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EUCALYPTUS PLANTATIONS, RURAL LIVELIHOODS, AND GENDER DIMENSIONS IN SENAN DISTRICT, NORTHWEST ETHIOPIA

Ph.D. Dissertation

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EUCALYPTUS PLANTATIONS, RURAL LIVELIHOODS, AND GENDER DIMENSIONS IN SENAN DISTRICT, NORTHWEST ETHIOPIA

A dissertation submitted to the Department of Geography and Environmental Studies at Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Geography and Environmental Studies Specialization in Socioeconomic Development Planning and Environment

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DISSERTATION APPROVAL

This is to certify that the dissertation prepared by Fasika Belay, entitled "Eucalyptus plantations, rural livelihoods, and gender dimensions in Senan district, Northwest Ethiopia," submitted in fulfillment of the requirements for the Degree of Doctor of Philosophy in Geography and Environmental Studies with a specialization in Socioeconomic Development Planning and Environment, complies with the regulations of the University and meets the accepted standards to originality and quality.

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DECLARATION

I, the undersigned, declare that this is my original work, has never been presented in this or any other University, and that all the resources and materials used for the dissertation have been fully acknowledged.

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This dissertation has been submitted for examination with my approval as university supervisor.

Supervisor Name: Messay Mulugeta (Ph.D.)

Signature: _____

Date: _____

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ACRONYMS AND ABBREVIATIONS

A-WEAI	Abbreviated Women's Empowerment in Agriculture Index
A-WEEI	Abbreviated Women Empowerment Eucalyptus plantations Index
ATE	Average Treatment Effect
ATT	Average Treatment Effect on the Treated
CSA	Central Statistics Agency
ETB	Ethiopian birr
FAO	Food and Agriculture Organization
GPI	Gender Parity Index
HDDS	Household Dietary Diversity Score
HFIAS	Household Food Insecurity Access Scale
IFPRI	International Food Policy Research Institute
LULC	Land Use and Land Cover
OLS	Ordinary Least Squares
PCA	Principal Component Analysis
PSM	Propensity Score Matching
SDGs	Sustainable Development Goals
SES	Socio Ecological System
TLU	Tropical Livestock Units
UN	United Nations
USGS	United States Geological Survey

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DEDICATION

To my beloved father, the late Mr. Belay Demissie,
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your wisdom, love, and dedication
remain my foundation.

This dissertation is my humble tribute to you
for the dreams you nurtured,
the sacrifices you made,
and the scholar you encouraged me to become.

“A father’s guiding hand lasts a lifetime.”

LIST OF PAPERS

This dissertation is built upon four independent published articles, each aligned with the specific objectives of the study.

1. Land use land cover change and expansion of eucalyptus plantations in Senan district, Ethiopia: Analysis of potential factors. Ethiopian Journal of Environment and Development. https://journal.du.edu.et/index.php/ejed/issue/view/85/83

2. Comparative analysis of income level in matched small farms with and without eucalyptus plantations in Senan, Ethiopia. Journal of Trees, Forests, and People. https://www.sciencedirect.com/science/article/pii/S2666719324002152

3. Eucalyptus-based livelihoods: Enhancing household food security and resilience in Northwest Ethiopia. Frontiers in Sustainable Food Systems. https://www.frontiersin.org/journals/sustainable-food-systems/articles/10.3389/fsufs.2025.1496756/full

4. Eucalyptus plantations and gender dynamics: Analyzing women's empowerment in Northwest Ethiopia. Journal of Trees, Forests, and People. https://www.sciencedirect.com/science/article/pii/S2666719325001074

ABSTRACT

The widespread expansion of eucalyptus plantations in Ethiopia's highlands represents a significant transformation of the agricultural landscape, leading to complex socioeconomic and environmental consequences. While economically appealing to smallholders, the conversion of cropland and its effects on rural livelihoods, food security, and gender equity are not fully understood. This dissertation investigates the socioeconomic implications of the rapid expansion of eucalyptus plantations in the Senan district of Northwest Ethiopia, where cropland conversion to eucalyptus has intensified in recent decades. Data were collected from 332 households (166 eucalyptus planters and 166 non-planters), supplemented by qualitative data from observations, interviews, and focus group discussions. Additionally, Landsat satellite images from 1990, 2000, 2010, and 2021 were utilized. Employing a mixed research approach, the study utilizes econometric and descriptive statistical techniques to analyze quantitative data complemented by thematic analysis for qualitative insights. Satellite imagery analysis reveals a significant land-use shift: cropland decreased from 58.4% to 38.1% between 2010 and 2021, while eucalyptus-dominated vegetation increased from 16.8% to 26.5%. Binary logit models identify key drivers of eucalyptus adoption, including household head age, land size, and savings, while factors like education, livestock ownership, and land fertility negatively influenced adoption. The findings show that eucalyptus ownership significantly impacts household income, livelihood assets, and food security. Households with eucalyptus plantations reported higher livelihood asset index scores across various categories, indicating positive contributions to overall well-being. Specifically, eucalyptus adopters experienced a 40.2% increase in household income (as determined by propensity score matching) and demonstrated better food security, with significantly higher Household Dietary Diversity Scores (5.28 vs. 4.73) and lower food insecurity rates (8.06 vs. 11.29 HFIAS). However, these benefits come with trade-offs: human capital indices are lower among eucalyptus-owning households, and women face disproportionate disempowerment. Women in households engaged in eucalyptus plantations are notably more disempowered than their counterparts in other households, highlighting a significant disparity. This disempowerment is rooted in systemic issues, including a lack of financial control, limited decision-making power, restricted access to credit, and diminished group participation. Addressing these barriers is crucial for enhancing women's empowerment. The dual nature of eucalyptus expansion is evident in

these findings: it enhances livelihoods and food security but also poses risks to gender equity. To address these complexities, the dissertation concludes with policy recommendations for rural road improvement, eucalyptus zoning regulations, sustainable agroforestry practices, gender-inclusive income interventions (emphasizing high-interest savings accounts for rural women), and diversified livelihood strategies aimed at balancing economic gains with long-term resilience and social equity.

Key words: Eucalyptus, Livelihoods, Food security, Women, Income

CHAPTER 1: GENERAL INTRODUCTION

1.1 Background of the Study

Eucalyptus, originating from Australia (Vuong, *et al.*, 2015), is a globally significant species, ranking among the most extensively planted trees worldwide (FAO, 2020). Its widespread adoption is due to its remarkable adaptability to diverse ecological environments (Birhanu & Kumsa, 2018) and a wide range of soil types, even infertile soils (Oballa *et al*., 2010). This adaptability, coupled with its rapid growth and profitability, has established eucalyptus as a fundamental component of forestry in many countries (Goded, 2019). The genus comprises over 700 species (Chandorkar *et al.*, 2021). Globally, eucalyptus is planted in 95 countries, covering over 22.57 million hectares (Lee, 2022), with Brazil being the world's largest producer and China ranking third after India (Florencio *et al*., 2022).

In Ethiopia, eucalyptus has become prominent (Kaba, 2024), introduced in the 1890s during the reign of Menelik II to address the rising demand for fuelwood and construction materials in Addis Ababa (Molla *et al*., 2023). It has rapidly spread across diverse agro-climate zones, now covering approximately 506,000 hectares (Belachew & Minale, 2025). Eucalyptus *globulus* and E. *camaldulensis* are the predominant species (Wasie, 2024). This growth has resulted in considerable land use and land cover changes, often replacing fertile agricultural land (Kuma *et al*., 2022). The drivers of this expansion in Ethiopia are multifaced including eucalyptus's rapid growth and resilience (Tefera & Kassa, 2017), higher profitability than growing crops (Gizachew, 2017), higher and growing market demand (Derbe *et al*., 2018), climate adaptability (Mosisa *et al.*, 2024), rising agricultural input costs (Sete *et al*., 2023), and household socio-economic factors (Kebede, 2022). Farmers are often driven by expectations of better income, affordable production costs, and market demand (Molla *et al*., 2023).

Eucalyptus is widely planted to meet the growing demand for fuelwood and building materials, as well as its various other uses (Belayneh, 2021). Its socio-economic benefits contribute to poverty alleviation and environmental improvement (Khan *et al*., 2020). In many developing countries including in Ethiopia, where 90.8% of households rely on firewood for cooking and heating (Azanaw & Melaku, 2023), eucalyptus plays a crucial role

in energy security. The increasing population and expanding construction sector further amplify the demand for eucalyptus-derived wood products (Sori *et al*., 2023).

Despite its benefits, the expansion of eucalyptus has raised environmental concerns. Critics argue that these concerns often focus on negative impacts without adequately considering the temporal and spatial scales at which these impacts become problematic (FAO, 2009). For instance, in arid and semi-arid environments, eucalyptus can have particularly detrimental environmental consequences (Shi *et al*., 2012).

One major issue is competition for water. Due to its significantly higher water consumption than other trees, eucalyptus *camaldulensis* poses a risk of groundwater depletion in arid regions (Zahid, 2010). This increased water use can lead to reduced water availability for native vegetation and crops, negatively impacting local ecosystems and farming practices (Chanie, 2013). Additionally, concerns about soil nutrient depletion and biodiversity loss have been raised (Liang *et al*., 2016). However, eucalyptus also offers environmental benefits. It can enhance the physical and chemical properties of the soil through decomposed litter, more so than intensively cultivated agricultural land (Mengistu *et al*., 2022). Through the process of carbon sequestration, these plantations absorb significant amounts of CO_2, thereby improving air quality (Amorim *et al*., 2021). When managed effectively, eucalyptus plantations provide sustainable opportunities for enhancing biodiversity and mitigating climate change (Sembiring *et al*., 2020).

The impact of eucalyptus is contingent on management and ecological context (Baye, 2019). While not environmentally equivalent to natural forests, eucalyptus often presents a better environmental profile than other common plantation species and crops in several key aspects (Yimam & Hailu, 2022). Although negative impacts can occur, the advantages of eucalyptus are generally greater and these negatives are largely manageable (Birhanu and Kumsa, 2018).

The Senan district in Northwest Ethiopia exemplifies this complex interplay of benefits and challenges. The district's agricultural sector is dominated by smallholder subsistence farming, facing poverty, food insecurity (Ferede *et al*., 2020), soil acidity, and erosion (Warke, 2024; Tesfaye *et al*., 2016). Recent land use shifts show declining cropland and expanding eucalyptus plantations (Tesfaw *et al*., 2022), potentially leading to socioeconomic implications.

Therefore, this dissertation examines the socio-economic implications of eucalyptus plantations in the Senan district. By integrating diverse perspectives, this research contributes to a deeper understanding of balancing economic benefits with environmental conservation and the advancement of gender inclusivity. Ultimately, this research informs policymakers, practitioners, and communities about the socioeconomic implications of eucalyptus plantations, thereby contributing to Sustainable Development Goals (SDGs), specifically those addressing poverty reduction, climate change mitigation, biodiversity protection, and gender equality.

1.2 Justification of the Study

Growing up in Finoteselam, a small town located approximately 387 kilometers Northwest of Addis Ababa, I observed profound transformations in the Ethiopian landscape. Over the years, as I frequently traveled between Addis Ababa and my hometown, I became captivated by the striking changes in land use, particularly the rapid expansion of eucalyptus plantations that increasingly dominated towns and villages along the route. My husband often remarked, *"Ah! These eucalyptus trees have transformed the once beautiful landscapes of many towns."* As a geographer, however, my curiosity extended beyond the aesthetic shifts. I found myself deeply intrigued by the underlying drivers of this widespread expansion of eucalyptus plantations across Ethiopia and its far-reaching implications for the rural livelihoods and gender dynamics. I was genuinely excited to join a thematic research project studying the socioeconomic and environmental implications of eucalyptus plantations in the Senan district, Ethiopia.

The expansion of eucalyptus plantations in Ethiopia is not merely a visual transformation of the landscape; it represents a complex interplay of ecological, economic, and social factors. Recent studies highlight significant land use and land cover (LULC) changes across the country, with eucalyptus plantations emerging as a dominant feature. For example, in the Mecha district, eucalyptus plantations expanded from 908.87 ha in 1991 to 26,261.9 ha in 2021, largely displacing fertile farmland (Molla *et al*., 2023). In the Gurage Zone, over 42% of households transitioned cropland to eucalyptus, leading to a 68.3% increase in eucalyptus coverage from 2000 to 2021 (Kerbo *et al*., 2024). Similarly, in Meket district, North Wollo zone, eucalyptus plantations expanded from 6022 ha in 2003 to 7930 ha in 2019 (Abebaw

and Betru, 2019). These changes underscore the scale and pace of eucalyptus expansion, raising critical questions about its drivers and consequences.

The rapid spread of eucalyptus plantations has sparked a contentious debate about their impacts on food security and rural livelihoods. On one hand, eucalyptus is celebrated for its economic benefits, providing fast-growing timber and a reliable source of income for rural households. Studies such as those by Alemayehu and Melka (2022) emphasize the role of eucalyptus in enhancing household income, creating jobs, and even serving as a form of financial security or "living insurance" for smallholder farmers (Hailemicael, 2012). Getnet *et al*. (2022) further corroborate these findings, showing that households with eucalyptus plantations experience higher total income, farm expenditure, and education spending compared to those without.

On the other hand, the expansion of eucalyptus plantations has raised significant concerns about their socio-economic trade-offs. The conversion of fertile croplands and natural ecosystems to eucalyptus plantations poses a direct threat to food security and sustainable agricultural production (Abate *et al*., 2022). Resource competition between eucalyptus and food crops, particularly in terms of water and soil nutrients, has been a recurring issue. For instance, Alebachew *et al*. (2015) found that eucalyptus trees negatively impact the productivity of neighboring crops, such as finger millet and maize, significantly reducing their grain yield and yield components. This divergence in findings points to a need for more comprehensive, context-specific studies that can reconcile these conflicting perspectives.

Despite ongoing debates regarding the socio-economic and environmental impacts of eucalyptus, its continued expansion in the Senan district necessitates localized, context-specific research. Furthermore, the growing body of literature on eucalyptus plantations often fails to account for the gender dimension of these plantations. Although women contribute significantly to the agricultural and rural economies of all regions of the world, their voices in decision-making processes are often marginalized (FAO, 2011). This exclusion extends to decisions related to eucalyptus plantations, such as land-use decisions, harvest use, and the allocation of income generated from these plantations. A number of researchers, including Ilesanmi (2018), Kahsay *et al.* (2021), and Silvano and Kweka (2020), have documented women's exclusion from decision-making processes in various sectors, including forestry. Studies also show that the availability and management of natural resources, including forests, are affected by gender dynamics (Haverhals *et al*, 2016).

The socio-economic implications of eucalyptus expansion are equally complex and multifaceted. While eucalyptus cultivation has provided economic opportunities for many rural households, its benefits are not equitably distributed. Gender dynamics, in particular, present a critical challenge, as women's access to and benefits from forest and agroforestry value chains are often restricted by cultural and regulatory biases that favor men (Haverhals *et al*., 2016). This raises important questions about the role of eucalyptus plantations in empowering women and addressing gender disparities in rural communities. However, existing studies on gender and eucalyptus cultivation are limited in scope and often fail to capture the nuanced ways in which women engage with and are affected by eucalyptus plantations. This represents a significant research gap that needs to be addressed to inform more inclusive and equitable policies.

In light of these complexities and research gaps, this dissertation seeks to explore the multifaceted socio-economic implications of eucalyptus plantation expansion in Ethiopia, with a particular focus on the Senan district. Specifically, the research assesses the nexus between eucalyptus plantations, rural livelihoods, and gender dimensions. The study seeks to address critical questions regarding the impact of eucalyptus plantations on household income, livelihood assets, food security, and gender relations within rural communities.

1.3 Objectives of the Study

1.3.1 General objective

The primary objective of this study is to examine the socio-economic implications of eucalyptus plantations in Northwest Ethiopia.

1.3.2 Specific objectives

The specific objectives of the study are to:

1. analyze the land use changes and the drivers behind farmers' conversion of croplands to eucalyptus plantations in Northwest Ethiopia.
2. evaluate the causal impact of owning eucalyptus plantations on household income in Northwest Ethiopia.
3. examine the impact of eucalyptus-based livelihoods on farmers' food security and capital assets in Northwest Ethiopia.

4. assess the effect of eucalyptus plantations on women's empowerment in Northwest Ethiopia.

1.4 Research Questions

This study addressed the following research questions:

1. Why do farmers convert their cropland into eucalyptus plantations in the study area?
2. What is the impact of eucalyptus plantations on household income?
3. What are the effects of eucalyptus plantations on household livelihoods in the study area?
4. What is the relationship between eucalyptus plantations and food security in the study area?
5. Is there any difference in decision-making authority between women and men regarding eucalyptus plantations?
6. What are the determinants of women empowerment in the study area?

1.5 Significance of the Study

This study investigates the complex interplay between eucalyptus plantations, rural livelihoods, and gender dynamics, offering a comprehensive and nuanced understanding of eucalyptus' multifaceted role in Ethiopia's rural development. By integrating socio-economic perspectives, the research sheds light on how eucalyptus cultivation influences food security, income generation, and resource allocation while also addressing the distinct experiences and challenges faced by women in rural communities. The findings will provide critical insights for crafting evidence-based policies and practices that promote sustainable land management, enhance food security, and advance gender equality, not only in Ethiopia but also in other regions grappling with similar land-use and socio-economic challenges. Furthermore, this study aligns with several United Nations Sustainable Development Goals (SDGs), including SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 5 (Gender Equality), and SDG 13 (Climate Action), thereby contributing to global efforts toward sustainable development. The research builds a firm foundation for future academic studies on the socio-economic impacts of rural tree plantations.

1.6 Scope of the Study

Geographically confined to the Senan district, Northwest Ethiopia, this study investigates the socio-economic implications of eucalyptus plantations, with a specific focus on their impacts on rural livelihoods, food security, household income, and gender dynamics. Methodologically, a mixed approach is adopted, integrating quantitative and qualitative data to provide a comprehensive and nuanced understanding of the interactions between eucalyptus cultivation and the community's socioeconomic structure.

1.7 Limitations of the Study

The geographical focus of this study is confined to the Senan district in Northwest Ethiopia. As a result, the findings may not be applicable to other areas with varying socio-economic, cultural, and environmental contexts. Additionally, as a female researcher, it is essential to recognize that my interpretations and conclusions from the qualitative analysis of the fourth paper: “Eucalyptus plantations and gender dynamics: Analyzing women's empowerment in Northwest Ethiopia” may be shaped by my personal viewpoints and inherent biases, even though I strive to uphold objectivity.

Moreove, political instability, especially in the study's final two years, hampered data collection as some potential participants were hesitant to engage openly in interviews and FGDs.

1.8 Structure of the Dissertation

This dissertation is structured across six chapters. Chapter one sets the foundational context, outlining the study's background, problem statement, research objectives and questions, significance, scope, limitations, and methodology, along with a literature review. Chapter two then explores land use and land cover change, and expansion of eucalyptus plantations. This chapter also examines the factors driving these changes, particularly the rationale behind farmers’ decisions to adopt eucalyptus cultivation. Moving to economic implications, chapter three analyzes the causal impact of eucalyptus plantations on household income in the study area. Following this, chapter four focuses on the effects of these plantations on rural household livelihoods and food security, also identifying the determinants of food security within the study area. Chapter five shifts focus to the gender aspects of eucalyptus plantations,

analyzing how their expansion influences women's roles and empowerment. This chapter discusses the challenges and opportunities women face regarding land use, decision-making, and economic benefits. Finally, chapter six presents the study's conclusions, recommendations, and policy implications.

1.9 Related Literature Review

1.9.1 Historical context of Eucalyptus plantations in Ethiopia

Eucalyptus plantations in Ethiopia date back to the late nineteenth century, under Emperor Menelik II (Dessie *et al.*, 2019; Alemu, 2016). To address the increasing demand for fuelwood and construction materials in the rapidly growing city of Addis Ababa, Emperor Menelik II introduced eucalyptus trees to Ethiopia around 1895 (Dessie *et al*., 2019). Today, eucalyptus is one of the most widely planted exotic tree species in Ethiopia (Kebede, 2022). The rapid growth and adaptability of eucalyptus trees to various ecological conditions have contributed to their increasing popularity over the years (Alemu, 2016). Eucalyptus plantation serves multiple purposes, providing fuelwood, construction materials, and income through wood sales (Zerga *et al*., 2024).

Despite its widespread cultivation, eucalyptus faces controversy, with critics arguing that the plantations can have detrimental environmental impacts, such as excessive water use, soil nutrient depletion, and suppression of native plant life (Yimam *et al*., 2024). Current research and policy interventions now focus on balancing the economic benefits with environmental well-being. This includes promoting techniques like intercropping eucalyptus with other plants, utilizing degraded lands for plantation development, and selecting eucalyptus varieties with higher productivity and lower environmental impact. These strategies aim to ensure that eucalyptus cultivation contributes positively to Ethiopia's economy and ecology, addressing the concerns raised by critics (Lemenih & Kassa, 2014).

1.9.2 Conceptual and theoretical overview

1.9.2.1 Livelihood transformation through land use and land cover change

Livelihood encompasses the resources, assets, and abilities individuals or families utilize to ensure their basic needs, such as food, shelter, income, and overall well-being (Khan *et al*., 2020), are intricately linked to land use and land cover (Ameneshewa *et al*., 2024). Land use categorizes human interactions with the land (e.g., agriculture, pasture, plantations), whereas

land cover describes the biophysical properties of the Earth's surface (e.g., forest, desert) (Zvoleff *et al*., 2014). Land Use and Land Cover (LULC) Change is a complex process influenced by various socioeconomic and natural environmental factors (Anteneh, 2022).

Land use and land cover (LULC) change significantly impacts livelihoods, especially in areas where communities rely heavily on natural resources for survival (Gessese, 2018). While these changes generally provide opportunities for increased revenue and infrastructure, they also present obstacles that must be carefully managed to guarantee fair and sustainable development (Lambin *et al*., 2003).

For instance, transitioning from subsistence farming to forestry can potentially increase household income and enhance food security (FAO, 2011). Eucalyptus plantations, in particular, can generate higher incomes for farmers, leading to improved livelihoods and enhanced food security (Bezabih *et al*., 2019). However, as Turner *et al*. (2007) argued, livelihood transformation through LULCC is a double-edged sword, presenting both potential benefits and significant risks.

The complexity of land use and land cover change has profound implications for livelihoods. Numerous studies, such as Kerbo *et al*. (2023), have pointed to the expansion of eucalyptus plantations as a major driver of observed changes in land use and land cover patterns.

1.9.2.2 The concepts of food security

The concept of food security, marked by its dynamic and ever-changing nature (Mulugeta, 2012; Shakeel, 2018), evolved significantly in response to the growing political will and policy efforts to combat increasing malnutrition and famine globally (Degaga, 2005). It first emerged in the mid-1970s in response to the global food crisis of that era (Mohammed, 2022). The 1974 World Food Conference, recognizing the urgency of addressing widespread hunger, defined food security as ensuring the availability and price stability of essential food items at both the international and national levels (FAO, 2006). This early definition emphasized the need for adequate food supplies and presented a rather limited perspective (Mulugeta, 2012), overlooking the multifaceted factors that contribute to food insecurity beyond mere physical access to food. At that time, over 25% of the world's population was affected by protein-energy insufficiency, underscoring the urgency of expanding food production (Peng and Berry, 2019).

However, this initial definition presented a simplistic perspective, viewing food insecurity solely as a result of insufficient food resources in quantitative terms and elevated levels of food prices globally (COOPI, 2023). This definition reflects the core tenet of the Food Availability Decline (FAD) theory (Degaga, 2005), which focuses on the necessity of maintaining sufficient food availability to prevent hunger and malnutrition. The FAD theory posits that all famines are caused by a sudden drop in food supply, frequently due to crop failures (Bowbrick, 2022).

However, it soon became apparent that despite adequate food supplies, poverty, inequality, and limited market access hindered many people from accessing nutritious food. This led to a shift in focus toward access to food, recognizing that poverty, income inequality, and limited purchasing power significantly impact an individual's ability to acquire sufficient food (Mohammed, 2022). Hence, in the 1980s, the definition of food security evolved further to include concepts of exchange entitlement and accessibility, describing it as "all people having access to enough food for an active, healthy life at all times" (FAO, 2007). This marked a significant transition from concentrating solely on food production to a more comprehensive understanding that incorporates access, utilization, and stability in achieving food security (Shakeel, 2018). The definition highlights that farm household food security relies not only on their production but also on their purchasing ability, underscoring how eucalyptus trees can help farmers enhance their income and maintain food security (Kerbo, 2024).

As the understanding of food security progressed, it became apparent that the issue was more complex. Consequently, during the World Food Summit in Rome in 1996, "food security" was defined broadly as "a situation where all people at all times have physical and economic access to sufficient, safe, and nutritious foods to meet their dietary needs and food preferences for an active and healthy life." This Summit further refined the concept of food security by introducing the "four pillars" of food security: availability, access, utilization, and stability (FAO, 1996). This framework acknowledged that even with adequate food availability and access, individuals may not be able to utilize food effectively due to factors such as poor health, inadequate sanitation, and lack of nutrition education. Food utilization became a critical dimension of food security, suggesting that an individual can consume food but still be food-insecure if their body does not effectively utilize it, resulting in poor absorption of essential nutrients. Successful food utilization occurs when “food is properly used; appropriate food processing and storage methods are applied, there is sufficient

knowledge of nutrition and child care practices, and adequate health and sanitation services are available" (Shakeel, 2018; Renzaho and Mellor, 2010). Furthermore, it emphasized the importance of stability in food systems, recognizing that shocks such as droughts, floods, and economic crises can disrupt food production and access, leading to food insecurity.

In conclusion, the development of the food security concept highlights an increasing awareness of its complexity. Initially centered on food availability and price stability in the 1970s, the contemporary understanding now encompasses access, utilization, and stability, adapting to the realities of a changing world.

1.9.2.3 Approaches to food security

Food security is a multifaceted issue that encompasses various dimensions, including the availability, access, utilization, and stability of food. Over the years, several approaches have emerged to address the complexities of food security challenges. This review explores key approaches, including the food availability approach, income-based approach, right-to-food approach, entitlement approach, and vulnerability approach.

The food availability approach has roots in the ideas of the Venetian philosopher Giovanni Botero (1588) but was popularized by Thomas Malthus (1789), focusing primarily on the availability of food (Burchi and Muro, 2016). Malthus is well-known for his assertion that food production exhibits arithmetic growth (1, 2, 3, 4, etc.), while human population growth follows a geometric pattern (1, 2, 4, 8, etc.)(Burger, 2020). To sustain this equilibrium, the rate of food availability growth must not fall below the rate of population growth (Barrus, 2004). Critics, however, point out that this approach often overlooks issues of access and utilization, which are crucial for achieving true food security.

The entitlement approach, developed by Amartya Sen, shifts the focus from food availability to the rights and entitlements individuals have to access food (Kurniawan, 2016). A central inquiry within the entitlement approach is: "Why do famines occur even when there is sufficient food available?" (Devereux, 2000). This approach highlights the significance of recognizing how individuals obtain food through legitimate channels, referred to as "entitlements" (Sen, 1991). Sen argues that food security is determined not only by food supply but also by the ability of individuals to acquire food through various means, including production, trade, and social safety nets. This approach underscores the importance of social

and economic structures that enable individuals to secure their food needs, thus integrating aspects of both availability and access. Although Sen's work has had a significant impact, it has faced criticism for its focus on methodological individualism and for prioritizing economic factors over sociopolitical influences, including corruption (Sohlberg, 2006). Nonetheless, the entitlement approach continues to be significant in studies of poverty and famine, promoting a more comprehensive understanding of these intricate issues (Devereux, 2001). The scope of food security approaches has expanded beyond individual entitlement to encompass political regimes, natural disasters, civil conflicts, governance, and environmental challenges like climate change (Kurniawan, 2016).

The right-to-food approach is grounded in human rights principles. The Universal Declaration of Human Rights, adopted in 1948, first acknowledged the right to food as a fundamental human right within the broader context of the right to an adequate standard of living, formally enshrined in Article 25(1) of the Declaration (FAO, 2014). This rights-based approach prioritizes human rights and obligates governments to create conditions that enable all people to access sufficient, safe, and nutritious food (Golay and Büschi, 2012). This emphasizes that combating hunger requires more than just providing food; it necessitates creating an enabling environment where everyone can access and utilize adequate food (Sassi, 2018). In 2004, the FAO Council issued the Voluntary Guidelines to Support the Progressive Realization of the Right to Adequate Food in the Context of National Food Security, providing a framework for its implementation (ACF, 2008).

The Vulnerability Approach offers a forward-looking perspective, contrasting with traditional analyses that provide a retrospective view of food insecurity. By examining vulnerability, this approach facilitates a dynamic understanding of its causes and potential solutions (Lovendal and Knowles, 2006). It defines vulnerability as the likelihood of experiencing food insecurity due to various hazards, considering factors like exposure, sensitivity, and coping capacity (Lucas & Hilderink, 2004). This approach focuses on identifying individuals and groups most at risk of food shortages and developing effective risk management strategies (Scaramozzino, 2006). By incorporating multiple levels of analysis, from individual households to larger regions, this framework allows for both micro- and meso-level assessments of food security (Droy & Rasolofo, 2004). The approach's capacity to predict future probabilities of food insecurity and evaluate risk management strategies renders it valuable for enhancing policy responses and interventions (Lovendal & Knowles, 2006; Scaramozzino, 2006).

1.9.2.4 Women in forestry

Women are crucial actors in the forestry sector globally, particularly in developing countries where they are the primary gatherers of forest resources (AUCN, 2011). Despite their significant contributions, women frequently face gender-based disadvantages that restrict their access to, use of, and control over forest resources (Bitzer *et al*., 2024). These barriers are often deeply rooted in cultural, socioeconomic, and institutional factors that limit women's access to and control over forest resources and economic opportunities compared to men (FAO, 2013).

The expansion of eucalyptus plantations has created further challenges for women. In Brazil, the growth of eucalyptus monoculture, combined with an influx of foreign workers, has led to increased sexual harassment and sexist attitudes, instilling fear in women and their families, which undermines rural women's independence and autonomy and exacerbates female disempowerment (WRM, 2009).

Moreover, women often face significant barriers to accessing and controlling forest resources and benefiting from economic opportunities, which stem from a complex interplay of cultural, social, economic, and institutional factors (Kai, 2022). Despite these challenges, women in forest communities possess extensive knowledge about forest species diversity, management, resource use, restoration, and product transformation, which directly contribute to food security and health (FAO, 2022).

Equal access to forests for women is likely to improve food security for those who rely on them for a livelihood (Kimanzu, 2021). However, the most commercially valuable forest resources, like timber, are typically controlled by men due to various social and economic factors (Martin and Kuriakose, 2017). A significant contributing factor to women's exclusion from forestry at various levels is the deeply entrenched societal perception that this sector is most suitable for men (Kai, 2022).

Furthermore, women are underrepresented in the formal forestry sector, with limited numbers of women professionals in government forestry departments and the forestry industry (WOCAN, 2012). This underrepresentation underscores the systemic barriers that perpetuate gender inequality within the forestry sector, highlighting the need for targeted interventions to promote women's empowerment and equal access to forest resources.

In conclusion, while women play a vital role in the forestry sector, their empowerment is severely hindered by gender-based disadvantages, cultural perceptions, and institutional barriers. Addressing these issues is essential for fostering gender equity and enhancing the contributions of women to sustainable forestry and food security.

1.9.3 Theoretical framework

This dissertation is grounded in Socio-Ecological Systems (SES) theory as its theoretical framework. The development of the SES concept can be traced back to the early to mid-1990s, arising from collaborative efforts among scholars in ecological economics and common-pool resource management, including influential figures like Berkes (1989), Ostrom (1990), and Costanza (1991) (Biggs *et al*., 2021). Since its inception, the SES framework has evolved to provide a comprehensive understanding of the intricate interactions between social, economic, and ecological dimensions.

At its core, SES theory integrates perspectives from both environmental and social sciences, embodying the "humans-in-nature" perspective. This viewpoint emphasizes the fundamental interconnectedness of human and natural systems, advocating for their study as integrated wholes rather than as isolated components (Manyani *et al*., 2024; Petrosillo *et al*., 2015). This study specifically utilizes the Ostrom social-ecological system framework, a widely recognized interdisciplinary tool for analyzing these linked human-natural systems (Vogt *et al*., 2015).

The Ostrom SES framework posits that outcomes within an SES are shaped by the dynamic interplay of several key components: the resource system, resource units, actors, and the governance system (Ostrom, 2009). The resource system characterizes the environmental setting where resources are found or generated, while the resource units focus on the measurable outputs of the system, such as timber or biodiversity (Delgado-Serrano & Ramos, 2015). Actors, encompassing individuals and groups, influence and are impacted by the resource system. Crucially, the governance system encompasses the rules and institutions that guide resource management within this interconnected system (Vogt *et al*., 2015).

A core tenet of SES theory is the recognition of interconnectedness between human and natural systems, emphasizing the need to study them as an integrated system rather than as isolated components (Manyani *et al*., 2024). This interconnectedness is further highlighted by the bidirectional relationships between social and ecological systems, where human actions,

such as land use changes, impact ecosystems, and environmental changes, such as climate change, affect societal well-being (Liu *et al*., 2007).

Several key concepts within SES theory provide valuable lenses for this research. Resilience, for instance, refers to the capacity of the system to absorb disturbances and reorganize while maintaining its core functions, a critical aspect for the long-term sustainability of both ecosystems and communities facing environmental and social shocks (Folke *et al*., 2010). Adaptive governance, another key principle, involves flexible, participatory decision-making processes that respond to changing conditions, enabling the management of complex and unpredictable systems (Dietz *et al*., 2003). Furthermore, feedback loops, where changes in one component of the system influence other components, often in nonlinear ways, further underscore the dynamic nature of SES (Walker *et al*., 2004).

The SES framework also acknowledges the co-evolution of social and ecological systems across various scales, highlighting the need for adaptive policies that foster resilience and avoid rigid, top-down approaches that can lead to fragile systems (Petrosillo *et al*., 2015). By employing the SES framework, this research aims to gain valuable insights into the intricate web of interactions between humans, social systems, and the environment in the context of eucalyptus expansion, ultimately contributing to strategies for greater well-being and resilience (Currie, 2008). As noted by UNESCO (2021), the SES framework offers a crucial mechanism for understanding the complex interplay of technical, environmental, social, economic, and political dimensions in agro ecological transitions, a particularly pertinent consideration for this study.

Therefore, this dissertation utilizes the SES framework to specifically explore how the expansion of eucalyptus plantations, a significant land use change, impacts the interconnected elements of livelihoods, food security, and women's empowerment in Northwest Ethiopia.

The following conceptual framework (Figure 1) highlights the interconnectedness of social and ecological systems and the role of governance in shaping outcomes related to food security, income, livelihoods, and women’s empowerment.

