THE ECONOMICS OF LAND DEGRADATION

The Economics of Land Degradation Neutrality in Ethiopia

Empirical analyses and policy implications for the Sustainable Development Goals

An Economics of Land Degradation study carried out in the framework of the "Reversing Land Degradation in Africa by Scaling up Evergreen Agriculture" project

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Acronyms and abbreviations

BCR	Benefit-Cost Ratio
CSA	Central Statistical Agency
ELD	Economics of Land Degradation
FAO	Food and Agriculture Organisation of the United Nations
FAOSTAT	Food and Agriculture Organisation of the United Nations Statistics
GDP	Gross Domestic Product
IV	Instrumental Variable
ha	Hectare
kg	Kilogram
kg/ha/yr	Kilogram per hectare per year
LDN	Land Degradation Neutrality
LULC	Land Use Land Cover Change
NPK	Nitrogen, Phosphorous, Potassium
NPV	Net Present Value
PCRS	Provisioning, Cultural, Regulating, and Supporting services
PPP	Purchasing Power Parity
PV	Present Value
r	Real discount rate
SDG	Sustainable Development Goal
SLM	Sustainable Land Management
SNNP	Southern Nations Nationalities and Peoples
TEV	Total Economic Value
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
USD	United States Dollar
WOCAT	World Overview on Conservation Approaches and Technologies

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About the ELD Initiative and the "Reversing Land Degradation in Africa through Scaling-up Evergreen Agriculture" project

Land degradation, desertification, and drought are widespread global issues that increasingly threaten the future of our environment. They lead to a loss of services from land and land-based ecosystems that are necessary for human livelihoods and economic development. Food production, water availability, energy security, and other services provided by intact ecosystems are jeopardised by the ongoing loss of land and soil productivity.

Desertification already affects around 45 per cent of the African continent (ELD Initiative 2017), indicating an urgent need for action. Failure to act on this threat would have serious negative impacts on the economies and sustainable development opportunities.

The Economics of Land Degradation (ELD) Initiative is an international collaboration initiated in 2012 with the aim of increasing and strengthening awareness of the economics of land degradation and SLM in the scientific, political and public discourse. Therefore, the Initiative highlights the value of land and its services to the society in reports and provides a global approach for the analysis of the economics of land degradation. The aim of ELD is that economic valuation of ecosystem services becomes an integral part of policy strategies and decision-making.

The ELD Initiative provides ground-truthed tools and assessments that allow stakeholders to undertake cost-benefit analyses of land and land uses through total economic valuation and include this information in decision-making. The Initiative is coordinated by the ELD Secretariat, hosted by the German International Cooperation (GIZ) in Bonn, Germany.

Land degradation is explicitly included in objective 15 of the United Nations' SDGs, which were adopted in 2015. SDG 15 aims at "protecting, restoring and promoting sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss". The objectives 15.3. and 15.9. aim at achieving land degradation neutrality as well as at the integration of ecosystems and biodiversity values into national and local planning. On international level, the UNCCD has been appointed as custodian agency for SDG 15.3 and, by developing economic arguments, the ELD Initiative complements the work of the scientific and technical committee of the UNCCD.

Land degradation is a complex and detrimental problem, affecting many critical aspects of human life, which cannot be eliminated easily by implementing specific technical or technological measures. The fight against degradation rather requires holistic measures, which will then simultaneously enable to reduce poverty (SDG 1), improve food security (SDG 2), sustainably manage water and waste water (SDG 6), enhance economic development (SDG 8), encourage sustainable consumption and production (SDG 12), improve adaptation to climate change (SDG 13), and to contribute to freedom and justice (SDG 16).

The project Reversing Land Degradation in Africa by Scaling-up Evergreen Agriculture – Regreening Africa started in 2017 and aims to improve livelihoods, food security, and climate change resilience by restoring ecosystem services. The project target countries are Ethiopia, Ghana, Kenya, Mali, Niger, Rwanda, Senegal, and Somalia. The action is financed by the the European Commission's Directorate for International Cooperation and Development (DG DEVCO) and Germany's Federal Ministry for Economic Cooperation and Development (BMZ). It is carried out jointly by the ELD Initiative and the World Agroforestry Centre (ICRAF).

The role of the ELD Initiative within this project is to raise awareness on the threats and opportunities of different land use options by supporting and communicating cost-benefit analyses in each target country. At the same time, the Initiative extends the capacity of national institutions and experts to assess the economic benefits of investments in sustainable land management in consideration of the costs of land degradation.

The present report has been developed in the framework of an ELD process on national level. Its outcomes will provide decision-makers and administrators with robust scientific information on the economic consequences of land degradation and optional pathways to rural growth.

Executive summary

With a total land area of 110 million hectares, of which only about 10 million hectares is covered with inland waters, Ethiopia is the second most populous countries in Africa with a rapidly growing population. Ethiopia's population is projected to reach 138.3 million by 2030 and 164.3 million by 2040 (FAOSTAT). Currently, the rural population constitutes approximately 78 per cent of the country's 112.76 million total population. These residents depend directly on land and land-based ecosystem services for their livelihood. The share of rural population will slightly decline to 73 per cent of the country's population by 2030 and to 67 per cent by 2040. In a country of rapid population growth like Ethiopia, land degradation is detrimental to agricultural ecosystems and crop production, and is thus a serious impediment in achieving food security and improving livelihoods of the growing population.

Land degradation and desertification is reducing the capacity of land to provide ecosystem services and is one of the greatest environmental challenges that many countries in the world are facing. To address this challenge, Sustainable Development Goal (SDG) 15 was established to protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation and stop biodiversity loss. SDG 15.3 in particular states that "By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral (LDN) world".

The United Nations Convention to Combat Desertification (UNCCD) defines LDN "as a state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems" (UNCCD 2017; UNCCD 2014). Progress on the goal is to be measured in terms of "the proportion of land that is degraded over total land area", and several sub-indicators of land cover and land cover change, land productivity, and both above and below ground carbon stocks. However, these proposed indicators are purely biophysical and empirical studies integrating biophysical indicators with socioeconomic factors are still limited, particularly at the national level. Generating empirical evidence based on biophysical and econometric modelling approaches is crucial to provide a framework in which the costs and benefits of interventions against land degradation can be assessed at different spatial and temporal scales. These types of results are essential tools for policy makers, practitioners, and other stakeholders as it allows informed decisions to be made towards sustainable land management (SLM). Moreover, such studies highlight policy implications and the co-benefits of achieving a specific SDG.

Thus, the main objective of this study is to assess the economic benefits and costs of SLM towards achieving agricultural LDN in Ethiopia and assess how SLM are cost-effective and helpful in achieving a number of other SDGs as co-benefits. Specifically, the study aims at assessing the policy implications of achieving SDG 15.3 particularly agricultural LDN, as well as economic growth (SDG 8.1), rural employment (SDG 8.5), poverty reduction (SDG 1.1 and SDG 1.2) and food security (SDG 2.3 and SDG 2.4) in Ethiopia, its regional states, and its administrative zones.

To achieve this, the study provides country, regional, and administrative zone level empirical analyses on 12.77 million hectares (ha) of cultivated agricultural land with 52 crop types during the study period 2003-2016. The study indicates that there was an increasing trend in agricultural land degradation in Ethiopia during the study period 2003-2016. The average soil nitrogen (N), phosphorus (P), potassium (K) depletion was 768 thousand tons per year (60.13 kilograms per hectare per year) whereas NPK loss through erosion, gaseous exchange, and leaching was 781 thousand tons per year (61.12 kilograms per hectare per year). As a result of both soil NPK depletion and NPK loss, the annual aggregate crop production loss amounts to 104 million tons with a market value of 48.35 billion in United States dollars (USD) at 2016 average weighted aggregate crop price. Both in terms of quantity and value, the aggregate crop production loss induced by NPK loss accounts close to 68 per cent whereas NPK depletion-induced crop production loss accounts for nearly 32 per cent. This implies that the country has the potential to increase agricultural productivity from 1.89 to 9.92 tons per hectare per year by investing in SLM technologies.

