucalyptus* at the expense of fertile crop lands.

5. It is generally factual that understanding such land change dynamics is central for scientific utilization of the existing lands in a sustainable way.

6.4. Research Directions

Despite the intensive coverage of this study with the four topics, future research areas still remain vacant.

1. The current study was carried out in the major *Eucalyptus* growing highlands of East Gojjam Zone of the Amhara National Regional State. It was recognized that the conclusions are valid to other areas with similar socioeconomic and environmental setups. In this regard, we invite further researches in the area with a wider spatial and temporal scope as a continuation of this study.
2. The study presented the ecological impacts of *Eucalyptus* on the basis of the existing knowledge and theoretical grounds. Researches on the ecological impact of *Eucalyptus* on experimental basis are quite imperative for drawing vital conclusions to these *Eucalyptus* growing areas.
3. Analysis of land use changes was based on supervised classification algorithm of Landsat images of 30mx30m spatial resolution. In addition, due to spectral similarity of bands, we faced difficulty in classifying the specific *Eucalyptus* vegetation. Therefore, we suggest future researches that can better classify images and show the species level map of *Eucalyptus* with a more fine resolution of 5mx5m or less.

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Appendix: Survey Questionnaire

Direction: This interview schedule is designed for gathering necessary information for a PhD study entitled *“Economic Impact and Ecological Implications of Eucalyptus Plantations in the Northwestern Highlands of Ethiopia”*. The study is being carried out by Mr. Amare Tesfaw currently following his PhD study at Addis Ababa University. The purpose of this data gathering tool is only for academic purpose. Therefore, you are kindly requested to give your genuine responses being confident that the information you provide will only be used for this study. We thank you for your kind cooperation in advance!

Name of Respondent: _____ District: _____ Kebele: _____
 Name of Interviewer: _____ Date: _____

I. Demographic Characteristics of Households

1. Name of the household head _____
2. Sex 0 = Female 1 = Male
3. Age 1 = <15 (Child headed family) 2 = 15-30 3 = 31-65 4 = > 65
4. Marital status 1 = Married 2 = Not married 3 = Divorce 4 = Widowed
5. Educational Status
 - 1 = Illiterate
 - 2 = Can read and write (informal)
 - 3 = Grade 1-6
 - 4 = Grade 7-12
 - 5 = College/University
 - 6 = Other (specify) _____
6. Responsibility in the community 1= Member of the community 2= Religious leader
 3= Coordinator of community development work 4= Kebele Administrator 5= Other
 (please specify) _____.
7. Family size

No	Age	Sex		
		Male	Female	Total
7.1	<10			
7.2	10-14 year			
7.3	>14-18			
7.4	>18-65 years			
7.5	> 65 year			
Grand Total				

II. Socioeconomic Data

a) Land

1. Do you have your own farm land 0=No; 1= Yes
2. What is the source of your land? 1=Inherited 2= Government 3=Rented in
 4=Other (specify) _____
3. If your answer for Q 1 is “Yes”, what is its size in hectare?

- a. Cultivated land _____ ha
 - b. *Eucalyptus* covered _____ ha
 - c. Homestead _____ ha
 - d. Land for other purposes _____ (ha)
 - e. Total land size _____ ha.
4. How is the status of your cultivated land fertility?
1=Not fertile 2=Somehow fertile 3= Fertile 4= Highly fertile
5. How is the slope of your cultivated land?
1=Plain 2=Hilly 3=Highly sloppy 4= Mountainous