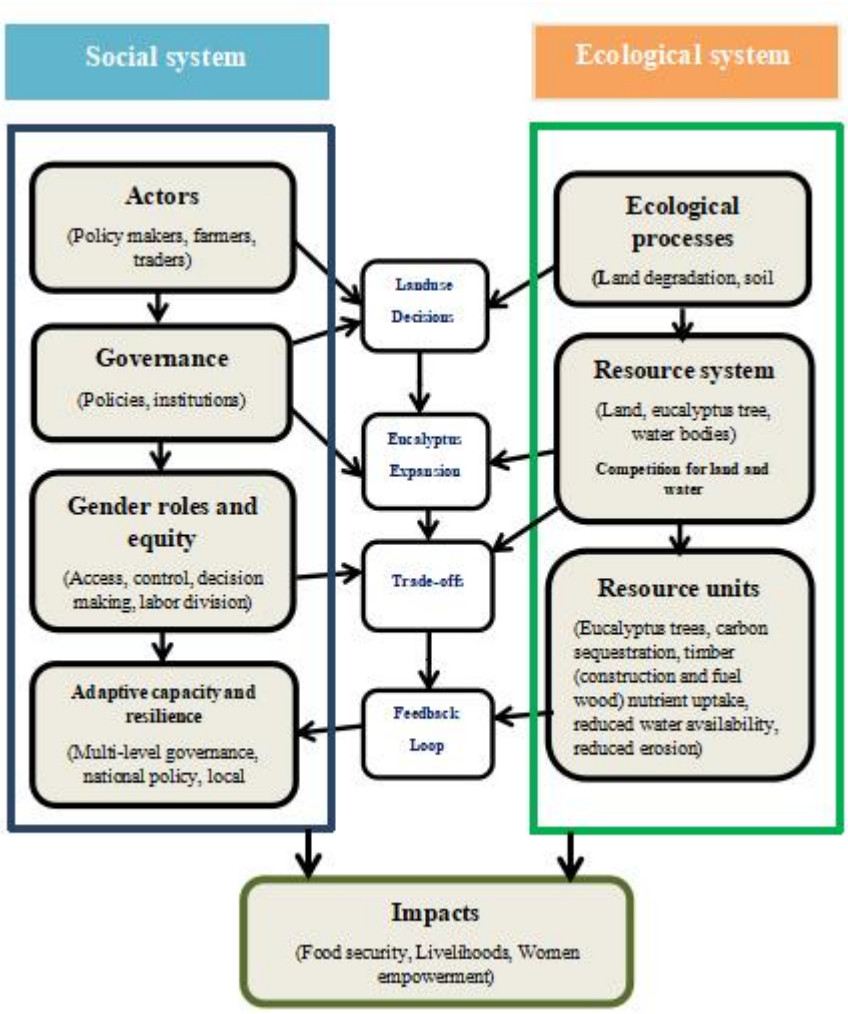

Figure 1: Conceptual framework (Adapted from Ostrom, 2009)

The conceptual framework illustrates the complex interplay between social and ecological systems, particularly in the context of eucalyptus expansion. This framework highlights how these interconnected systems jointly influence food security, income, livelihoods, and gender dynamics, emphasizing the need for integrated management approaches. The key components of the framework includes:

Actors: The socioecological system is characterized by the dynamic interactions of diverse actors, including farmers, traders, and local communities. Their land-use decisions, particularly regarding eucalyptus cultivation, significantly impact ecological health and socioeconomic well-being. This underscores the importance of effective stakeholder engagement in balancing economic benefits with sustainable land management practices.

Governance structures: Governance structures, encompassing existing policies and institutions, are crucial for regulating land use and ensuring equitable resource distribution. Effective governance fosters collaboration among stakeholders, enabling adaptive management that balances eucalyptus expansion with the sustainability of local food systems and livelihoods.

Gender roles: Gender dynamics, a critical aspect of the socioecological framework, significantly influence resource access and decision-making. Prevailing norms shape access to resources, control over them, participation in decision-making, and the division of labor, thereby affecting how various groups interact with eucalyptus plantations. Understanding these roles is essential to assess the differential impacts of eucalyptus expansion on income generation and livelihood opportunities for men and women.

Adaptive capacity and resilience: Communities' ability to adapt is influenced by multi-level governance, national policies, and local factors, which shape their responses to changes in land use. To effectively cope with these changes, communities must strengthen their adaptive capacity through social networks, institutional support, and improved access to resources. Enhancing resilience is crucial for mitigating the socioeconomic and ecological disruptions caused by eucalyptus expansion.

Ecological processes: Eucalyptus plantations alter critical ecological processes, including soil fertility, water availability, and biodiversity. These changes impact ecosystem services that underpin food production and community well-being, necessitating sustainable land-use strategies.

The resource system: This includes land, eucalyptus trees, and water bodies, highlighting the potential competition for these essential resources, which determine the long-term livelihood viability.

Resource Units: Outcomes such as carbon sequestration, timber production, nutrient uptake, and changes in water availability and erosion are key indicators of the ecological impact.

Impacts: This framework emphasizes the comprehensive impacts of social-ecological interactions on food security, income stability, livelihoods, and gender equity. These

outcomes highlight the need for a socioecological approach to land management that prioritizes ecological sustainability and community resilience.

This framework underscores the importance of analyzing eucalyptus expansion not as an isolated phenomenon, but as a complex socio-ecological process. By promoting sustainable land use practices that improve ecological health and community welfare, the framework helps to strengthen household livelihoods, food security, and resilience while mitigating the risks of eucalyptus expansion.

1.9.4 Empirical review

This section reviews empirical studies on the drivers of eucalyptus plantation expansion and its socioeconomic impact, specifically on income, food security, livelihoods, and women's empowerment. The increasing prevalence of eucalyptus plantations and their implications for land use and cover change have attracted considerable research attention.

Numerous studies have employed diverse analytical methods to investigate the socioeconomic factors that influence this expansion. Several studies have examined the drivers of eucalyptus plantation expansion. For example, Kerbo et al. (2024) utilized Ordinary Least Squares (OLS) regression in the Gurage Zone, Ethiopia, identifying land size and market accessibility as significant factors. They argued that larger landholdings offer greater opportunities for eucalyptus cultivation, while better market access incentivizes investment due to potential sales.

Similarly, Wubetie et al. (2025) employed binary logistic regression in the Senan and Mecha districts of Northwest Ethiopia, revealing that the need for alternative income, declining soil fertility, and high demand for eucalyptus wood products drive expansion. The anticipated long-term financial rewards were also identified as a key motivator for farmers.

Focusing on adoption decisions, Munuyee et al. (2022) used a probit model in the Mecha district, finding that farmers' perceptions of woodlot production, farming practices, and access to loans significantly influenced adoption. Market accessibility, the number of land parcels, family size (negatively), and landholding size also affected the intensity of adoption.

Further corroborating these drivers, Tefera and Lerra (2016) applied binary logit regression in the Maket district, North Wollo, Ethiopia, identifying farmland size, access to credit and

loans, household income, and age as positive influences on eucalyptus cultivation decisions. Conversely, a higher dependency ratio and risk perception had negative effects.

Kebede et al. (2024) reinforced these findings in central Ethiopia, using a binary logit model to show that land size, forest income, education level, and length of residence significantly impacted the conversion of agricultural land to forest land (often eucalyptus). Belachew and Desta (2025) further supported these drivers with their binary logit regression analysis, highlighting strong demand for construction materials and fuelwood, income generation opportunities, and the use of unproductive land as key motivators, alongside larger farm sizes, access to credit, higher income, and the availability of unproductive land.

In summary, the literature consistently points to several key socioeconomic and environmental drivers of eucalyptus plantation expansion, including land size, market accessibility, income opportunities, and farmers' perceptions of eucalyptus woodlot production. These factors collectively underscore the complex interplay of socioeconomic variables driving land use and cover change, emphasizing the need for context-specific policies to support sustainable eucalyptus plantations while addressing concerns about land degradation and food security.

Beyond the drivers, research has also explored the socioeconomic impacts of eucalyptus plantations. Several studies indicate a positive influence on household income and livelihoods. Alemayehu and Melka (2022) highlighted eucalyptus's role in achieving wood self-sufficiency and generating substantial cash income, emphasizing its importance in rural livelihoods. Zerga et al. (2024) conducted a study on the impacts of eucalyptus plantations on the livelihoods of rural farm households in central-south Ethiopia. Using descriptive and dispersive statistics with SPSS version 20, they discovered that eucalyptus cultivation provides a sustainable means to meet financial needs, often surpassing the profitability of other agricultural ventures.

Supporting these positive impacts, Mekonnen's (2010) mixed approach study in the Arsi Zone highlighted the significant influence of eucalyptus cultivation on rural communities, particularly due to their reliance on wood energy. Tesgera (2024) also confirmed its substantial contribution to improving household livelihoods across Ethiopia using a mixed approach. Zerga and Woldetsadik (2016), employing descriptive and inferential statistics, concluded that eucalyptus is more economically viable than traditional food crops, providing

a safety net and enhancing livelihood prospects, a perspective echoed by Bezabih et al. (2019). According to the results from the Propensity Score Matching (PSM) model's Average Treatment Effect on the Treated (ATT), income derived from selling farm forest products significantly contributes to the total household income, particularly compared to non-planter households (Getnet et al., 2022).

Takele's (2024) analysis advises against blanket bans, advocating for a comprehensive evaluation of its socioeconomic roles through mixed approach research that analyzes quantitative data using percentages, means, standard deviations, t-tests, and chi-square tests, while summarizing qualitative data textually.

However, a contrasting perspective emerges regarding food security. Kerbo et al. (2024) applied a composite food security indicator model and multinomial logistic regression analysis to evaluate the food security status of eucalyptus-growing farmers in the Gurage Zone, Ethiopia. Their study revealed that the expansion of eucalyptus negatively impacts food security by reducing land available for crop production and limiting grazing areas for livestock, consequently affecting livestock holdings. This underscores the necessity of selecting appropriate sites for eucalyptus plantations to mitigate adverse effects on food production. Kebebew (2010) utilized independent t-tests and paired t-tests to assess differences in annual income between eucalyptus growers and non-growers, as well as to compare income before and after eucalyptus cultivation. The study also cautioned that discouraging eucalyptus cultivation without careful consideration could increase vulnerability to food insecurity.

In conclusion regarding socioeconomic impacts, the literature presents a nuanced picture. While many studies highlight the income-generating and livelihood-enhancing potential of eucalyptus, others raise concerns about food security due to land-use changes. This divergence suggests a need for further research to understand the specific contexts and thresholds determining the overall impact on rural household well-being.

A separate body of literature examines the intersection of gender and forestry, although less focused on household-level eucalyptus initiatives in Ethiopia. Studies in South Asia, particularly Nepal, India, and China, have explored women's participation in community forestry management (Kimanzu et al., 2021). Kimanzu et al. (2021) also provided a gender-sensitive perspective on agroforestry in Africa, noting women's distinct roles and challenges

in accessing and controlling forest resources, a pattern often shaped by household and community dynamics (Nesmith, 1991; Bitzer et al., 2024; Elias et al., 2017). Mai and Wan (2011) highlighted challenges in effectively integrating gender into forestry research, including conceptual clarity and technical skills. Existing gender mainstreaming approaches often overlook historical and social factors shaping gender roles (Tyagi and Das, 2017), and a gendered division of control over tree products often exists (Mengesha et al., 2021; Anteneh, 2012; Kiptot and Franzel, 2011).

Despite the extensive research on land use change drivers, a gap remains in specifically addressing the drivers of eucalyptus plantation expansion. While broader land use changes have been examined, the specific socioeconomic and environmental factors driving eucalyptus proliferation require further investigation. Furthermore, while some studies explore the impacts of eucalyptus on food security and livelihoods, the findings are divergent, and methodologies could be more robust, necessitating clearer analyses. Critically, the intersection of eucalyptus plantation expansion and women's empowerment has been largely overlooked, particularly within the Ethiopian context. Understanding the specific impacts of eucalyptus plantations on women's roles within rural communities is crucial for developing effective and equitable policies.

These gaps highlight important areas for future research. Addressing them will not only enhance the understanding of eucalyptus plantation dynamics but also contribute to more informed decision-making regarding land use policy, food security, and women's empowerment in Ethiopia.

1.10 General Methodology

1.10.1 Description of the study area

Location and administrative setting: The study area, Senan district, is situated in the East Gojjam Zone of the Amhara Region in Ethiopia. Its geographical coordinates, as shown in Figure 2, are between 10° 25' 13" N and 10° 40' 30" N latitude, and 37° 40' E and 37° 50' 20" E longitude. The district is bordered by *Bibugn* district to the North, *Gozamin* district to the South, *Debay Tilat Gin* district to the East, and *Machakel* district to the West (Tamer, 2016). Additionally, Senan district is 277.2 kilometers from Bahir Dar, the regional capital, and 27 kilometers from Debre Markos, the zonal capital (Senan District Communication Affairs Office, 2021). Officially established on October 11, 2006, the district includes 17 rural and 2

urban sub-districts, spanning a total area of 43,636 hectares (Senan District Communication Affairs Office, 2020).

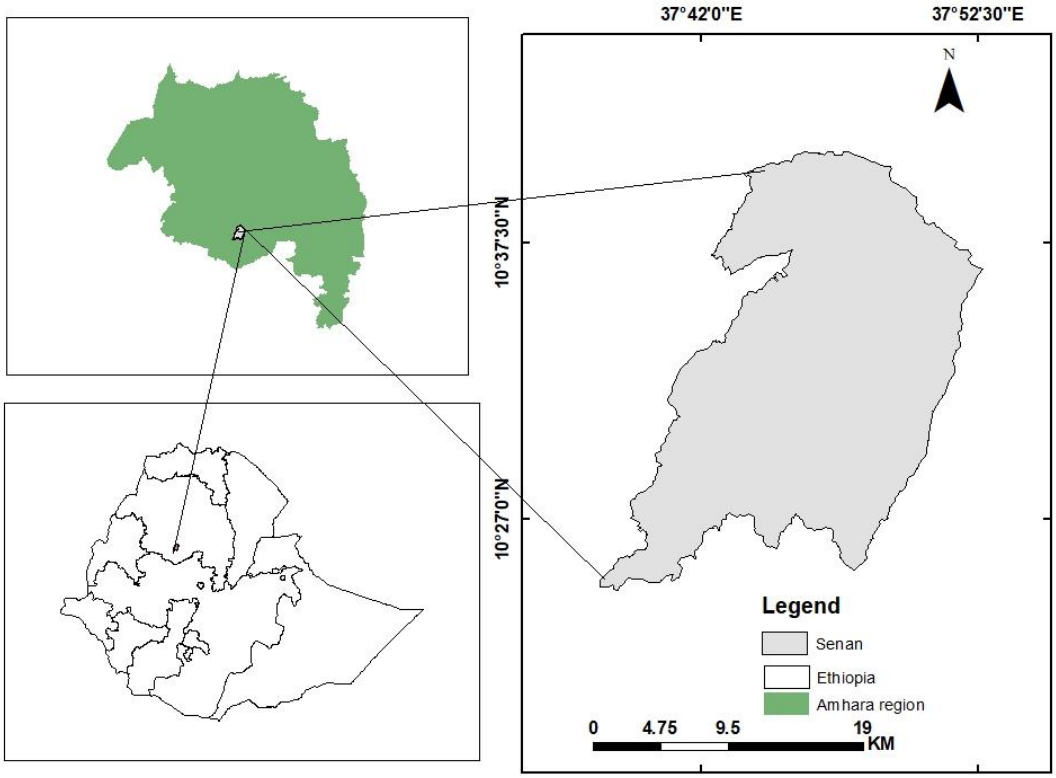

Figure 2: Geographic location of the study area

Biophysical characteristics: In terms of biophysical characteristics, Senan district has an altitude ranging from 2,300 to 4,154 meters above sea level, with an average elevation of 2,940 meters (Bongasie *et al*., 2024). The terrain consists of 25% plateau and plains, 60% mountains and hills, and 15% valleys (Senan District Communication Affairs Office, 2020). The area is highly susceptible to soil erosion, with slope gradients ranging from 0% to 54% (Bongasie *et al*., 2024). The agro-climatic zones include *dega* (highland cold zone, approximately 75%), *woina dega* (temperate zone, around 23%), and *wourch* (hail-prone zone, about 2%) (Gebremichael, 2008).

The average daily temperature is 15°C, with annual rainfall between 900 and 1,500 mm (CSA, 2022). The dominant soil types are Leptosols and Luvisols (Bitew and Workie, 2024), while the vegetation is characterized by *Juniperus procera* and *Eucalyptus*

globulus (Gebeyehu, 2024). In recent decades, farmers in the region have increasingly converted agricultural land to eucalyptus *globulus* plantations, leading to its growing prominence as a tree species (Yimam *et al*., 2024).

Socioeconomic conditions: The socioeconomic conditions of the Senan district are primarily shaped by subsistence agriculture (Tesfaw *et al.,* 2022), with over 96% of the population dependent on farming (CSA, 2024). The farming system is a small-scale mixed crop-livestock system, where wheat, barley, maize, beans, and potatoes are the main crops (Simane *et al*., 2012). However, the average landholding is only 0.5 hectares per household, leading to intensive cultivation and land degradation (Simane *et al*., 2012). The expansion of eucalyptus plantations has replaced some croplands, providing fuelwood, construction materials, and income opportunities (Tesfaw *et al*., 2021).

The livelihoods of farming communities are under pressure due to soil erosion, declining fertility, overgrazing, and deforestation (Gebremichael, 2008). The reliance on traditional farming practices makes the population highly vulnerable to food insecurity, worsened by soil infertility from population pressure (Eshete, 2015).

As of 2021, the total population was estimated at 122,204 (60,581 males and 61,623 females), a rise from 98,939 in the 2007 census (Senan District Communication Affairs Office, 2021; CSA, 2007). Household labor is generally divided along gender and age lines, with men typically serving as household heads (Merid and Emirie, 2020). According to the 2021 annual report from the Senan Woreda Communication Office, the net enrollment rate for primary education (grades 1-8) in the district was 48.9%.

The age structure reflects a high youth dependency rate, with 41.35% of the population under 15 years (resulting in a dependency ratio of 75.77), while only 4.08% are over 64 years (with a dependency ratio of 7.48). This culminates in an overall age dependency ratio of 83.25% (Senan District Communication Affairs Office, 2021). Furthermore, a multidimensional poverty analysis by Ayele *et al*. (2025) indicated that over 40% of the population (40.2%) is classified as living in moderate to severe poverty.

1.10.2 Philosophical foundations

This dissertation adopts pragmatism as its overarching philosophical orientation. Embracing a pragmatic ontology, the study views reality as dynamic and context-dependent, moving

beyond rigid objectivity-subjectivity binaries (Creswell, 2014). The epistemological approach of the study is therefore pragmatic, employing a mixed approach that integrates elements of both positivism and interpretivism. Different research questions and the various aspects of the phenomenon the study investigates necessitate different approaches to yield meaningful and comprehensive insights.

Pragmatism's epistemological flexibility justifies the use of mixed methods. This approach involves integrating quantitative data (e.g., household surveys, satellite imagery) with qualitative insights (e.g., interviews, FGDs, observations) to triangulate findings and ensure both empirical rigor and contextual relevance (Peter *et al*., 2005). Given the complex socioeconomic dynamics of eucalyptus expansion in Ethiopia's highlands, pragmatism provides a flexible framework to address the research problem through mixed-methods integration.

The use of mixed approach overcomes the limitations of both quantitative and qualitative methodologies, enabling researchers to gather rich information that would not be possible using either method alone (Almeida, 2018). The basic premise of this methodology, aligned with our pragmatic philosophy, is that such integration allows for a more comprehensive and synergistic use of data, leading to a deeper understanding than separate quantitative and qualitative data collection and analysis could achieve (Wisdom and Creswell, 2013).

1.10.3 Data sources and methods of data collection

This study utilized both primary and secondary data sources to ensure comprehensive and accurate information. Data collection was conducted using Kobo Toolbox, a digital platform for data gathering.

Primary data were collected through a variety of methods. Questionnaires, translated into Amharic and pilot-tested for clarity, were administered digitally via Kobo Toolbox to 166 households with eucalyptus plantations and 166 households without. This questionnaire data was collected by the districts' agriculture extension experts. Personal observations, conducted in collaboration with these extension officers, provided insights into eucalyptus plantation expansion and market dynamics. Qualitative data were gathered through interviews with both eucalyptus-owning and non-owning households, as well as focused group discussions involving selected farmers including women (both eucalyptus owners and non-owners), local agriculture extension experts, and the district's gender focal person. These interviews and

focused group discussions were conducted by the researcher herself, guided by the principle of saturation to determine data collection cessation. GPS instruments were used to conduct surveys for ground control points, enhancing the accuracy of spatial data.

1.10.4 Sampling technique and sample size determination

This study used a cross-sectional design and a multistage sampling technique. Senan district was purposively chosen for its eucalyptus plantations. Its 17 rural sub-districts were then grouped into *dega* (temperate) and *woina dega* (subtropical) zones, from which *Gedamawit* and *Tach Chabi* were selected for representation. Households in these sub-districts were stratified into eucalyptus owners and non-owners. Subsequently, 166 planters and 166 non-planters were proportionally and randomly selected from each stratum within the sub-districts.

Given the relatively small population of the study area, the sample size for this research was determined using the Cochran modified formula for small populations.

$$n = \frac{n_o}{1 + (n_0 - 1)/N}$$

In this formula, n_0 represents the sample size suggested by the standard Cochran calculation, N denotes the total population size, and n is the resulting adjusted sample size.

$$n = \frac{385}{1+(385-1)/2392} = 331.89 = 332$$

Consequently, a sample of 332 households was selected for this study. This sample was proportionally distributed across the two selected sub-districts, *Gedamawit* and *Tach Chabi.* In *Gedamawit*, which had a target household population of 1,518, 105 households were selected from eucalyptus planters (the treatment group) and 105 households from non-planters (the control group), totaling 210 households. In *Tach Chabi*, with a target household population of 874, 61 households were selected from eucalyptus planters and 61 households from non-planters, totaling 122 households. Therefore, the final sample comprised 166 eucalyptus-planting households and 167 non-planting households, totaling 332 households across the two sub-districts.

1.10.5 Method of data analysis

This study employed a comprehensive and integrated approach to data analysis to assess the multifaceted implications of eucalyptus plantations. The analysis began with a land use and land cover change assessment, utilizing maximum likelihood supervised classification for the land use classifications. ERDAS IMAGIN and ArcGIS 10.8 software were used to make this analysis. Then to identify the drivers of eucalyptus plantations in the study area, a binary logit econometric model was employed. Differences in income levels between households with and without eucalyptus plantations were assessed using a two-sample t-test. Principal Component Analysis (PCA) was then applied to identify key factors influencing household income, reducing the number of variables while preserving the original data's informational integrity. Propensity Score Matching (PSM) was then utilized to estimate the causal impact of eucalyptus plantation ownership on household income, enabling robust comparisons by controlling for confounding variables.

The effect of eucalyptus plantations on household livelihood status was evaluated using the livelihood asset index method. PCA was used to determine the weights for various livelihood capital assets, and a radar chart, generated in Office 365, visually represented the resulting asset index to provide a comprehensive overview of household livelihood status.

Household food security status was assessed using the Household Food Insecurity Access Scale (HFIAS) and the Household Dietary Diversity Score (HDDS). Independent sample t-tests were conducted to compare the average HFIAS and HDDS scores between households with and without eucalyptus plantations to identify differences in food security indicators. Furthermore, a multinomial logistic regression analysis explored the factors influencing food security status of households.

Women's empowerment was assessed using the Abbreviated Women's Empowerment in Eucalyptus plantation Index (A-WEEI) for eucalyptus-owning households and the Abbreviated Women Empowerment in Agriculture Index (A-WEAI) for non-owning households. To triangulate these quantitative findings, thematic analysis was conducted on qualitative data, focusing on key quotations relevant to the core research questions. Additionally, a probit regression model was used to identify the determinants of women's empowerment in the study area.

CHAPTER 2: LAND USE LAND COVER CHANGE AND EXPANSION OF EUCALYPTUS PLANTATIONS IN SENAN DISTRICT, ETHIOPIA: ANALYSIS OF POTENTIAL FACTORS

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Abstract

Farmers in Ethiopia's highlands are rapidly converting their agricultural land into eucalyptus plantations, which may have socioeconomic and environmental implications for local communities. The objective of this study is to assess the expansion of eucalyptus tree plantations at the expense of other land use practices in Northwest Ethiopia, specifically in the Senan district, and the factors that contribute to it. Data were collected from 332 (166 eucalyptus planters and 166 non-planter) households and analyzed using the binary logit model. Land use and land cover changes in the study area were investigated using Landsat satellite images of four periods (1990, 2000, 2010, and 2021). The land use and land cover classes were categorized using a supervised classification method. The findings revealed a decrease in cropland from 58.4% in 2010 to 38.1% in 2021, whereas the vegetation cover, predominantly consisting of eucalyptus, experienced an increase from 16.8% to 26.5% during the same period. The results of the binary logit analysis indicate that the age of the household head, the size of the farmers' land, and savings had a positive and significant impact on the adoption of eucalyptus plantation, while the family size of households, educational status, livestock ownership, and the fertility level of farmers' land had a significant negative effect on eucalyptus plantation.

K*ey words*: *Eucalyptus, Driving factors, Land-use change, GIS, Ethiopia*

2.1. Introduction

Eucalyptus is the most widely planted tree species in the world (Birara *et. al*.., 2019**)**. Over the last century, it has spread rapidly throughout the world. In the 1890s, it was introduced to Africa, specifically Ethiopia (Jaleta *et al*., 2016).

Mekonen (2016) noted that in terms of livelihoods, eucalyptus plays an important role in addressing food security. Besides, according to Elli *et al*. (2019), the availability of fuelwood is one of the most important contributions of eucalyptus to food security. Cooking, for example, is the most common method of ensuring food utilization through high nutritional absorption from food, and 2.4 billion people use fuelwood to cook.

Despite the numerous benefits of eucalypt plantations, particularly in East Africa, where most people rely on wood for construction and fuel, there is still some criticism. Because Eucalyptus tree users, growers, environmentalists, researchers, and policymakers have different views on the economic, social, and environmental sustainability of the species. The majority of concerns raised are related to the environmental impact, particularly concerning soils, water, and biodiversity (FAO, 2011). On the contrary, according to Birhanu and Kumsa (2018) and Sembiring, *et al.* (2020), eucalyptus is a plant that has many environmental benefits, including the ability to reduce the risk of forest fires, floods, and erosion, be more efficient with water use, make nature more natural, restore land degradation or unproductive land, and the growth of these plants has long-term potential for biodiversity. On the other hand, Gebreegziabher (2006) stated that eucalyptus has a negative impact on yield and inhibits undergrowth. However, almost all the firewood, building materials for houses, farm implements, and other materials in the village are made from Eucalyptus. As a result, the benefits outweigh the negative impacts, which can be mitigated by planting Eucalyptus in areas that are unsuitable for agriculture and spacing them widely apart, even in farmlands and borders.

Despite the fact that eucalyptus plantations are generally criticized, farmers in Ethiopia particularly in the Northwest highlands, including the Senan district have been converted their cropland into eucalyptus plantations (Tesfaw *et al.*, 2022).

Previous studies have identified various factors associated with the expansion of eucalyptus plantations in Ethipia. For instance, the age of the household head (Derbe *et al*., 2018; Gebreegziabher *et al*., 2010), education level (Alemayehu & Melka, 2022; Gizachew, 2017), sex of the household head (Gebreegziabher *et al.*, 2020), family size (Abebaw & Dea, 2016), wood demand (Gemechu, 2010), land degradation (Tefera & Kassa, 2017), the need for immediate cash (Gemechu, 2010), adaptability to wider agro-ecological zones, affordable cost of production (Molla *et al.,* 2023) and low labor requirements for management (Tefera& Kassa, 2017) have all been identified as significant factors influencing land use patterns and

the expansion of eucalyptus plantations in Ethiopia. These factors play a significant role in shaping land use patterns and the expansion of eucalyptus plantations in Ethiopia. However, it is important to acknowledge that these factors may vary in different contexts.

While previous studies have provided some insights into the conversion of croplands to eucalyptus plantations in Ethiopia, including the Senan district, there is a lack of adequate research specifically focusing on the land use and land cover change in this district and the reasons behind the conversion. Tesfaw *et al.* (2022) highlighted that smallholder farmers in the Northwestern highlands, including the Senan district, have recently started converting their croplands to eucalyptus plantations. However, the study was conducted across three districts and did not separately analyze the driving factors specific to the Senan district. Therefore, this study assesses the land use land cover change and the factors that motivate farmers to convert their croplands into Eucalyptus plantations in Senan district.

2.2 Material and Methods

2.2.1 Study area

Senan is located in the East Gojjam Zone of the Amhara Region, Ethiopia which lies within the range of 10° 25' 13" N and 10° 40' 30"N latitudes and 37° 40' E and 37° 50' 20" E longitudes (Figure 4). The district has 19 kebeles; 17 rural and 2 urban kebeles. The altitude within the district varies from 2300 meters to 4154 meters. Notably, Mount Choqe, known as the 'water tower of Ethiopia,' is located in this district, serving as the highest point in both the district and the East Gojjam Zone, reaching an elevation of 4154 meters above sea level (Senan District Communication Affairs Office, 2021).

Approximately 25% of the land in the district consists of plateau and plain surfaces, while mountains and hills make up around 60%, and valleys account for approximately 15% of the landform. Eucalyptus globules are the dominant vegetation in the study area (Senan District Communication Affairs Office, 2021).

According to the Central Statistical Agency of Ethiopia’s 2007 national census, this district has a total population of 98,939 people.

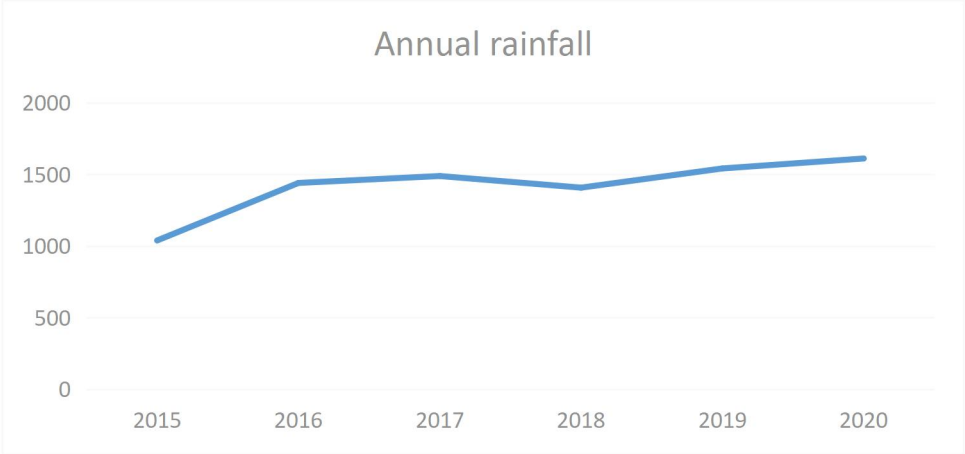

Figure 3: Annual rainfall of Senan District (2015-2020)(CSA, 2022)

The daily average temperature is 15 degrees Celsius and the annual rainfall in the district is between 900-1500 mm (Central Statistics Agency, 2022).

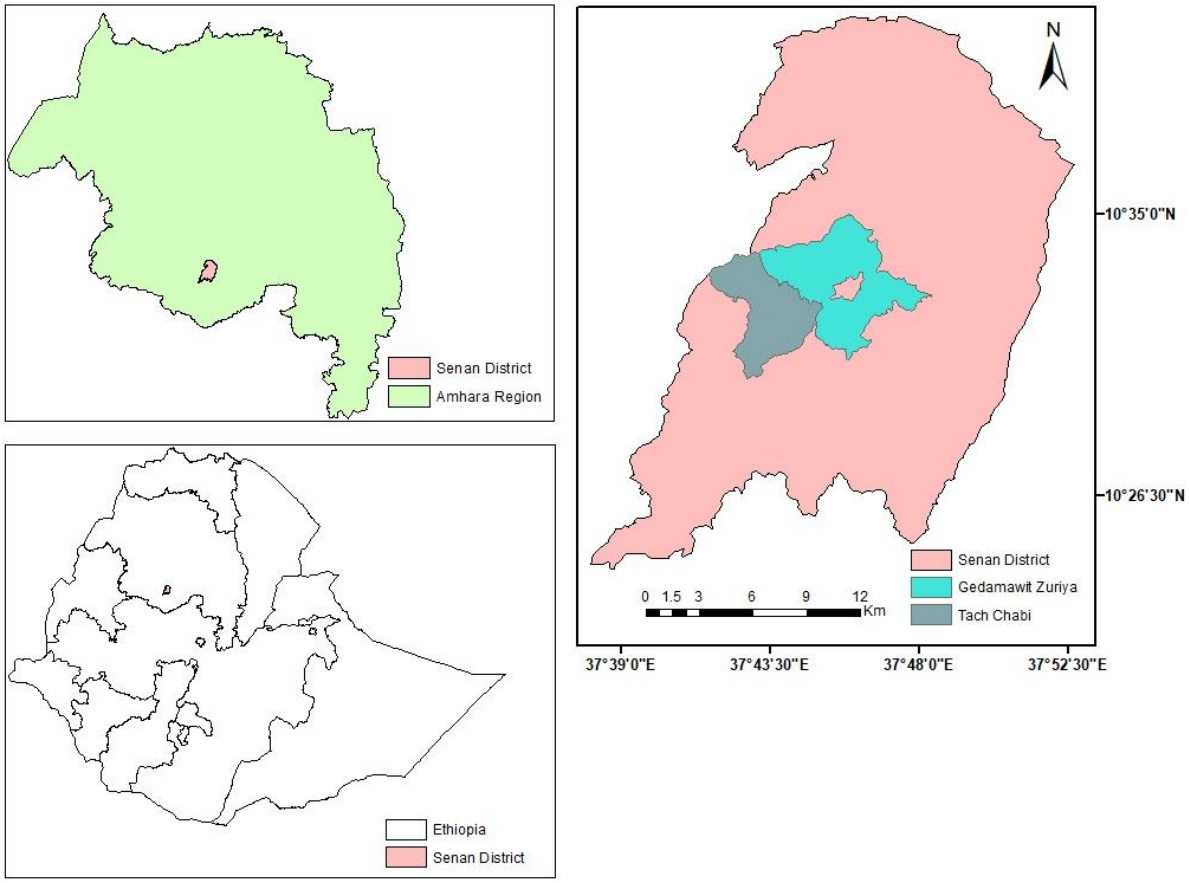

Figure 4: The location of the study area

2.2.2 Data sources and processes

This study used both primary and secondary data sources. The primary data were collected using questionnaires, personal observations, key informant interviews, focused group discussions, and surveys using GPS instruments, whereas the secondary data were collected from satellite images and various organizations' documents and reports.

Questionnaire

A questionnaire was used to collect quantitative data from 166 households that had planted eucalyptus and 166 households that had not planted eucalyptus. It was translated into the local language, Amharic, before being pilot-tested.

Personal Observations

We conducted field observations by walking through the district with agricultural office experts in the area. This method assisted us in comprehending the expansion of eucalyptus plantations. The observation was also carried out at the district's local marketplace, where we asked questions and took notes on what we had seen, further enhancing our understanding of the situation.

Key Informant interviews and focus group discussions

To understand the determinants of eucalyptus plantations from their experiences and opinions, thirteen farmers were interviewed, and four focus group discussions were held with purposefully selected elderly farmers and agricultural bureau officers. Saturation was used as a criterion for deciding when to stop collecting qualitative data.

Satellite Image

Landsat satellite images of the study area were acquired from the United States Geological Survey (USGS: https://earthexplorer.usgs.gov) for four periods: 1990, 2000, 2010, and 2021. The 1990, 2000, and 2010 images were Landsat 4-5 Thematic Mapper, whereas the 2021 image was the Landsat 8 Operational Land Image and Thermal Infrared Sensor (OLI/TIRS). The images were extracted in Tiff data format during the month of January. This is the time when there is clear sky season in the study area and important to detect vegetation. Moreover,

this time is important to reduce atmospheric and radiometric problems. The detailed feature of the four Landsat satellite images is indicated in Table 1.