The results of the cost-benefit analysis indicate that Ethiopia needs to invest USD 97 billion (USD 7,434 per hectare) and/or USD 192 billion (USD 15,008 per hectare) in present values to develop SLM technologies on the 12.77 million hectares of its agricultural land over the periods 2020-2030 and/or 2020-2040, respectively. The present values of the flows of total benefits from such investments are estimated at about USD 392 billion (USD 30,706 per hectare) for 2020 2030 and USD 882 billion (USD 69,088 per hectare) for 2020 2040. This means Ethiopia could create a net present value (NPV) of about USD 295 billion (USD 23,132 per hectare) with a benefit-cost ratio (BCR) of 4.05 for the period 2020-2030, and close to USD 691 billion (USD 54,079 USD per hectare) with a BCR of 4.6 for the period 2020-2040, respectively.

Furthermore, the study indicates that investing in SLM technologies and achieving agricultural LDN would enable Ethiopia to reduce the poverty gap to zero by 2030. It will also help the country create up to about 10 million rural job opportunities, increase the total per capita domestic food crop production to 1,146 kilograms by 2030, and result in economic growth as well as expansion of the agricultural sector.

01 Introduction and background of the study

1.1. Overview of land degradation in Ethiopia

Land degradation is a global environment and development issue in the 21st century because of its adverse impacts on agronomic productivity, the environment, and its effect on food security and the quality of life (Eswaran et al. 2001). Land degradation can be defined as all processes that decrease the capacity of land resources to perform essential functions and services in ecosystems (Blaikie and Brookfield 2015). The United Nations Convention to Combat Desertification (UNCCD) defines land degradation as: "any reduction or loss in the biological or economic productive capacity of the land resource base. Land degradation is caused by human activities and exacerbated by natural processes, and often magnified by and closely intertwined with climate change and loss of biodiversity" (UNCCD 2017). This definition implies that land degradation is contextual and there has been no accurate measurement of the extent of degradation (Reynolds et al. 2011).

Land degradation can be triggered by various processes that lower the potential productivity of land, leading to long term (sometimes irreversible) deterioration. Principal processes of land degradation include soil erosion by water and wind, acidification, salinisation, fertility depletion, and decrease in cation retention capacity, crusting, compaction, hard setting, reduction in total and biomass carbon, and decline in biodiversity (Sivakumar and Ndiangui 2007).

Trends show that land degradation is increasing across the world. For example, an analysis of 23 years using Global Inventory Modelling and Mapping Systems (GIMMS) data of Normalised Difference Vegetation Index (NDVI) reveals a declining trend across some 24 per cent of the global land area (Bai et al. 2008a). Out of the 24 per cent, degraded areas were mainly in Africa south of the equator, southeast Asia and south China, north-central Australia, the Pampas, and swaths of the Siberian and North American taiga (Bai et al. 2008b). It was estimated that 1.5 billion people live in these areas. However, Nkonya et al. (2016) indicated that land degradation stretches to about 30 per cent of the total global land area and 3 billion people reside in the areas with land degradation hotspots. Thiombiano and Tourino-Soto (2007) also found an increasing trend of severity and extent of land degradation from the humid zones of the Congo and Zambezi basins (24 to 29 per cent) to the dry areas of the Nile, Niger, and Lake Chad basins (78 to 86 per cent). However, the extent and trend of land degradation varies depending on agro-ecology and river basins.

Land degradation is a continuous process and an important concern affecting food security and the wealth of nations, as well as the livelihood of almost every person on planet earth (Tefera 2002). Natural resource degradation in Ethiopia has been going on for centuries (Hurni et al. 2010). Loss of land resource productivity is an important problem in Ethiopia and, combined with continued population growth, is likely to become even more pressing in the future (Berry 2003). Estimations using satellite imagery of the last three decades demonstrate that land degradation covers around 23 per cent of the land area in the country (Gebreselassie et al. 2016). The recorded yearly soil erosion in Ethiopia ranges from 16 to 300 tons per hectare per year depending mainly on the slope, land cover, and rain fall intensities (Nkonya et al. 2016). Annually, Ethiopia loses over 1.5 billion tons of topsoil in the highlands from erosion. This could have added about 1.0 to 1.5 million tons of grain to the country's harvest (Taddese 2001).

Land degradation in Ethiopia is a severe problem that affects agricultural productivity and food insecurity (Muluneh et al. 2017, FDRE 2011). Specifically, soil erosion by water is the most common form of land degradation in Ethiopia and has accelerated over recent decades due to unsustainable land use practices (Gebreselassie et al. 2016). Land degradation induced by soil erosion is considered to be among the major factors responsible for environmental challenges and food insecurity of the population and for impeding future development prospects of the country (Wagayehu 2003). With one of the highest rates of soil erosion in Africa, Ethiopia is highly vulnerable to the effects of land degradation (Jolejole-Foreman et al. 2012). Woldemariam et al. (2018) estimated soil loss rates in the Gobele Watershed and East Hararghe zone using spatial modelling and they found that the mean annual soil loss accounted for 51.04 tons per hectare per year in 2000 and 34.26 tons per hectare per year in 2016. The decline in soil loss rate is probably due to some conservation measures taken by the local people in recent years. However, this soil loss estimate is much greater than the maximum tolerable soil loss estimate (18 tons per hectare per year) at a national scale (Ayalew 2015, Hurni 1985).

Although there has been considerable information in the literature about soil erosion in Ethiopia since the mid-1980s, there is a lack of reliable and consistent data on the extent and rate of soil loss (Gebreselassie et al. 2016). There are only very few estimates available about the overall soil loss rates at regional or national scale and these few studies used different methods and reported different estimates on the amount of soil loss (Haregeweyn et al. 2015). For example, Sonneveld et al. (2011) provided a tentative nationwide mean annual soil loss map combining the results of different model estimates and they stated that soil loss varies from 0 to 1 ton per hectare per year in the eastern and south-eastern parts of Ethiopia to more than 100 tons per hectare per year in the north-western part of the country. However, their study did not note what caused this huge spatial variation. Making such estimates of soil erosion rate is the result of the complex patterns of spatial and temporal variations and conceptual and methodological difficulties (Gebreselassie et al. 2016).

Available information in the literature suggests that over the last decades, there has been a significant increase in soil degradation processes in Ethiopia, and there is evidence that these processes will further increase if no action is taken. For example, in the northwest Ethiopian highlands near Lake Tana, about 68 per cent of the watershed is facing erosion rates that vary from low to moderate, 31 per cent is subject to high to extreme erosion rates, and in 1 per cent is eroding at more than 100 tons per hectare per year (Mekonnen and Melesse 2011). Miheretu and Yimer (2018) found a mean rate of soil loss of 24.3 tons per hectare per year from the Gelana sub-watershed. Compared to previous studies, the result of Miheretu and Yimer (2018) was very low. This might be attributed to area closure, and soil and water conservation measures implemented in the study area by the Ethiopian government in the last two decades. Haregeweyn et al. (2014) also found an increase in annual surface runoff of 101 millimetres and a decrease in groundwater recharge of 39 millimetres over the period 1976–2003 in Gilgel Tekeze catchment in the highlands of northern Ethiopia. Gessesse et al. (2015) also found that an overall increase in surface runoff (14.2 per cent) and sediment yield (37 per cent) in the Modjo watershed, Ethiopia. More recently, Le et al. (2016) showed that land degradation occurred over about 228,160 square kilometres (or 23 per cent of total land area) between 1982 and 2006 in Ethiopia. In contrast, Nyssen et al. (2009) found a positive change in vegetation and improved soil protection over the last 140 years in northern Ethiopia. Similarly, Belay et al. (2015) reported an improved vegetation cover in Eastern Tigray, Ethiopia since 1994. The review showed that the trend of land degradation is location-dependent.