b) Income and Livelihood

1. What is your main source of income? 1=Crop production 2= Livestock rearing 3=Off-farm and non-farm activities (more than one choice is possible).
2. If your choice for Q1 is 3, what are your activities? 1=Petty trading 2= Selling fuel wood/charcoal 3=Renting pack animals and tools 4=Wage 5=Remittance 6=Common property 7= Other (specify) _____
3. To which of the following items do you expend more? (Please prioritize, give 1 for the highest share) 1=Food consumption 2= Nonfood consumption 3= Gift 4= Other (specify) _____
4. How many times a day do you have a meal? 1=Twice 2=Three times 3=Four times 4= Other (specify) _____
5. How many rooms does your house possess? _____ rooms.
6. What is your current wealth status (the estimate of all property values) in Ethiopian Birr? ____ Birr.
7. Do you have job opportunities other than farming? 0=No; 1=Yes
8. If your answer is “Yes” for Q7, please list them _____
10. How do you rate improvement of your wealth status since 2007 E.C.?
1= Highly improved 2= Improved slightly 3= Has no change 4= There is decrement
11. What is/are your source of income? 1) Farming (crop) 2) Livestock rearing 3) Both 4) *Eucalyptus* 4) Trading 5) Others (Please specify) _____
12. Estimated annual income from:
 - 1) Crop _____ Birr
 - 2) Livestock _____ Birr
 - 3) Income from crop production and livestock rearing _____ Birr
 - 4) Income from sale of *Eucalyptus* _____ Birr
 - 5) Income from trading activities _____ Birr

III. Land Use-Land Cover Changes

1. Do you grow *Eucalyptus*? 0=No; 1= Yes
2. If your answer for Q 6 is “Yes”, what is its size land planted with *Eucalyptus*? _____ ha.
3. When did you begin planting *Eucalyptus*? In _____ E.C.
4. Do you grow *Eucalyptus* on crop lands? 0=No; 1= Yes

5. If your answer for Q 9 is “Yes”, what is your reason?
 - a. Land became lesser and lesser productive for crops
 - b. *Eucalyptus* is more profitable than crops
 - c. *Eucalyptus* requires less management than crops
 - d. It secures land ownership
 - e. Other (specify) _____
6. What seems the trend of *Eucalyptus* plantation cover in your area?
 - a) Increasing
 - b) Decreasing
 - c) No change
 - d) Other (specify) _____
7. What was the establishment cost of your *Eucalyptus* per hectare? _____ Birr.

IV. Economic Impact of *Eucalyptus*

a) Cost of Inputs

1. Cost of *Eucalyptus* seedlings per ha? _____ Birr.
 2. Cost of management of *Eucalyptus* field per hectare per year? _____ Birr.
- Cost of inputs per hectare per production season

Investment Nexus	Cost of seedlings per ha (Birr)	Cost of fertilizer per ha (Birr)	Amount of labor per ha (Birr)	Cost of labor for Management (Birr)	Total Expenditure (Birr)
<i>Eucalyptus</i>					
Crop					
Both					

3. Average wage rate for silvicultural activities _____, for crop cultivation of crops -----

b) Constraints

Constraint	Minimum Amount	Maximum Amount
Land		
Labor		
Credit		
Capital		

c) Revenue

Item	Income obtained per ha (Birr)
<i>Eucalyptus</i>	
Crop	
Both	

d. Crops

1. Do you practice crop rotation in your farmland? 0=No; 1=Yes
2. What are the sequences of crop rotation you practice most? _____, _____,
3. What cropping patterns do you use in your farm land? 1= Mono cropping 2=Mixed cropping 3=Both 4= Other, if any _____
4. Do you grow *Eucalyptus* around your crop land? 0=No; 1=Yes
5. Input required for crop production

Crop Produced	Year	Land Size (ha)	Input utilization				Yield (kg)
			Inorganic Fertilizer	Organic Fertilizer	Improved (kg)	Local (kg)	
Wheat							
Teff							
Maize							
Barley							
Faba bean							
Pea							
Chick pea							
Haricot bean							
Sorghum							

e. Livestock

1. Type and number of livestock owned in 2019/2020?

Livestock owned	Year				
Ox					
Cow					
Sheep					
Poultry					
Bee colony					
Goat					
Horse					
Mule					
Donkey					
Other					

2. What is the main feed source for your animals? 1= Grazing 2=Straw 3=Both 4=Cut and carry 5=Other (specify) _____

V. *Eucalyptus* and Ecosystem

a) Ecological Roles

- When did the soil and water conservation practices begin in your area? Began in _____
- Do you use *Eucalyptus* for soil conservation? 0=No; 1= Yes
- What addition role does *Eucalyptus* have in addition to its direct use as wood products?
 - As shade for livestock
 - For maintaining soil moisture
 - Plays role for cooling the surrounding
 - Improves ground water potential