Table 1: Sources of secondary data

No	Data Type	Sensor	Date of acquisition	Path/Row	Resolution	Source
1	Landsat image	TM	07/01/1990	169/053	30m by 30m	USGS
2	Landsat image	TM	19/01/2000	169/053	30m by 30m	USGS
3	Landsat image	TM	14/01/2010	169/053	30m by 30m	USGS
4	Landsat image	ETM+	28/01/2021	169/053	30m by 30m	USGS

Ground Control Points

Data collected by satellite sensors should be validated and compared to reality using reliable ground truth data. Therefore, real-world data were gathered using a hand-held GPS instrument for model validation and accuracy evaluation. To have the proper spectral value for each class, training data from the field was gathered to create a land-use land-cover map. Google Earth Pro image was also employed to validate the land use land cover result.

2.2.3 Sample size determination and sampling technique

The choice of the Senan district as the study area was driven by the presence of extensive eucalyptus plantations within the region. Since the population of the study area is small, the modified formula of Cochran, which is designed for a small population, was used.

$$n = \frac{n_o}{1 + (n_0 - 1)/N}$$

Here n_0 is Cochran's sample size recommendation, N is the population size, and n is the new, adjusted sample size. Hence, the sample size will be

$$n = \frac{385}{1+(385-1)/2392} = 331.89 = 332$$

To ensure representative coverage, a multistage sampling technique was employed. First, the seventeen rural *kebeles* of the district were categorized into two distinct agro-climatic groups: *woina dega* (subtropical) and *dega* (temprate) dominated *kebeles*. Then, the *kebeles* of *Gedamawit* and *Tach Chabi* were selected from each group. Households within the selected

kebeles were stratified based on ownership of eucalyptus plantations. Employing a proportionate stratified sampling technique, 166 planters and 166 non planters were selected proportionately from both planters and non-planters within each *kebele*. Agricultural extention experts of the two *kebeles* assisted us in collecting data from households who plant and do not plant eucalyptus trees.

2.2.4 Methods of data analysis

Preparing digital images for human interpretation is known as digital image processing (Bakker *et al*., 2001). Pre-processing procedures have been carried out after downloading and extracting the satellite image. These include atmospheric rectification, layer stacking/merging, gap-filling, image mosaicking, clipping, and other image enhancement pre-processing procedures that were used to enhance the quality and interpretability of the image so that the images are appropriate and prepared for further analysis.

The development of thematic maps involves classifying the satellite image. The subjects could range from general categories to in-depth analyses of specific groups (Schowengerdt, 2007).

Images were composed in different ways in order to identify surface features in the study area. True color composites, usually known by RGB 321 for Landsat 4-5 TM where band 3 reflects red, band 2 reflects green, and band 1 reflects blue color combination, and RGB 432 combination for Landsat 8 ETM+ were used to conduct the classification.

The land use classifications were conducted by using the maximum likelihood supervised classification. 155 training areas for all spectral classes were developed, composing each information class to be identified by the classifier. Based on prior research (Agenagnew *et.al.,* 2019; Fetene *et.al..,* 2014) in the area and observations (ground truthing) made by the researcher, the following classification schemes were developed as follows.

Table 2: LULC classes used for classification

No.	Classes	Description
1	Settlement	Scattered settlements with houses separated from one another.
2	Cropland	This category includes the area allotted for annual rain-fed and irrigated cultivation. Lands mostly used for cereal production in subsistence farming. Potato, barley, and beans are the main crops produced in the district. They farm using oxen and horse ploughs most traditionally.
3	Grassland	Area predominantly covered by small grasses with a small proportion of shrubs and trees.
4	Vegetation	This unit includes a collection of plant species. Eucalyptus is the prominent species in the area.
5	Shrub land	Dominated land with isolated small trees, always with a lower range of grass.

Calculation of the area in hectare and percent of the resulting LULC types for each study year and subsequently comparing the results were used as a major data analysis method to identify the change from cropland to vegetation. ERDAS IMAGIN and ArcGIS 10.8 software were used to make this analysis.

2.2.5 The binary logit model

In order to assess the drivers of eucalyptus plantations in the study area**,** the dependent variable was categorized into two qualitative parts, whether or not to have eucalyptus plantation. Therefore, a binary logit econometrics model was employed to examine the factors that influence farmers' decisions to plant eucalyptus trees. In binary logistic regression analysis, it is essential that the dependent variable should be categorical (it can be coded as 0 and 1) (Cokluk, 2010).

The functional form of logit model is specified as follows, according to Gujarati (2003);

$$P_i = E(Y = 1 \mid X_i) = \frac{1}{1 + e^{-(\beta_1+\beta_2 X_i)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

For ease of exposition, we write as

$$P_i = \frac{1}{1 + e^{-Z_i}} = \frac{e^z}{1 + e^z} \quad \text{……..……………………………………………………..…… (2)}$$

Where $Z_i = \beta_1 + \beta_2 X_i$.

If P_i, the probability of owning eucalyptus plantation, is given by (2), then $(1 - P_i)$, the probability of not owning eucalyptus plantation, is

$$1 - P_i = \frac{1}{1 + e^{Z_i}} \quad \text{…………………………………………………………………….…. (3)}$$

Therefore, we can write

$$\frac{P_i}{1 - P_i} = \frac{1 + e^{Z_i}}{1 + e^{Z_i}} = \quad \text{…………………………………………….………………….…. (4)}$$

Now $P_i / (1 - P_i)$ is simply the odds ratio in favor of owning eucalyptus plantations: the ratio of the probability that a household will own the plantation to the probability that it will not own it. Finally, taking the natural log of equation we obtain:

$$L_i = \ln \left(\frac{P_i}{1 - P_i} \right) = Z_i = \beta_0 + \beta_i X_i + \beta_2 + \ldots \beta_{nXn} \quad \text{……………………………………..….. (5)}$$

$$Z_i = \beta_0 + \beta_1 + X_i + \beta_2 + X_2 \ldots + \ldots \beta_{nXn} \quad \text{………………...……………………….……….(6)}$$

β_0 is an intercept; , $\beta_1, \beta_2 \ldots\ldots \beta_n$ are slopes of the equation in the model.

L_i = is log of the odds ratio, which is not only linear in X_i but also linear in the parameters

Xi = is vector of relevant household characteristics

If the disturbance term (U_i) is introduced, the logit model that has been used to analyze drivers of eucalyptus plantation in this study becomes;

$$Z_i = \beta_0 + \beta_1 + X_i + \beta_2 + X_{2\ldots} + \beta_{nXn} + U_i \quad \text{………………………………………...………. (7)}$$

Table 3: List of independent variables in drivers of eucalyptus plantations

Independent variables	Description	Expected Effect
Age of household head (years)	Continuous	+
Sex of Household head	Female = 0, Male = 1	-
Marital status of household head	Married= 1 Otherwise = 0	+
Education level of household head (years)	Continuous	+
Family size (number)	Continuous	-
Farm size (Ha)	Continuous	+
Farm fertility (%)	Continuous	-
Livestock ownership (TLU)	Continuous	-
Membership of cooperatives	Not a member = 0 Member = 1	+
Savings	No savings = 0 Have savings= 1	+
Access to savings and credit service	No access = 0 Have access = 1	+

2.3 Results and Discussions

2.3.1 Land use and land cover analysis

The analysis comprises the land use land cover analysis and the factors behind the expansion of eucalyptus plantations. As the classification scheme indicated cropland, grassland, vegetation settlement and shrub land area are the major LULC classes of the study periods. The classified images were acquired when crop harvesting had already been completed, and farmlands appear bare and grasslands look relatively bright in their color.

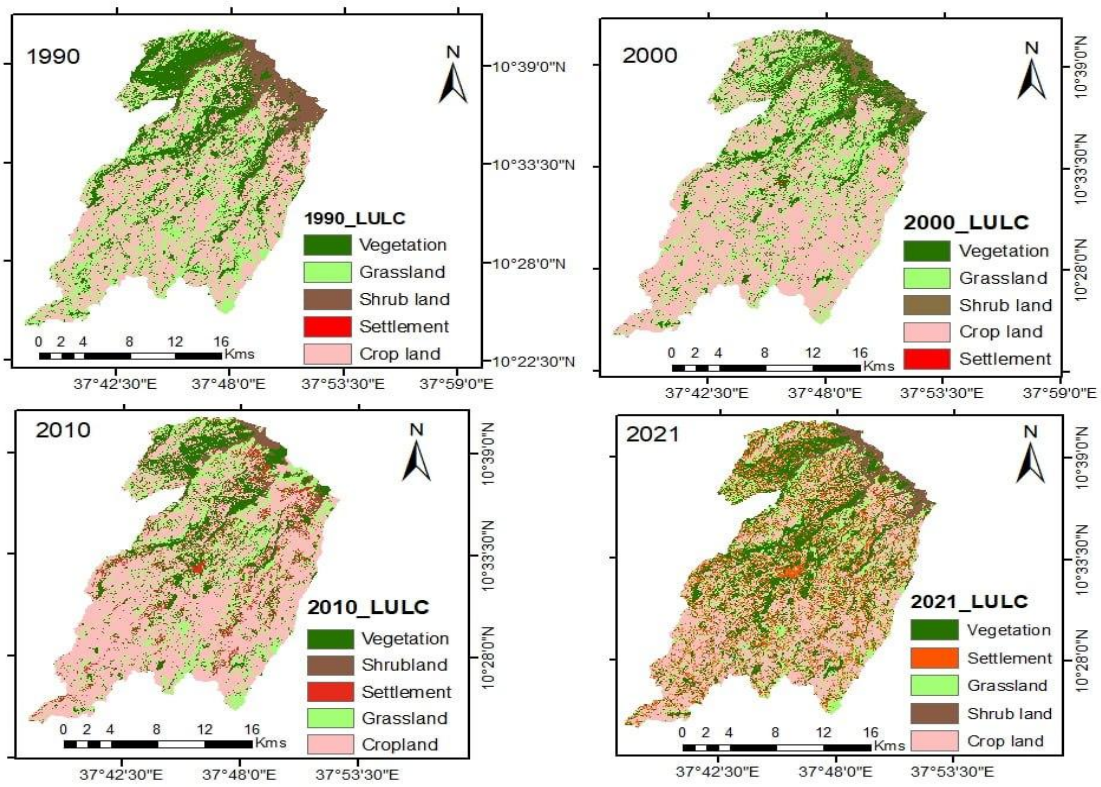

Figure 5: Land use land cover map of Senan district (1990, 2000, 2010, and 2021)

Figure 5 shows the land use/land cover (LULC) maps of the Senan District in Northwest Ethiopia, depicting changes over time: 1990, 2000, 2010, and 2021.

Table 4: LULC classes and their spatial extent with the observed changes over time

LULC classes	1990		2000		2010		2021	
	Area (ha)	Percent	Area (ha)	Percent	Area (ha)	Percent	Area (ha)	Percent
Crop land	19750	45.2	25049	57.4	25500	58.4	16647	38.1
Vegetation	10408.5	23.8	7456	17.1	7294	16.8	11558	26.5
Grassland	10151.6	23.3	9406	21.6	6911	15.8	6297	14.4
Settlement	110.9	0.3	128	0.3	2334	5.4	6996	16.1
Shrub land	3215	7.4	1597	3.6	1597	3.6	2138	4.9
Total	43636	100	43636	100	43636	100	43636	100

For 1990, 2000, 2010, and 2021, five major LULC types (cropland, vegetation, settlement, grassland, and shrub-land) were classified. The result reveals that there is a recent land-use change, especially in cropland and vegetation cover.

As the LULC classification result shows that cropland has increased from 45.2 % in 1990 to 57.4 % in 2000 and 58.4 % in 2010 but it has decreased to 38.1 % in 2021. On the contrary, the vegetation cover has decreased from 23.8 % in 1990 to 17. 1% in 2000 and 16.8% in 2010 but it has increased from 16.8% in 2010 to 26.5% in 2021. According to our personal observation, the highest proportion of the vegetation cover in Senan district is eucalyptus plantation which has been expanded recently. The focus group discussion result also confirmed that a significant number of farmers has been converted their cropland into eucalyptus plantations during the last 10 years.

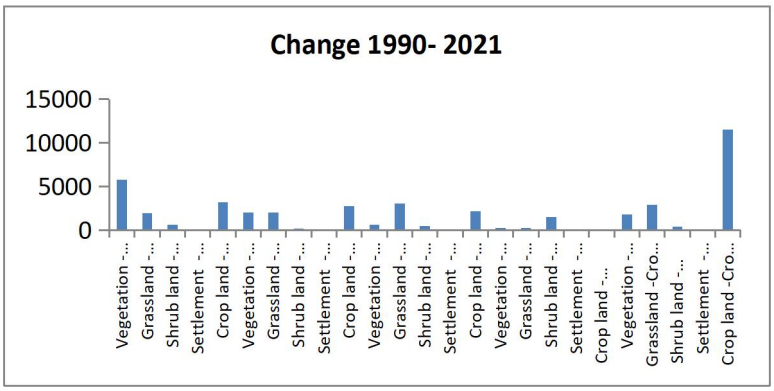

Figure 6: Change detection matrix

The change matrix (1990-2021) shows that the highest proportion of land has been converted from cropland to vegetation. This is mainly because farmers have been changing their farmland into eucalyptus plantations. From 2010 to 2021, the conversion of cropland to vegetation experienced the most significant rate of change, with a total of 3,353 hectares, equivalent to 13% of the initial cropland, being transformed into vegetation. Based on personal observation almost all forests of the area are Eucalyptus. The key informant interview also approved that farmers are aware of the economic advantage of eucalyptus and tried to cover their cropland with this plant.

2.3.2 Factors affecting eucalyptus tree plantations

Binary logit model result

Table 5: Logistic regression results

Explanatory variables	B	S.E.	Wald	Sig.	Exp(B)
Sex of household head	-.185	1.091	.029	.865	.831
Age of household head	.169	.031	29.382	.000***	1.184
Marital status	5.701	6.104	.872	.350	299.189
Educational Status	-1.730	.465	13.833	.000***	.177
Livestock ownership (TLU)	-.385	.140	7.601	.006***	.681
Farm size in hectare	3.039	.548	30.766	.000***	20.883
Family size (adult equivalent)	-.957	.203	22.203	.000***	.384
Farm fertility	-2.204	.497	19.665	.000***	.110
Membership of cooperatives	.363	.604	.362	.548	1.438
Having savings	1.453	.432	11.300	.001***	.234
Access to saving and credit service	.850	.449	3.583	.058	2.340
Constant	-8.738	6.409	1.859	.173	.000

Land Use and Land Cover (LULC) is influenced by a variety of factors, encompassing both natural processes and human activities (Tolessa *et al.*, 2019). We categorized the driving factors and implications of landuse land cover change and expansion of eucalyptus plantations in the Senan district into four broad categories based on the result of the binary logistic regression model, the focus group discussion and key informant interview result, as described below.

2.3.2.1 Socio-demographic characteristics

Studies by Derbe *et al*. (2018), Gebreegziabher *et al*. (2020), and Gebreegziabher *et al*. (2010), have all found that age, gender, and education are factors that increase the likelihood and number of trees planted by farmers. However, according to Alemayehu and Bewket's (2018) finding, tree planting activity is negatively influenced by the education level of the household. On the other hand Tefera and Kassa (2016) noted that household size has a

positive and significant influence on the adoption of eucalyptus plantation by farmers. In relation to this, the binary logit results of this study shows that age of the household head positively and significantly affected eucalyptus plantation while family size of smallholder, and educational status had a significant negative effect on the eucalyptus plantation. This means that as the age of the household head increases, the likelihood of adopting eucalyptus plantation also increases by a factor of 1.18. The key informant interview also reveals that farmers' motivation in making the decision to plant eucalyptus trees increases as their age increase. This is because tree planting does not require much labor force. Therefore, elders prefer to plant eucalyptus trees to practicing crop production. Furthermore, due to the fact that eucalyptus plantations do not require more labor than crop production, female-headed households in the study area prefer planting eucalyptus to crop production.

According to the binary logistic regression model, the exp (b) value for family size is 0.38, indicating that the odds of adopting eucalyptus plantation decrease by a factor of 0.38 for every one-unit increase in family size. The study's focus group discussions also revealed that farmers with large families are less likely to plant eucalyptus trees, which negatively affects their decision-making. In contrast, households with fewer family members tend to use their farmlands to grow eucalyptus because it is less labor-intensive than crop production. However, one of the key informant interviewees noted that even households with large families experience labor constraints due to increasing school enrolment rates in Senan district, which has led to a shift towards eucalyptus plantations that require less labor. This finding aligns with previous studies, such as Alemayehu *et al*. (2023), which found that family size has a detrimental impact on the adoption of eucalyptus tree plantations. Based on the results of the focus group discussions and key informant interviews, it was found that female-headed households with smaller family sizes tended to choose eucalyptus planting over other crops due to its low labor requirements. A widow female-headed household also stated: "*My husband was a hard-working farmer who was capable of working day and night. But after I lost him, I turned the cropland into eucalyptus plantation. Because there is no one who can help me on the farm."* This highlights labor constraints as a key determinant in farmers' decisions to plant eucalyptus plantations.

2.3.2.2 Economic drivers

The decision-making process of farmers regarding eucalyptus tree planting is influenced by resource ownership, including access to land, labor, livestock, agricultural inputs, and market

opportunities. Alemayehu and Melka (2022) stated that planting eucalyptus tree offers a considerably better return on investment than growing crops and raising animals. Other previous studies (Abebaw & Dea, 2016; Gebreegziabher *et al*., 2020; Gizachew, 2017; Jenbere *et al*., 2011), on the other hand emphasized that the size of the farmland owned by farmers is a crucial factor in determining their decision to plant eucalyptus trees. Gebreegziabher *et al*. (2010) found that the number of cattle owned by households had a significant negative impact on the likelihood of participating in eucalyptus plantations. The findings of the binary logistic regression model in the study area also confirmed that the total land size and savings had a positive and significant effect on eucalyptus plantation, while livestock ownership had a negative effect. The odds ratio of livestock ownership and farm size indicates that, holding all other variables constant, the decision of smallholder farmers to adopt eucalyptus plantation decreases by a factor of 0.68 times as livestock ownership increases by 1, while the likelihood of eucalyptus plantation increases by a factor of 20.8 times as the farm size of households' increases by 1. Interviewees also reported that farmers with a large number of cattle do not have eucalyptus plantation due to the fact that eucalyptus trees are not used for animal grazing, unlike crop residues. As Abebaw and Dea (2016) described that the farmers who have small landholdings are preferring to produce crops and other purposes like growing fruits and vegetables than growing eucalyptus tree. The family who has large landholding uses their land for diversifying the source of income like growing crops, fruit, tree planting, vegetable, and animal raising.

Farmers may choose to plant eucalyptus on marginal land that has limited potential for crop production. The binary logistic regression model and focus group discussions indicate that farmers are less likely to adopt eucalyptus plantation on highly fertile land. Moreover, on**e** of the interviewees described that

> *"I do have four temad (one hectar) land. The two temad are very fertile but the remaining two temad are not suitable for crop production. That's why I planted eucalyptus trees on the plot of land which is not fertile."*

The findings of focus group discussion revealed that farmers plant eucalyptus in order to make a lot of money at a time so that they will be able to either construct a house or pay school fees to their children or move to urban areas.

Moreover, Zerga *et al.* (2021) also revealed that the growing need for fuelwood, construction, and cash for various purposes are the primary economic drivers behind the planting of eucalyptus plantations.

2.3.2.3 Environmental drivers

Senan is one of the districts in the Amhara Region of Ethiopia which is predominantly *dega* and it is not suitable to produce high-value products like Teff. Therefore, the farmers preferred to plant eucalyptus than to produce low-value products like potato.

Moreover, according to Bahtimi (2016), Gemechu, (2010), and Jenbere *et al*., (2011) land degradation and depletion of natural vegetation are also the driving factors of eucalyptus plantations. The key informant interviewees described that land degradation is the most common problem of the district which is usually related to the acidity of the soil. In relation to this, Regassa and Agegnehu (2011) stated that Ethiopia's highland areas are experiencing an increase in soil acidity. These issues are the result of continuous cropping and the use of acidifying fertilizers. The logit result reveals that farm fertility level and eucalyptus plantation have a negative and significant relationship. According to the interview and focus group discussion reduced crop yield because of declining soil fertility made farmers convert their cropland into eucalyptus plantations.

2.3.2.4 Properties of the eucalyptus species

According to Tefera & Kassa (2017), coppicing ability, straight pole growth, quick growth and thus shorter maturity period, multiple uses of the wood, low labor required for management, and drought, disease, and pest resistance are important characteristics of the species. These characteristics are also one of the farmers' driving factors to plant eucalyptus in Senan district. One of the interviewees stated that

> *"Eucalyptus is a good species because it saves my time and labor; it teaches me to save a lot of money; it is free from natural hazards; unlike crops, it is not consumed by animals which make it easy to have the plantation."*

The focus group discussion participants also stated that shorter growing seasons and higher biomass, increasing price of farm input such as fertilizer and improved seed, the negative effects of nearby eucalyptus plantation shades on a crop, and other farmers' successful experiences are some of the factors related to the properties of the species.

In relation to this, an interviewee emphasized that *"The shade of my neighbors' eucalyptus plantation on my cropland affects its productivity. Hence, I was obligated to convert my cropland into a eucalyptus plantation* even *though I did not want to do that."*

Birhanu and Kumsa (2018) also stated that eucalyptus plants are typically taller than other plants of equal age due to their rapid growth, and their shade may affect nearby crops by reducing the sunlight required for growth. Moreover, Molla *et al.* (2023) described that the detrimental effects that eucalyptus plantations have on nearby cropland made farmers to convert their crop land into eucalyptus tree plantations.

2.4 Conclusion

The results indicated a decline in cropland area from 58.4% in 2010 to 38.1% in 2021, while there was an increase in vegetation cover, primarily eucalyptus, from 16.8% to 26.5% over the same time frame. This is mainly caused by socio-demographic characteristics of the household, economic factors, environmental factors, and the characteristics of the eucalyptus species such as the availability of large plots of land for ownership, infertile agricultural land, a small labor force, a shorter growing period, the species' shading impacts, and easily accessible market opportunities are responsible for the rapid expansion of eucalyptus plantation in the study area. As a result, agricultural experts should provide support to farmers through various land-use planning strategies that take into account their socio-demographic, economic, and environmental elements and the country's land use policy.

CHAPTER 3: COMPARATIVE ANALYSIS OF INCOME LEVEL IN MATCHED SMALL FARMS WITH AND WITHOUT EUCALYPTUS PLANTATIONS IN SENAN, ETHIOPIA

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Abstract

The cultivation of eucalyptus trees is a widely practiced economic activity in the highlands of the Amhara region, Ethiopia. This study investigates the causal impact of eucalyptus plantation ownership on household income within the Senan District of Ethiopia. Using cross-sectional data from 332 rural households, comprising 166 households with eucalyptus plantations and 166 without, the study employed a two-sample t-test comparison to compare the income level of households in the two groups. To identify the key factors influencing household income, the study conducted a Principal Component Analysis (PCA) and Propensity Score Matching (PSM) to isolate the causal impact of eucalyptus plantations on household income. This involved estimating propensity scores using a binary logistic regression model. The Average Treatment Effect on the Treated (ATT) analysis revealed that households that plant eucalyptus trees had 40.2% higher total household income than those that did not participate in such activities. Therefore, considering potential demand and market fluctuations, eucalyptus tree growers need to diversify their livelihood strategies by utilizing the income generated from their plantations.

Keywords: *Eucalyptus, Household Income, Impact Evaluation, Propensity Score Matching, Principal Component Analysis*

3.1 Introduction

Eucalyptus, native to Australia, has become increasingly familiar in many regions around the world due to its adaptability to diverse climatic conditions and rapid growth (Stanturf *et al*., 2013). In Ethiopia, its introduction by Emperor Menelik II in 1895 aimed to address the shortage of fuelwood and other forest products around the country's capital, Addis Ababa (Abebe and Tadesse, 2014; Dessie *et al*., 2019). Since then, eucalyptus plantations have become an attractive option for Ethiopian farmers by providing options for income

diversification, cash generation, and meeting local wood product demands (Alemayehu and Melka, 2022). The high demand for wood products and the continuous depletion of natural forests led to the rapid expansion of eucalyptus plantations in Ethiopia (Jenbere *et al*., 2011). This made Ethiopia a country that has the largest eucalyptus plantation in East Africa, establishing it as a leader in the adoption of this species (FAO, 2011).

Income derived from eucalyptus tree plantations has become an essential contributor to rural household economies in Ethiopia (Alemayehu and Melka, 2022). However, the impact of eucalyptus cultivation on farmers' income remains a subject of debate among scholars. While some studies indicate a positive effect on farmers' income, others present contrasting findings across different regions. For example, research in the Amhara Region by Addis *et al*. (2016) and Tewodros *et al*. (2022) shows a positive contribution to farmers' income from eucalyptus trees. Furthermore, a study in Southwest Ethiopia reports higher profits from eucalyptus trees than from food crops (Tesfaw *et al*., 2022). Conversely, Bazzana *et al*. (2021) have identified a negative effect of eucalyptus tree plantations on the welfare of rural communities arising from physical and economic constraints that limit access to food and services. These divergent findings highlight the need for more localized and in-depth research, particularly in the context of the Senan district in the Amhara Region, which offers a unique opportunity to contribute novel insights to the existing body of literature.

The Senan district faces numerous challenges, including over-cultivation, overgrazing, deforestation, soil erosion, fertility degradation, and a high demand for fuelwood. Additionally, the district's agricultural practices are constrained by the production of low-value and low-yielding crops like potatoes, barley, and *Sinar* crop (wild oat) which are commonly grown due to the area's agro-climatic conditions (Belay *et al.*, 2023). As a Productive Safety Net Program (PSNP) participant, the district also contends with food insecurity. By focusing on the Senan district, this study aims to provide a more in-depth analysis of the economic effects of eucalyptus plantations, considering these specific local contexts and challenges. Previous studies such as Kebede (2022) have suggested that local factors influence the relationship between eucalyptus plantations and household incomes. This study explores how these contextual elements impact the economic implications of eucalyptus cultivation in the Senan district.

Unlike broader studies that have examined the relationship between eucalyptus and household incomes, this research focuses on the complex economic effects of land-use

change in the Senan district. By focusing on this specific location, the study aims to uncover insights that may have been obscured in previous, more geographically expansive analyses. This comprehensive investigation can inform policy decisions and sustainable development initiatives in the region and beyond.

Given the increasing trend of smallholder farmers shifting their croplands towards eucalyptus plantations, driven by factors such as rising demand for wood products, declining land productivity, and socio-demographic considerations (Tesfaw *et al*., 2022; Belay *et al*., 2023), the focus on the Senan district is particularly significant. This localized approach allows for a deeper examination of the economic impacts of land-use changes, revealing insights that broader studies may overlook. The district's unique agricultural and environmental challenges, and demographic upsurge, along with its reliance on the Productive Safety Net Program, further underscore the contextual significance of this research. To address methodological limitations in previous studies, particularly potential selection bias, our study employed a PSM model. This model paired households engaged in eucalyptus cultivation with comparable households that were not, based on observable characteristics, ensuring a robust comparison and minimizing confounding factors. Therefore, the primary objective of this study is to determine the causal impact of eucalyptus plantation ownership on household income within the Senan District of Amhara Region, Ethiopia.

3.2 Material and Methods

3.2.1 The study area

The study was carried out in the Senan district, East Gojjam Zone of the Amhara Region, within the upper reaches of the Blue Nile Basin., Ethiopia. It is located between 10◦20′35″ and 10◦50′38″ latitudes and 37◦35′10″ and 37◦52′20″ longitudes as indicated in Figure 7.

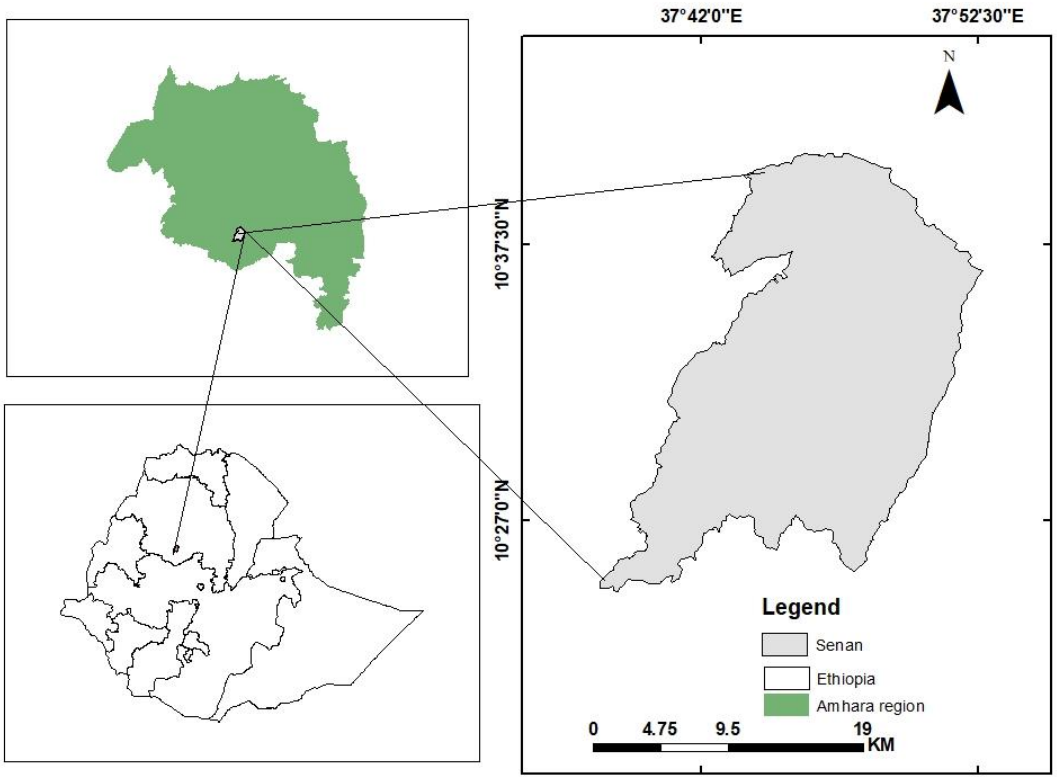

Figure 7: Geographic location of the study area

Senan district, similar to many rural areas in Ethiopia, lacks extensive historical records to have a detailed representation of previous circumstances. However, it was officially established as a district on October 11, 2006, and is comprised of seventeen rural sub-districts and two urban sub-districts. The study area covers a total of 43,636 hectares. The terrain of the district is 25% plain, 60% mountainous, and 15% hilly (Senan District Communication Affairs Office, 2020). The district experiences an average daily temperature of 15 degrees Celsius and receives between 900-1500 mm of rainfall annually (Central Statistics Agency, 2022).

According to the recent data from the Senan District Communication Affairs Office (2021), the projected population of the district was estimated to be 60,581 males and 61,623 females, totaling 122,204 people. Approximately 95% of the population in the Senan district lives in rural areas and is engaged in traditional mixed farming activities to support its households, with smallholder farmers performing subsistence agriculture on a cropland area of 0.5 hectares on average. The commonly grown crops in the district are wheat, barley, maize,

beans, and potatoes (Simane *et al.*, 2012), which indicates that households' crop production is not diversified enough.

In terms of land use and land cover, there has been a notable trend in which the proportion of cropland has shown an upward trajectory, increasing from 45.2% in 1990 to 57.4% in 2000 and further to 58.4% in 2010. However, the proportion drastically dropped to 38.1% in 2021. Conversely, natural vegetation cover exhibited a contrasting pattern and decreased from 23.8% in 1990 to 17.1% in 2000 and 16.8% in 2010. Since 2010, the woody vegetation cover of the district has been increasing continuously due to successive shifts of croplands to eucalyptus tree plantations. Hence, currently, the main vegetation species in the district is the eucalyptus tree (Belay *et al*., 2023). According to the research by Tesfaw *et al*. (2022), the rapid expansion of eucalyptus plantations in the study area can be attributed to several key factors. Firstly, there has been a decline in overall land productivity due to widespread land degradation issues. Secondly, the district is in proximity to the Zonal capital, *Debre Markos* contributing to an escalating demand for wood products in the region, which promoted the growth of eucalyptus plantations. Additionally, various other socio-demographic and economic factors such as age and sex of household head, family size, and the economic contribution of the plantation have contributed to the shift towards increased eucalyptus cultivation in the area (Belay *et al*., 2023).

Due to its proximity to Choke Mountain, which has a peak elevation exceeding 4,000 meters above sea level (Simane, 2013), the area is home to a diverse range of plant species, including *Acanthus sennii, Echinops ellendekii, Erythrina brucei, Euryops pinifolius, Kniphofia foliosa,* and Lobelia *rhynchopetalum* (Teferi *et al*., 2010). However, the rapid expansion of eucalyptus *globulus* in the study area has been happening at the expense of croplands, natural vegetation, and grazing lands, leading to a major shift in the land-use system of the area (Belay *et al.*, 2023; Yimam *et al.*, 2024).

The continuous expansion of eucalyptus tree plantation at the expense of croplands in the Senan district secured a sustainable wood supply in the area that should be commercialized, as eucalyptus trees offer a variety of products and services, including fuelwood, charcoal, construction materials, household and farm tools, and poles; however, the prices of eucalyptus wood products fluctuate significantly over time (Tesfaw *et al*., 2021).

3.2.2 Data sources, and methods of data collection

Our primary data source consists of surveys conducted with local farmers in the Senan district. The study targeted households both involved and not involved in eucalyptus cultivation to facilitate a comprehensive comparison.

The questionnaire captured a wide range of socioeconomic and demographic characteristics of the participating households. It was translated into the local language (Amharic) language and pilot-tested to ensure clarity and cultural relevance, with necessary adjustments made based on feedback.

The survey data was collected through face-to-face interviews with farmers. Highly motivated enumerators with a strong understanding of the local socio-cultural context were recruited and trained to administer the surveys. To maintain data quality, trained supervisors and researchers oversaw the process. Additionally, enumerators were supported by local agriculture extension experts.

Data was collected in January 2023. At that time, respondents were asked about specific sources of income related to eucalyptus plantations and crop production, including timber sales, firewood sales, charcoal production, and other eucalyptus-related activities. The study then considered the annual income of households from those sources for the year 2014 in the Ethiopian calendar (September 11, 2021 - September 10, 2022).

3.2.3 Sampling method

In this study, a cross-sectional study design was employed using a multistage sampling technique. First, the Senan district was purposively selected based on the presence of large eucalyptus plantations and their use. Second, the 17 rural sub-districts of the district were grouped into two major agro-climate groups: *dega* (temperate) and woina *dega* (subtropical) sub-districts. In the third stage, *Gedamawit* and *Tach Chabi* sub-districts were selected from the two sub-districts of the agro-climatic zone to ensure the representation of both groups.

In the fourth stage, households in the sub-districts were stratified into eucalyptus plantation owners and non-owners. Finally, in the last stage, households were selected proportionally from planters and non-planters within each sub-district using a simple random sampling

design. Specifically, a proportionate stratified sampling approach was used to select 166 planters and 166 non-planters from *Tach Chabi* and *Gedamawit* sub-districts.