1.2. Drivers of land degradation in Ethiopia

Ethiopia is facing serious land degradation, particularly soil erosion, nutrient depletion, and land cover changes due to natural and anthropogenic influences (Urgessa 2016). Researchers identified different modern causes of land degradation for different areas in Ethiopia. For example, Lemenih (2004) argued that land degradation is a biophysical process driven by socioeconomic and political causes in which subsistence agriculture, poverty, and illiteracy are important causes of land and environmental degradation. Similarly, Taddese (2001) stated that the major causes of land degradation in Ethiopia are rapid population increase, severe soil loss, deforestation, low vegetative cover, unbalanced crop and livestock production, inappropriate land-use systems and land-tenure policies, utilisation of dung and crop residues for fuel, and low supply of inputs such as fertiliser, farm machinery, and credits. Meshesha et al. (2014) and Samuel (2014) suggested that in the highlands of eastern Ethiopia, the higher vulnerability of water-induced soil erosion is associated with the adverse effects of land use and land cover changes, unsustainable land management, and less emphasis being given to soil and water conservation practices. In the northern Ethiopian highlands, mismanagement, overpopulation and droughts are among the factors contributing to severe environmental degradation (Lanckriet et al. 2015). Forest burning and expansion of cultivated lands to marginal lands have also contributed to the widespread problem of land degradation in the country (Gebreselassie et al. 2016). Of the several factors that contribute to unsustainable land management, poor land use practices and population pressure are the major drivers of land degradation in Ethiopia (Berry 2003).

Studies conducted by Meshesha et al. (2014) in the Central Rift Valley of Ethiopia identified population and livestock growth in regions of limited resources, unsustainable farming techniques, land tenure system, and poverty as major causes of land use and land cover change (LULC) and land degradation in the area. Angassa (2014) found heavy grazing intensity as the main cause of vegetation decline in southern Ethiopia. Girmay et al. (2010) also found land use and land cover change as a main driver of land degradation and surface runoff in two catchments of northern Ethiopia.

As mentioned by Hurni et al. (2005) and Nyssen et al. (2007), land degradation has been mainly attributed to population growth, climate change, and the lack of effective land and water management practices in Ethiopia. Paulos (2001) found that topography, soil types, and agro-ecological parameters are also additional factors playing significant roles in the man-made degradation processes. Kassa et al. (2017) urged that the increasing trend of cereal cropping, resettlement and commercial agriculture causes the deterioration of natural forest cover in southwest Ethiopia.

Miheretu and Yimer (2017) found LULC changes – driven by population growth as well as growing land demand for cultivation, rural settlement, and forest resources – aggravates soil erosion and biodiversity loss. Similarly, Woldeyohannes et al. (2018) indicated LULC change in Abaya-Chamo Basin (southern Ethiopia) increased soil erosion, the volume of surface runoff, and sediment transport in the landscape which in turn affected the levels and water quality of the lakes.

1.3. Objectives of the study

Achieving the Sustainable Development Goals (SDGs) has become an aspiration for many countries, particularly developing countries like Ethiopia, which strive to improve the livelihoods of its growing population. One of the things that Ethiopia and many other developing countries need to do is to manage natural resources sustainably. Soils, especially the topsoil of agricultural ecosystems, are an important natural resource for the production of food, fibers, and biomass energy.

Land degradation causes the loss of the topsoil and the nutrients they contain, which in turn leads to a reduction in crop production and productivity of agricultural ecosystems. A report produced by the ELD Initiative and UNEP with the title "*Economics of Land Degradation in Africa: Benefit of Action Outweigh the Costs*" (2015) highlights this fact for a number of African countries including Ethiopia. Soil erosion-induced nutrient depletion from 105 million hectares of cereal croplands in 42 African countries causes the loss of 280 million tons of cereal crops per year. The results from the same study show that the benefits of action against land degradation through sustainable land management (SLM) are on average seven times higher than the costs (ELD Initiative and UNEP 2015).

On the sixth special session of the African Ministerial Conference on Environment, African ministers of environment decided to welcome the said-report – ELD Initiative and UNEP 2015 – and used its outcomes as a vehicle "*for creating new data and generation of policy relevant information that links the biophysical aspects of land degradation with the economic drivers of change*". This is stated in number five of Decision SS.VI/4*: "Action for combating desertification, drought, floods and restoring degraded land to achieve a land-degradation-neutral world*".[1] In this regard, detailed country-specific studies on the economics of land degradation are important for promoting and scaling-up SLM practices for countries like Ethiopia in their effort to achieve land degradation neutrality (LDN) (SDG 15.3) and to derive policy implications to other related SGDs.

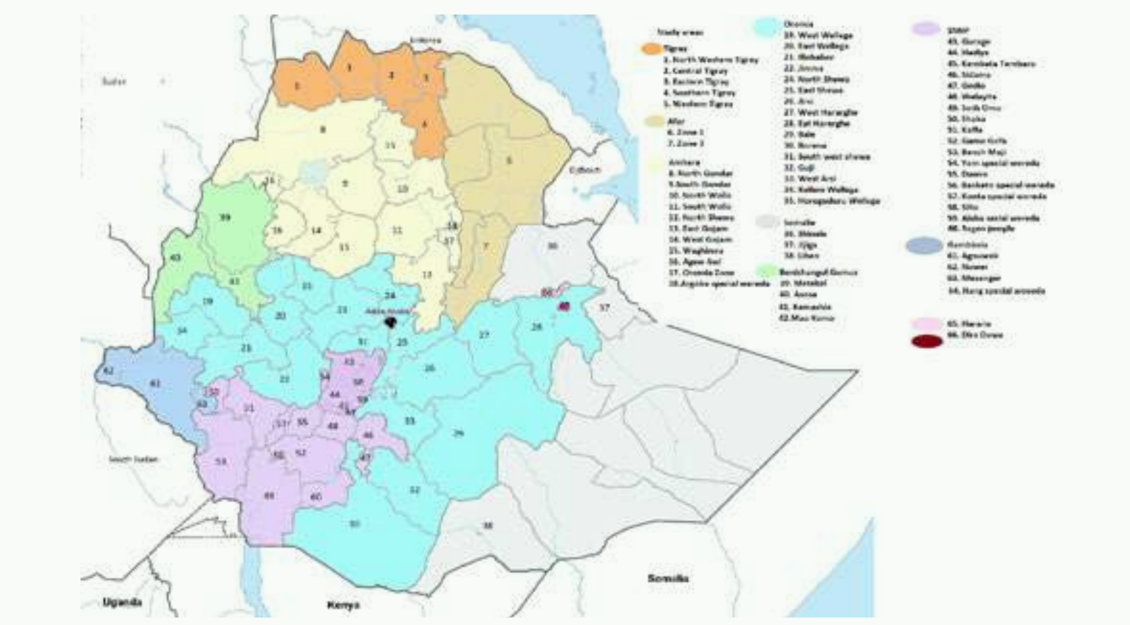
Thus, the main objectives of this study are:

1. To assess the costs of agricultural land degradation and the economic viability of alternative land management approaches in Ethiopia in order to contribute to the national SDG vision of achieving a LDN state and derive implications to related SDG targets as co-benefits.
2. To assess the effect of agricultural land degradation mainly with a focus on ecosystem services (provisioning and supporting services) that are directly affected by land management.