- 5 = Other (specify) _____
4. What are potential benefits of growing *Eucalyptus* compared to other tree species? List as much as you can.
 - a. _____
 - b. _____
 - c. _____
 - d. _____
 - e. _____
 - f. Other (specify) _____
 5. What challenges and problems does the community face following intensive plantation of *Eucalyptus*? 1= Scarcity of grazing land 2= Prohibition from using own property 3= Lack of time to get involved in own work 4) Other (please specify) _____.
 6. How long does it take to grow and harvest *Eucalyptus* for selling as construction wood? _____ years.
 7. How do you see the plantation of *Eucalyptus* for the last ten years? 1= Increasing 2= Decreasing 3= Has no change 4= Is being planted only on less fertile lands 5) Is succeeding fertile arable lands
 8. Do you believe that *Eucalyptus* have negative impacts to the soil/water? 0= No; 1= Yes
 9. If your answer is “Yes” for Q8, what are the negative impacts? _____
 10. How do you grow *Eucalyptus* on your land?
 - a. Only in homestead areas
 - b. On the sides of crop lands
 - c. As sole crop (sole *Eucalyptus* on arable lands)
 - d. Other (please specify) _____.

b) Choice Scenarios and Conceptual Attributes and Levels

Choice 1

Attribute	Option I	Option II	Option III
Intended land use plan (%)	25	50	75
Fertility status of land	Not fertile	Fertile	Highly fertile
Number of other tree species grown	2	3	4
Payment (USD)	31.21	62.41	93.62
Your choice (Please tick)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Choice 2

Attribute	Option I	Option II	Option III
Intended land use plan (%)	50	75	25
Fertility status of land	Fertile	Highly fertile	Not fertile
Number of other tree species grown	3	4	2
Payment (USD)	62.41	93.62	31.21
Your choice (Please tick)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Choice 3

Attribute	Option I	Option II	Option III
Intended land use plan (%)	75	25	50
Fertility status of land	Highly fertile	Not fertile	Fertile
Number of other tree species grown	4	2	3
Payment (USD)	93.62	31.21	62.41
Your choice (Please tick)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

VI. Value Chain Analysis of *Eucalyptus* Forest Products

1. What is the size of your land planted with *Eucalyptus*? _____ ha.
2. What is the age of your *Eucalyptus* stand?

Size of land planted with <i>Eucalyptus</i>	Planted since (E.C.)	Cost incurred (Birr)	Harvested (Year)	Will be harvested in (Year)

3. For what do you use your product (*Eucalyptus*)?
 - a) Own construction
 - b) Fuel wood
 - c) Sell to wood retailers
 - d) Other (Please Specify)
4. What is the amount of *Eucalyptus* product/s you supply to:
 - a) Used for self-consumption _____ (kg)
 - b) Sold for fuel wood _____ (kg)
 - c) Sold to fuel wood retailers _____ (kg)
 - d) Sold to construction wood retailers _____ (kg)

e) Sold as construction poles _____(kg)

5. Where do most of your buyers come from?

NO	Market centers	Amount sold (Ton)
1	Debre Markos	
2	Dega Segnin	
3	Rebu Gebeya	
4	Debre Markos	
5	Amanuel	
6	Addis Ababa	
7	Wood factories	
8	Others (specify)	

6) Who do you think governs the *Eucalyptus* forest value chain? _____

7) For what is your product used for?

Purpose	Amount sold (ton)	Price/ton			
Self-consumption					
Charcoal makers					
Sawmills					
Pulp and paper					
Poles					
Construction (as logs)					
Rods (<i>atana</i>)					

8. What is the cost of transport of *Eucalyptus* products?

Means of transport	Cost/tonne/km	Total cost
Truck		
Drafted cart		
Pack animal		

Thank you for your kind cooperation.