3.2.4 Sample size determination

Since the population of the study area is small, the Cochran modified formula, which is designed for small populations, was used.

$$n = \frac{n_o}{1 + (n_0 - 1)/N}$$

Here n_0 is the Cochran sample size recommendation, N is the population size and n is the new adjusted sample size.

$$n = \frac{385}{1+(385-1)/2392} = 331.89 = 332$$

Therefore, the sample size was 332 households as shown in Table 6.

Table 6: Sample size

Name of sub-districts	Target household population	Planters (Treatment group)	Non-planters (Control group)	Total
Gedamawit	1,518	105	105	210
Tach Chabi	874	61	61	122
Total	2,392	166	167	332

3.2.5 Permission for research on human subjects

The research was conducted in an ethical manner and in compliance with all applicable regulations. Before any individuals participated in the study, they were provided with a written informed consent form. This form gave a clear and concise overview of the research topic, objectives, and procedures. It also explained how participant data would be collected, stored, and utilized.

3.2.6 Method of data analysis

This study distinguishes itself from previous research in the region by employing a rigorous methodological approach that incorporates a two-sample t-test, Principal Component Analysis (PCA), and Propensity Score Matching (PSM). These techniques enabled us to

accurately identify key factors influencing household income and isolate the causal impact of eucalyptus plantation ownership. First, the study used a two-sample t-test comparison to compare income levels between households with and without eucalyptus plantations. Next, the study identified the factors that determine household's income through PCA, which minimizes the number of variables while preserving the information in the original data. To assess the causal impact of eucalyptus tree plantations on household income accurately, the study PSM, a model that allows a precise comparisons by controlling for confounding variables.

The estimation of the effect of eucalyptus plantations on household income may be biased, with farmers not randomly assigned to the treatment group or control group. For instance, one issue with utilizing Equation (1) presented below to examine the impact of eucalyptus on households' income arises from the fact that households possessing eucalyptus plantations may possess distinct characteristics when compared to those who do not own the plantation. Consequently, determining the impact of the plantation on income becomes a challenge. This is due to the possibility of other confounders that exert influence on household income levels.

$$Income_i = \beta_o + \beta_1 eucalyptus_i + \beta_2 X2_i + \beta_3 X3_i + \varepsilon_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Household income Ownership of eucalyptus other independent variables

Caliendo and Kopeinig (2005) suggested that the propensity scores matching approach can mitigate bias in estimating the average treatment effect obtained from observational studies by mimicking randomization. Consequently, to accurately assess the causal impact of eucalyptus tree plantations on household income, the study employed PSM.

In this method, the households in the treatment group (those who plant eucalyptus tree) matched with the control group (those who do not) based on their propensity scores. Subsequently, the study compared the income of the households matched in the two groups (treatment and control).

Predicted treatment: $D = \beta_O + \beta_1 X$ ……..…….…. (2)

Propensity score: $P(Xi) = prob\ (D = 1/Xi) = E(D/Xi)$…….....……..... (3)

Xi denotes the pre-treatment characteristics (characteristics of households that might affect the plantation decision).

X_1 = age of the household head (years)

X_2 = Sex of the head of household (1 = male and 0 = otherwise)

X_3 = Marital status of the head of the household (1 = Married, and 0 = otherwise)

X_4 = Education level of the head of household (years)

X_5 = Family size (number)

X_6 = Farm size (Ha)

X_7 = Farm fertility (%)

X_8 = livestock ownership (TLU)

X_9 = Membership of cooperatives (1 = member and 0 = otherwise)

X_{10} =Savings (1 = have saving, 0 = otherwise)

X_{11} =Access to savings and credit service (1 = have access, 0 = otherwise)

The generated propensity score is typically used to generate matched samples of farmers with similar characteristics that will be used to adjust the data (Guo and Fraser, 2009).

Treatment (D) eucalyptus plantation, a binary variable that determines whether the household has eucalyptus plantation or not, D = 1 for those who plant and D = 0 otherwise.

According to Baum (2013), a logit or probit model is usually used to estimate the propensity score of a binary variable. Therefore, the logit model was used to estimate the propensity scores for the two different treatments to analyze the determinants of the plantation.

The propensity score (P(x)) is written as $(x) = (T) = 1/X = x$ …….. (4)

According to Equation 3, the probability that a household decides to plant eucalyptus is dependent on its pretreatment attributes.

$$y = \begin{cases} y_1 \; if \; D = 1 \\ y_0 \; if \; D = 0 \end{cases} \quad \text{…….. (5)}$$

In Equation 5, y is the outcome variable which represents the treatment effects i.e. the impact of eucalyptus plantation on income.

Following matching, the outcome y for the households with the plantation (y_1) and the households without the plantation (y_0) will be compared to determine the impact of the

treatment variable on the household income. The impact of treatment on an individual household, denoted "i," can be expressed as follows.

$t_{i=yi(1)yi(0)}$ ……..……..……..…… (6)

Empirical investigations often estimate two treatment effects. The difference between the predicted results after participation and non-participation is known as the (population) average treatment effect, or ATE (Caliendo and Hujer, 2005). The second one is the average treatment effect on the treated (ATT), which shows the most important assessment of the treatment observation's pure effect (Chekol *et al.,* 2022). The ATT examines the income differences between eucalyptus-planting and non-planting households after matching them based on their propensity scores.

The following formulas can be used to calculate the average treatment effect (ATE) and the average treatment effect on the treated (ATT), respectively:

$$t_{ATE} = E(\tau)$$
$$= E[Y_1 | D = 1] - E[Y_o | D = 0] \text{ …….,,……..……..…... (7)}$$
$$t_{ATT} = E\{Y_{1i} - Y_{oi} | D_i = 1\}$$
$$= E\{Y_{1i} - Y_{oi} | D_i = 1, p(x_i)\}$$
$$= E\{Y_{1i} | D_i = 1, p(X_i)\} - E\{Y_{0i} | D_i = 0, p(X_i)\} | D_i = 1 \text{ ……..……..…… (8)}$$

Where:

D_i: A binary treatment indicator for individual i, where $D_i = 1$ indicates that the household has eucalyptus plantations, and $D_i = 0$ indicates they do not.

Y_{1i}: the potential income for individual i if they had eucalyptus plantation (i.e., when $D_i = 1$)

Y_{oi}: the potential income for individual i if they did not have the plantations (when $D_i = 0$)

τ: the individual level causal effect, representing the difference between Y_{1i} and Y_{oi}

$p(X_i)$: the propensity score, or the probability of having eucalyptus plantations given a set of observed characteristics X_i

$E\{Y\,1i\ |D_i = 1,\ p(X_i)\}$: the expected income for households with eucalyptus plantations, conditioned on having the plantation and their propensity score.

$E\{Y\,0i\ |D_i = 0,\ p(X_i)\}$: the expected income for households without the plantation, conditioned on not having the plantation, and their propensity

However, the average treatment effect on the treated (ATT) is the most significant measure of the true impact of the treatment for those who received it (Chekol *et al.*, 2022).

Estimating the propensity score

The binary logit model was used to generate individual propensity scores, which were used to match households involved in eucalyptus plantations with those who were not.

The findings of the binary logit analysis revealed that several factors had a significant impact on the adoption of eucalyptus tree plantations. Specifically, the age of the head of the household, the size of the farmland, and savings were found to have a positive and significant effect on the likelihood of adopting a eucalyptus tree plantations. On the other hand, variables such as the family size of households, educational status, livestock ownership, and the fertility level of farmland had a significant negative effect on the adoption of eucalyptus tree plantations (Belay *et al.,* 2023).

Common support region

Assessing the overlap and the region of common support between the treatment and comparison groups is a crucial step in the analysis of propensity score matching (Tewodros *et al*., 2022). The balance test is a method used to determine the degree of overlap in observed characteristics between the treatment and control groups (Austin, 2019). The propensity score of the treatment and control groups is sufficiently overlapped, as shown in Figure 8. The Y-axis represents the kernel density of propensity scores, while the X-axis shows the propensity scores ranging from 0 to 1. The blue line indicates the treated group, and the red line represents the control group.

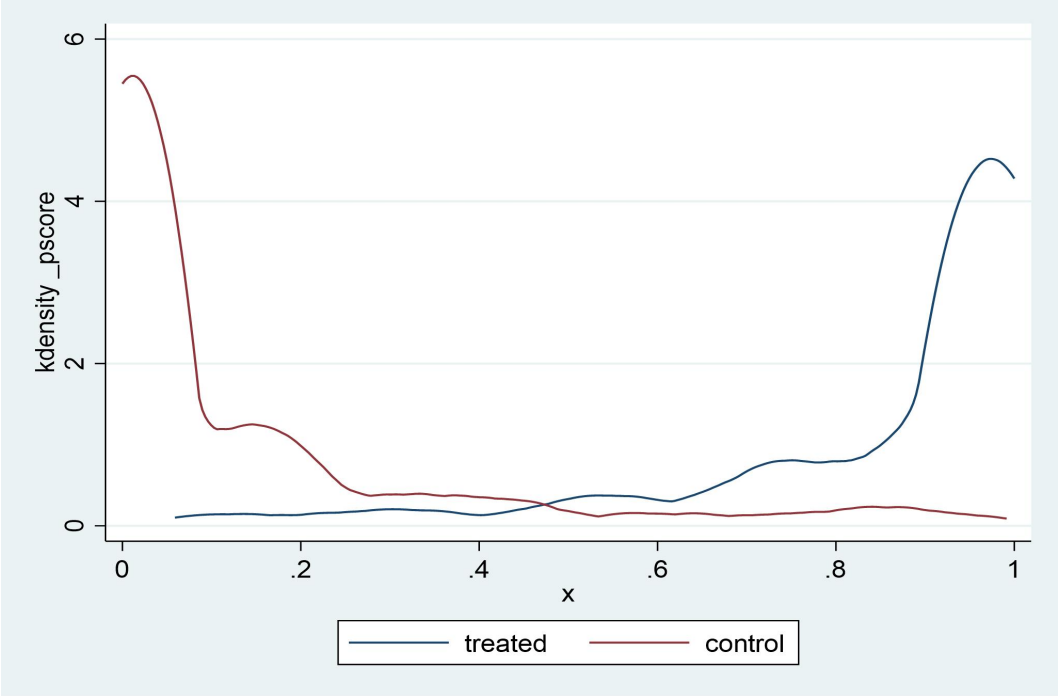

Figure 8: Common support region between the treatment and comparison groups

Figure 8 helps ensure that the treatment and control groups are comparable, which is essential for drawing accurate conclusions about the impact of the treatment variable on the outcome of interest. The evaluation of the comparability of the groups is crucial to minimize the influence of confounding variables and strengthen the internal validity of the study (Stuart, 2010).

By examining the overlap in observed characteristics between the treatment and control groups, researchers can assess whether the matching method used has achieved balance (Austin, 2019). Balance refers to the similarity in the distribution of observed characteristics between the groups, both before and after matching. If balance is achieved, it suggests that the groups are comparable in terms of their observed characteristics, reducing the potential for bias and improving the validity of the research findings (Stuart, 2010).

The estimated distribution of propensity scores for households involved in eucalyptus tree plantation and those who are not involved ranges from 0.0000123 to 0.99999. Based on Figure 9, it is evident that the matched pairs exhibit comparability, as their propensity scores to receive the treatment are similar. This successful matching process enables the study to accurately measure the impact of eucalyptus tree plantations on household income using these comparable groups.

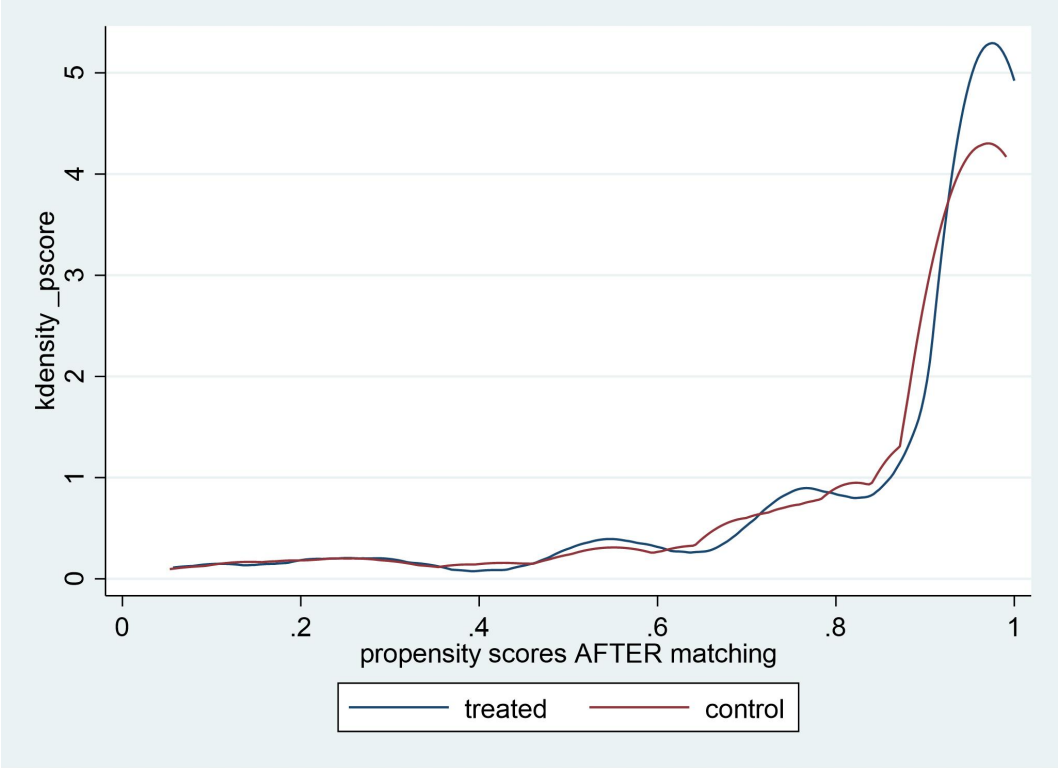

Figure 9: Distribution of propensity scores after matching

Matching methods

To assess the average treatment effect of eucalyptus plantations on household income, the study used the nearest-neighbor matching algorithm. This algorithm was chosen because it effectively addressed the significant mean differences across all explanatory variables after matching the treated and control groups. Furthermore, the analysis used a substantial matched sample comprising 121 observations, which was deemed the most suitable matching estimator for the study.

3.3 Results and Discussion

3.3.1 Income disparity between households engaged in eucalyptus tree planting and those that are not

The two-sample t-test results in Table 7 indicate that households not involved in eucalyptus tree planting have an average income of 36,387.95 ETB/year, which is much lower than the income of households involved in eucalyptus tree planting, which is 66,399.4 ETB. Importantly, this income difference was found to be statistically significant at a 1% level of significance, underscoring a substantial disparity between the two groups.

Table 7: Two-sample t-test with equal variances

Group	Obs	Mean	Std. err.	Std. dev.	[95% conf. interval]	
0	166	36387.95	1076.0	13863.4	34263.42	34263.42
1	166	66399.4	1650.9	21270.3	63139.79	69659.01
Combined	332	51393.67	1283.8	23392.1	48868.22	53919.13

Based on the aforementioned findings, it can be concluded that eucalyptus tree plantation has a positive effect on smallholder household income. Households that own eucalyptus trees had higher income levels compared to non-owners, and this difference is statistically significant.

However, it is important to note that income variations may not be solely attributed to eucalyptus tree plantations.

A wide range of socioeconomic and demographic factors, including age, gender, education, family size, farm size, cooperative membership, and access to savings and credit services, significantly influence agricultural income levels. The study used PCA to determine the factors that have the greatest impact on household income.

Before performing the PCA, all indicators were normalized to ensure that each variable was on the same scale, enabling a fair evaluation of their relative importance. After normalizing the indicators, we employed SPSS software to conduct the PCA analysis.

Before the analysis, we reviewed the key assumptions of PCA to confirm that the data was suitable for factor analysis. Bartlett's test of sphericity indicated a significant correlation ($p < 0.05$) among the dimensions, suggesting that further investigation was warranted. This result indicates that the observed correlation matrix significantly differs from an identity matrix, confirming the appropriateness of the variables for factor analysis. The KMO score was 0.61, indicating that the current data is suitable for PCA.

Using PCA on fourteen variables, we identified nine reduced variables that can help explain factors influencing household income. The first four components had eigenvalues exceeding one and collectively accounted for approximately 68.4% of the variation.

The results revealed that eucalyptus ownership, the age and educational level of the household head, total farmland size, fertility level of farmland, ownership of livestock (measured in Tropical Livestock Units), household size (measured in adult equivalent), access to savings and credit, and cooperative membership are the major factors influencing household income in the Senan district. These findings align with previous studies that identified education (Abrha *et al*., 2015), age (FAO, 2014), family size (Bitana *et al*., 2023), farm size (Doti, 2017), cooperative membership (Daksa *et al*., 2017), and access to credit (Mitiku *et al*., 2019) as significant determinants of household income.

Educated households are better equipped to utilize technology, obtain inputs, and market their products effectively (Abrha *et al*., 2015). However, a primary challenge for youth in agricultural contexts is their limited access to practical knowledge, information, and experience, which hinders productivity and skill acquisition which are crucial elements for success in farming (FAO, 2014). Farm size is another critical factor affecting income levels; besides the amount of agricultural land, average land productivity, and non-farm income significantly influence variations in farmer income (Doti, 2017). Additionally, gender can restrict the mobility of young rural women in underdeveloped nations, impeding their access to markets and income opportunities (FAO, 2014). As family size increases, consumption-to-income ratios also rise, as additional household members require resources typically sourced from current income (Bitana *et al*., 2023).

Cooperatives play a significant role in shaping farmers' income and productivity by providing essential services that cater to their members' needs (Daksa *et al*., 2017). By facilitating better access to markets and resources, cooperatives enhance the overall income potential of their members. Furthermore, limited access to financing is one of the most significant barriers to agricultural output. Credit enables smallholder farmers to overcome capital constraints and invest in high-yield crops, fertilizers, and labor, thereby increasing agricultural productivity and production (Mitiku *et al*., 2019). Therefore, improved access to financial resources is essential for farmers seeking to enhance their productivity and income.

Table 8: Component matrix

	Components			
	1	2	3	4
Eucalypt ownership	.878			
Age	.658		.398	
Total land size	.649			
Educational level	.599			.435
Productivity of land		.661		
Saving and credit access		.572		-.418
TLU			.674	
Cooperative membership			.568	-.398
Household size	-.508	.323		.626

The highest loading of 0.8 for eucalyptus ownership suggests a strong association between owning eucalyptus plantations and higher household income as indicated in Table 8. To isolate the specific impact of eucalyptus plantations on household income, we employed PSM, which allows us to control for confounding factors and accurately estimate the causal effect.

3.3.2 The impacts of eucalyptus plantations on the household income

The findings of the analysis of the average effect of treatment on treated (ATT) in Table 9 reveal that households engaged in eucalyptus tree plantation activities show a higher average annual income of 64,689.3 ETB, which is 40.2% higher than the income collected by households that do not participate in eucalyptus tree plantation activities. These results highlight the positive impact of the participation of eucalyptus plantations on total household income.

Table 9: ATT of eucalyptus tree plantation on household income

Estimation methods	No of treated	No of control	ATT (Treated)	Average outcome (Control)	Difference	Stand. error	t-statistics
Nearest-neighbor	121	166	64,689.3	38,679.3	26,010	5.4	7.4***

*** denotes the 1% significance level;

These findings are consistent with global experiences. Studies in Indonesia (Mahendra, 2023), Kenya (Kluthe, 2016), India (Devi, 2023), and Thailand (Ubukata, 2011) show substantial income increases from eucalyptus plantations. Samdin (2020) found that these plantations not only generate additional income but also create employment opportunities. The potential for higher profits compared to other crops offers long-term economic benefits that improve rural livelihoods. While some criticize eucalyptus for potential environmental impacts, Kluthe (2016) argues that economic advantages outweigh these concerns.

The finding also aligns with research by Alemayehu and Melka (2022), Province and Manan (2022), and Tewodros *et al*. (2022), showing that eucalyptus plantations offer higher income compared to crops. This trend is evident in areas with land degradation and reduced arable productivity. Such lands, often high in acidity and low in fertility, remain suitable for eucalyptus (Tesfaw *et al*., 2023).

As traditional farming faces challenges, eucalyptus offers a viable alternative, enabling smallholders to transition from less profitable crops to more lucrative ones (Getnet *et al*., 2022). Its resilience to water fluctuations makes it especially suitable for farmers engaged in rain-fed agriculture, particularly in regions like the Ethiopian highlands that are grappling with recurrent drought, soil erosion, and land degradation (Bazzana *et al*., 2020). Furthermore, eucalyptus's rapid growth, high biomass production, and ability to coppice enhance its economic value (Abebe and Tadesse, 2014).

The increasing demand for eucalyptus products in Ethiopia is driven by several factors, including a growing population, urbanization, and the diverse uses of eucalyptus for housing construction, timber, firewood, charcoal, fencing, and agricultural tools (Dessie *et al*., 2019; Kebede, 2022), which aligns with Ethiopian traditional housing construction methods that currently rely heavily on wood (Allerbo and Waldemarsson, 2013). Additionally, the reliance

on biomass for energy, due to limited access to alternative sources like electricity and natural gas creates a favorable market for eucalyptus. Rising demand for building materials and energy sources significantly influences prices (Dessie *et al*., 2019). However, price reductions may occur due to economic downturns or shifts in consumer preferences, and the presence of unlicensed traders as noted by Sarmento *et al*. (2019) and Tesfaw *et al*., (2021). Demand and price fluctuations are also affected by political instability (Alemayehu *et al*., 2024). Furthermore, threats to eucalyptus *globulus* plantations, such as fire, pests, and diseases, pose additional challenges (Tome *et al*., 2021).

Increasing farmer income is crucial for alleviating poverty and enhancing quality of life, as noted by Dessie *et al*. (2019) and Mahendra (2023). In the same vein, Tewodros *et al*. (2022) acknowledge that eucalyptus plantations help households cope with emergencies and prevent impoverishment by boosting annual income. Additionally, Seware and Woldetsadik (2016) argue that eucalyptus harvesting provides financial security during difficult times.

3.4 Conclusion

Based on the findings of the Average Treatment Effect on the Treated (ATT) analysis, it can be concluded that households involved in eucalyptus tree plantation activities in the Senan district of the national regional state of Amhara, Ethiopia, experience a significant increase in their average annual income. These results show that participating in the planting of the tree improves the income of the household in the study area. The higher income level observed among the households involved in the activity suggests that this economic activity can serve as a viable income-generating opportunity for the rural communities in the district.

A comprehensive approach that incorporates diversification, cooperative efforts, and training can significantly enhance the sustainability and economic feasibility of eucalyptus plantations, ultimately benefiting farmers' livelihoods. Encouraging farmers to diversify their eucalyptus-based products, such as timber, firewood, and charcoal, along with exploring alternative income generation opportunities, can help stabilize revenue and reduce dependence on a single market. Additionally, promoting the establishment of cooperatives among smallholder eucalyptus growers and developing rural infrastructure can enhance market access. This, in turn, can lead to more stable prices and provide greater opportunities for farmers to receive training on early pest and disease detection, as well as best practices for maintaining their eucalyptus plantations.

CHAPTER 4: EUCALYPTUS-BASED LIVELIHOODS: ENHANCING HOUSEHOLD FOOD SECURITY AND RESILIENCE IN NORTHWEST ETHIOPIA

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ABSTRACT

Farmers in Northwest Ethiopia have been transforming their livelihood strategies, however, the impact of this transformation on food security status and resilience is hardly investigated. The study aimed to analyze the contribution of livelihood strategy transformation to farmers' food security and capital assets in the Senan district, Ethiopia. A multistage sampling technique was utilized, and a total of 332 households were taken, of whom 166 households that had transformed their livelihood strategy, and 166 households had not. The results of the independent sample t-test revealed a statistically significant difference in average scores for the Household Food Insecurity Access Scale (M = 8.06 compared to 11.29) and the Household Dietary Diversity Score (M = 5.28 compared to 4.73) between households with and without eucalyptus plantations. The econometric analysis revealed that variables such as total land holding size, annual income, and livelihood diversification had a positive influence on the probability of a household being categorized as food secure. Moreover, the outcome of the livelihood asset index reveals that households that possess eucalyptus plantations exhibit higher indices for natural, physical, financial, and social assets compared to households without plantations. However, households that own eucalyptus plantations demonstrate a lower index for human capital than those without eucalyptus plantations. These findings underscore the role of eucalyptus plantations in enhancing food security and improving livelihoods for farmers in the study area. Furthermore, diversifying income sources through eucalyptus plantations can significantly amplify its overall benefits for local households.

***KEYWORDS**: Food insecurity, Asset index, Dietary diversity, Principal Component Analysis, Annual income*

4.1 Introduction

Livelihoods, encompassing the activities, assets, and capabilities necessary for survival, are closely linked to food security (Ellis, 2000; Serrat, 2008). In this context, individuals and communities adopt diverse livelihood strategies based on available resources to ensure their well-being (Silaban, 2021). Farmers, in particular, adjust these strategies in response to evolving opportunities (Irawan, 2023), risks (Kahan, 2013), and constraints (Kuang *et al*., 2020) to optimize their circumstances. In recent years, there has been a growing trend in Ethiopia where croplands are being increasingly converted into eucalyptus plantations (Zerga, 2021). This shift in land use patterns is mainly driven by several factors, including land degradation (Jenbere *et al*., 2011), increased demand for eucalyptus for construction and fuel (Derbe *et al*., 2018), socioeconomic and demographic characteristics of households (Alemayehu and Melka, 2022; Gebreegziabher *et al*., 2010), and rising agricultural input expenses (Tefera and Kassa, 2017). Eucalyptus based agroforestry practices have also played a crucial role in supporting rural livelihoods, with findings indicating that farmers who adopt such practices have a higher average annual income compared to those who do not (Tebkew *et al*., 2024).

However, the relationship between eucalyptus plantations, livelihoods, and food security is complex and often contradictory. Some studies suggest that eucalyptus can enhance livelihoods and food security (Edesa, 2021; Kiyingi *et al*., 2016), with findings indicating its vital role for smallholder farmers and its contribution to rural household incomes (Zerga and Woldetsadik, 2016). Under current market conditions, eucalyptus plantations often yield higher returns on investment compared to traditional crop production (Alemayehu and Melka, 2022), promoting rural development and poverty alleviation (Tebkew *et al*., 2024).

Conversely, concerns exist regarding the implications of eucalyptus expansion for food security. Studies by Admassu (2016) and Tesfaw *et al*. (2022) warn that the rapid conversion of agricultural land to eucalyptus might exacerbate food insecurity. These conflicting findings highlight the necessity for further investigation, particularly within the specific context of the Senan district.

In the Senan district, farmers are increasingly following the national trend of converting cropland to eucalyptus plantations (Tesfaw *et al*., 2022). Despite the widespread presence of eucalyptus and the conversion of agricultural land, the effects on livelihoods and food

security remain unclear. The district's diverse agricultural landscape and reliance on subsistence farming (Ferede *et al*., 2020) provide a unique opportunity to examine how eucalyptus plantations influence household capital assets and food security. As many households depend on agricultural outputs for their livelihoods, understanding the potential implications of eucalyptus cultivation is crucial. While eucalyptus may enhance income generation (Zerga and Woldetsadik, 2016), its impact on local food systems and market dynamics could complicate food access.

Despite the growing interest in eucalyptus plantations, comprehensive research comparing food security status and livelihood capital assets of households with and without eucalyptus plantations is lacking. Existing literature often overlooks the nuanced impacts of land use changes on local food security and livelihood resilience, indicating a pressing need for comparative studies.

This study specifically addresses the following research questions: What is the effect of eucalyptus plantations on the food security status of households in the Senan district, Northwest Ethiopia? What are the other determinants of food security in the district? How does eucalyptus cultivation influence the capital assets of these households?

4.2. Material and Methods

4.2.1 Site description

Senan district is located between 10°20′35″ and 10°50′38″ North and 37°35′10″ and 37°52′20″East as indicated in Figure 10. The district, which covers 436 km^2 (Yimam *et* al., 2024), has elevations between 2300 and 4154 m above sea level (Senan District Communication Affairs Office, 2021). The district's economy is primarily agrarian, with smallholder subsistence farming serving as the main source of income (Tesfaw *et al.,* 2022).

A mixed crop-livestock production system predominates in the area, with cereals, pulses, and oil seeds being the principal crops (Mekuriaw *et al*., 2018). According to Belay *et al*.'s (2023) land use and land cover research, cropland declined from 58.4% in 2010 to 38.1% in 2021, while vegetation cover, primarily eucalyptus increased from 16.8% to 26.5% during the same period.

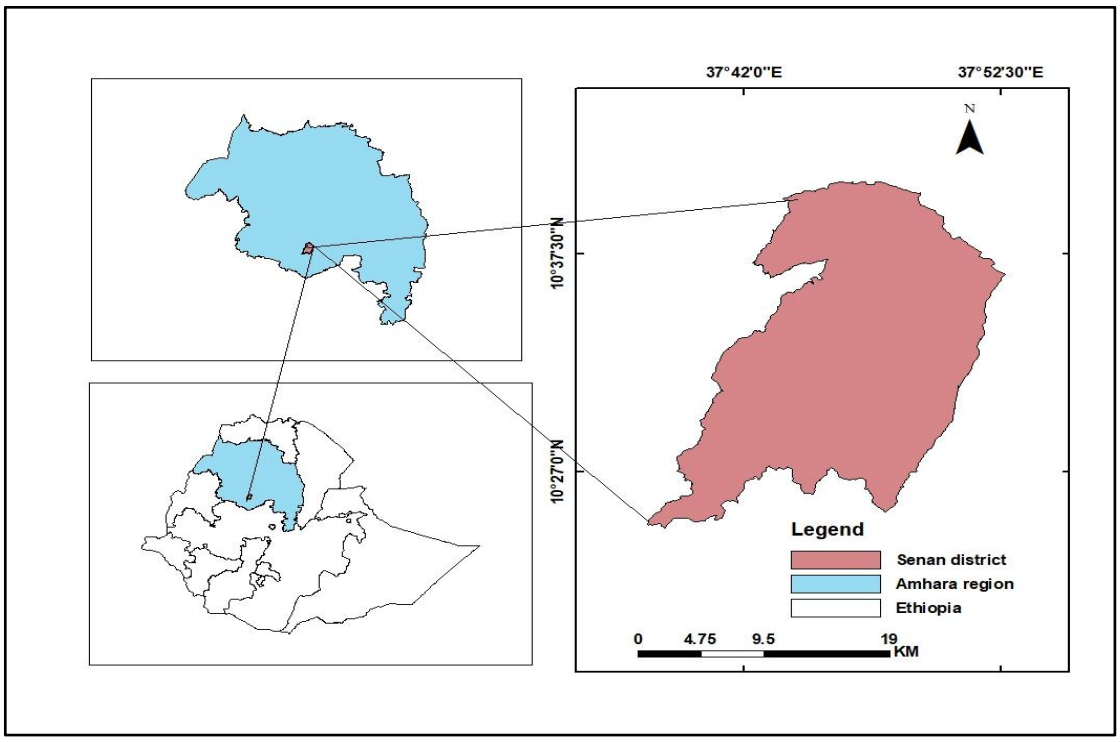

Figure 10: Location map of the study area

4.2.2 Study design and approaches

To achieve the objective of the study, a cross-sectional survey was conducted, utilizing primary data collection methods. A mixed research approach was employed to collect comprehensive and diverse insights from the study's participants. This approach helps in triangulating the results and improves the validity and reliability of the study (Bryman, 2007).

Data collection in this study were conducted using the Kobo Toolbox, and the analysis was performed using the Statistical Package for the Social Sciences (SPSS) Version 26 and Stata 17.

4.2.3 Sampling technique and sample size determination

A multistage sampling technique was employed to ensure the sample was representative of the population, accounting for diversity within the study area. Initially, the Senan district was chosen due to its extensive eucalyptus plantations. Within this district, sub-districts were classified into two distinct agro-climatic categories: temperate and subtropical. From each category, the Kebeles of *Gedamawit* and *Tach Chabi*, known for their significant eucalyptus plantations, were selected for the study. Lastly, households within these sub-districts were classified into two categories: those with transformed livelihood strategies (eucalyptus

owners) and those without (non-owners). Participants were then randomly selected in proportion to their representation in each category.

Given the small population size of the study area, the Cochran modified formula, which is specifically tailored for finite populations, was applied.

$$n = \frac{n_o}{1 + (n_0 - 1)/N}$$

Here n0 is the Cochran sample size recommendation, N is the population size and n is the new adjusted sample size.

$$n = \frac{385}{1+(385-1)/2392} = 331.89 = 332$$

The proportional sampling formula was employed to distribute a total of 332 units to households residing in two *kebeles*.

$$n_1 = \frac{n \times N_i}{N} = \frac{332 \times 1518}{2392} = 210$$

$$n_2 = \frac{n \times Ni}{N} = \frac{332 \times 874}{2392} = 121$$

Where n_i is the sample of strata *I;* N_i s is the population of strata; n = total sample size.

4.2.4 Data types and data collection tools

This study relied on a combination of primary and secondary data to investigate the impact of eucalyptus plantations on household livelihood resilience and food security in the Senan district, Ethiopia.

The primary data for this study involved the utilization of a questionnaire survey, key informant interviews, direct observations, and focus group discussions. The secondary data were collected from a variety of sources, including reports from the Central Statistical Agency (CSA), the Senan District Communication Affairs Office, and various research studies. The questionnaire was carefully designed with multiple sections to gather different types of data relevant to the research objectives. Notably, specific sections focused on

capturing household food security indicators, and the factors influencing their food security status. Additionally, the questionnaire included targeted inquiries to collect data on livelihood capital assets, encompassing human capital, financial resources, social networks, natural resources, and physical assets.

The study employed purposive sampling to select key informants, including women and elders involved in and not involved in eucalyptus cultivation. Focus group participants were also selected purposively, ensuring representation of agricultural experts, elderly farmers, and women in separate groups. Eight key informant interviews and six focus group discussions were conducted, three in each sub-district. Informed consent was obtained from all individual participants included in the study.

To gain a comprehensive understanding of food security in households, the study employed two food security measurement methods; the Household Food Insecurity Access Scale (HFIAS) and the Household Dietary Diversity Score (HDDS). Both the HFIAS and HDDS data were collected twice (in January and August) to account for seasonal variations in the food security status of the households, and the average results were used for analysis purposes.

4.2.5 Method of data analysis

To evaluate the effect of eucalyptus plantations on the household's livelihood status, the livelihood asset index method was utilized. Principal component analysis (PCA) was employed to determine the weights for the indicators of livelihood capital assets. A radar chart was then created in Office 365, providing a visual representation of the assets index and offering a comprehensive overview of the household's livelihood status.

Livelihood assets in this study include the physical, financial, human, social, and natural assets which are measured by a set of variables as defined in Table 10.