1 http://www.unep.org/sites/default/files/amcen6/decision_4_desertification_final.pdf

FIGURE 1.1:

Map of administrative zones of Ethiopia covered in this study.



3. To identify the roles of the affected ecosystem services in the livelihood of rural communities and the national economy by estimating the economic values of the losses of ecosystem services and the socioeconomic benefits (e.g. employment, economy, food security, etc.) of preventing these losses through sustainable land management practices.
4. To assess agricultural land degradation patterns over time (for the study period 2003-2016) by developing an econometric model of agricultural land degradation that can assess and project the effects of biophysical and socioeconomic drivers on land resources.
5. To assess the future costs and benefits of adopting SLM practices.
6. To undertake a cost-benefit analysis (CBA) to compare net benefits of adopting SLM practices to the net benefits of a business-as-usual (BAU) scenario.
7. To derive policy implications for SDG 15.3 and related targets and national development goals.

1.4. Scope and outline of study

This study focuses on cultivated agricultural land degradation in Ethiopia because agriculture is the dominant sector in its economy and dominates land cover in the country. In terms of geographical coverage, the study covers the nine regional states and one city administration of Ethiopia[2]. In total, the study covers 66 administrative zones (Figure 1.1).

The study is organised into five chapters. The first chapter introduces the background, objectives, and scope of the study. The second chapter comprises of the methodological approaches used to undertake the economic analysis of agricultural land degradation and LDN, as well as the results found in the context of Ethiopia. The third chapter provides details on the methods used and results of costs of SLM technologies in Ethiopia. Based on the results from chapter two and chapter three, chapter four deals with the cost-benefit analysis of sustainable land management interventions, and the final chapter provides discussions on some policy implications and concludes this report.

2 1. Tigray regional state (five administrative zones); 2. Afar regional state (two administrative zones); 3. Amhara regional state (ten administrative zones and one special wereda); 4. Oromia regional state (seventeen administrative zones); 5. Ethiopian Somalie regional state (three administrative zones); 6. Benshangul Gumuz regional state (four administrative zones); 7. Southern Nations Nationalities and Peoples (SNNP) regional state (fourteen administrative zones and four special weredas); 8. Gambella regional state (three administrative zones and one special wereda); 9. Harari regional state (one administrative zone); 10. Dire Dawa city administration

02 Economics of agricultural land degradation neutrality: assumptions and methods

2.1. Introduction

This chapter aims at providing details on the conceptual framework, empirical methods and underlying assumptions used in the estimation of soil nutrient depletion[3] and soil nutrient losses[4] as proxy variables of agricultural land degradation. Furthermore, the chapter also deals with the methodological approaches used in modelling the impact of soil nutrient depletion and soil nutrient losses on aggregate crop yield.

The next section of this chapter provides a brief review of the concept of total economic value and methods of economic valuation in the context of assessing the value of agricultural land and the ecosystem services it provides. The materials and methods used for biophysical and econometric modelling and analyses are presented in the third section with a discussion of the results following each method. Section four of this chapter deals with the estimation and valuation of preventing agricultural land degradation and presents results at national, regional and zone level. The last section summarises the main findings of the chapter.

2.2. The concept of total economic value and valuation approaches

Land as a factor of production is versatile and land users have to make trade-offs in the use of land (e.g., for agriculture, forestry, mining, infrastructure development, settlement, etc.). At the same time, investments to enhance the value of a specific land with a specific land use need to be guided with decision tools that can assess the trade-off between investing and not investing. Investments in sustainable land management (SLM) to enhance the productivity of agricultural land have to be evaluated and such evaluations can be guided by economic valuation as a tool in assessing the trade-offs between losses due to land degradation and the net gains of investments in SLM technologies, for instance. In this regard, the concepts of total economic value (TEV) and ecosystem services are important in the broader context of economic valuation of ecosystem services and the valuation of costs and benefits associated with measures to curb land degradation at different spatial scales.

The concepts of TEV and typology of ecosystem services into provisioning, supporting, regulating and cultural services (Millennium Ecosystem Assessment 2005) are important frameworks in the broader context of environmental valuation and the valuation of agricultural ecosystems at different special scales. Economists define the TEV as the sum of *use* and *non-use* values that humans derive from nature and/or the environment (Perman et al. 2011, Pearce 1993). Table 2.1 provides a brief summary of the different components of use and non-use values that human beings could drive from agricultural ecosystem resources/products and services.

A conceptual framework of valuation that distinguishes between values of assets (e.g., stocks of soil nutrient in agricultural landscapes) and products (food crops, fiber, and energy crops as flow value of agricultural ecosystem services) is essential to integrate such data into the national account (green gross domestic product or GDP) of a country (Table 2.1).

Valuation of ecosystem services at the required spatial and/or temporal scale requires the use of appropriate valuation methods. In the valuation literature, the common methods to value ecosystem services can be classified into revealed

3 Soil nutrient depletion refers to the decline in soil nutrients due to higher nutrient outputs (through leaching, erosion, crop harvest, etc.) than nutrient inputs (through manure, mineral fertiliser, fallow, rainfall, atmospheric deposition, etc.), resulting in a negative nutrient balance.

4 Soil nutrient losses refer to the amount of soil nutrients lost through gaseous exchanges, leaching, erosion, immobilisation (fixation), and also includes crop and animal residues not recycled. In the calculation of soil nutrient balance, nutrient loss is estimated indirectly as: nutrient inputs + nutrients depleted from the soil - nutrient outputs in the crop.

TABLE 2.1:

Description of components of the Total Economic Value of agricultural ecosystem services

Value	Sub-value	Description	Examples	Flow/ stock	Ecosystem service
Use	Direct	Goods and services that directly accrue to the consumers from direct use or interaction with the agricultural ecosystem resources and services.	Food	Stock	Provisioning
			Fiber	Flow	
			Energy crops		
			Recreation and tourism of agricultural landscapes		Cultural
	Indirect	Functions of agricultural ecosystems that accrue indirectly as support and protection to economic activity and property.	Education, research, aesthetic, and spiritual values		
			Carbon sequestration		Regulating
			Carbon stock	Stock	
			Soil erosion protection, water purification, etc.	Flow	Supporting
			Nutrient cycling		
			Nutrient stock	Stock	
	Option	Future uses of the agricultural land or its biodiversity and other functions.	Biodiversity	Stock	PCRS
Non-Use	Existence	The intrinsic values that non-users are willing to pay purely for the existence of the agricultural ecosystem resources and services.	The demand of non-users for conservation of agricultural ecosystem resources and services etc.	Stock	PCRS
	Bequest	People's willingness to pay for ensuring that agricultural ecosystem resources and services will be preserved for the welfare of future generations.	Biodiversity; areas of scenic beauty	Stock	PCRS
Land conversion value		*Agricultural ecosystems may be converted to other land uses (e.g. forest, infrastructure like road, or mining site).*	*The net benefit from alternative land uses*	*Stock/ flow*	*PCRS*

Source: Adapted from (Pearce 1993, CBD 2007, MEA 2005).

preference and stated preference approaches. The revealed preference method includes a variety of approaches like use of market price, effects on production, replacement cost, travel cost, hedonic pricing, opportunity cost, damage cost, and averted expenditure whereas the stated preference approach involves contingent valuation and choice experiments (Garrod and Willis 1999, CBD 2007, Noel and Soussan 2010). Further details on TEV and the revealed and stated preference valuation methods can be found in Tilahun et al. (2018) and ELD and UNEP (2015).