Table 10: Summary of the variables employed to construct the livelihood asset index

Capital Asset	Indicators	Measurement
Natural Capital	Total land	Land size in hectares
	Average fertility level of land	Percentage
Physical capital	Solar lamp	0.No 1.Yes
	Iron sheet number	in number
	Livestock ownership	TLU
	Radio	0.No 1.Yes
	Mobile phone	No 1.Yes
	Access to drinking water	1.Ponds/rivers 2.Unprotected springs/wells 3.Protected springs 4.Drilled/tube wells with hand pumps 5.Piped water connections and community water taps
Human capital	Sex of household head	0. Female 1. Male
	Educational level of household head	1.Cannot read and write 2.Read and write only 3.Elementary (grade 1 -8) 4.Secondary (grade 9-12) 5.College diploma/BA/BSc and above
	Household Size	Adult equivalent
	Labor shortage	0.No 1.Yes
	Age of household head	Age in years
	Training opportunity	Number of training received in a year
Financial capital	Total annual Income	Income in ETB
	Access to savings and credit	0.No 1.Yes
	Savings (amount saved)	Saving in ETB
Social capital	High level of participation in *Mahber*[1]	1. I am not even a member. 2.Strongly disagree
	High level of participation in *Debo*[2]	3.Disagree
	High level of participation in *Edir*[3]	4.Neutral
	High level of participation in *Equb*[4]	5.Agree 6.Strongly agree
	Membership of cooperative	0.No 1.Yes

[1] A community-based socio-religious group where individuals commit to treating each other as equals.

[2] A group of individuals working together to reach a shared objective.

[3] Edir is a traditional system of social funeral insurance.

[4] Rotating savings and credit association (ROSCA)

The food security status of households in the study area was evaluated using two indicators: HFIAS and HDDS. Additionally, an independent sample t-test was performed to compare the average scores of HFIAS and HDDS between households with and without eucalyptus plantations. This analysis aimed to investigate potential differences in food security indicators based on the presence of eucalyptus plantations.

To identify the factors influencing food security, a multinomial logistic regression analysis was conducted. For this analysis, the households were initially categorized into distinct groups based on their food security status. To achieve this, HFIAS was utilized, merging the categories of mildly food insecure and moderately food insecure into a single category called "food insecure." This categorization allowed for the creation of three distinct groups: food secure, food insecure, and severely food insecure. Consequently, the dependent variable became a categorical variable with three groups.

Dependent Variable:

Y represents the food security status of households based on HFIAS categories:

$Y \in \{1, 2, 3\}$

1 = Severely Food Insecure

2 = Food Insecure

3 = Food Secure

Independent Variables:

X represents the vector of independent variables:

X_1: *Kebele* of households (0 = *Tach chabi*, 1 = *Gedamawit*)

X_2: Sex of household head (0 = Female, 1 = Male)

X_3: Age of household head (in years)

X_4: Marital status of household head (0 = Unmarried, 1 = Married)

X_5: Educational rank of household head (in years)

X_6: Family size (Adult equivalent)

X_7: Ownership of eucalyptus plantations (0 = No, 1 = Yes)

X_8: Livestock ownership (TLU)

X_9: Size of farmland (in hectares)

X_{10}: Distance from the main road (in kilometers)

X_{11}: Livelihood diversification (Eucalyptus only/ crop production only = 1, Eucalyptus and crop production = 2, Diversified livelihoods (on-farm, off-farm and non-farm, including eucalyptus plantations) = 3)

X_{12}: Total annual income (in ETB)

X_{13}: Farm fertility (1 = low fertility, 2 = medium fertility, 3 = high fertility)

X_{14}: Membership of cooperatives (0 = No, 1 = Yes)

X_{15}: Access to savings and credit service (0 = No, 1 = Yes)

X_{16}: Savings in ETB (amount saved in local currency)

The likelihood of belonging to category k, where k equals 1, 2, or 3, can be represented as:

$$P(Y=k \mid X) = \frac{e^{\beta_K^T X}}{\sum_{j=1}^{3} e^{\beta_j^T x}}$$

Where $^{\beta}K$ is the vector of coefficients for category K.

For K= 2 (Food insecure):

$$\log\left(\frac{P(Y=2|X)}{P(Y=1|X)}\right) = \beta_2^T x$$

For K= 3 (Food secure):

$$\log\left(\frac{P(Y=3|X)}{P(Y=1|X)}\right) = \beta_3^T x$$

4.3. Result

4.3.1 Socio-economic and demographic characteristics of respondents

Table 11: Descriptive result of continuous variables

Variable name	Eucalyptus planters			Non-planters			Total mean
	Min	Max	Mean	Min	Max	Mean	
Age of household head (yrs)	23	78	55.8	21	68	47	51.4
Household size (Adult equiv.)	2	7.5	4.6	2	8	4.8	4.7
Land size (ha.)	0.25	2.75	0.61	0.25	2	0.5	0.5
Livestock ownership (TLU)	0.52	4.3	3.3	1.1	5.7	3.5	3.4
Income (ETB)	25,000	135,000	66399.4	17,000	85,000	36,387.95	51,393.67

Eucalyptus planters and non-planters exhibit notable differences and similarities in their characteristics. On average, eucalyptus planters are older, with a mean age of 55.8 years, compared to 47 years for non-planters. This suggests that older individuals may be more inclined to engage in eucalyptus farming. Additionally, household sizes among eucalyptus planters are slightly smaller, averaging 4.6 (adult equivalent) members, while non-planters average 4.8 members. In terms of land ownership, planters have a larger average area of 0.61 hectares, compared to 0.5 hectares for non-planters, which may support their agricultural activities. Interestingly, non-planters own a bit more livestock, averaging 3.5 tropical livestock units (TLU) compared to 3.3 TLU for planters. The expansion of eucalyptus plantations has decreased grazing lands, adversely affecting livestock production (Desta *et al.*, 2023). Furthermore, livestock often depend on crop by-products for feed, which has resulted in eucalyptus non owners having a greater number of livestock compared to eucalyptus owners.

The other most significant difference, however, lies in income; eucalyptus planters report an average income of 66,399.4 ETB, substantially higher than the 36,387.95 ETB reported by non-planters.

Table 12: Descriptive results of categorical variables

Variable name	Description	Percentage		
		Eucalyptus planters	Non planters	Total
Gender of household head	Female	9.0	7.3	8.2
	Male	91.0	96.7	93.7
Marital status	Never married	0	0	0
	Married	86.2	88.6	87.3
	Divorced	6.6	3.6	5.1
	widowed	7.2	7.8	7.6
Education level of household head	Cannot read and write	36.7	57.2	47
	Read and write only	39.2	39.2	39.2
	Elementary (grade 1 -8)	19.3	2.4	10.8
	Secondary (grade 9-12)	4.2	1.2	2.7
	College diploma, BA/BSc and above	0.6	0	0.3

Female-headed households are more prevalent among eucalyptus owners compared to non-owners. In terms of marital status, a substantial majority of both planters (86.2%) and non-planters (88.6%) are married, resulting in an overall average of 87.3% across the population. The percentages of divorced and widowed individuals are relatively low, although planters exhibit a slightly higher divorce rate of 6.6% compared to 3.6% among non-planters.

In addition to these demographic trends, eucalyptus planters generally demonstrate higher levels of education than non-planters. A significant portion of non-planters, 57.2%, are illiterate, while the illiteracy rate among planters is lower at 36.7%. Furthermore, planters are more likely to have completed various educational milestones: 19.3% have finished elementary education compared to just 2.4% of non-planters, and 4.2% have completed secondary education compared to 1.2% of non-planters. Additionally, a small proportion of planter household heads (0.6%) have attained a college diploma or bachelor's degree, while none of the non-planter household heads have with this level of education.

4.3.2 Livelihood asset estimates

Before calculating the household livelihood index, all indicators were standardized to ensure all variables were on a common scale, enabling a fair comparison of their relative importance. After standardizing each indicator, we performed PCA through SPSS software.

Before the analysis, the main assumptions of principal component analysis have been checked to look at the adequacy of the data for factor analysis. Bartlett's test of sphericity was found significant ($p < 0.05$), indicating a sufficient correlation between the dimensions to continue with the analysis. It indicates that the observed correlation matrix is significantly different from an identity matrix. This suggests that the variables are suitable for factor analysis.

The KMO value was 0.722. This result indicates that the present data are acceptable for principal component analysis. The weights of each variable for the indexes constructed are presented in Table 13.

Table 13: Weights of livelihood capital asset indicators generated through PCA

Capital asset	**Indicators**	**Weight**
Natural Capital	Total land	0.782
	Average fertility level of land	0.761
Physical capital	Solar lamp	0.777
	Iron sheet number	0.660
	TLU	0.156
	Radio	0.338
	Mobile phone	- 0.105
	Access to drinking water	0.103
Human capital	Sex of household head	- 0.938
	Educational level of household head	0.646
	Household Size	0.138
	Labor shortage	0.491
	Age of household head	0.453
	Number of training received	- 0.938
Financial capital	Total annual Income	0.721
	Savings	0.751
	Access to savings and credit	0.872
Social capital	Level of participation in *Mahber*	- 0.483
	Level of participation in *Debo*	0.174
	Level of participation in *Edir*	0.719
	Level of participation in *Equb*	0.740
	Membership of a cooperative	- 0.432

The livelihood asset index result indicates that households owning eucalyptus plantations have higher natural, physical, financial, and social asset indices than those who do not own the plantation as indicated in Figure 11.

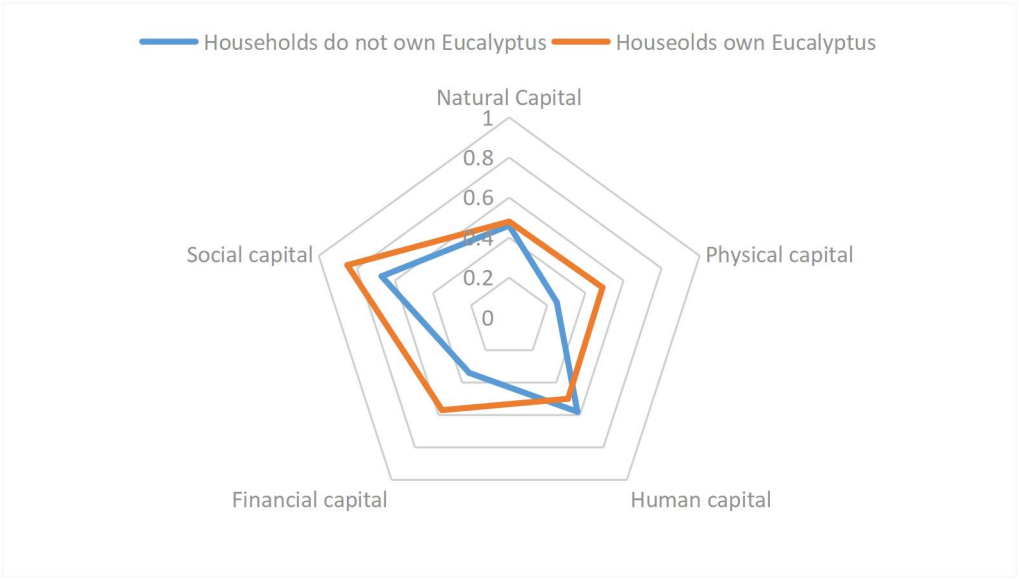

Figure 11: Livelihood asset index

The findings presented in Table 14 show that households that own eucalyptus plantations have higher indices for natural capital (0.48 compared to 0.46), physical capital (0.49 compared to 0.25), financial capital (0.57 compared to 0.34), and social capital (0.85 compared to 0.67) in comparison to households without eucalyptus ownership. However, households that own eucalyptus plantations show a lower index for human capital (0.50 compared to 0.58), than those without eucalyptus plantations.

Table 14: Livelihood asset index of households

Capital asset	Households do not own Eucalyptus	Households own Eucalyptus
Natural Capital	0.46	0.48
Physical capital	0.25	0.49
Human capital	0.58	0.50
Financial capital	0.34	0.57
Social capital	0.67	0.85

The higher indices for natural, physical, financial, and social capital among households that own eucalyptus plantations indicate that such ownership can significantly contribute to asset

accumulation. Concerning this, one of the key informant farmer expressed that the presence of eucalyptus plantations significantly increased their financial resources as stated below.

"Due to the planting of eucalyptus trees, we have experienced a level of financial prosperity that has been unprecedented for us."

This suggests that the economic benefits gained from eucalyptus farming have provided community members with increased income, enabling them to improve their livelihoods.

An agricultural expert from the district noted, "*Eucalyptus plantations are improving the livelihoods of farmers not only in the Senan district but also in other regions of Ethiopia. For example, communities in Wollo often express that 'survival is challenging without remittances from sending their daughters to Arab countries or through the plantations of eucalyptus trees'."*

4.3.3 Food security status of households

4.3.3.1 Household food insecurity access scale

To better understand household food insecurity, four types of indicators were computed: an overview of food security conditions, domains, scores, and the prevalence of Household Food Insecurity Access.

Household food insecurity access-related conditions: Regarding food insecurity access concerns, a larger percentage of households expressed their worries about running out of food, particularly among those who do not own eucalyptus trees (86.1%) as indicated in Figure 12. Additionally, a notable 10.2% of smallholder farming households faced severe conditions where they left home morning and sleep night empty stomach resulting from a shortage of food.

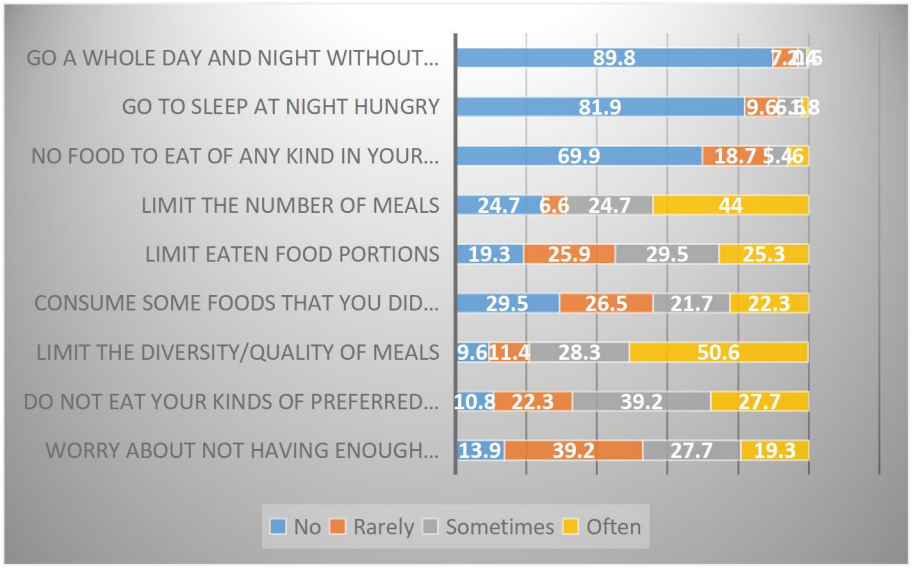

Figure 12: Household food insecurity access conditions of households without eucalyptus ownership

Contrarily, 79.5%, and 3.6% of eucalyptus owner households worry about running out of food and going days and nights on empty stomachs respectively as presented in Figure 13.

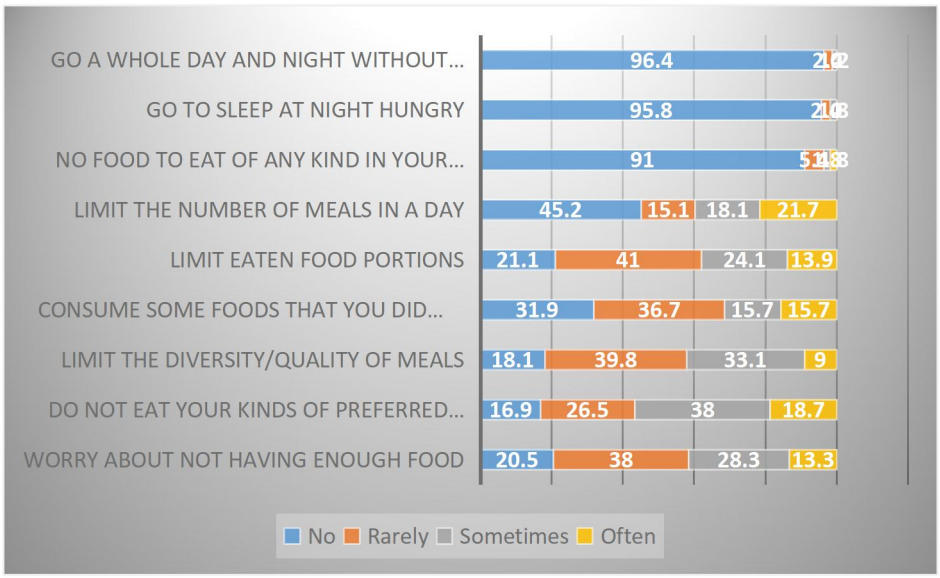

Figure 13: Household food insecurity access-related conditions of eucalyptus owners

Household food insecurity access-related domains: The findings in Figure 14 indicated that a significant portion of households (86.1%) without eucalyptus plantations faced concerns and uncertainties regarding having enough food to meet the needs of all household

members. Additionally, 83.3% of households experienced challenges related to insufficient food quality and limited access. Furthermore, approximately 42.9% of the households surveyed were able to cope with inadequate food intake during the past four weeks.

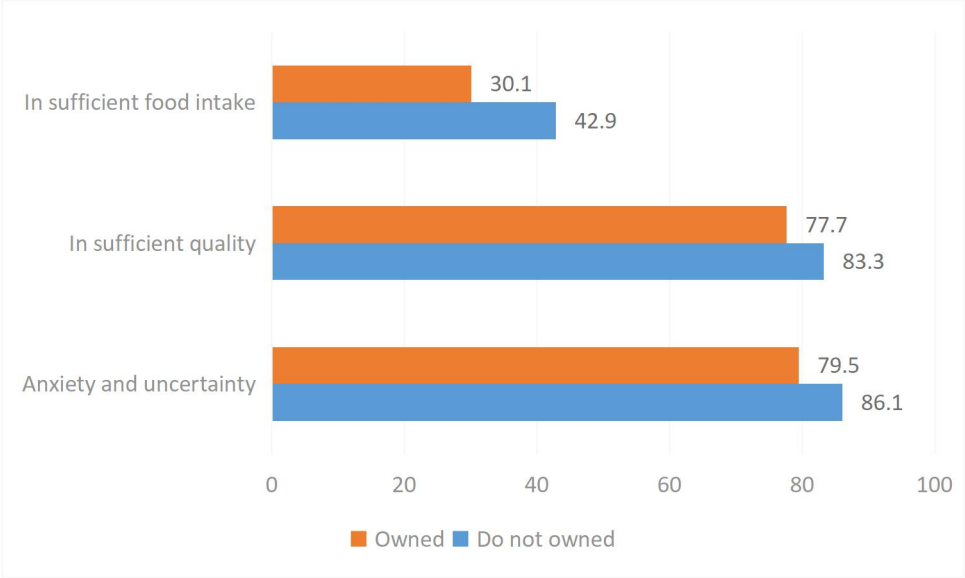

Figure 14: Household Food Insecurity Access-related Domains

Household food insecurity access scale score: As displayed in Table 15, households with eucalyptus plantations scored a lower with mean score (M = 8.06, SD = 5.0), indicating a better food security status, compared to households without the plantation (M = 11.29, SD = 5.6). The HDDS showed that households that own eucalyptus trees have greater dietary diversity than those households that do not own.

Table 15: HFIAS and HDDS scores of households

Variables	Eucalyptus	Mean	Std. Deviation	Std. Error	*t*-value	*p*-value	Sig.
HFIAS	No	11.29	5.6	0.436	5.509	.000	***
	Yes	8.06	5.0	0.391	5.509	.000	***
HDDS	No	4.73	1.3	0.105	-3.756	.000	***
	Yes	5.28	1.5	0.104	-3.756	.000	***

*** $p < 0.01$

Household food insecurity access prevalence: The prevalence results of HFIAS among the sampled households in Table 16 reveal a striking disparity in food security between households with eucalyptus plantations and those without. Specifically, households without eucalyptus plantations experience a higher incidence of food insecurity (81.9%) compared to those who own the plantation (75%).

Among the households without plantations, detailed classifications of food security status underscore the severity of the issue: only 18.1% are categorized as food secure, while a substantial 39.2% are classified as mildly food insecure, 35.5% as moderately food insecure, and 7.2% as severely food insecure. So the prevalence of household food insecurity was 81.9%.

Table 16: Household food insecurity access prevalence of households who do not own eucalyptus plantations

HFIAS Question Non owners	Frequency		
	Rarely	Sometimes	Often
1a	65	46	32
2a	37	65	46
3a	19	47	84
4a	44	36	37
5a	43	49	42
6a	11	41	73
7a	31	9	10
8a	16	11	3
9a	12	4	1

Key	
	Food secure = 18.1%
	Mildly food insecure = 39.2%
	Moderately food insecure = 35.5%
	Severely food insecure = 7.2%

When we compare the levels of food insecurity between households with and without eucalyptus plantations, the HFIAS results show a positive correlation between eucalyptus plantations and food security. As Table 17 shows a quarter (25%) of households with

eucalyptus plantations are classified as food secure. This stability may be attributed to the income generated from the eucalyptus plantations, which can enhance households' purchasing power and allow them to invest in food and other essential resources. The data also shows that 43.7% of eucalyptus owner households experience mild food insecurity. This means they may face occasional food shortages but generally have sufficient food to meet their basic needs. On the other hand, a relatively small proportion of households specifically, 26.2% are classified as moderately food insecure, while 5.1% are categorized as severely food insecure, as presented in Table 17.

Table 17: Household food insecurity access prevalence of households who own eucalyptus plantations

HFIAS Question	Frequency		
Owners	Rarely	Sometimes	Often
1a	63	47	22
2a	44	63	31
3a	66	55	15
4a	61	26	26
5a	68	40	23
6a	25	30	36
7a	9	3	3
8a	4	3	0
9a	4	2	0

Key
Food secure = 25.0%
Mildly food insecure = 43.7%
Moderately food insecure = 26.2%
Severely food insecure = 5.1%

4.3.3.2 Household dietary diversity score

The results of the independent sample t-test revealed a significant average difference in food security levels between households that owned eucalyptus plantations (M = 5.28, SD = 1.5) and those without the plantation (M = 4.73, SD = 1.3), with a significance level of 0.005.

This finding underscores the positive impact of eucalyptus ownership on food security, suggesting that households with plantations are better positioned to access a more diverse and nutritious diet compared to their non-plantation counterparts.

The dietary patterns observed in the study provide further insights into the food consumption habits of these households. All sampled households reported consuming cereals, indicating that this staple food forms a fundamental part of their diet. However, the absence of fish consumption across the board highlights a potential gap in protein sources, which may have implications for overall nutritional health.

Legumes, roots, and spices emerged as the most widely consumed food groups in the study area, as illustrated in Figure 15. Among households without eucalyptus plantations, a notable majority reported consuming legumes, nuts, and seeds (81.1%), indicating a reliance on these nutrient-dense foods. Additionally, tubers and roots were consumed by 76.5% of these households, along with spices and beverages by 57.8%. However, the consumption of animal products was markedly low, with only 4.8% consuming eggs, and 7.8% meat. This limited intake of animal-based foods could reflect economic constraints, which may affect the overall nutritional quality of their diets. Fruits were consumed by 7.2% of eucalyptus non owner households.

In contrast, households that owned eucalyptus plantations demonstrated slightly higher consumption rates of certain food groups. A significant 84.3% consumed legumes, nuts, and seeds, while 72.2% consumed tubers and roots, and 61.4% reported eating spices and beverages. This suggests that the additional income generated from eucalyptus cultivation may enable these households to access a wider variety of foods. However, similar to eucalyptus plantation non owners, the consumption of eggs (9.6%), fruits (15%), and meat (10.8%) remained low among plantation owners as well, indicating that despite the economic benefits of eucalyptus cultivation, gaps in dietary diversity persist.

Generally while eucalyptus plantation ownership correlates with slightly greater dietary diversity, both groups still face challenges in accessing a well-rounded diet that includes more protein sources and fresh products.

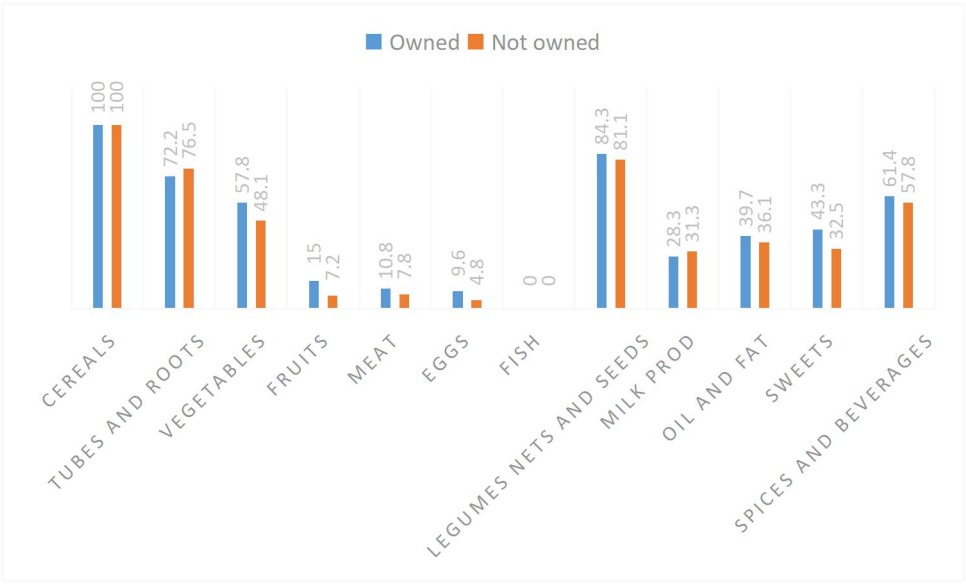

Figure 15: Household dietary diversity score

Generally among the households that owned eucalyptus plantations, 60.2%, 36.7%, and 36.7% had low, medium, and high dietary diversity consumption, respectively. In contrast, among households without eucalyptus plantations, 74.1%, 23.5%, and 23.5% had low, medium, and high dietary diversity consumption, respectively as clearly presented in Figure 16.

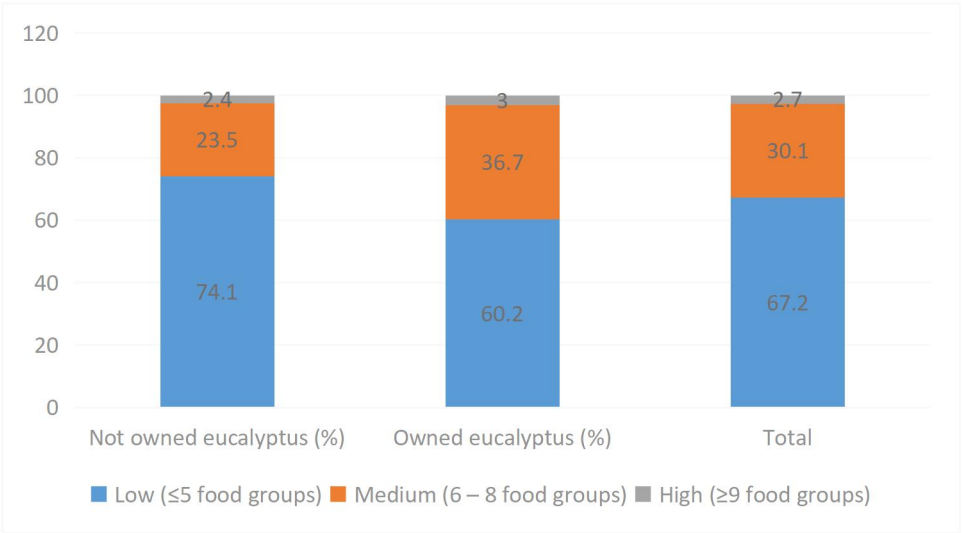

Figure 16: Level of dietary diversity score

4.3.4 Determinants of food security

To investigate the factors influencing households' food security status, a multinomial logit (MNL) model was employed. Before conducting the model, an assessment was carried out to identify any multicollinearity among the explanatory variables. The Variance Inflation Factor (VIF) values were calculated, and it was found that all of them were below the threshold of 10, indicating the absence of significant multicollinearity. The model fitting information revealed a log-likelihood ratio of 78.4 and a chi-square value of 528.4, both of which were highly significant ($P < 0.001$). Furthermore, the pseudo-R-squared value of 0.839 (with a p-value of 0.001) suggests that the explanatory variable accounted for approximately 83.9% of the variation observed in households' food security status. These results indicate that the model provides a good fit and possesses strong explanatory power concerning households' food security status.

Table 18 displays the computed MNL model coefficients and their corresponding standard error. The coefficients revealed that several variables influenced household food security. The variables found to have a positive significant influence include the location of the household where they live (*kebele*), eucalyptus ownership status, land size, livelihood diversification, and annual income. On the other hand, family size and distance from the main road have a negative significant influence on the food secure group compared to the food insecure group.

A positive coefficient on the *kebele* variable indicates that households residing in *Gedamawit* have a higher likelihood of falling into the food secure group compared to food insecure category. According to the marginal effect result, holding all other variables constant, households living in *Gedamawit kebele* have a 9.1% higher probability of being in the food secure category, and a 6.1% lower probability of being in the severely food insecure category compared to households living in *Tach Chabi kebele*. This implies that the food security status of households is influenced by location-specific factors including infrastructure and resulting market conditions.

Our findings also suggest that the coefficient for distance from the major road shows households located closer to roads are more likely to be food secure as compared to the food insecure category. It also implies that, in comparison to food insecure households, those

located farther away from the major route are more likely to experience severe food security, indicating geographical proximity to major roads is a significant factor influencing food security.

Similarly, the coefficient for distance from the major road shows that a one-unit increase in the distance from the main road is associated with a 3.2% decrease in the probability of a household being in the food secure category and a 5.2% increase in the probability of a household being in the severely food insecure category holding all other variables constant. This negative marginal effect suggests that households located farther away from the main road are less likely to be food secure, likely due to reduced access to markets, and transportation, that are more readily available near the main road. The positive coefficient on the eucalyptus ownership variable indicates that households with eucalyptus trees are more likely to fall into the food secure category than the food insecure category. The result also shows that compared to the food insecure category, households with eucalyptus trees are less likely to be identified as severely food insecure.

Table 18: Coefficient estimation of multinomial logit model (base outcome, food insecure)

Variables	Food secure		Severely food insecure	
	Coeff	Std. err	Coeff	Std. err
KebeleHH	0.409**	0.026	-0.722*	0.051
SexHH	0.034	0.481	0.193	0.688
AgeHH	-0.401	0.331	0.013	0.371
MariStat	0.004	0.244	0.351	0.335
EduStat	0.293	0.017	-0.521	0.052
FamilySize	-0.656*	0.591	1.061**	0.443
Eucalyptus	2.01**	0.051	-0.629*	0.154
Livestock	0.053	0.536	- 0.144	0.598
LandSize	7.021***	0.103	- 3.015**	0.006
DistanceFromRoad	-0.716***	0.215	0.331***	0.322
Livelihood diversification	1.137***	0.769	-5.226**	0.001
AnnualIncome	1.320	0.021	-0.908*	0.003
LandQuality	0.034	0.538	0.329	0.491
CooperativesMembership	0.015	0.066	0.002	0.115
Savings	0.414	0.131	- 0.680	0.271

The symbols *, **, and *** represent the findings at the 1, 5, and 10% probability levels, respectively.

The marginal effect of eucalyptus ownership in Table 19 shows that holding all other variables constant, a household owning eucalyptus trees is associated with an 11.4% increase in the probability of being in the food secure category. This positive marginal effect indicates that owning eucalyptus trees increases the possibility that a household will have access to food, possibly as a result of the several advantages it may offer, mainly income. Households with eucalyptus plantations may also be able to engage in other income-generating activities, as eucalyptus farming is relatively less labor-intensive. On the contrary, the marginal effect of eucalyptus ownership on the probability of being in the food insecure category is 0.013. This indicates that a household owning eucalyptus trees is associated with a 1.3% increase in the probability of being in the food insecure and a 7.5% lower probability of being severely food insecure category. Although owning eucalyptus could improve food security for certain households, it may also raise the chance of food insecurity for other households, as indicated by the positive marginal effect for the food insecure group. This may be the result of

unforeseen effects or trade-offs associated with eucalyptus planting, such as the location of the plantation, and other socio-demographic issues that could have a detrimental effect on food supply or access.

A positive coefficient on the farmland size and annual income variables implies that all else equal, households with higher land size and annual income have a higher probability of being in the food secure category and a lower probability of being in the severely food insecure category compared to the food insecure category. Holding all other variables constant, the marginal effect also shows that a one-hectare increase in land size is associated with a 19.0% increase in the probability of a household being in the food secure category, a 4.5% decrease in the probability of a household being in the food insecure category, and 69.1% decrease in the probability of a household being in the severely food insecure category. Similarly, the marginal effect of livelihood diversification shows that a one-unit increase in livelihood diversification is associated with a 15.7% increase in the probability of a household being in the food secure category, 9.1% decrease in the probability of a household being in the food insecure category, and 14.8% decrease in the probability of a household being in the severely food insecure category. It indicates that households with more diversified livelihoods are more likely to be food secure (or less likely to be moderately food insecure) compared to those with less diversified livelihoods.

Finally, the negative coefficient for family size indicates that the likelihood of falling into the food secure category decreases with increasing family size while the coefficient for the severely food insecure group shows that the probability of falling into the severely food secure category increases when family size increases. The marginal effect of family size shows that adding one extra person to a household is associated with a 7.3% decrease in the probability of a household being in the food secure category and an 8.1% increase in the probability of a household being in the severely food insecure category holding all other variables constant.

Table 19: Marginal effect estimation of multinomial logit model

Variables	Food secure		Food insecure		Severely food insecure	
	dydx	Std. err	dydx	Std. err	Dydx	Std. err
KebeleHH	0.091**	0.162	0.017**	0.023	-0.061***	0.010
SexHH	0.005	0.034	0.002	0.001	-0.009	0.003
AgeHH	-0.016	0.028	0.009	0.007	0.002	0.006
MariStat	0.008	0.041	0.001	0.012	0.044	0.001
EduStat	0.059	0.011	0.021	0.005	-0.14	0.021
FamilySize	-0.073**	0.033	0.081	0.025	0.040**	0.003
Eucalyptus	0.114*	0.012	0.013*	0.101	-0.075**	0.020
Livestock	0.004	0.002	0.002	0.022	0.032	0.009
LandSize	0.190***	0.009	- 0.045**	0.004	-0.691**	0.015
DistanceFrom Road	-0.032**	0.014	-0.059	0.012	0.052*	0.021
LivelihoodDiv.	0.157**	0.030	-0.091*	0.006	-0.148	0.002
AnnualIncome	0.133	0.010	-0.801	0.001	-0.192	0.022
LandQuality	0.007	0.006	0.004	0.015	0.025	0.033
Cooperatives Membership	0.004	0.040	0.002	0.061	0.006	0.002
Savings	0.078	0.005	-0.051	0.003	0.081	0.006

*, **, and *** indicate statistical significance at 1, 5, and 10% probability levels, respectively

4.4. Discussion

The observed variations in food security status and livelihood asset ownership between households who own eucalyptus plantations and those who do not own the plantation reveal significant insights into the link between eucalyptus plantations, livelihoods, and food security. The findings of the livelihood asset index revealed that households that own eucalyptus plantations had higher levels of various livelihood assets compared to households that do not have plantations. Specifically, these households did better on their natural, physical, financial, and social assets. Several research has also clearly shown the potential benefits of eucalyptus to household livelihood. This finding aligns with research by Gusu *et al*. (2023) which argues that eucalyptus growers have more sustainable household livelihoods and improved food security status.

Research consistently demonstrates that eucalyptus plantations can significantly enhance household income and improve overall lifestyles. For instance, Bezabih *et al*. (2019) highlighted the significant role of eucalyptus in improving rural livelihoods compared to traditional crops and livestock. However, Bayle (2019) cautioned that the economic benefits derived from eucalyptus cultivation can exacerbate income inequality between landowners and non- owners in rural areas. Supporting this observation, Belay *et al*. (2024) found that households with eucalyptus plantations in the Senan district experienced a 40.2% increase in total household income compared to those without, indicating a significant positive treatment effect. Moreover, the economic viability of eucalyptus has increased significantly, with recent trends showing that eucalyptus tree production is now more profitable than food crop production (Kassie, 2018). Furthermore, eucalyptus can be successfully integrated into agroforestry systems, such as those involving intercropping with species like cowpea, wheat, rice, and maize. These systems, as highlighted by Thumbar *et al*. (2024), offer greater economic profitability compared to traditional monoculture crop production.

Furthermore, a key informant farmer remarked, "the eucalyptus plantation has played a crucial role in transforming housing in the Senan community, prompting the shift from traditional grass structures to more resilient iron sheet houses." This suggests that the economic benefits gained from eucalyptus farming have provided community members with increased income, enabling them to enhance their livelihoods.

Getnet *et al.* (2022) found households involved in eucalyptus plantations allocate more resources toward education which improves their human capital. However, our findings contradict this, indicating lower human capital indices for eucalyptus-growing households. Several factors related to family structure might explain this discrepancy. Age, gender, and family size could influence the prioritization of human capital development. Research suggests that age and gender influence tree-planting decisions (Gebreegziabher *et al*., 2010; Derbe *et al.*, 2018; Gebretsadik *et al*., 2006). For example, older household heads are more likely to plant eucalyptus, which might come at the expense of human capital development. This could be because elderly farmers are less inclined to participate in capacity-building programs or pursue further education. Similarly, female-headed households, whose opportunities for human capital development are often limited by social factors, favor eucalyptus over crop production. Moreover, Belay *et al.* (2023) found that farmers with larger families are less likely to plant eucalyptus. The size of a household can have important

implications for the accumulation and utilization of various forms of human capital. Our findings suggest that households with eucalyptus plantations have a greater abundance of natural resources compared to those without them, as measured by the natural capital index. This finding aligns with existing research (Pattanayak & Sills, 2001) which suggests that incorporating trees into agricultural practices can improve the natural resources available to rural communities.

Our findings indicate that the physical and social capital indices are higher among households that grow eucalyptus compared to non-growers. This suggests that eucalyptus cultivation may be associated with a greater accumulation of physical and social capital for these households. Some studies suggest eucalyptus plantations might create competition for scarce resources and lead to social conflict within communities (Larson & Ribot, 2007). Conversely, others such as Gebreegziabher *et al.* (2010) have argued that tree plantations, such as eucalyptus, can potentially generate income that households can then invest in building their physical and social capital. The fact that eucalyptus is a good source of income for rural families, the income could allow them to participate more actively in community religious and social organizations such as *edir*, and *mahber*, which potentially strengthen social ties. Moreover, since eucalyptus plantation activities do not require much time, the resulting free time has the potential to strengthen social ties within the community.

Our findings indicate that households with eucalyptus plantations generally exhibit higher levels of food security and dietary diversity compared to those without. This aligns with previous research by Hailu *et al*. (2010), Binam *et al*. (2015), and Owusu *et al*. (2011), which demonstrate the positive impacts of tree plantations, including eucalyptus, on household food security and dietary diversity. Hailu *et al*. (2010) highlight the role of eucalyptus plantations as a buffer against food insecurity during periods of reduced agricultural productivity.

Furthermore, recent studies, such as Datta *et al*. (2024), emphasize the importance of well-managed agroforestry systems. In these systems, eucalyptus can be integrated with diverse crops, such as small onions, red gram, sesame, and sorghum, to enhance income and food security while minimizing negative environmental impacts. This approach aligns with the findings of Ramesh (2023) and Thumbar (2024), who highlight the benefits of integrated agroforestry systems in enhancing agricultural productivity and supporting rural livelihoods. Likewise, Owusu *et al*. (2011) also reported that households cultivating fast-growing trees

like eucalyptus were more resilient to seasonal food shortages and dietary gaps compared to those without these resources.

While the potential benefits of eucalyptus-based agroforestry are evident, its adoption in the Senan district appears limited. This highlights the need for increased awareness and implementation of these beneficial systems. A key informant farmer from the district shed light on some reasons behind this limited adoption. Farmers expressed concerns about competition for water and nutrients from eucalyptus trees, as well as the potential negative impact of tree shade on crop growth. Addressing these concerns through proper management practices, including the incorporation of appropriate silvicultural techniques as emphasized by Raj *et al*. (2022), is crucial. This will help maximize the benefits of eucalyptus-based agroforestry while minimizing negative impacts, ultimately enhancing income and supporting ecological stability.

However, the impact of eucalyptus plantations on household food security is context-dependent. While our study and others suggest benefits, Schreckenberg *et al*. (2006) documented a contrasting effect, linking the expansion of commercial tree plantations, including eucalyptus, to decreased dietary diversity and food access for nearby communities. These divergent findings likely reflect the complex and context-dependent nature of the relationship between eucalyptus cultivation and household food and nutrition outcomes. Factors such as household characteristics, land use patterns (over-investment in eucalyptus at the expense of food crop production), market access, and environmental conditions all play a role in determining the impact. That's why Aklilu (2024) concluded that planting eucalyptus trees needs to be customized to the particular situation of each household to improve rural livelihoods and food security.

Our study confirms existing knowledge about factors influencing household food security in the study area. Location, land size, livelihood diversification, and annual income positively influence food security, while larger family size and road inaccessibility are associated with higher food insecurity. This aligns with research by Bahiru *et al.* (2023) (income), Astemir (2014); Assefa and Abide (2023); Abafita and Kim (2014) (farm size), Abafita and Kim (2012); Aysheshim *et al.* (2023); Astemir (2014) (household size), Derso *et al.* (2022); Abegaz (2017) (location), Minyiwab *et al.* (2024); Abera *et al.* (2021); Zeleke (2017) (livelihood diversification). Furthermore, key insights from a key informant farmer

emphasized the importance of diversifying income streams for eucalyptus owners to maximize their profits.

Despite the benefits of eucalyptus plantations, some researchers have raised concerns about their potential environmental impacts. Allelopathy, which can adversely affect the growth of nearby crops (Ali *et al.*, 2018), is one of the main environmental problems associated with eucalyptus plantations. As stated by Sasikumar *et al*. (2002), the harmful chemicals emitted from the extracts of eucalyptus leaves, stems, and roots can hinder the germination of crops and the growth of seedlings. Hence, food security may ultimately be threatened by this deterioration, particularly in areas where subsistence farming is a major source of income for local populations. Jagger and Pender (2003) also stated that eucalyptus plantation has a limited economic impact on neighboring farmers' crops, especially in comparison to the financial benefits gained by the eucalyptus owners.

On the other hand, under certain circumstances, eucalyptus plantations may also benefit soil health (Chavan *et al*., 2023). For example, the decomposition of eucalyptus litter can improve the physical and chemical characteristics of the soil, increasing soil fertility (Mengistu, *et al.,* 2020). Additionally, eucalyptus has demonstrated the ability to restore damaged areas that were formerly utilized for subsistence farming, which can enhance soil fertility (Liang *et al.*, 2016). Accordingly, Durai *et al*. (2019) state that eucalyptus may have restorative effects in some situations but may also be harmful to soil health in others. The adverse impact of eucalyptus plantations on the environment can be mitigated by careful species selection, site suitability assessments, and effective management practices (Amenu, 2017). However, there are significant concerns about relying on a single cash crop. As noted by Abokyi *et al*. (2020), smallholder farmers in developing countries often face income instability due to price fluctuations in their products. Households that depend too heavily on monoculture eucalyptus plantations are particularly vulnerable to price changes. The ongoing armed conflict between *Fano* and the Ethiopian government in the Amhara region could significantly impact the demand and price of eucalyptus products. This poses a risk for households in the Senan district, especially those heavily dependent on eucalyptus income. As Senan is located within the conflict zone, these economic uncertainties are compounded by the challenging circumstances. Notably, the conflict erupted after the completion of our data collection.

Effective land-use planning is crucial to overcoming these obstacles. Promoting eucalyptus growth on marginal land instead of ideal agricultural areas can lessen competition with food

crops and ensure food security. As noted by Alemayehu and Melka (2022), when planted and managed appropriately, eucalyptus can have positive impacts that outweigh its negative effects.

4.5. Conclusion and Recommendations

Eucalyptus ownership was identified as a significant factor influencing household livelihood assets and food security in the study area. Households with eucalyptus plantations displayed significantly higher livelihood asset index scores across multiple categories compared to those without plantations. This suggests that eucalyptus ownership contributes to overall household well-being.

Food security analysis further strengthens this association. Households owning eucalyptus plantations had a statistically lower HFIAS score (M = 8.06, SD = 5.0) compared to non-owning households (M = 11.29, SD = 5.6). This indicates a more secure food supply for eucalyptus-owning households. Furthermore, their higher HDDS (M = 5.28 compared to M = 4.73), implies a greater dietary variety, suggesting a more balanced and nutritious diet.

In addition to ownership of eucalyptus plantations, several additional factors influenced food security. Households in *Gedamawit Kebele* have enhanced food security as a result of improved market access and infrastructure. Road connectivity was also important, as closeness to the main road permitted market access and transportation, so improving food security. Livelihood diversification, larger land holdings, higher income, and smaller family sizes were all associated with increased food security.

In conclusion, although ownership of eucalyptus plantations appears to be a significant driver of improved livelihood assets and enhanced food security in the study area. There are risks associated with relying solely on this resource, making it crucial for households to manage trade-offs effectively.

- Diversifying livelihoods using income from eucalyptus products can enhance resilience and food security.
- Implement policies to invest in rural infrastructure development, particularly improving road accessibility, to enhance market access and transportation, thereby boosting household food security.

- Sustainable land use planning is essential to maximize the advantages of eucalyptus and minimize its negative impacts.
- Tailoring food security interventions to specific locations and households by considering the socioeconomic characteristics of households, market access, and infrastructure, could be more effective.

CHAPTER 5: EUCALYPTUS PLANTATIONS AND GENDER DYNAMICS: ANALYZING WOMEN'S EMPOWERMENT IN NORTHWEST ETHIOPIA

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ABSTRACT

Men and women often play distinct roles in forest management, each experiencing varying levels of empowerment. This study investigates the effect of eucalyptus plantations on women's empowerment in the Senan District of Northwest Ethiopia. It employed a mixed approach and a multistage sampling method. The data were collected using questionnaire surveys administered to 328 households, key informant interviews, focus group discussions, and observations. The Abbreviated Women Empowerment in Agriculture Index (A-WEAI) and the Abbreviated Women Empowerment in Eucalyptus plantations Index (A-WEEI) questionnaires were administered to both men and women within the same households. A probit model was used to identify the major determinants of women's empowerment. The findings reveal significant disparities in empowerment levels between households with eucalyptus plantations and those without. While women across both types of households experience considerable disempowerment, those in eucalyptus-owning households face greater challenges, marked by heightened inadequacy and reduced empowerment. Lack of control over income (27.4% for owners, 24.1% for non-owners) is identified as the leading contributor to women's disempowerment in both household types, with a greater impact in eucalyptus-owning households. The estimated probit model found that women's age, residential area, and educational levels (including their husbands' educational attainment), and mobile phone ownership positively and significantly affect women's empowerment. In contrast, the age difference between spouses and the academic disparity between them negatively and significantly affect women's empowerment. Thus, interventions must prioritize empowering women's income control by promoting individual savings accounts with competitive interest rates, alongside mandatory gender-responsive capacity-building programs (financial literacy, leadership, and negotiation training) at local and regional levels.

KEYWORDS: *Eucalyptus, A-WEAI, Women's disempowerment, Income control, Gender inequality, Senan district*

5.1 Introduction

Women in rural areas play a vital role in sustaining local and global economies (FAO, 2011). Despite their substantial contributions, they encounter significant gender-based barriers that limit their involvement in agricultural decision-making processes, particularly in sub-Saharan Africa (Perelli *et al*., 2024). While traditional gender roles confine women to domestic tasks like food preparation, water and fuelwood collection, and family care, Ethiopian women actively participate in nearly all agricultural activities, with the primary difference in labor being the degree of involvement (Belay and Oljira, 2016). Nonetheless, men maintain key roles in crop and livestock production and primarily control the income derived from these activities (Mare, 2015).

Furthermore, despite the crucial role women could play in managing and utilizing forest resources, their participation in decision-making within the forestry sector remains restricted due to its predominantly patriarchal nature (Agarwal, 2009; Kakungulu, 2012).

In Ethiopia's rural areas, the expansion of eucalyptus plantations has significant economic implications. A recent study in the Senan District by Yimam *et al*. (2024) revealed a substantial 180% increase in eucalyptus coverage between 1991 and 2023. While this expansion holds potential for altering household income dynamics (Belay *et al.*, 2024), it often leads to a concentration of decision-making power in the hands of men. Consequently, women in these communities are often limited to low-value activities like collecting fuelwood and non-timber forest products, hindering their economic independence and negatively impacting their well-being. (CIFOR, 2014; Radel & Coppock, 2013).

Although there has been a growing recognition of women's roles in this sector in recent years (UN Women, 2022), men and women frequently engage in distinct roles in forest management, with varying levels of understanding, access, and utilization of forest resources (FAO, 2016). The traditional division of labor exacerbates gender inequality by assigning men to more lucrative activities, such as the production and marketing of high-value forestry products, including charcoal production and timber harvesting, while limiting women to gathering less important forest resources (Bitzer *et al*., 2024). This dominance in forest

management and decision-making by men often restricts women's access to and control over these resources (Agarwal, 2009).

Moreover, women in these communities face financial burdens due to men's mismanagement of income from timber sales, which can lead to funds being spent on non-essential activities, neglecting crucial expenses like children's education and healthcare (Dowhaniuk, 2022).

As farmers convert cropland to eucalyptus plantations in Ethiopia's highlands (Belay *et al*., 2023), there is a critical research gap on how this shift affects women's empowerment. While previous studies have examined the broader implications of eucalyptus for livelihoods and food security, the connections between eucalyptus plantations and gender aspects remain under-explored. This research addresses this gap and aligns with the global commitment to the 2030 Agenda for Sustainable Development, particularly Sustainable Development Goal 5 (SDG 5), which aims to achieve gender equality and empower all women and girls. Understanding the impacts of eucalyptus plantations on women's empowerment is essential for ensuring equitable decision-making in land use, harvest, and income allocation. This study aims to investigate the effect of eucalyptus plantations on women's empowerment in Northwest Ethiopia, contributing to the broader discourse on gender, forestry, and sustainable development.

5.2 Materials and Methods

5.2.1 Description of the study area

The research was conducted in the Senan District, located in the Northwest region of Ethiopia (Figure 17). The district is located 277.2 km from the regional capital, Bahir Dar, and 27 km from the zone capital, Debre Markos (Senan District Communication Office, 2021). The study area is characterized by its elevated terrain and undulating topography (Simane *et al*., 2016), where the economy is largely agrarian. Subsistence farming, livestock rearing, and the gathering and sale of eucalyptus products are the region's primary livelihood activities. Teff, wheat, barley, and different pulses are the most widely produced crops in the area. However, the region faces issues such as soil erosion, land degradation, and lack of access to agricultural inputs (Belay *et al*., 2023).

Eucalyptus *globulus* has become an increasingly common tree species in the region, with farmers turning agricultural land into Eucalyptus plantations in recent decades (Yimam *et al*,

2024). This shift has been driven by the high demand for Eucalyptus wood products, as well as other socioeconomic and environmental factors (Belay *et al*., 2024).

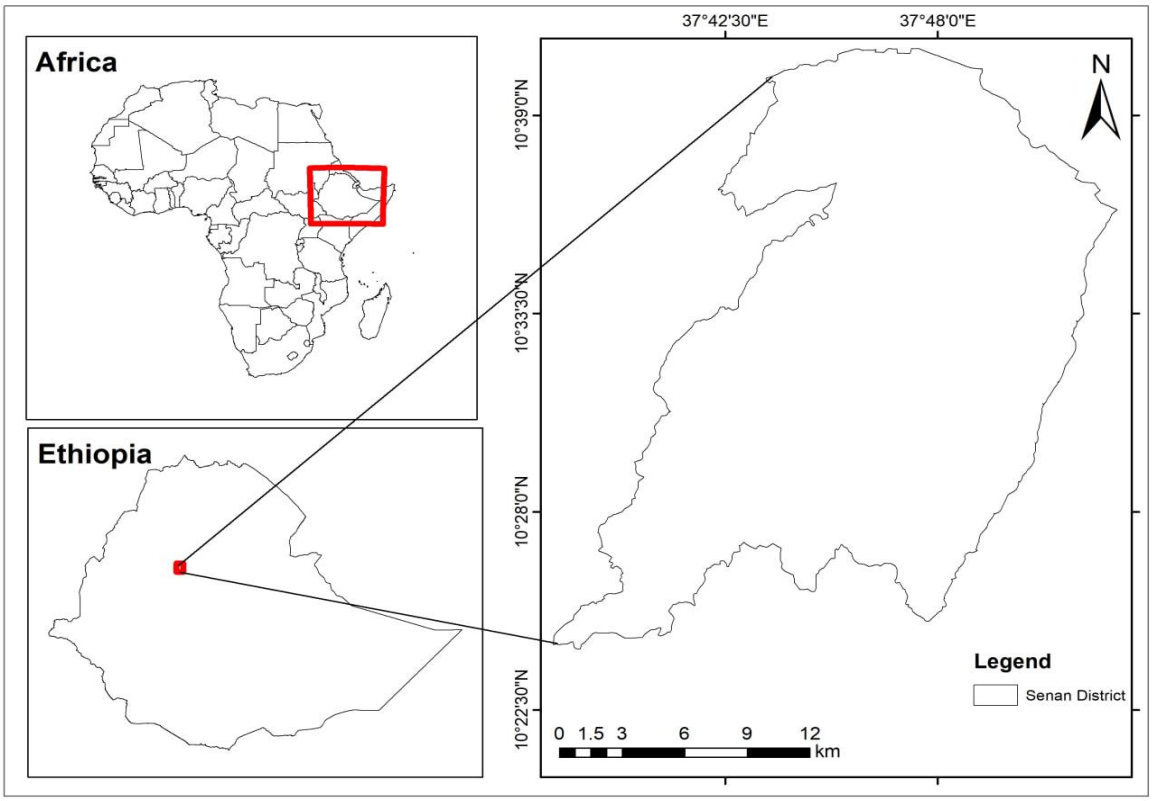

Figure 17: The location map of the study area

5.2.2 Data sources and method of data collection

Data for this study were collected using a mixed-methods approach, integrating questionnaire surveys, semi-structured interviews, focus group discussions, and field observations. This combination of quantitative and qualitative techniques was deliberately chosen to address the multifaceted nature of the research problem and to provide a comprehensive understanding of the relationship between eucalyptus plantations and women's empowerment in Northwest Ethiopia.

To gather quantitative data, questionnaire surveys based on the Abbreviated Women Empowerment in Agriculture Index (A-WEAI) and the Abbreviated Women Empowerment in Eucalyptus Plantation Index (A-WEEI) were administered. These tools enabled the collection of data on key dimensions of women's empowerment, with the A-WEAI focusing on agricultural contexts and the A-WEEI on eucalyptus plantation activities. To facilitate a

comparative analysis, both questionnaires were administered to men and women within the same households, distinguishing between eucalyptus-owning and non-owning households.

The questionnaires were pilot-tested for clarity and cultural relevance. A multistage sampling technique resulted in 328 respondents, evenly split between eucalyptus-owning and non-owning households. Data collection was carried out through face-to-face interviews conducted by trained enumerators with strong local knowledge, supported by experts from the local agriculture office. To ensure privacy and accuracy, data collectors traveled in male and female pairs, conducting separate interviews with men and women using both the A-WEAI and A-WEEI questionnaires. This method enhanced the quality and reliability of the data collected.

Complementing the quantitative data, qualitative methods were employed. Semi-structured interviews were conducted with 12 interviewees, representing a diverse range of perspectives. The profiles of the interviewees are summarized in Table 20.

Table 20: Summary of participants' socio-demographic characteristics

Interviewee ID	Gender	Age	Education level	Eucalyptus ownership
I-1	Female	25	College diploma	Owner
I-2	Female	48	Cannot read and write	Owner
I-3	Female	32	Primary education	Non owner
I-4	Female	24	Secondary education	Owner
I-5	Female	52	Cannot read and write	Owner
I-6	Female	21	Secondary education	Owner
I-7	Female	55	Cannot read and write	Owner
I-8	Female	41	Read and write	Non owner
I-9	Male	44	Secondary education	Non owner
I-10	Male	59	Read and write	Owner
I-11	Male	28	Secondary education	Owner

These interviews, along with five focus group discussions (FGDs), explored the relationship between eucalyptus plantations, women's empowerment, and household decision-making.

Five separate FGDs were conducted with selected women, men (both eucalyptus owners and non-owners), and local extension officers, including the district's gender focal person. These methods provided a platform for participants to share their voices, perceptions, and lived realities. Field observations further enriched the data, providing firsthand contextual understanding of the dynamics within eucalyptus plantations and their surrounding communities.

By combining these methods, the study achieved triangulation, enhancing the validity and reliability of the findings.

5.2.3 Method of data analysis

The study employed A-WEEI, a modified version of A-WEAI, to assess women's empowerment within eucalyptus plantations, and A-WEAI to measure empowerment in non-owning households. To achieve triangulation, thematic analysis of qualitative data, focusing on key quotations relevant to core research issues, was conducted.

The Women's Empowerment in Agriculture Index (WEAI) is the first-ever measure to directly capture women's empowerment and inclusion levels in the agricultural sector (IFPRI, 2012). It was initially developed in 2012 as a tool to monitor the impact of USAID's Feed the Future initiative on women's empowerment in developing countries by USAID, the International Food Policy Research Institute, and the Oxford Poverty and Human Development Initiative to track women's engagement in agriculture in five areas (Tsegaye, 2020). The overall WEAI is a weighted average of two sub-indices: the Five Domains of Empowerment (5DE) measured by 10 indicators and the Gender Parity Index (GPI), with weights 0.9 and 0.1, respectively (Tesfay and Abidoye, 2020).

The A-WEAI was developed in 2017 as an easier version of the original WEAI, with the purpose of saving time and resources for data collection and analysis (Malapit *et al*., 2017). The A-WEAI has the same two sub-indices (5DE and GPI) as the complete WEAI, but it uses a smaller set of six indicators across the five domains of empowerment. A-WEAI retains the following indicators: 1) input into productive decisions; 2) ownership of land and other assets; 3) access to credit decisions; 4) control over income usage; 5) group membership; and 6) workload. (Malapit *et al.*, 2020).

The A-WEAI is also divided into two sub-indices. The first assesses women's empowerment in five domains of empowerment (5DE) in agriculture based on individual-level empowerment scores that reflect each person's achievements in the five domains as measured by six indicators. The second sub-index, the Gender Parity Index (GPI), captures relative empowerment by reflecting a woman's achievements in the five domains in comparison to the primary male in the same household. Households are considered gender parity if either the woman is empowered (her empowerment score is 80% or higher) or her score is greater than or equal to the male decision maker in her household. All of these indices have a value between 0 and 1, with higher values indicating greater empowerment (Malapit *et al*., 2017).

This article introduces the WEEI and its five key indicators of empowerment: (1) role in decision making regarding land use, tree species selection, harvest timing, product processing, and eucalyptus product sales; (2) access to and ownership of productive resources, including land, livestock, assets related to eucalyptus, and credit; (3) the management of income and expenditures generated from eucalyptus products; (4) participation in community leadership, measured by membership in economic or social groups; (5) time allocation to eucalyptus-related activities, household chores & childcare. WEEI measures assess women's empowerment, inclusion, and gender parity within the context of eucalyptus plantations, identifying key areas for improvement.

For the purposes of the analysis, we adopted the A-WEAI score classification developed by the International Food Policy Research Institute (IFPRI, 2014). This categorization divides scores into high (≥ 0.85), medium (0.73–0.84), and low (≤ 0.72) groups, allowing for comparative analysis.

Empowerment calculation using the A-WEAI and A-WEEI

Women's empowerment was measured using the 5DE aggregate index, which incorporates six binary components (Table 21). Each indicator is assigned a value of one if a person's achievement is adequate, and zero if it is insufficient. The empowerment score is the weighted percentage of dimensions in which a person has achieved adequacy. A woman is deemed 'empowered' if she meets the adequacy criteria in at least four out of five categories, or achieves 80% of the weighted indicators (Malapit *et al.*, 2020).

Table 21: Five domains of empowerment in the A-WEAI and A-WEEI

Domain	Indicator	Inadequacy cut-off	Weight
Production	Input in productive decisions	Inadequate if an individual contributes but lacks any input in decision-making, or if she neither makes the decisions nor feels capable of doing so.	1/5
Resources	Ownership of assets	Inadequate if a household does not possess any assets, or if it owns a certain type of asset but the individual does not have sole ownership of the majority of it.	2/15
	Access to and decisions on credit	Inadequate if a household has no credit, or if it has used a credit source but the individual did not participate in any decisions regarding it.	1/15
Income	Control over use of income	Inadequate if an individual participates in an activity but has little to no input in decisions about the income generated, or if they do not feel capable of making decisions regarding the use of household income.	1/15
Leadership	Group membership	Inadequate if an individual is not part of at least one group, and also inadequate if no groups are reported in the community.	1/15
Time	Workload	Inadequate if an individual works more than 10.5 hours a day.	1/15

Moreover, the probit regression model was selected for its ability to effectively manage dichotomous dependent variables and to clarify the relationship between these variables and the explanatory factors.

The dependent variable (Y) is whether or not a woman is empowered.

$$Y = \begin{cases} 1 \text{ if the woman is empowered} \\ 0 \text{ otherwise} \end{cases}$$

The model is specified as follows:

$$P(Y = 1) = \Phi(X\beta)$$

Where:

- P(Y=1) is the probability that a woman is empowered
- Φ is the cumulative distribution function (CDF) of the standard normal distribution, which transforms the linear combination of predictors into a probability between 0 and 1.
- X is a vector of independent variables (age of the woman, age of spouse, age difference between spouses, education level, education of spouse, household size, difference in education between spouses, land size, access to training, ownership of mobile phone, ownership of eucalyptus plantations) that may influence women's empowerment (Table 22).
- β is a vector of coefficients representing the impact of each predictor on the likelihood of empowerment.

Table 22: Description of independent variables in determinants of women's empowerment

Independent variables	Type (Dummy/Continuous)	Expected Effect
Kebele	Dummy	+
Age	Continuous	+
Age of spouse	Continuous	-
Age difference between spouses	Continuous	-
Level of education (years)	Continuous	+
Education of spouse	Continuous	+
Difference in education between spouses	Continuous	-
Household size	Continuous	-
Land size (ha)	Continuous	+
Access to training	Dummy	+
Ownership of a mobile phone	Dummy	+
Ownership of eucalyptus plantations	Dummy	-

5.3. Results

5.3.1 A-WEAI and A-WEEI of the study area

The study reveals significant disparities in women's empowerment when comparing eucalyptus-owning and non-owning households within the Senan District. The Women's Empowerment in Eucalyptus Plantation Index (WEEI) for the Senan District is 0.72, while the Women's Empowerment in Agriculture Index (WEAI) stands at 0.76, as indicated in Table 23. These findings suggest that while women in the study area exhibit moderate empowerment overall, their involvement in eucalyptus plantations further restricts their empowerment.

An intra-household analysis further highlights significant gender disparities within both household types. The Gender Parity Index (GPI) was lower for households with eucalyptus plantations (0.69) compared to those without (0.73), indicating greater gender inequality in eucalyptus-owning households. This translates to approximately 31% of women in

eucalyptus-owning households and 27% in non-owning households experiencing gender inequality. Despite the modest difference in these gaps, the GPI shows better gender parity in non-owning households.

The disempowerment headcount (H) further underscores this trend: 72.6% of women in eucalyptus-owning households are disempowered, compared to 66.4% of women in non-owning households. Consequently, the percentage of women achieving empowerment (1-H) was notably higher in non-owning households (33.6%) than in eucalyptus-owning households (27.4%), emphasizing a higher degree of disempowerment in both contexts, which is most pronounced among eucalyptus owners. The average inadequacy score (A) further highlights this. Women in eucalyptus-owning households showed inadequacy in 38.1% of 5DE domains, compared to 35% for women in non-owning households meaning only 61.9% and 65% of empowerment indicators were sufficiently met, respectively. Similarly, the 5DE index (1 - MO) showed lower average empowerment for eucalyptus owners (0.73) versus non-owners (0.77). Intra-household dynamics reveal significantly higher disempowerment for women than men in both contexts. The disempowerment index (MO) for women in eucalyptus-owning households was 0.27, compared to 0.08 for men. In non-owning households, the MO for women was 0.23, compared to 0.10 for men. This highlights a significant pro-male bias in intra-household power relations, which is more pronounced in eucalyptus-owning households.

Table 23: A-WEAI and A-WEEI of the Senan district

Indexes	Eucalyptus owners		Eucalyptus Non-Owners	
	Women	Men	Women	Men
Disempowerment headcount (H)	72.6%	23.7%	66.4%	27.2
Average inadequacy score (A)	38.1%	36.3%	35.0	37.5
Disempowerment Index (MO) = H*A	0.27	0.08	0.23	0.10
5DE Index (1 - MO)	0.73	0.92	0.77	0.90
Average Empowerment Gap (1 - GPI)	31%		27%	
Gender Parity Index (GPI)	0.69		0.73	
A-WEEI = (0.9*5DE) + (0.1*GPI)	0.72		0.76	
% of women achieving empowerment (1-H)	27.4%		33.6%	

results in Table 24 indicate a statistically significant difference in empowerment scores between eucalyptus owners and non-owners, as measured by both the Five Domains of Empowerment (5DE) index and the Abbreviated Women's Empowerment in Agriculture Index (A-WEAI). Specifically, Eucalyptus non-owners reported higher mean scores on both indices (5DE: 0.77; A-WEAI: 0.76) compared to Eucalyptus owners (5DE: 0.73; A-WEAI: 0.72). The differences were significant, with p-values of 0.03 for 5DE and 0.00 for A-WEAI.

These findings suggest that eucalyptus ownership is associated with lower levels of empowerment among participants. This may be closely linked to the gender-based division of labor, where men traditionally control high-value resources like eucalyptus plantations, thereby restricting women's active participation in related decision-making processes. Overall, eucalyptus plantations appear to reinforce existing patriarchal systems, limiting women's decision-making power and resource access.

Table 24: Comparison of 5DE and A-WEAI scores between eucalyptus owners and non-owners

Variables	Group	Mean	Std. error	t-value	p-value
5DE	Eucalypt owners	0.73	0.006	3.37	0.03
	Eucalypt non-owners	0.77	0.07	3.37	0.03
A-WEAI	Eucalypt owners	0.72	0.004	5.96	0.00
	Eucalypt non-owners	0.76	0.007	5.96	0.00

5.3.2 Contribution of each domain to disempowerment

To understand which factors contribute most to disempowerment, we analyzed the disempowerment index (M0) across different domains for both women and men. The results from the 5DE index (Table 25) indicated that the most significant contributor to women's disempowerment in eucalyptus owning households is a lack of control over income (87% headcount, 27.4% contribution). This lack of control reflects broader systemic issues that limit women's agency in economic matters, as they often do not have the authority to make decisions regarding their earnings.

The qualitative data strongly supports this finding. Women consistently reported exclusion from income-related decision-making. One interviewee remarked, *"Since the income from eucalyptus is substantial, husbands typically sell eucalyptus products and deposit the money into their own bank accounts"* (Female participant: February 2, 2023).

Focus group participants noted that *"Eucalyptus plantations create both good and bad situations for women. They reduce workload, as there are fewer farming activities, but they also pose financial challenges because the husband controls the income"* (FGD participant: February 10, 2023).

Even male perspectives acknowledged this dynamic. A male interviewee stated, *"Living without eucalyptus plantations has become challenging today. But the husband needs to be wise, as he manages the household income from the sale of eucalyptus products. If the husband is prudent, he will invest the money from eucalyptus in important family needs; if not, he may end up spending it all on alcohol*" (Household head: February 2, 2023).

Further, the qualitative insights reveal that societal norms and perceived burdens discourage women from engaging in decision-making. As another female participant elaborated, *"The household head makes all the decisions regarding the eucalyptus tree. Wives don't try to interfere. Some even consider participation in such decisions an overwhelming workload. Sometimes, when husbands try to consult them, they say, 'Oh, you decide for yourself, I won't bother myself interfering in this*' (Female participant: February 3, 2023).

While eucalyptus plantations reduce workload compared to crop production, as noted by a household head, "*Crop production requires continuous effort; however, once eucalyptus is planted, it does not require additional work"*. (Household head: February 2, 2023). However, this reduced workload does not address the underlying power imbalances, as women remain excluded from critical financial decisions.

Cultural norms play a crucial role in shaping financial decision-making. An FGD participant explained, *"Traditionally, decisions about crop type selection, selling, marketing, and the use of income are made by the household head or jointly by husband and wife, with the husband leading but incorporating the wife's input. However, all decisions related to eucalyptus plantations are made solely by the household head. For example, income from eucalyptus products is typically deposited by the husband. If it goes into a bank account, it is often*

exclusively in the husband's name due to traditional practices regarding financial management" (FGD participant: February 13, 2023).

Despite these challenges, some husbands and wives engage in discussions to ensure mutual understanding. As one FGD participant noted, *"Although husbands typically make most decisions, discussions with wives are common to ensure mutual understanding regarding priorities. For instance, they may agree on providing financial support to their older children to help them become self-sufficient, such as starting a business"* (FGD participant: February 12, 2023).

Beyond income control, Table 25 indicates that 72.3% of women in eucalyptus-owning households have inadequate access to and decisions on credit, while 67.8% have inadequate input in production decisions. Focus group discussants noted that decisions about land use, including whether to plant eucalyptus or grow crops, are typically made by the husband. One woman also shared her thoughts on the decision of whether to plant eucalyptus or grow crops: *"The husband makes all the decisions. If he decides to plant eucalyptus trees and his wife asks, 'What are we going to eat if we only plant eucalyptus trees?' he won't listen to her if he has already made up his mind. Moreover, he is always the one who decides on eucalyptus-related activities*." This underscores the entrenched power dynamics that limit women's voices and agency in critical household decisions.

Table 25: The 5DE indicators decomposed by dimension and indicators for men and women eucalyptus owning households

Statistics	Production	Resources		Income	Leadership	Time
	Input in productive decisions	Asset ownership	Access to and decisions on credit	Control over the use of income	Group Membership	Workload
Indicator weight	0.20	0.13	0.07	0.20	0.20	0.20
			Women			
% Headcount	67.8%	64.4%	72.3%	87.0%	62.8%	31.7%
%Contribution	21.4%	13.2%	8.1%	27.4%	19.8%	10.1%
Contribution	0.06	0.04	0.02	0.07	0.05	0.03
%Contribution by dimension	21.4%	21.3%		27.4%	19.8%	10.1%
			Men			
% Headcount	39.8%	61.2%	71.8%	31.7%	59.9%	29.0%
%Contribution	17.7%	17.6%	11.2%	14%	26.6%	12.9%
Contribution	0.01	0.02	0	0.01	0.02	0.01
%Contribution by dimension	17.7%	28.8%		14%	26.6%	12.9%
t-value (%contribution)	2.45	-2.00		-3.25	6.67	- 8.12
P-value	0.04	0.09		0.00	0.08	0.01

A comparative analysis of deprivation across various empowerment indicators for women and men in eucalyptus-owning and non-owning households reveals significant gender disparities. As Table 25 shows, there is a statistically significant difference in percentage contribution to disempowerment between men and women in eucalyptus owning households in the production, income, and time domains. Notably, a highly significant difference ($t = 6.67$, $p < 0.001$) confirms that women in eucalyptus owning households are disproportionately deprived of control over income, contributing 27.4% to disempowerment compared to men's 14%. Conversely, women experience the least deprivation in workload (10.1% contribution), suggesting fewer time-related constraints in this domain. In contrast,

men in eucalyptus-owning households face the highest deprivation in group membership (59.9% headcount, 26.6% contribution) and the least deprivation in workload (29.0% headcount, 12.9% contribution).