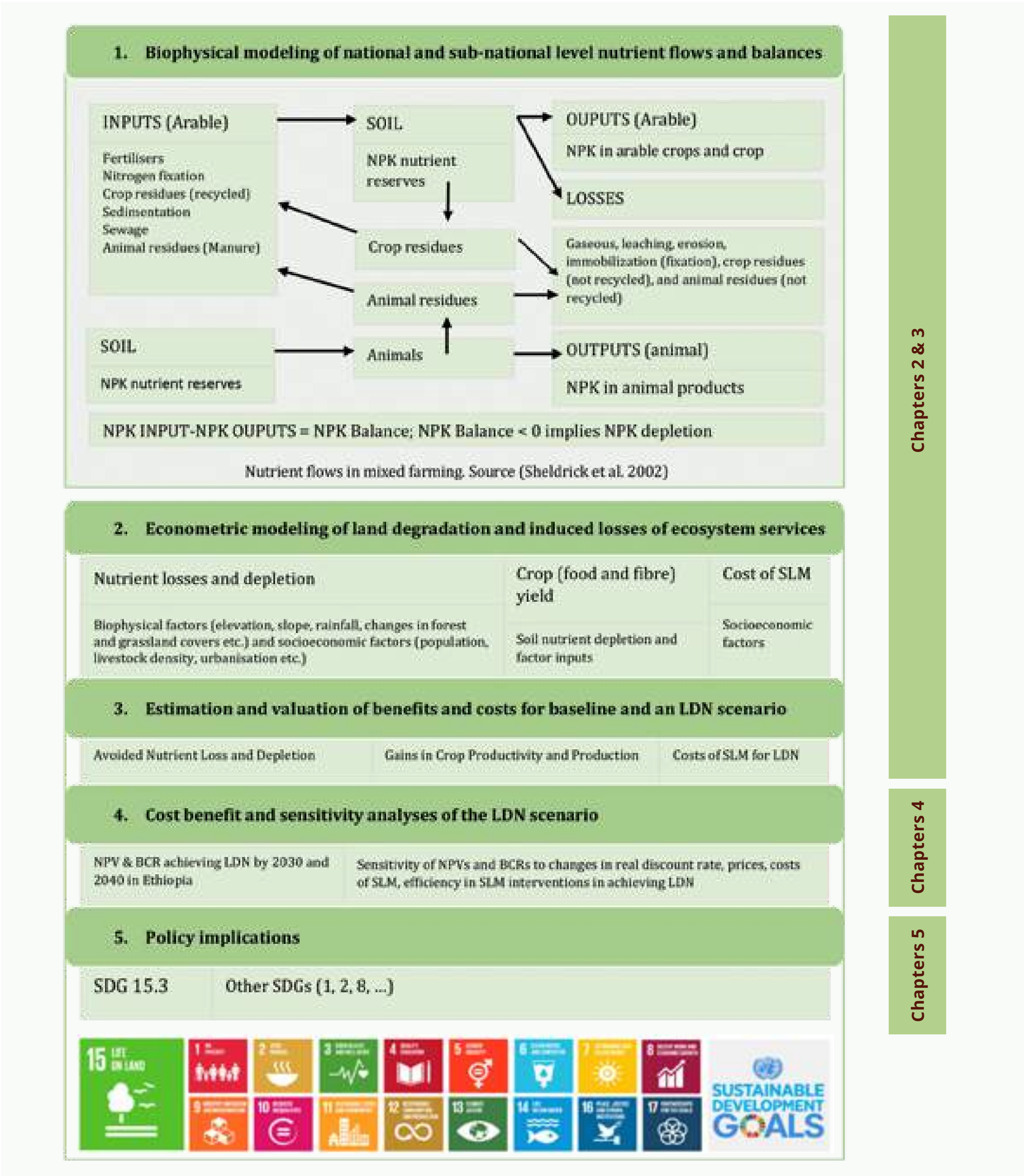
2.3. Materials and methods with results

2.3.1. Conceptual framework

The modelling, estimation, valuation, CBA and derivation of policy implications were guided by the conceptual framework described in ELD and UNEP (2015) and Tilahun et al. (2018). The conceptual framework (Figure 2.1) provides flows of modelling approaches that integrate biophysical modelling of soil nutrient auditing with econometric modelling approaches and CBA. The conceptual framework also highlights how the steps used in the analysis are related to the chapters of the study and the logical flow of chapters of the study.

FIGURE 2.1:

Conceptual framework of analysis adapted from ELD and UNEP (2015) and Tilahun et al. (2018).



In addition to the above conceptual framework, the study is delimited by the assumption indicated in Box 1 below.

BOX 1:

Assumptions and limitations of the ELD Ethiopia study

Assumptions and limitations

1. Land degradation influences society through its on-site and off-site impacts. We have considered only the on-site impacts.
2. Amongst the on-site impacts, flows of various ecosystem services are impaired. Due to unavailability of data at the appropriate scale for all administrative zones of Ethiopia, we have focused only on nutrient loss and soil nutrient depletion from croplands cultivated by smallholder farmers. The study does not cover commercial farms.
3. Land degradation on croplands has been approximated with the loss of N, P, and K nutrients and soil N, P, and K depletion. The model in the study allows for the assessment of the impact of biophysical factors (e.g., forest cover, sparse vegetation cover, grassland cover) on agricultural land degradation.
4. Changes in productivity due to changes in the nutrient depletion and nutrient losses have been fully captured.
5. The study relies on crop production data of croplands cultivated by smallholder farmers in the main production season (Meher season) of the country and does not cover the minor production season (Belg season).
6. Data used in the analysis do not explicitly capture and explain spatial variability within an administrative zone.
7. In conclusion, this estimate is very conservative and would fall in the lower bound.

Source: adapted from ELD and UNEP 2015, Tilahun et al. 2018.

2.3.2. Biophysical modelling and modelling results of nutrient auditing in cropland

Soil fertility is one of the key production factors for most farmers in developing countries. Soil nutrient depletion and nutrient losses, which are the major problems of soil degradation, are affecting negatively the current and future food production. Soil nutrient depletion and losses cannot be visualised easily, and indicators are often used to assess trends and levels of soil fertility so that soil fertility management intervention could be made. Soil nutrient balances are a commonly used indicator and are defined as the difference between the sum of nutrient input flows and the sum of nutrient output flows within a specific system (field, farm, nation, continent, or global) over a certain period of time. Soil nutrient balances reflect the net change in soil fertility and indicate trends in time. According to Powlson (1997), Johnston and Cameron introduced the first accounting of national level soil nutrient balance in the United Kingdom in 1877. Stoorvogel and Smaling (1990) reported soil nutrient balances of 35 Sub-Saharan African countries including Ethiopia. The work of Stoorvogel and Smaling (1990) provides details on the technical accounting and auditing of national scale nutrient balances.

Regional and global level studies on soil nutrient balances are also available in the work of Sheldrick et al. (2002). This study provides a conceptual framework for auditing national and regional level nutrient balances using mainly relevant national level data available in the FAO database. Tilahun et al. (2018) have applied the methods in Sheldrick et al. (2002) and reported soil nutrient balances for 44 Asian countries for the period 2002 to 2013.

The latest national level soil nutrient balance available for Ethiopia is from the work of Stoorvogel and Smaling (1990) that reported -41 kg N, -6 kg P and -26 kg K per hectare per year, which is among the highest nutrient depletion rates for Sub-Saharan Africa (Stoorvogel and Smaling 1993). Recent work by Van Beek et al. (2016) reported nutrient balances from farm plot level studies in the highlands of Ethiopia and their work indicated average N, P, and K balances of -23 ± 73, 9 ± 29 and -7 ± 64 kg/ha, respectively.