For men, in eucalyptus plantation-owning households, group membership (26.7%), limited input into productive decisions (17.7%), and asset ownership (17.6%) are also significant contributors to disempowerment, as shown in Figure 18. Conversely, the domain that contributed least to women's disempowerment in eucalyptus owning households was workload (10.1%).

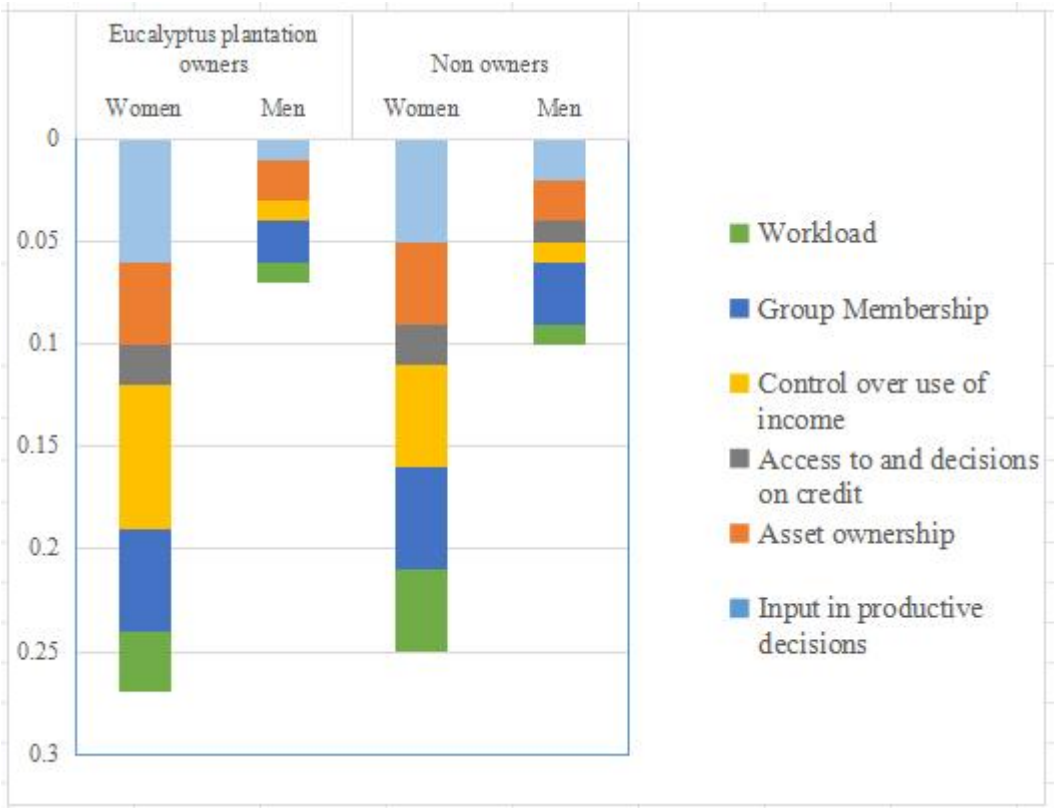

Figure 18: Contribution of each indicator to disempowerment

Figure 18 illustrates the contributions of various domains to disempowerment for women and men in both eucalyptus plantation owning and non-owning households. Each domain is represented by distinct colors, allowing for a visual comparison of how different factors contribute to overall disempowerment for each gender. Generally, for women in eucalyptus plantation owning households, the most significant contributions to disempowerment come

from control over the use of income. In contrast, men in eucalyptus plantation owning households experience lower contributions to disempowerment across all domains.

The gendered division of labor is captured in Figure 19, which shows a woman and her two daughters carrying heavy loads of firewood, likely for cooking and heating. The participation of young girls in these duties also suggests an intergenerational transmission of gendered responsibilities. Moreover, this image highlights existing sociocultural norms that perpetuate gender-based asset ownership, demonstrating that women typically hold rights only to specific tree components, such as firewood, branches, or leaves, rather than the tree itself.

Figure 19: A woman and her daughters carrying firewood (Photograph by the researchers)

In non-owning households (Table 26), the primary drivers of women's disempowerment are limited input in productive decisions and lack of control over income. Although a substantial proportion of women face inadequacy in access to and decisions on credit (79.1% headcount) and group membership also plays a role, their overall influence appears less pronounced. One woman interviewee noted, *"My husband asked for my thoughts regarding credit, but he is the one who makes the final decision and forces me to agree with him"* (Household head: February 3, 2023). This suggests that even when women are consulted, their agency remains

constrained by patriarchal decision-making structures, reinforcing their economic dependence. Furthermore, the t-test results indicate significant gender differences in the percentage contribution of production, income, and resource to disempowerment within these households.

When comparing women in eucalyptus-owning versus non-owning households, a few key distinctions emerge. Women in non-owning households also experience significant deprivation, with the highest levels observed in control over income (75.0% headcount, 24.1% contribution) and input in productive decisions (63.5% headcount, 20.4% contribution). Although both groups face similar challenges, women in eucalyptus-owning households report a higher degree of deprivation in control over income (87% vs. 75%), suggesting that eucalyptus ownership exacerbates this issue. Additionally, deprivation of input into productive decisions is also higher among women in eucalyptus-owning households (67.8% vs. 63.5%). This indicates that women, especially in eucalyptus-owning households, face greater deprivation in terms of financial autonomy and decision-making.

Table 26: The 5DE Indicators decomposed by dimension and indicators for men and women, eucalyptus non-owning households

Statistics	**Production**	**Resources**		**Income**	**Leadership**	**Time**
	Input in productive decisions	Asset ownership	Access to and decisions on credit	Control over the use of income	Group Membership	Workload
Indicator weight	0.20	0.13	0.07	0.20	0.20	0.20
Women						
% Headcount	63.5%	66.4%	79.1%	75.0%	59.9%	41.7%
%Contribution	20.4%	13.9%	8.9%	24.1%	19.3%	13.4%
Contribution	0.05	0.04	0.02	0.05	0.05	0.04
%Contribution by dimension	20.4%	22.8%		24.1%	19.3%	13.4%
Men						
% Headcount	49.8%	63.2%	73.3%	34.2%	61.7%	32.9%
%Contribution	20.3%	16.7%	10.5%	13.9%	25.2%	13.4%
Contribution	0.02	0.02	0.01	0.01	0.03	0.01
%Contribution by dimension	20.3%	27.2%		13.9%	25.2%	13.4%
t-value (%contribution)	0.00	-2.00		6.67	-3.25	- 8.12
p-value	0.03	0.00		0.00	0.06	0.99

5.3.3 Determinants of women's empowerment

The probit model analysis (Table 27) reveals that women's empowerment is influenced by their age, kebele (residence), spousal age difference, and their own and their husbands' education levels.

The proximity of a household's *kebele* to an urban center has a positive relationship with women's empowerment, suggesting that being in the *Gedamawit kebele* slightly increases the likelihood of empowerment, with a marginal effect of 1.7%. This indicates that local administrative contexts may play a role in shaping empowerment opportunities. *Gedamait* is located closer to the district's capital, *Erob Gebeya,* than *Tach Chabi.*

A woman’s age is another significant factor, with a coefficient of 0.375, statistically significant at the 1% level. This indicates that older women are more likely to be empowered, with each additional year of age increasing the probability of empowerment by 9%. Conversely, the age difference between spouses has a negative coefficient of -0.204, implying that a larger age gap reduces women’s empowerment, decreasing the probability of empowerment by 7.5%. This suggests that a larger age gap between partners may negatively impact women's empowerment, potentially reflecting dynamics such as power imbalances or social norms that restrict women's agency in relationships.

A woman’s education is a strong predictor of empowerment, with a correlation of 0.617. In contrast, a husband's education positively influences empowerment but is statistically insignificant, with a coefficient of 0.018 and a marginal effect of only 1%. Notably, the educational gap between spouses negatively correlates with empowerment, with a coefficient of -0.120, resulting in a 4.3% decrease in the probability of empowerment for each unit increase in the educational gap. Education equips women with the knowledge, skills, and information necessary to develop leadership and decision-making abilities.

Annual income also positively affects empowerment, with a coefficient of 0.201, suggesting that higher income correlates with increased empowerment, resulting in a marginal effect of 1.5%.

Finally, ownership of a mobile phone has a notably strong positive effect, with a coefficient of 0.710. This indicates that having a mobile phone significantly increases the likelihood of empowerment, with a substantial marginal effect of 41.2%. In contrast, ownership of eucalyptus plantations has a strong negative effect, with a coefficient of -0.441. This suggests that owning eucalyptus plantations significantly reduces the likelihood of empowerment, with a marginal effect of 10.4%.

Table 27: Probit model: Estimation of the likelihood of women's empowerment

Covariate	Coef.	Std. Err.	Marginal effect
Kebele	0.015*	0.117	0.017
Age	0.375***	0.539	0.090
Age of husband	0.025	0.119	0.007
Age difference between spouses	- 0.204**	0.165	-0.075
Level of education (years)	0.617***	0.250	0.107
Education of the husband	0.018**	0.122	0.010
Difference in education between spouses	- 0.120*	0.122	- 0.043
Household size	- 0.351	0.191	0.117
Annual income	0.201**	0.133	0.015
Access to training	0.318*	0.451	0.110
Ownership of a mobile phone	0.710***	0.011	0.412
Ownership of eucalyptus plantations	- 0.441**	0.355	0.104

***, ** and* represent of statistically significant at 1%, 5%, and 10% level of significance, respectively.

5.4 Discussion

The WEAI and WEEI scores in the study area indicate a contextual disparity in women's empowerment levels, falling between those reported in higher-scoring African countries like Malawi and Uganda (Malapit *et al*., 2014) and lower-scoring ones such as Tunisia (Kruse, 2019) and Bangladesh (Malapit *et al*., 2014). According to IFPRI's ranking, the WEAI falls into the medium category, while the WEEI is classified as low. Interestingly, women in households without eucalyptus plantations exhibited slightly higher empowerment levels than those in households with plantations, suggesting a potential disempowering effect of eucalyptus cultivation. This aligns with Sell and Minot's (2018) observation that men often

dominate decisions regarding cash crops, while women have more control over food crop production, a pattern that could reinforce gender inequalities in forestry-dependent communities where women face greater barriers in accessing and controlling resources (FAO, 2016).

Our A-WEAI findings for eucalyptus owners align with findings from other Ethiopian regions, such as the Toke Kutaye District of Oromia, where the 5DE score was 0.736, the WEAI score was 0.731, and the GPI value was 0.684 (Abebe *et al*., 2016). The study found that Women's disempowerment was primarily driven by excessive workload, limited access to and control over income derived from credit, and poor public speaking skills. Similarly, in the Damot Gale Woreda of Wolaita Zone, the WEAI was 0.739, indicating slightly higher empowerment levels (Didana, 2019). However, a nationwide study of rural Ethiopia (Habtewold, 2021) indicated a considerably lower 5DE score of only 0.46. These findings collectively highlight the regional variability in empowerment levels across Ethiopia and the powerful influence of contextual cultural factors.

However, our A-WEAI findings for eucalyptus non-owners are higher than those reported in the literature mentioned above. This suggests that the level of women's empowerment in the Senan District is better than in other parts of Ethiopia, even though eucalyptus ownership appears to disempower women in the study area. Despite eucalyptus ownership, intra-household gender disparities persisted, with the GPI indicating marginally better parity in non-owning households. This suggests that the level of women's empowerment in the Senan District is better than in other parts of Ethiopia, even though eucalyptus ownership appears to disempower women in the study area. Despite eucalyptus ownership, intra-household gender disparities persisted, with the GPI indicating marginally better parity in non-owning households. This suggests that eucalyptus plantations may exacerbate existing gender inequalities, a finding supported by literature indicating that agricultural economic benefits often disproportionately favor men (Agarwal, 2010; FAO, 2016) and that women have limited decision-making power in forestry (Leisher *et al*., 2016).

Consistent with this dynamic, women in eucalyptus-owning households scored lower on both the 5DE and A-WEAI indices compared to non-owning households. This disparity likely stems from the gendered division of labor, where men control high-value resources like eucalyptus, restricting women's participation in related decision-making processes. Similar

patterns are reported by Elias *et al*. (2024), who observed that women in forestry sectors are often systematically excluded from decision-making authority and resource control.

Several studies highlight key indicators and domains that most contributed to women's disempowerment. For example, in the Gamo Zone of Southern Ethiopia, Jemaneh & Shibeshi (2023) identified workload and access to credit as major factors in women's disempowerment. Conversely, Yimer and Tadesse (2015) pinpointed group membership as a strong indicator of disempowerment in Ethiopia.

In contrast, women in the Sargodha District of Punjab Province, Pakistan, excel in the leadership domain, possessing stronger public speaking skills than their male counterparts, who often lag in this area (Amber and Fakhar, 2019). Our study specifically identifies a lack of income control as the primary driver of disempowerment within eucalyptus-owning households, hindering women's ability to invest in their own and their families' well-being (FAO, 2016). This situation reflects traditional gender roles, where men typically dominate control over valuable resources and income, evident in practices such as large animal sales (Bitzer *et al*., 2024).

The UN (2009) emphasizes that women's empowerment relies on equal access to and control over economic resources, which directly enhances family welfare (Sida, 2023). These findings underscore systemic challenges where women's financial access is mediated by male relatives, reinforcing economic dependency (World Bank, 2012). Such dynamics perpetuate traditional gender roles, restricting women's agency and exacerbating economic inequalities (Quisumbing *et al*., 2023). Ilesanmi (2018) attributes this to societal norms that discourage women from participating in financial decision-making, further marginalizing them.

The study also finds that ownership of eucalyptus plantations reduces women's workload. While reducing women's workload is often seen as progress, it does not address underlying power imbalances if women remain excluded from financial decisions. As Doss (2013) argues, true empowerment requires both a reduction in labor burdens and greater decision-making authority. Persistent patriarchal norms prioritize male control over high-value resources like eucalyptus (Care, 2023). Although women's input may be acknowledged, it rarely translates into substantive influence (FAO, 2011). Interestingly, men also face structural barriers in economic decision-making (Hansen & Hoyer, 2022), though to a lesser extent. Meanwhile, sociocultural norms continue to assign women disproportionate

responsibility for household tasks (Bitzer *et al*., 2024) and restrict their asset ownership. This aligns with Mengesha's (2021) observation that African women often hold rights only to tree byproducts (e.g., firewood), rather than the trees themselves.

Our findings on factors influencing women's empowerment are consistent with the existing literature. Geographic location significantly influences women's autonomy, with rural women having less decision-making power than their urban counterparts (Acharya *et al*., 2010; Karki & Thapa, 2021). In remote communities, stronger patriarchal structures (Zinia *et al*., 2022) and limited access to training opportunities (Khatun, 2015) further exacerbate women's disempowerment (Sell & Minot, 2018).

Age also emerges as a significant determinant of women's empowerment. Older women tend to have more decision-making autonomy compared to younger women (Acharya *et al*., 2010). Those who marry at a young age often experience reduced capacity for decision-making (Tomar *et al*., 2024), and women married to older men frequently have limited roles in household decisions. For example, in the Anna Sorra District of Guji Zone, Ethiopia, older women demonstrate greater empowerment (Beriso *et al*., 2023). In Nigeria, the empowerment of women within couples is influenced by age differences, particularly among those with older spouses (Akpan and Ayinmoro, 2024).

Education is a crucial catalyst for empowerment, enabling women to challenge gender norms (Dhiman, 2023) and promote equality (Yahya *et al*., 2024). However, in Toke Kutaye District, education was not significantly associated with empowerment (Abebe *et al*., 2016), highlighting the complexity of empowerment dynamics. While women's education positively correlates with empowerment, spousal educational parity has an even stronger effect (Sell & Minot, 2018).

Household income is another factor positively associated with decision-making power within the household (Sultana, 2011; Didana, 2019). Additionally, access to training shows a positive relationship with empowerment, consistent with findings by Tiwari and Malati (2023). Furthermore, women's ownership of mobile phones enhances their access to information and participation in household decision-making, which is linked to an overall increase in empowerment (Warner *et al*., 2023).

5.5 Conclusions

This study reveals that eucalyptus cultivation significantly impacts women's empowerment in the Senan District of Northwest Ethiopia. While eucalyptus plantations may provide economic opportunities, they often exacerbate gender inequalities, with women in these households experiencing greater disempowerment compared to those without eucalyptus. The key indicators contributing to this disempowerment include a lack of control over income, restricted decision-making authority, limited access to and decisions on credit, and group membership. Addressing these systemic barriers is crucial for enhancing women's empowerment within this context.

The findings of the study highlight the pressing need for gender-sensitive policies that ensure women can participate in and benefit from eucalyptus plantations on an equitable basis. To achieve this, a comprehensive policy strategy is essential. Firstly, fostering women's financial autonomy and control over eucalyptus income requires securing their direct earnings through the promotion of individual savings accounts, incentivizing financial institutions to offer competitive interest rates. Secondly, recognizing the importance of long-term empowerment, the Ministry of Education should implement mentorship programs for girls in rural areas to reduce dropout rates, thereby contributing to a more educated and empowered future generation capable of effective engagement in economic activities like eucalyptus plantations. Thirdly, it is essential to provide women with access to specialized credit programs and microloans to strengthen their economic independence. Fourthly, supporting the formation of women’s groups or cooperatives will enhance their voices and influence within eucalyptus plantation governance, encouraging collective action and empowerment. Lastly, developing and enforcing gender-responsive policies at local and regional levels that mandate structured capacity-building programs (leadership, financial literacy, and negotiation skills) will actively empower women's participation in critical decision-making. These interconnected strategies are vital for addressing gender disparities and promoting sustainable empowerment within the context of eucalyptus plantations.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

The expansion of eucalyptus plantations has become a major driver of land use and land cover change in the Senan district, resulting in significant repercussions for household income, rural livelihoods and food security and, gender dynamics. This synthesis chapter, integrating the findings of four interrelated studies, provides a comprehensive analysis of these interconnected themes, offering a thorough understanding of the multifaceted impacts of eucalyptus plantations. By examining the drivers of eucalyptus expansion, its effects on household income, rural livelihoods, food security, and women's empowerment, this chapter seeks to unravel the complex interplay between environmental change and socioeconomic outcomes.

6.2 Synthesis of findings

Senan district has been experiencing a reduction in cropland and an increase in eucalyptus plantations. The rapid spread of eucalyptus plantations, which increased the vegetation cover in the study area from 16.8% to 26.5% between 2010 and 2021 is attributed to a combination of factors: household socio-demographics, economic incentives, and environmental pressures like land degradation, accessible markets, and the species' unique characteristics. Farmers are drawn to eucalyptus due to its faster and greater financial returns compared to crops, especially. Additionally, environmental pressures, such as land degradation, make eucalyptus an appealing alternative due to its resilience on marginal lands. Furthermore, the consistent market for eucalyptus wood, particularly for construction and fuel, ensures stable demand. Additionally, its low labor requirements enable farmers to pursue other income sources. Ironically, even its negative effects on surrounding crops, such as shading, contribute to its accelerated expansion, creating a self-reinforcing cycle of adoption.

Building on this foundation, the dissertation examines the economic impacts of eucalyptus plantations using impact evaluation methods. The Average Treatment Effect on the Treated (ATT) analysis indicated that households engaged in planting eucalyptus trees experienced a total household income that was 40.2% higher than those who did not participate in such activities within the Senan district. These findings demonstrate that involvement in eucalyptus planting enhances household income in the study area. The higher income levels

experienced by households involved in this economic activity could provide a viable income source for rural communities in the district, enhancing both food security and household livelihood capital.

The third study, titled 'Eucalyptus-Based Livelihoods: Boosting Household Food Security and Resilience in Northwest Ethiopia,' explores the social implications of eucalyptus expansion, particularly how transitioning from food crops to eucalyptus impacts food security and livelihood approaches. Findings from an independent sample t-test revealed a statistically significant disparity in average Household Food Insecurity Access Scale (HFIAS) and Household Dietary Diversity Score (HDDS) between households with eucalyptus plantations and those without. Econometric analysis confirmed that owning eucalyptus plantations significantly and positively influences food security in the region. Additionally, households cultivating eucalyptus scored substantially higher on livelihood asset indices across multiple categories compared to non-eucalyptus-growing households. This widespread change from food crops to eucalyptus creates concerns about long-term economic sustainability, potentially narrowing agricultural diversity and increasing reliance on external markets. As a result, local food independence may be undermined, and households may face increased vulnerability to timber price volatility. The ongoing conflict in the study area exacerbates these challenges, potentially disrupting demand and market conditions for eucalyptus products, which could further affect the food security status of eucalyptus-growing households.

As land use and income generation evolve, women's roles, resource access, and empowerment within households are altered, often leading to increased gender inequality. Women in eucalyptus-growing households face greater disempowerment than those not involved in plantation. This disparity arises from limited control over income, weaker decision-making authority, and restricted access to credit, and reduced participation in community groups. These factors reinforce existing inequalities, leaving women with diminished influence over financial and household matters, which complicates their ability to contribute meaningfully to household resilience and food security.

In general, the landscape of economic, social, and gender interactions related to eucalyptus expansion is complex and demands careful consideration in future policies and interventions.

6.3 Policy implications

This study highlights the critical trade-offs between the immediate economic benefits of eucalyptus cultivation and the long-term implications for food security, and social equity. To effectively balance these competing demands, the following policy interventions are recommended:

- **Invest in rural infrastructure to improve market access:** The government should prioritize investments in upgrading and maintaining rural road networks connecting eucalyptus producing areas to markets. This will reduce transportation costs, and improve the overall efficiency of the eucalyptus product supply chain.
- **Strengthen agricultural extension services and livelihood diversification:** The Ministry of Agriculture and the regional agricultural bureaus should mandate and resource local agricultural extension experts to provide targeted support to farmers in diversifying their eucalyptus products. Additionally, develop programs that empower farmers to use income from eucalyptus to invest in alternative or supplementary livelihood activities, such as livestock rearing.
- **Support and strengthen farmer cooperatives and market linkages:** The Ministry of Agriculture in collaboration with financial institutions, should support the formation and strengthening of farmer cooperatives involved in eucalyptus production and processing. This support should include facilitating access to credit and financial resources and offering training in business management, marketing, and quality control. Furthermore, the government should also actively promote the linkages between eucalyptus producers and value-adding industries, such as furniture manufacturers, and construction companies. This can be achieved through trade fairs, and business matchmaking initiatives.
- **Promote sustainable agroforestry systems and zoning regulations:** To enhance household food security resilience, local agricultural extension experts should promote the integration of eucalyptus with food crops. This agroforestry approach can enhance long-term farm productivity, thereby improving food security. Furthermore, strict zoning regulations must limit eucalyptus planting near water sources and fertile farmland, safeguarding vital water resources and prime agricultural land crucial for sustainable food production.

- **Conduct ongoing policy evaluations:** Implement a robust, evidence-based monitoring and assessment system for eucalyptus plantation regulations. This should combine statistical data with contextual insights to evaluate policy impacts on land utilization, food security, economic benefits, and gender equity.
- **Establish targeted savings accounts:** Financial institutions should create high-interest savings accounts specifically for rural women engaged in eucalyptus plantations to promote financial independence and livelihood diversification. Additionally, providing tailored training in product marketing, negotiation skills, and sustainable harvesting methods is essential to enhance women's economic agency and market participation.
- **Organize community gender dialogues:** The local gender experts should facilitate gender dialogues at the *Kebele* and *Got (sub kebele)* level to challenge restrictive societal norms and promote equitable decision-making in land use and resource management, involving both men and women.

6.4 Future research directions

Understanding the long-term impacts of eucalyptus cultivation requires future research to prioritize longitudinal studies that track household income, livelihood sustainability, and food security across various market and ecological contexts. These studies should also assess the simultaneous ecological impacts, including soil quality and water resource changes. Investigations should also focus on identifying optimal agroforestry systems that balance eucalyptus production with food crops, and resilience studies could evaluate household responses to market volatility or conflict. Furthermore implementation research is also needed to evaluate the efficacy of policy interventions, such as zoning laws and gender-focused programs. These research directions would collectively contribute to the development of sustainable and equitable eucalyptus cultivation practices that support both livelihoods and environmental conservation.

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Appendices

Appendix I Survey Questionnaire

Dear Participant,

Thank you for taking the time to participate in our survey. We are conducting this survey to gather valuable insights on the socioeconomic impacts of eucalyptus plantations in Northwest Ethiopia. Your feedback is crucial in helping us understand the link between eucalyptus plantations, rural livelihoods and gender dimensions in the Senan district. Your responses will remain confidential and will only be used for research purposes. We appreciate your honest and thoughtful answers.

Thank you for your participation!

Questionnaire Identification

Date_____/_____/

Questionnaire ID _____

Kebele _____

Interviewer Name_____

Supervisor Name_____

Part I: Household Characteristics

Section I: Demographic and Socio-economic characteristics of household head		
S.N	**Questions**	**Options of Answer**
1	Sex of household head	☐Male ☐Female
2	Age of household head (years)	_____
3	Marital status	☐Never married ☐Married ☐Divorced ☐Widowed
4	Education level of household head	☐Cannot read and write ☐Read and write only ☐Elementary (grade 1 -8) ☐Secondary (grade 9-12) ☐College diploma/BA/BSc and above
5	Education level of household head (in years)	
6	**Household size** <1 year 3 years 4 - 6 years 7 - 9 years 10 - 12 years 13 - 15 years 16 - 19 years 20 - 39 years 40 - 49 years 50 - 59 years 60 - 69 years 70 year +	**Male** **Female** _____

7	Size of farmland (in hectares)	_____
8	Location of your land (Distance from the main road (in kilometers)	_____
9	Livelihood strategy	☐Eucalyptus only/ crop production only ☐Eucalyptus and crop production ☐Diversified livelihoods (on-farm, off-farm and non-farm including eucalyptus plantations)
10	Membership of cooperatives	☐No ☐Yes
11	Access to savings and credit service	☐No ☐Yes
12	Do you to savings and credit? If so, what is the amount saved?	_____
Part II Livelihood capital asset indicators		
1	Total land size (in hectare)	_____
2	How would you assess the average fertility status of all your plots of land? Please express it as a percentage.	_____
3	Do you have Solar lamp?	☐No ☐Yes
4	Iron sheet number	_____
5	**Type of livestock** Calf Donkey (young) Weaned Calf Heifer Sheep and goat (adult) Cow and ox Sheep and goat (young) Horse Chicken Donkey (adult)	**Number** _____ _____ _____ _____ _____ _____ _____ _____ _____ _____
6	Do you have radio?	☐No ☐Yes

7	Do you have mobile phone?	☐No ☐Yes
8	Access to drinking water	☐Ponds/rivers ☐Unprotected springs/wells ☐Protected springs ☐Drilled/tube wells with hand pumps ☐Piped water connections and community water taps
9	Is there a labor shortage in your household?	☐No ☐Yes
10	Did you have any training opportunities in the last year? If yes, how many?	_____
11	I am an active participant in *Mahber*.	☐I am not even a member. ☐Strongly disagree ☐Disagree ☐Neutral ☐Agree ☐Strongly agree
12	I am an active participant in *Debo.*	
13	I am an active participant in *Edir.*	
14	I am an active participant in *Equb.*	
15	I am a member of a cooperative in my community.	☐No ☐Yes
16	Do you have eucalyptus plantations?	☐No ☐ Yes

Did you or any of your household members receive cash income from any of the following sources of income within the last year?

Source of income		Income in ETB	Source of income		Income in ETB	Source of income		Income in ETB
1	Cereal crops		12	Carpentry		23	Metalwork	
2	Vegetables		13	Selling eucalyptus tree products		24	Woodwork	
3	Oil seeds		14	Animal feed (Grass or fodder)		25	Remittance	
4	Leasing out Cropland		15	Tailoring clothes		26	Farm tools selling	
5	Livestock sale		16	Baskets or mats making and selling		27	Other	
6	Poultry and poultry Products		17	Traditional healer				
7	Milk and milk products		18	Grain trading				
8	Honey and wax		19	Livestock and livestock products trading				
9	Salary		20	Petty trading				
10	Wage labor		21	Spinning or weaving				
11	Military service and or pension		22	Pottery making				

Part III. Household Food Insecurity Access Scale (HFIAS) Measurement Tool

S.N	Questions	Response Option
1	In the past four weeks, did you worry that your household would not have enough food? *(If the answer is "no," please proceed to Question 2.)*	☐No ☐Yes
1 a	How often did this happen?	☐Rarely (1 or 2 times) ☐Sometimes (3 to 10) ☐Often (>10)
2	In the past four weeks, were you or any household member not able to eat the kinds of foods you preferred because of a lack of resources? *(If the answer is "no," please proceed to Question 3.)*	☐No ☐Yes
2a	How often did this happen?	☐Rarely (1 or 2 times) ☐Sometimes (3 to 10) ☐Often (>10)
3	In the past four weeks, did you or any household member have to eat a limited variety of foods due to a lack of resources? *(If the answer is "no," please proceed to Question 4.)*	☐No ☐Yes
3a	How often did this happen?	☐Rarely (1 or 2 times) ☐Sometimes (3 to 10) ☐Often (>10)
4	In the past four weeks, did you or any household member have to eat some foods that you really did not want to eat because of a lack of resources to obtain other types of food? *(If the answer is "no," please proceed to Question 5.)*	☐No ☐Yes
4a	How often did this happen?	☐Rarely (1 or 2 times) ☐Sometimes (3 to 10) ☐Often (>10)
5	In the past four weeks, did you or any household member have to eat a smaller meal than you felt you needed because there was not enough food? *(If the answer is "no," please proceed to Question 6.)*	☐No ☐Yes
5a	How often did this happen?	☐Rarely (1 or 2 times) ☐Sometimes (3 to 10) ☐Often (>10)

6	In the past four weeks, did you or any other household member have to eat fewer meals in a day because there was not enough food? *(If the answer is "no," please proceed to Question 7.)*	☐No ☐Yes
6a	How often did this happen?	☐Rarely (1 or 2 times) ☐Sometimes (3 to 10) ☐Often (>10)
7	In the past four weeks, was there ever no food to eat of any kind in your household because of lack of resources to get food? *(If the answer is "no," please proceed to Question 8.)*	☐No ☐Yes
7a	How often did this happen?	☐Rarely (1 or 2 times) ☐Sometimes (3 to 10) ☐Often (>10)
8	In the past four weeks, did you or any household member go to sleep at night hungry because there was not enough food? *(If the answer is "no," please proceed to Question 9.)*	☐No ☐Yes
8a	How often did this happen?	☐Rarely (1 or 2 times) ☐Sometimes (3 to 10) ☐Often (>10)
9	In the past four weeks, did you or any household member go a whole day and night without eating anything because there was not enough food?	☐No ☐Yes
9a	How often did this happen?	☐Rarely (1 or 2 times) ☐Sometimes (3 to 10) ☐Often (>10)

Part IV: Dietary Diversity Questionnaire

Please describe the foods (meals and snacks) that you ate yesterday during the day and night, whether at home or outside the home.

(Write down all food and drinks mentioned by the respondent. When the respondent has finished, for any food groups not mentioned, ask the respondent if a food item from this group was consumed.)

S.N	Questions	Example	Yes	No
1	Cereals	maize, rice, wheat, sorghum, millet or any other grains or foods made from these (e.g. bread, porridge or other grain products) + local foods e.g. porridge, pasta, Bread		
2	White tuber and roots	White potatoes, or other foods made from roots.		
3	Vegetables	carrot, squash, or sweet potato that are orange inside + other locally available vitamin A rich vegetables (e.g. red sweet pepper); Dark green leafy vegetables, including wild forms + locally available vitamin A rich leaves such as amaranth, cassava leaves, kale, spinach; other vegetables (e.g. tomato, onion, eggplant) + other locally available vegetables.		
4	Fruits	ripe mango, cantaloupe, apricot (fresh or dried), ripe papaya, dried peach, and 100% fruit juice made from these + other locally available vitamin A rich fruit; other fruits.		
5	Meat	Liver, kidney, heart or other organ meats or blood-based food; Beef, pork, lambs, goat, chicken, other birds, insects.		
6	Eggs	Eggs from chicken or any other egg		
7	Fish	Fresh or dried fish or shellfish		
8	Legumes, nuts and seeds	Dried beans, dried peas, lentils, nuts seeds or foods made from these (e.g. hummus, peanut butter).		
9	Milk and milk products	Milk, cheese, yogurt or other milk products,		

10	Oils and fats	Oil, fats or butter added to food or used for cooking		
11	Sweets	Sugar, honey, sweetened soda or sweetened juice drink, sugary foods such as chocolates, candies, cookies and cakes		
12	Spices, condiments and beverages	Spices (black pepper, salt) condiments (soy sauce, hot sauce), coffee, tea, alcoholic beverages.		

Part V: Women Empowerment in Agriculture Index – A-WEAI Version

MODULE G1. INDIVIDUAL IDENTIFICATION

	Code		Code
G1.01. Household identification:	☐☐☐☐☐☐	Outcome of interview:	Completed.....1 Household member too ill to respond/cognitively impaired ……..……..2 Respondent not at home/temporarily unavailable…….. 3respondent not at home/extended absence ……..4 Refused.....5 Could not locate.....6
Name of respondent currently being interviewed (id code Household roster): **Surname, other name** **Name:_____**	☐☐	Ability to be interviewed alone:	Alone..... 1 With adult females present.....2 With adult males present.....3 With adults mixed sex present.....4 With children present.....5 With adults mixed sex and children present.....6
Sex of respondent:	Male..... 1 Female.....2		
Type of household	Male and female adult……..…1 female adult only.....2		

MODULE G2: ROLE IN HOUSEHOLD DECISION-MAKING AROUND PRODUCTION AND INCOME GENERATION

Household identification | | | | | | |

Respondent id code

"now i'd like to ask you some questionsabout your participation in certain types of work activities and on making decisions on various aspects of household life"		Did you yourself participate in [activity] in the past 12months (that is, during the last [one/two] cropping seasons), from [present month] last year to [present month] this Year?	When decisions are made regarding[activity], who is it that normally takes the decision? **Circle <u>all</u> applicable** **If the response is self only skipto question g2.05**	How much input didyou have in making decisions about [activity]? **Use decision codes for g2.03/g2.05;** **If no decsion made, enter 98 and move to the next activity**	To what extent do you feel you can make your own personal decisions regarding [activity] if you want(ed) to? **Circle <u>one</u>**	How much inputdid you have in decisions on theuse of income generated from [activity] **Use codes for g2.03/g2.05**
Activity code	**Activity description**	**G2.01**	**G2.02**	**G2.03**	**G2.04**	**G2.05**
A	Food crop farming: These are crops that are grown primarily for household food consumption	Yes..... 1 No ..... 2 *activity b*	Self..... 1 Spouse…..... 2 Other hh member.....3 Other non-hh member..... 4 Not applicable…..... 98 *Next activity*		Not at all..... 1 Small extent..... 2 Medium extent..... 3 To a high extent.... 4	
B	Cash crop farming: Theseare crops that are grown primarily for sale in the market eg. coffee	Yes..... 1 No ..... 2 *activity c*	Self..... 1 Spouse…..... 2 Other hh member.....3 Other non-hh member..... 4 Not applicable…..... 98 *Next activity*		Not at all..... 1 Small extent..... 2 Medium extent..... 3 To a high extent.... 4	
C	Livestock raising	Yes..... 1 No ..... 2 *activity d*	Self..... 1 Spouse…..... 2 Other hh member.....3 Other non-hh member..... 4 Not applicable…..... 98 *Next activity*		Not at all..... 1 Small extent..... 2 Medium extent..... 3 To a high extent.... 4	

D	Non-farm economic activities: This would includethings like running a small business, self-employment, buy-and-sell	Yes..... 1 No ..... 2 *activity e*	Self..... 1 Spouse…..... 2 Other hh member.....3 Other non-hh member..... 4 Not applicable…..... 98 *Next activity*		Not at all..... 1 Small extent..... 2 Medium extent..... 3 To a high extent.... 4	

G2.03/g2.05 decision codes:
No input or input in few decisions..... 01
Input into some decisions.....02
Input into most or all decisions.....03
No decision made..... 98

		Did you yourself participate in [ACTIVITY] in the past 12 months (thatis, during the last [one/two] cropping seasons), from [PRESENT MONTH] last year to[PRESENT MONTH] this year?	When decisions are made regarding [ACTIVITY], who is it that normally takes the decision? **CIRCLE ALL APPLICABLE; IF THE RESPONSE IS SELF ONLYSKIP TO QUESTION G2.05**	How much input didyou have in making decisions about [ACTIVITY]? **USE DECISION CODES FOR G2.03/G2.05** **IF NO DECSION MADE, ENTER 98**	To what extent do you feel you can make your own personal decisions regarding [ACTIVITY] if you want(ed) to? **CIRCLE ONE**	How much input did you have in decisions on the useof income generated from [ACTIVITY] **USE CODES FOR G2.03/G2.05**
ACTIVITY CODE	**ACTIVITY DESCRIPTION**	**G2.01**	**G2.02**	**G2.03**	**G2.04**	**G2.05**
E	Wage and salary employment: This could be work that is paid for in cashor in-kind, including both agriculture and other wage work	YES..... 1 NO .....2 *ACTIVITY F*	SELF.....1 SPOUSE.....2 OTHER HH MEMBER….....3 OTHER NON-HH MEMBER...4 NOT APPLICABLE.....98 *NEXT ACTIVITY*		NOT AT ALL..... 1 SMALL EXTENT. 2 MEDIUM EXTENT3 TO A HIGH EXTENT 4	

F	Fishing or fishpond culture	YES..... 1 NO .....2 *ACTIVITY G*	SELF.....1 SPOUSE.....2 OTHER HH MEMBER….....3 OTHER NON-HH MEMBER...4 NOT APPLICABLE.....98 *NEXT ACTIVITY*		NOT AT ALL..... 1 SMALL EXTENT. 2 MEDIUM EXTENT3 TO A HIGH EXTENT 4	
G	Major household expenditures (such as a bicycles, land, boda boda)		SELF.....1 SPOUSE.....2 OTHER HH MEMBER….....3 OTHER NON-HH MEMBER...4 NOT APPLICABLE.....98 *NEXT ACTIVITY*		NOT AT ALL..... 1 SMALL EXTENT. 2 MEDIUM EXTENT3 TO A HIGH EXTENT 4	
H	Minor household expenditures (such as foodfor daily consumption or other household needs)		SELF.....1 SPOUSE.....2 OTHER HH MEMBER….....3 OTHER NON-HH MEMBER...4 NOT APPLICABLE.....98 *MODULE G3(A)*		NOT AT ALL..... 1 SMALL EXTENT. 2 MEDIUM EXTENT3 TO A HIGH EXTENT 4	

G2.03/G2.05 DECISION CODES:
NO INPUT OR INPUT IN FEW DECISIONS.....01
INPUT INTO SOME DECISIONS.....02
INPUT INTO MOST OR ALL DECISIONS.....03
NO DECISION MADE.....98

MODULE G3(A): ACCESS TO PRODUCTIVE CAPITAL

"Now I'd like to ask you about your household's access to and ownershipof a number of items that could be used to generate income."		Does anyone in your household currently have any [ITEM]?	Do you own any of the item? **CIRCLE ALL APPLICABLE**
PRODUCTIVE CAPITAL[1]		**G3.01**	**G3.02**
A	Agricultural land(pieces/plots)	YES....1 NO.....2 *ITEM B*	YES, SOLELY..... 1 YES, JOINTLY..... 2 NO..... 3
B	Large livestock (oxen, cattle)	YES....1 NO.....2 *ITEM C*	YES, SOLELY..... 1 YES, JOINTLY..... 2 NO..... 3
C	Small livestock (goats, and sheep)	YES....1 NO.....2 *ITEM D*	YES, SOLELY..... 1 YES, JOINTLY..... 2 NO..... 3
D	Chickens	YES....1 NO.....2 *ITEM E*	YES, SOLELY..... 1 YES, JOINTLY..... 2 NO..... 3
E	Fish pond or fishing equipment	YES....1 NO.....2 *ITEM F*	YES, SOLELY..... 1 YES, JOINTLY..... 2 NO..... 3
F	Farm equipment (non-mechanized: hand tools, animal-drawn plough)	YES....1 NO.....2 *ITEM G*	YES, SOLELY..... 1 YES, JOINTLY..... 2 NO..... 3
G	Farm equipment (mechanized: tractor-plough,power tiller, treadle pump)	YES....1 NO.....2 *ITEM H*	YES, SOLELY..... 1 YES, JOINTLY..... 2 NO..... 3
H	Nonfarm business equipment (solar panels used for recharging, sewing machine, brewing equipment, fryers)	YES....1 NO..... *ITEM I*	YES, SOLELY..... 1 YES, JOINTLY..... 2 NO..... 3
I	House or other structures	YES....1 NO.....2 *ITEM J*	YES, SOLELY..... 1 YES, JOINTLY..... 2 NO..... 3

"Now I'd like to ask you about your household's access to and ownershipof a number of items that could be used to generate income."		Does anyone in your household currently have any [ITEM]?	Do you own any of the item? **CIRCLE ALL APPLICABLE**
PRODUCTIVE CAPITAL[1]		**G3.01**	**G3.02**
J	Large consumer durables (refrigerator, TV, sofa)	YES.....1 NO.....2 *ITEM K*	YES, SOLELY.....1 YES, JOINTLY.....2 NO.....3
K	Small consumer durables(radio, cookware)	YES.....1 NO.....2 *ITEM L*	YES, SOLELY.....1 YES, JOINTLY.....2 NO.....3
L	Cell phone	YES.....1 NO.....2 *ITEM M*	YES, SOLELY.....1 YES, JOINTLY.....2 NO.....3
M	Other land not used for agricultural purposes (pieces/plots, residential or commercial land)	YES.....1 NO.....2 *ITEM N*	YES, SOLELY.....1 YES, JOINTLY.....2 NO.....3
N	Means of transportation (bicycle, motorcycle, car)	YES.....1 NO.....2 *MODULE G3(B)*	YES, SOLELY.....1 YES, JOINTLY.....2 NO.....3

MODULE G3 (B): ACCESS TO CREDIT

"Next I'd like to ask about your household's experience with borrowing money or other itemsin the past 12 months."		Would you or anyone in your household be able to take a loan or borrow cash/in-kind from [SOURCE] if you wanted to? *	Has anyone in your household taken any loans or borrowed cash/in-kind from [SOURCE] in the past 12months? **CIRCLE ONE**	Who made the decision to borrow from [SOURCE] most of the time? **CIRCLE ALL APPLICABLE**	Who makes the decision about what to do with the money/ item borrowed from [SOURCE] most of the time?**CIRCLE ALL APPLICABLE**
LENDING SOURCE NAMES[2]		**G3.03**	**G3.04**	**G3.05**	**G3.06**
A	Non-governmental organization (NGO)	YES.....1 NO….....2 *NEXT SOURCE* MAYBE.....3	YES, CASH.....1 YES, IN-KIND.....2 YES, CASH AND IN-KIND.....3 NO.....4 *NEXT SOURCE* DON'T KNOW.....97 →	SELF.....1 SPOUSE.....2 OTHER HH MEMBER.....3 OTHER NON-HH MEMBER.....4 NOT APPLICABLE.....98	SELF.....1 SPOUSE.....2 OTHER HH MEMBER.....3 OTHER NON-HH MEMBER.....4 NOT APPLICABLE….....98
B	Formal lender (bank/financial institution)	YES.....1 NO….....2 *NEXT SOURCE* MAYBE.....3	YES, CASH.....1 YES, IN-KIND.....2 YES, CASH AND IN-KIND.....3 NO.....4 *NEXT SOURCE* DON'T KNOW.....97 →	SELF.....1 SPOUSE.....2 OTHER HH MEMBER.....3 OTHER NON-HH MEMBER.....4 NOT APPLICABLE.....98	SELF.....1 SPOUSE.....2 OTHER HH MEMBER.....3 OTHER NON-HH MEMBER.....4 NOT APPLICABLE….....98
C	Informal lender eg *Arata*	YES.....1 NO….....2 *NEXT SOURCE* MAYBE.....3	YES, CASH.....1 YES, IN-KIND.....2 YES, CASH AND IN-KIND.....3 NO.....4 *NEXT SOURCE* DON'T KNOW.....97	SELF.....1 SPOUSE.....2 OTHER HH MEMBER.....3 OTHER NON-HH MEMBER.....4 NOT APPLICABLE.....98	SELF.....1 SPOUSE.....2 OTHER HH MEMBER.....3 OTHER NON-HH MEMBER.....4 NOT APPLICABLE….....98
D	Friends or relatives	YES.....1 NO….....2 *NEXT SOURCE* MAYBE.....3	YES, CASH.....1 YES, IN-KIND.....2 YES, CASH AND IN-KIND.....3 NO.....4 *NEXT SOURCE* DON'T KNOW.....97	SELF.....1 SPOUSE.....2 OTHER HH MEMBER.....3 OTHER NON-HH MEMBER.....4 NOT APPLICABLE.....98	SELF.....1 SPOUSE.....2 OTHER HH MEMBER.....3 OTHER NON-HH MEMBER.....4 NOT APPLICABLE….....98
E	Group based micro-finance or lending	YES.....1 NO….....2 *NEXT SOURCE* MAYBE.....3	YES, CASH.....1 YES, IN-KIND.....2 YES, CASH AND IN-KIND.....3 NO.....4 *NEXT SOURCE* DON'T KNOW.....97	SELF.....1 SPOUSE.....2 OTHER HH MEMBER.....3 OTHER NON-HH MEMBER.....4 NOT APPLICABLE.....98	SELF.....1 SPOUSE.....2 OTHER HH MEMBER.....3 OTHER NON-HH MEMBER.....4 NOT APPLICABLE….....98
F	Informal credit/savings groups such as merry-go-rounds, tontines, funeral societies, etc.	YES.....1 NO….....2 *NEXT SOURCE* MAYBE.....3	YES, CASH.....1 YES, IN-KIND.....2 YES, CASH AND IN-KIND.....3 NO.....4 *MODULE G4* DON'T KNOW.....97	SELF.....1 SPOUSE.....2 OTHER HH MEMBER.....3 OTHER NON-HH MEMBER.....4 NOT APPLICABLE.....98	SELF.....1 SPOUSE.....2 OTHER HH MEMBER.....3 OTHER NON-HH MEMBER.....4 NOT APPLICABLE….....98

MODULE G4: TIME ALLOCATION

G4.01: PLEASE RECORD A LOG OF THE ACTIVITIES FOR THE INDIVIDUAL IN THE LAST COMPLETE 24 HOURS (STARTING YESTERDAY MORNING AT 4 AM, FINISHING 3:59 AM OF THE CURRENT DAY). THE TIME INTERVALS ARE MARKED IN 15 MIN INTERVALS AND ONE ACTIVITY CAN BE MARKED FOR EACH TIME PERIOD BY DRAWING A LINE THROUGH THAT ACTIVITY.

"Now I'd like to ask you about how you spent your time during the past 24 hours. We'll begin from yesterday morning, and continue through to this morning. This will be a detailed accounting. I'm interested in everything you do (i.e. resting, eating, personal care, work inside and outside the home, caring for children, cooking, shopping, socializing, etc.), even if it doesn't take you much time."

		Night								**Morning**																**Day**																							
	Activity	4				5				6				7				8				9				10				11				12				13				14				15			
A	Sleeping and resting																																																
B	Eating and drinking																																																
C	Personal care																																																
D	School (also homework)																																																
E	Work as employed																																																
F	Own business work																																																
G	Farming/livestock/fishing																																																
J	Shopping/getting service (incl health services)																																																
K	Weaving, sewing, textile care																																																
L	Cooking																																																
M	Domestic work (incl fetching wood and water)																																																
N	Care for children/adults/elderly																																																
P	Travelling and communiting																																																
Q	Watching TV/listening to radio/reading																																																
T	Exercising																																																
U	Social activities and hobbies																																																
W	Religious activities																																																
X	Other, specify…																																																

MODULE G4 continued: TIME ALLOCATION

								Evening						Night																																						
	Activity	16				17				18				19				20				21				22				23				24				1				2				3			
A	Sleeping and resting																																																
B	Eating and drinking																																																
C	Personal care																																																
D	School (also homework)																																																
E	Work as employed																																																
F	Own business work																																																
G	Farming/livestock/fishing																																																
J	Shopping/getting service (incl health services)																																																
K	Weaving, sewing, textile care																																																
L	Cooking																																																
M	Domestic work (incl fetching wood and water)																																																
N	Care for children/adults/elderly																																																
P	Travelling and commuting																																																
Q	Watching TV/listening to radio/reading																																																
T	Exercising																																																
U	Social activities and hobbies																																																
W	Religious activities																																																
X	Other, specify																																																

QNO.	QUESTION	RESPONSE
G4.02	In the last 24 hours did you work (at home or outside of the home) more than usual, aboutthe same as usual, or less than usual?	MORE THAN USUAL.. 1 ABOUT THE SAME AS USUAL…... 2 LESS THAN USUAL….. 3

Module G- 5: Group Membership

"Now I'm going to ask you about groups in the community. These can be either formal orinformal and customary groups."		Is there a [GROUP] in your community?		Are you an active member of this [GROUP]?
	GROUP CATEGORIES	**G5.01**		**G5.02**
A	Agricultural / livestock/ fisheries producer's group (including marketing groups)	YES..... 1 NO..... 2 DON'T KNOW….97	*GROUP B*	YES.....1 NO..... 2
B	Water users' group	YES..... 1 NO..... 2 DON'T KNOW….97	*GROUP C*	YES.....1 NO..... 2
C	Forest users' group	YES..... 1 NO..... 2 DON'T KNOW….97	*GROUP D*	YES.....1 NO..... 2
D	Credit or microfinance group eg *Equb*	YES..... 1 NO..... 2 DON'T KNOW….97	*GROUP E*	YES.....1 NO..... 2
E	Mutual help or insurance group eg *Edir*	YES..... 1 NO..... 2 DON'T KNOW….97	*GROUP F*	YES.....1 NO..... 2
F	Trade and business association group	YES..... 1 NO..... 2 DON'T KNOW….97	*GROUP G*	YES.....1 NO..... 2
G	Civic groups (improving community) or charitable group (helping others)	YES..... 1 NO..... 2 DON'T KNOW….97	*GROUP H*	YES.....1 NO..... 2
H	Religious group eg *Mahber*	YES..... 1 NO..... 2 DON'T KNOW….97	*GROUP J*	YES.....1 NO..... 2
I	Other [women's/men's] group (only if it does not fit into one of the othercategories)	YES..... 1 NO..... 2 DON'T KNOW….97	*GROUP K*	YES.....1 NO..... 2
J	Other (SPECIFY)_____	YES..... 1 NO..... 2 DON'T KNOW….97		YES.....1 NO..... 2

Part VI_Women's Empowerment in Eucalyptus Plantations Index – A-WEEA -Modified A-WEAI Version

MODULE G1. INDIVIDUAL IDENTIFICATION

	Code		Code
G1.01. Household identification:	☐☐☐☐☐☐	Outcome ofinterview:	Completed..... 1 Household member too ill to respond/cognitively impaired ……..2 Respondent not at home/temporarily unavailable…….. 3 respondent not at home/extended absence ……..4 Refused.....5 Could not locate..... 6
Name of respondent currently being interviewed (id code Household roster): **Surname, other name** **Name:**_____	☐☐	Ability to be interviewed alone:	Alone..... 1 With adult females present.....2 With adult males present.....3 With adults mixed sex present..... 4 With children present.....5 With adults mixed sex and children present.....6
Sex of respondent:	Male.....1 Female.....2		
Type of household	Male and female adult……1 female adult only……2		

MODULE G2: ROLE IN HOUSEHOLD DECISION-MAKING AROUND PRODUCTION AND INCOME GENERATION

Household identification | | | | | | |

Respondent id code

"now i'd like to ask you some questions about your participation in certain types of work activities and on making decisions on various aspects of household life"		Did you yourself participate in [activity] in the past 12months (that is, during the last [one/two] cropping seasons), from [present month] last year to [present month] this Year?	When decisions are made regarding [activity], who is it that normally takes the decision? **Circle all applicable** **If the response is self only skipto question g2.05**	How much input did you have in making decisions about [activity]? **Use decision codesfor g2.03/g2.05;** **If no decsion made, enter 98 and move to the next activity**	To what extent do you feel you can make your own personal decisions regarding [activity]if you want(ed) to? **Circle one**	How much input did you have in decisions on the use of income generated from [activity] **Use codes for g2.03/g2.05**
Activity code	**Activity description**	**G2.01**	**G2.02**	**G2.03**	**G2.04**	**G2.05**
A	Selection of tree species for planting	Yes..... 1 No ..... 2 *activity B*	Self..... 1 Spouse…..... 2 Other hh member.....3 Other non-hh member.....4 Not applicable…..... 98 *Next activity*		Not at all.....1 Small extent..... 2 Medium extent..... 3 To a high extent.....4	
B	Harvest eucalyptus products	Yes..... 1 No ..... 2 *activity C*	Self..... 1 Spouse…..... 2 Other hh member.....3 Other non-hh member.....4 Not applicable…..... 98 *Next activity*		Not at all.....1 Small extent..... 2 Medium extent..... 3 To a high extent.....4	
C	Collecting and transporting eucalyptus products	Yes..... 1 No ..... 2 *activity D*	Self..... 1 Spouse…..... 2 Other hh member.....3 Other non-hh member.....4 Not applicable…..... 98 *Next activity*		Not at all.....1 Small extent..... 2 Medium extent..... 3 To a high extent.....4	

G2.03/g2.05 decision codes:
No input or input in few decisions.....01
Input into some decisions.....02
Input into most or all decisions.....03
No decision made.....98

		Did you yourself participate in [ACTIVITY] in the past 12 months (thatis, during the last [one/two] cropping seasons), from [PRESENT MONTH] last year to [PRESENT MONTH] this year?	When decisions are made regarding [ACTIVITY], who is it that normally takes the decision? **CIRCLE ALL APPLICABLE;** **IF THE RESPONSE IS SELF ONLY SKIP TO QUESTION G2.05**	How much input did you have in making decisions about [ACTIVITY]? **USE DECISION CODES FOR G2.03/G2.05** **IF NO DECSION MADE, ENTER 98**	To what extent do you feel you can make your own personal decisions regarding [ACTIVITY] if you want(ed) to? **CIRCLE ONE**	How much input did you have in decisions on the useof income generatedfrom [ACTIVITY] **USE CODES FOR G2.03/G2.05**
ACTIVITY CODE	**ACTIVITY DESCRIPTION**	**G2.01**	**G2.02**	**G2.03**	**G2.04**	**G2.05**
D	Deciding the time when and how to take products to market	Yes..... 1 No ..... 2 *activity e*	Self..... 1 Spouse…..... 2 Other hh member.....3 Other non-hh member.....4 Not applicable…..... 98 *Next activity*		NOT AT ALL.....1 SMALL EXTENT..... 2 MEDIUM EXTENT..... 3 TO A HIGH EXTENT4	
E	Marketing of eucalyptus products	Yes..... 1 No ..... 2 *activity F*	Self..... 1 Spouse…..... 2 Other hh member.....3 Other non-hh member.....4 Not applicable…..... 98 *Next activity*		NOT AT ALL.....1 SMALL EXTENT..... 2 MEDIUM EXTENT..... 3 TO A HIGH EXTENT..... 4	
F	Processing of eucalyptus products	Yes..... 1 No ..... 2 *activity G*	Self..... 1 Spouse…..... 2 Other hh member.....3 Other non-hh member.....4 Not applicable…..... 98 *Next activity*		NOT AT ALL.....1 SMALL EXTENT..... 2 MEDIUM EXTENT..... 3 TO A HIGH EXTENT..... 4	
G	Non-farm economic activities: This would include things like running a small business related to eucalyptus, eg: self-employment, buy-and-sell	Yes..... 1 No 2	Self..... 1 Spouse…..... 2 Other hh member.....3 Other non-hh member.....4 Not applicable…..... 98 *Next activity*		NOT AT ALL.....1 SMALL EXTENT..... 2 MEDIUM EXTENT..... 3 TO A HIGH EXTENT..... 4	

"Now I'd like to ask you about your household's access to and ownershipof a number of items that could be used to generate income."		Does anyone in your household currently have any [ITEM]?	Do you own any of the item? **CIRCLE ALL APPLICABLE**
PRODUCTIVE CAPITAL		**G3.01**	**G3.02**
A	Land(pieces/plots)	YES.....1 NO.....2 *ITEM B*	YES, SOLELY..... 1 YES, JOINTLY.....2 NO..... 3
B	Assets related to eucalyptus plantation work	YES.....1 NO.....2 *ITEM C*	YES, SOLELY..... 1 YES, JOINTLY.....2 NO..... 3
C	Small livestock (goats, and sheep)	YES.....1 NO.....2 *ITEM D*	YES, SOLELY..... 1 YES, JOINTLY.....2 NO..... 3
D	Chickens	YES.....1 NO.....2 *ITEM E*	YES, SOLELY..... 1 YES, JOINTLY.....2 NO..... 3
E	Farm equipment (non-mechanized: hand tools, animal-drawn plough)	YES.....1 NO.....2 *ITEM G*	YES, SOLELY..... 1 YES, JOINTLY.....2 NO..... 3
F	Farm equipment (mechanized: tractor-plough,power tiller, treadle pump)	YES.....1 NO.....2 *ITEM H*	YES, SOLELY..... 1 YES, JOINTLY.....2 NO..... 3
G	Nonfarm business equipment (solar panels used for recharging, sewing machine, brewing equipment, fryers)	YES.....1 NO..... *ITEM I*	YES, SOLELY..... 1 YES, JOINTLY.....2 NO..... 3
H	House or other structures	YES.....1 NO.....2 *ITEM J*	YES, SOLELY..... 1 YES, JOINTLY.....2 NO..... 3

MODULE G3(B): ACCESS TO CREDIT

"Next I'd like to ask about your household's experience with borrowing money or other itemsin the past 12 months."		Would you or anyone in your household be able to take a loan or borrow cash/in-kind from [SOURCE] if you wanted to? *	Has anyone in your household taken any loans or borrowed cash/in-kind from [SOURCE] in the past 12months? **CIRCLE ONE**	Who made the decision to borrow from [SOURCE] most of the time? **CIRCLE ALL APPLICABLE**	Who makes the decision about what to do with the money/ item borrowed from [SOURCE] most of the time?**CIRCLE ALL APPLICABLE**
LENDING SOURCE NAMES[2]		**G3.03**	**G3.04**	**G3.05**	**G3.06**
A	Non-governmental organization (NGO)	YES.....1 NO….....2 *NEXT SOURCE* MAYBE.....3	YES, CASH.....1 YES, IN-KIND.....2 YES, CASH AND IN-KIND.....3 NO.....4 *NEXT SOURCE* DON'T KNOW.....97 →	SELF.....1 SPOUSE.....2 OTHER HH MEMBER.....3 OTHER NON-HH MEMBER.....4 NOT APPLICABLE.....98	SELF.....1 SPOUSE.....2 OTHER HH MEMBER.....3 OTHER NON-HH MEMBER.....4 NOT APPLICABLE….....98
B	Formal lender (bank/financial institution)	YES.....1 NO….....2 *NEXT SOURCE* MAYBE.....3	YES, CASH.....1 YES, IN-KIND.....2 YES, CASH AND IN-KIND.....3 NO.....4 *NEXT SOURCE* DON'T KNOW.....97 →	SELF.....1 SPOUSE.....2 OTHER HH MEMBER.....3 OTHER NON-HH MEMBER.....4 NOT APPLICABLE.....98	SELF.....1 SPOUSE.....2 OTHER HH MEMBER.....3 OTHER NON-HH MEMBER.....4 NOT APPLICABLE….....98
C	Informal lender eg *Arata*	YES.....1 NO….....2 *NEXT SOURCE* MAYBE.....3	YES, CASH.....1 YES, IN-KIND.....2 YES, CASH AND IN-KIND.....3 NO.....4 *NEXT SOURCE* DON'T KNOW.....97	SELF.....1 SPOUSE.....2 OTHER HH MEMBER.....3 OTHER NON-HH MEMBER.....4 NOT APPLICABLE.....98	SELF.....1 SPOUSE.....2 OTHER HH MEMBER.....3 OTHER NON-HH MEMBER.....4 NOT APPLICABLE….....98
D	Friends or relatives	YES.....1 NO….....2 *NEXT SOURCE* MAYBE.....3	YES, CASH.....1 YES, IN-KIND.....2 YES, CASH AND IN-KIND.....3 NO.....4 *NEXT SOURCE* DON'T KNOW.....97	SELF.....1 SPOUSE.....2 OTHER HH MEMBER.....3 OTHER NON-HH MEMBER.....4 NOT APPLICABLE.....98	SELF.....1 SPOUSE.....2 OTHER HH MEMBER.....3 OTHER NON-HH MEMBER.....4 NOT APPLICABLE….....98
E	Group based micro-finance or lending	YES.....1 NO….....2 *NEXT SOURCE* MAYBE.....3	YES, CASH.....1 YES, IN-KIND.....2 YES, CASH AND IN-KIND.....3 NO.....4 *NEXT SOURCE* DON'T KNOW.....97	SELF.....1 SPOUSE.....2 OTHER HH MEMBER.....3 OTHER NON-HH MEMBER.....4 NOT APPLICABLE.....98	SELF.....1 SPOUSE.....2 OTHER HH MEMBER.....3 OTHER NON-HH MEMBER.....4 NOT APPLICABLE….....98
F	Informal credit/savings groups such as *equb*	YES.....1 NO….....2 *NEXT SOURCE* MAYBE.....3	YES, CASH.....1 YES, IN-KIND.....2 YES, CASH AND IN-KIND.....3 NO.....4 *MODULE G4* DON'T KNOW.....97	SELF.....1 SPOUSE.....2 OTHER HH MEMBER.....3 OTHER NON-HH MEMBER.....4 NOT APPLICABLE.....98	SELF.....1 SPOUSE.....2 OTHER HH MEMBER.....3 OTHER NON-HH MEMBER.....4 NOT APPLICABLE….....98

MODULE G4: TIME ALLOCATION

G4.01: PLEASE RECORD A LOG OF THE ACTIVITIES FOR THE INDIVIDUAL IN THE LAST COMPLETE 24 HOURS (STARTING YESTERDAY MORNING AT 4 AM, FINISHING 3:59 AM OF THE CURRENT DAY). THE TIME INTERVALS ARE MARKED IN 15 MIN INTERVALS AND ONE ACTIVITY CAN BE MARKED FOR EACH TIME PERIOD BY DRAWING A LINE THROUGH THAT ACTIVITY.

"Now I'd like to ask you about how you spent your time during the past 24 hours. We'll begin from yesterday morning, and continue through to this morning. This will be a detailed accounting. I'm interested in everything you do (i.e. resting, eating, personal care, work inside and outside the home, caring for children, cooking, shopping, socializing, etc.), even if it doesn't take you much time."

		Night								Morning																Day																								
	Activity	4				5				6				7				8				9				10				11				12				13				14				15			
A	Sleeping and resting																																																
B	Eating and drinking																																																
C	Personal care																																																
D	School (also homework)																																																
E	Work as employed																																																
F	Own business work																																																
G	Harvesting of forest products																																																
J	Shopping/getting service (incl health services)																																																
K	Marketing of forest products																																																
L	Cooking																																																
M	Domestic work (including fetching wood and water)																																																
N	Care for children/adults/elderly																																																
P	Travelling and communiting																																																
Q	Watching TV/listening to radio/reading																																																
T	Processing of forest products																																																
U	Social activities and hobbies																																																
W	Religious activities																																																
X	Other, specify…																																																

MODULE G4 continued: TIME ALLOCATION

										Evening				Night																																	
	Activity	16				17				18				19				20				21				22				23				24				1				2				3			
A	Sleeping and resting																																																
B	Eating and drinking																																																
C	Personal care																																																
D	School (also homework)																																																
E	Work as employed																																																
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U	Social activities and hobbies																																																
W	Religious activities																																																
X	Other, specify																																																

QNO.	QUESTION	RESPONSE
G4.02	In the last 24 hours did you work (at home or outside of the home) more than usual, aboutthe same as usual, or less than usual?	MORE THAN USUAL... 1 ABOUT THE SAME AS USUAL…... 2 LESS THAN USUAL….. 3

Module G- 5: Group Membership

"Now I'm going to ask you about groups in the community. These can be either formal orinformal and customary groups."		Is there a [GROUP] in your community?	Are you an active member of this [GROUP]?
	GROUP CATEGORIES	**G5.01**	**G5.02**
A	Agricultural / livestock/ fisheries producer's group (including marketing groups)	YES..... 1 NO..... 2 DON'T KNOW…..97 *GROUP B*	YES.....1 NO.....2
B	Water users' group	YES..... 1 NO..... 2 DON'T KNOW…..97 *GROUP C*	YES.....1 NO.....2
C	Forest users' group	YES..... 1 NO..... 2 DON'T KNOW…..97 *GROUP D*	YES.....1 NO.....2
D	Credit or microfinance group such as *Equb*	YES..... 1 NO..... 2 DON'T KNOW…..97 *GROUP E*	YES.....1 NO.....2
E	Mutual help or insurance group such as *Edir*	YES..... 1 NO..... 2 DON'T KNOW…..97 *GROUP F*	YES.....1 NO.....2
F	Trade and business association group	YES..... 1 NO..... 2 DON'T KNOW…..97 *GROUP G*	YES.....1 NO.....2
G	Civic groups (improving community) or charitable group (helping others)	YES..... 1 NO..... 2 DON'T KNOW…..97 *GROUP H*	YES.....1 NO.....2
H	Religious group e.g. *Mahber*	YES..... 1 NO..... 2 DON'T KNOW…..97 *GROUP J*	YES.....1 NO.....2
I	Other [women's/men's] group (only if it does not fit into one of the othercategories)	YES..... 1 NO..... 2 DON'T KNOW…..97 *GROUP K*	YES.....1 NO.....2
J	Other (SPECIFY)_____	YES..... 1 NO..... 2 DON'T KNOW…..97	YES.....1 NO.....2

Appendix II: FGD and Interview Guide

Part I Driving factors of and impacts of eucalyptus plantations

1. How would you describe the land use and cover change in your *Kebele*?

2. In your opinion, why do farmers convert their farmland into eucalyptus plantations?

3. What is the contributions of eucalyptus plantations for the livelihood of rural households in your community?

Part II The relationship between gender and eucalyptus plantations.

1. Who is involved in the decision to plant eucalyptus trees, and what factors influence that decision? Can you describe the discussions or considerations that take place?
2. When it comes time to sell the eucalyptus trees, who makes the final decision? Is it primarily the husband, the wife, or do you work together? What influences this decision?
3. Who handles the actual sale of the eucalyptus trees? Can you describe the roles each person plays in this process?
4. Once the trees are sold, who is responsible for depositing the money? If it goes into a bank account, whose name is it under, and why was that decision made?
5. How is the income from the eucalyptus trees spent? Who decides on the allocation of these funds? Are there discussions or agreements between you and your partner about this?
6. Who is primarily responsible for choosing the type of crop to plant? Can you describe how you make this decision together? What factors influence your choice?
7. Who ultimately decides whether to sell the harvested crops? Is this a joint decision, or does one partner take the lead? What considerations are taken into account during this decision-making process?
8. Who handles the marketing and selling of the crops? Can you explain the roles each person plays in this process? How do you decide who will take on these responsibilities?
9. After the crops are sold, who decides how to use the proceeds? Is this decision made together, or does one partner typically have more influence? What discussions do you have about spending the income?

10. In your experience, who tends to have a heavier workload: household heads with eucalyptus plantations or those without? What factors do you believe contribute to this difference, particularly in relation to husbands?
11. In your experience, who is more likely has more workload? Women with eucalyptus plantations or those without? What factors do you believe contribute to this difference, particularly concerning wives?
12. In your experience, who tends to have a heavier workload: women with eucalyptus plantations or those without? What factors do you think contribute to this difference, particularly regarding wives?

Appendix III Comparison of A-WEAI and A-WEEI domains

Module	Women's Empowerment in Agriculture Index (A-WEAI)	Women's Empowerment in Eucalyptus Plantation Index (Modified A-WEAI)
Module G1: Individual Identification	- Captures household identification, respondent details, and ability to be interviewed alone or with others.	- Same as A-WEAI.
Module G2: Role in Household Decision-Making	- Focuses on agricultural activities (e.g., food crop farming, cash crop farming, livestock raising, and non-farm economic activities).	- Focuses on eucalyptus plantation-related activities (e.g., selection of tree species, harvesting eucalyptus, marketing eucalyptus products), and non-farm economic activities.
Activities in G2	- Food crop farming, cash crop farming, livestock raising, non-farm economic activities, wage employment, fishing, and major/minor expenditures.	- Selection of tree species, harvesting eucalyptus, collecting/transporting eucalyptus, marketing eucalyptus, processing eucalyptus, wage employment, non-farm eucalyptus-related activities.
Module G3(A): Access to Productive Capital	- Includes agricultural land, livestock, farm equipment, non-farm business equipment, consumer durables, and transportation.	- Includes land, assets related to eucalyptus plantation work, livestock, farm equipment, non-farm equipment, consumer durables, and transportation.
Module G3(B): Access to Credit	- Explores access to credit from NGOs, formal lenders, informal lenders, friends/relatives, and microfinance groups.	- Same as A-WEAI.
Module G4: Time Allocation	- Tracks time spent on general agricultural activities (farming, livestock, and fishing), domestic work, and other daily activities.	- Tracks time spent on eucalyptus-related activities (harvesting, marketing, processing forest products) alongside domestic work and other daily activities.
Module G5: Group Membership	- Assesses membership in agricultural, water users, forest users, credit, mutual help, trade, civic, and religious groups.	- Same as A-WEAI, but with a potential emphasis on forest users' groups due to the eucalyptus context.
Key Focus Areas	- Empowerment in general agriculture, including crop production, and livestock.	- Empowerment specifically in eucalyptus plantation activities, including tree selection, harvesting, marketing, and processing.