To our knowledge, the existing studies on nutrient balance in Ethiopia mostly focus on the highland parts of the country (eg. Aticho et al. 2011, Elias and Scoones 1999, Elias et al. 1998, Haileslassie et al. 2006) and there is no recent nutrient balance study at national and regional levels that covers most administrative zones in the country. Such a study could help designing policies for soil fertility management. Such kind of study at different special scales aligned with the administrative structure in the country would benefit detail planning and implementation of interventions of soil fertility management. Furthermore, such a study is important to carry out further studies and develop national scale econometric models of nutrient depletion and nutrient losses by relating them with national/regional/zonal level biophysical and socioeconomic factors. As indicated in the conceptual framework (Figure 2.1) such study results could also be used to assess the impact of soil nutrient depletion and soil nutrient losses on aggregate crop production and productivity and hence could be used in further cost-benefit analyses of SLM interventions. Thus, this study applies the conceptual framework of national level soil nutrient auditing described in Stoorvogle and Smaling (1990) and Sheldrick et al. (2002) and later applied in Tilahun et al. (2018) to conduct nutrient auditing in cultivated lands of Ethiopia.

This study mainly uses data (on crop production, harvested area, livestock population, livestock product production, fertiliser use) from the Central Statistical Authority (CSA) for the main production seasons of 2003/2004 to 2015/2016. The study also uses data on rainfall and population for the period 2003- 2016 from the database of AidData[5] that provides access to zonal level geospatial data. Using these data from the indicated sources, we calculate NPK nutrient balances and evaluate the trends in nutrient depletion in cropland of the 66 administrative zones in the 9 regional states and in 1 city administration of Ethiopia from 2003 to 2016. Further detail on the methodology of nutrient auditing can be found in Sheldrick et al. (2002) and Stoorvogle and Smaling (1990).

The scope of this nutrient auditing covers croplands cultivated with 52 crop types of which 8 are cereals, 11 are pulses, 6 are oil seeds, 7 are vegetable crops, 8 are root and tuber crops, 8 are fruit types, and 3 are other crops. According to the CSA database,6 the average land area cultivated with these 52 crops was about 12.77 million hectares (ha) per year (yr) over the period 2003-2016 (Annex Table A2.1) covering the main production seasons7 of 2003/04 to 2015/2016. In the main production season of 2015/2016, the total area cultivated with these crops was on average 14 million hectares, accounting for almost 14 per cent of the total land area of the country. Land cultivated with cereals accounts for the highest (70 per cent) of the 12.77 million hectares (Figure 2.2B and Figure 2.3) followed by pulses (14 per cent) and oil crops (7 per cent). The other crop categories together cover the remaining 9 per cent of the 12.77 million hectares of cultivated land (Figures 2.2A and 2.2B). In terms of average annual production, the country produced 24.21 million tons per year (1.89 tons/ha/yr) over the indicated period, with cereal production accounting for 71 per cent of the production, followed by vegetables (10 per cent) and pulses (8 per cent). The oil seeds, root and tuber crops, fruits, and other crops together account for 11 per cent of the average annual production (Figures 2.2A and 2.2C).

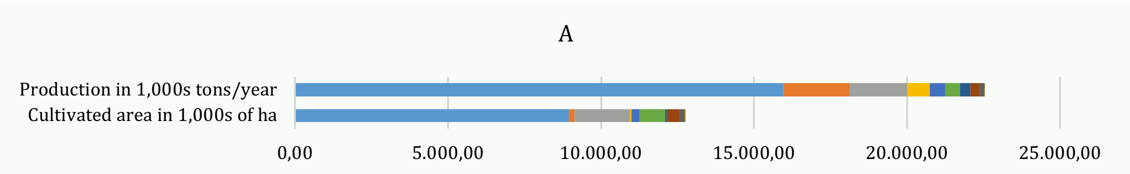
5 *Goodman, S., BenYishay, A., Runfola, D., 2016. Overview of the geo Framework. AidData. Available online at geo.aiddata.org. DOI: 10.13140/RG.2.2.28363.59686*

6 *Central Statistical Agency of the Federal Democratic Republic of Ethiopia:* www.csa.gov.et

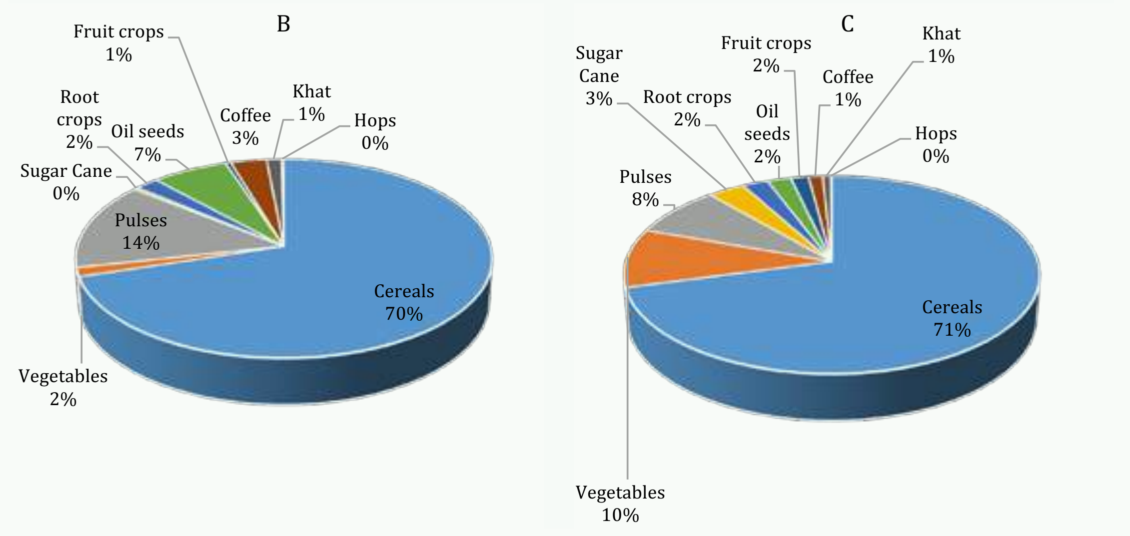
7 *The main production season "Meher season" in Ethiopia is the period from September to February.*

FIGURE 2.2:

Average crop production for the study period 2003-2016 in Ethiopia.



	Cultivated area in 1,000s of ha	Production in 1,000s tons/year
Cereals	8.943,66	15.961,40
Vegetables	189,18	2.169,55
Pulses	1.807,71	1.865,53
Sugar Cane	50,42	741,99
Root crops	260,55	509,92
Oil seeds	849,67	475,29
Fruit crops	60,37	352,48
Coffee	399,18	282,52
Khat	165,77	158,32
Hops	26,35	24,64



(A) Average annual cultivated area and crop production by crop categories; (B) Distribution of average annual cultivated area of 12.77 million hectares by crop categories; (C) Distribution of average crop production of 24.54 million tons per year by crop categories.

FIGURE 2.3:

Average cereal production (15.96 million tons per year) and average crop land cultivated with cereals (8.94 million hectares per year) by cereals type from 2003-2016.

	Cultivated area in 1,000s of ha	Production in 1,000s tons/year
Teff	2.557,14	3.180,06
Barley	1.003,55	1.562,86
Wheat	1.504,48	2.782,02
Maize	1.790,87	4.717,29
Sorghum	1.576,77	3.007,79
Fingermillet	419,12	494,46
Oats	55,81	38,81
Rice	35,93	39,55

2.3.2.1. Results of NPK auditing

National and regional level NPK inputs, outputs, balances, and losses: Figure 2.4 shows the average **NPK inputs** and **NPK outputs** over the main production seasons of the study period 2003/2004-2015/2016 in the nine regional states and one city administration of Ethiopia. The country-level average annual flows of NPK input was 2.01 million tons (Figure 2.4) over the indicated period.

NPK input flow from soils accounts for the largest share (38.3 per cent) followed by NPK inputs from manure (35 per cent) and NPK inputs from commercial fertiliser application (13.15 per cent). Crop residues, biological fixation, sewage, and atmospheric deposition together account for 13.55 per cent of the 2.01 million tons of annual flows of NPK inputs in the 12.77 million hectares of cropland in the country (Figure 2.4). The average annual NPK inputs in the four regional states (Oromia, Amhara, SNNP, and Tigray) amounts to 97.28 per cent of the total 2.01 million tons of country level NPK inputs, with Oromia comprising the largest share (49.42 per cent) followed by Amhara (30.76 per cent), SNNP (11.08 per cent), and Tigray (6.03 per cent). The other five regions (Benishangul Gumuz, Somalie, Afar, Harari, Gambella) and the Dire Dawa city administration together account for only 2.72 per cent of the annual country level NPK inputs. These regional differences are mainly due to differences in cultivated land area and levels of crop production. For example, out of the total 12.77 million hectares of cultivated area in the country, the four regions account for 97.19 per cent of the cultivated land whereas the other regions hold only 2.81 per cent.

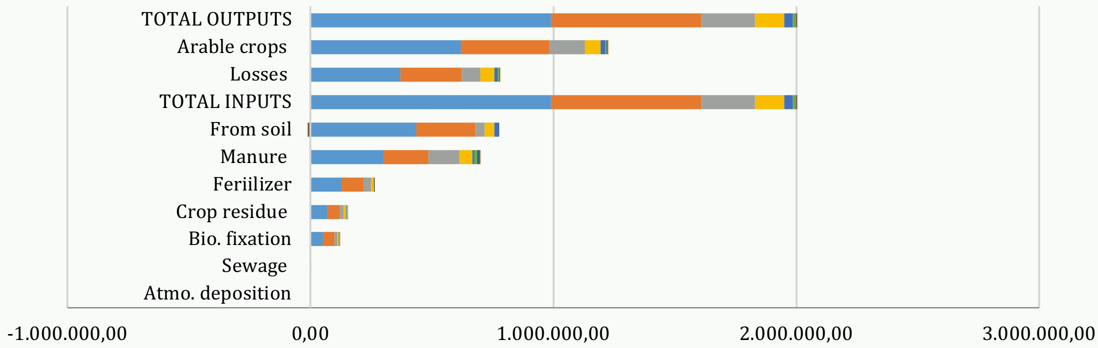
The average country level **NPK nutrient balance**, which is a negative NPK input flows from soils, was -0.77 million tons per year for the period 2003/2004 to 2015/2016 (Figure 2.4). The country-level NPK balance in 2003/2004 was less than a quarter of a million ton (-0.19 million tons), which was a depletion of 0.19 million tons, and the balance drastically declined to -1.25 million tons in 2015/2016, indicating an increasing trend in soil NPK depletion (Figure 2.6A). On a per hectare basis, the country-level soil NPK balance was -21.12 kg/ha in the 2003/2004 production year and it reached -76.70 kg/ha in the production year 2015/2016, indicating a rise in NPK depletion from soils (Figure 2.6B).

The sum of average annual NPK depletion in the four regional states (Oromia, Amhara, SNNP, and Tigray) accounts for 98.49 per cent of the total 0.77 million tons of country level NPK depletion, with Oromia taking the largest share (56.85 per cent) followed by Amhara (31.64 per cent), Tigray (5.13 per cent), and SNNP (4.88 per cent). The other five regions (Benishangul Gumuz, Somalie, Afar, Harari, Gambella) and the Dire Dawa city administration together amount to only 1.51 per cent of the annual country-level NPK depletion. However, on a per hectare basis, the NPK depletion was 60.13 kg/ha/year nationally and the highest depletion rate was in Benishangul Gumuz (99.97 kg/ha/yr). It was followed by Oromia (72.23 kg/ha/yr), Amhara (59.22 kg/ha/yr), Tigray and SNNP. In contrast, the other regions (Afar, Gambella, Somalie) and Dire Dawa city administration showed positive soil NPK balances (Figure 2.5), which was mainly due to the fact that the share of land cultivated in these regions is very small relative to the others. Moreover, the three regions have large livestock populations relative to their cultivated land; hence, manure from livestock consisted of the largest share of NPK input flows (Figure 2.4). The major crop producing regions (Oromia, Amhara, SNNP, and Tigray) showed an increasing trend in NPK depletion over the period 2003/2004 to 2015/2016 (Figures 2.6A and 2.6B).

NPK nutrient outputs should balance with nutrient inputs in nutrient auditing indicating that the total nutrient inputs should equal total nutrient outputs. Nutrient outputs in arable crops amounted to 61.08 per cent of the total 2.01 million tons of NPK outputs whereas **NPK losses** through erosion, gaseous exchange, and leaching accounted for the remaining 38.93 per cent – or 0.77 million tons per year (Figure 2.4). The nutrient auditing model stated in Sheldrick et al. (2002) does not allow calculating NPK loss directly, but it is possible to calculate NPK loss indirectly after determining NPK depletion. As stated in Sheldrick et al. (2002), we calculated total nutrient loss as the difference between nutrient inputs plus nutrients depleted from the soil, and nutrient outputs in the crop. In the production year of 2003/2004, NPK losses were 0.430 million tons or 46.82 kg/ha at country level. The figures increased to 1.15 million tons or 70.85 kg/ha

FIGURE 2.4:

Average annual inputs and outputs of NPK nutrients in tons per year by regional state of Ethiopia from 2003-2016.



	Atmo. deposition	Sewage	Bio. fixation	Crop residue	Feriilizer	Manure	From soil	TOTAL INPUTS	Losses	Arable crops	TOTAL OUTPUTS
Oromia	17,82	76,48	51.446,34	72.374,02	129.170,68	301.435,63	436.598,47	991.119,44	370.993,44	620.125,98	991.119,42
Amhara	12,16	52,93	48.485,62	49.349,06	90.514,26	185.481,96	243.004,54	616.900,53	253.007,47	363.895,58	616.903,05
SNNP	4,44	39,19	12.145,39	14.682,76	29.489,44	128.331,64	37.483,52	222.176,39	76.673,71	145.502,67	222.176,38
Tigray	1,92	8,28	5.113,15	11.093,20	13.143,84	52.111,29	39.383,67	120.855,35	56.468,73	64.386,64	120.855,36
Benishangul Gumuz	0,74	0,48	1.925,80	2.845,95	893,57	6.986,45	22.162,88	34.815,85	14.269,94	20.550,70	34.820,64
Ethiopian Somalie	0,13	12,80	244,20	959,10	0,00	13.510,72	-2.922,77	11.804,18	5.912,51	5.891,67	11.804,18
Afar	0,03	0,02	65,90	252,46	3,73	6.792,62	-3.431,32	3.683,44	1.264,52	2.418,92	3.683,44
Harari	0,04	0,84	142,71	124,59	474,97	3.423,49	-2.563,20	1.603,43	796,96	806,47	1.603,43
Gambella	0,04	0,04	43,42	111,38	50,70	2.815,29	-1.604,22	1.416,65	559,39	857,26	1.416,65
Dire Dawa	0,03	0,42	57,36	142,18	0,41	1.058,88	-69,83	1.189,46	724,93	464,53	1.189,46

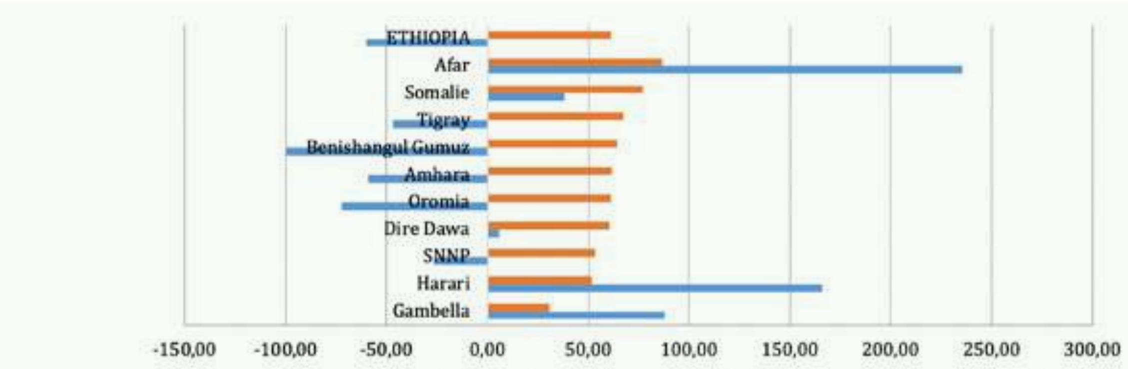
in the year 2015/2016 (Figures 2.7A and 2.7B). NPK loss showed an increasing trend in the largest producing regions (Figures 2.7A and 2.7B).

Close to 97 per cent of the NPK loss was in the four regions with Oromia accounting for 47.52 per cent, followed by Amhara (32.41 per cent), SNNP (9.82 per cent) and Tigray (7.23 per cent) of the annual national NPK loss. The national NPK loss was on average 61.12 kg/ha/year over the period 2003/2004 to 2015/2016 (Figure 2.5). The NPK loss per hectare was the highest in Afar (86.73 kg/ha/yr) followed by Somalie (77.08 kg/ha/yr), Tigray (67.46 kg/ha/yr), and Benishangul Gumuz (64.25 kg/ha/yr) whereas the lowest was in Gambella (30.72 kg/ha/yr) (Figure 2.5).

Readers interested in NPK balances and NPK losses per hectare and average cultivated area at zonal administrative level can consult Annex Table A2.2, which provides detailed results of average annual NPK depletion and losses from cultivated lands of smallholder farmers as well as the average cultivated cropland by smallholder farmers in the 66 administrative zones covered in this study.

FIGURE 2.5:

Average annual NPK depletion and losses per hectare from cultivated cropland by regional state of Ethiopia from 2003-2016.



	Gambella	Harari	SNNP	Dire Dawa	Oromia	Amhara	Benishangul Gumuz	Tigray	Somalie	Afar	ETHIOPIA
Losses in kg/ha/yr	30,72	51,64	53,65	60,35	61,38	61,66	64,25	67,46	77,08	86,73	61,12
NPK depletion in kg/ha/yr	88,10	166,08	-26,23	5,81	-72,23	-59,22	-99,79	-47,05	38,10	235,34	-60,13

FIGURE 2.6:

Trends in soil NPK balance at country, regional, and city administration level in Ethiopia from 2003-2016. (A) Aggregate soil NPK balance; (B) Per hectare level soil NPK balance.

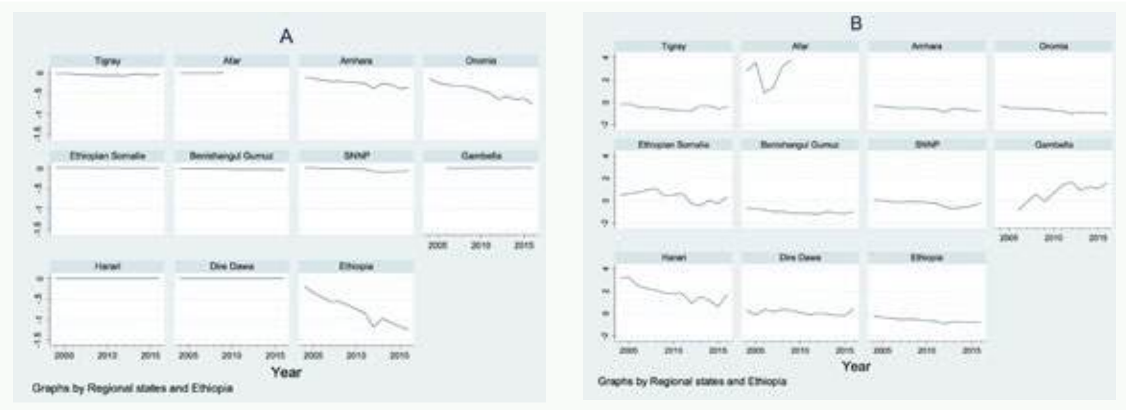
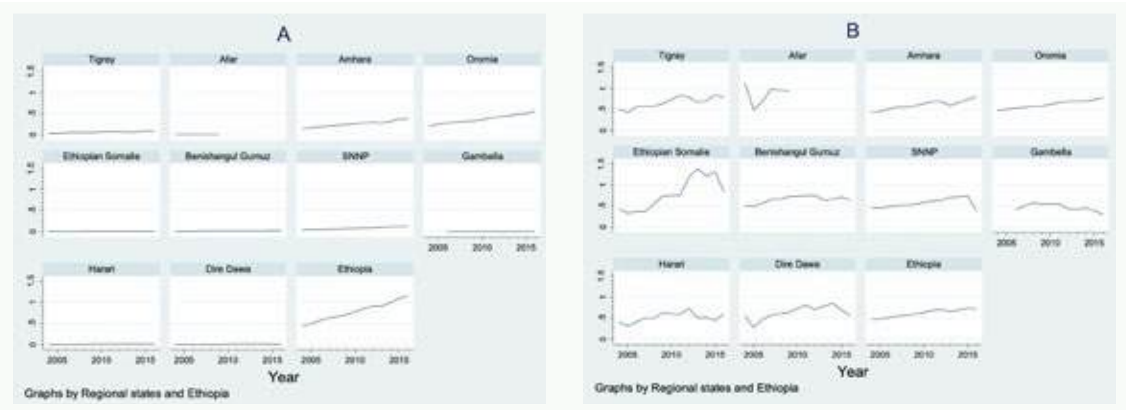


FIGURE 2.7:

Trends in NPK losses at country, regional, and city administration level in Ethiopia from 2003-2016. (A) Aggregate NPK loss; (B) Per hectare level NPK loss.



2.3.3. Econometric modelling of nutrient losses and soil nutrient depletion

Results of the soil NPK auditing in section 2.3.2 above indicate the levels and trends of soil NPK depletion and NPK losses at national, regional, and zonal administrative levels of Ethiopia. The derived information can only provide the level of NPK nutrient flows and balances for the period of the study for which the NPK auditing was made. Relating the results of the NPK auditing as indicators of agricultural land degradation with socioeconomic and biophysical factors using econometric modelling approaches will allow for the inclusion of results of NPK nutrient auditing into policy analyses (Tilahun et al. 2018). In addition, econometric models of NPK nutrient depletion and NPK losses could be used as alternative approaches to estimate and predict future levels using country/regional and/or zonal level socioeconomic and biophysical factors as predictor variables. Thus, the next sub-sections provide details on the data used for developing national level econometric models of soil NPK depletion and NPK loss as proxy variables of agricultural land degradation. Estimation results using the models are also presented at the end of this section.

2.3.3.1. Data, the empirical models, and results

The data used to develop econometric models of NPK nutrient depletion and NPK nutrient loss include the results of NPK depletion and NPK loss from the nutrient auditing for the study period 2003-2016 and zonal level socioeconomic and biophysical data for the same period from CSA and databases of AidData.org.
The NPK depletion and NPK loss at zone levels are used as a panel of dependent variables in the econometric modelling. Based on literature on the proximate and underlying causes of land degradation (Kirui and Mirzabaev 2014), panel data on socioeconomic factors (livestock population[8], human population[9], composites of night-time lights[10]) and biophysical factors such as land cover (sparse vegetation, grasslands, forest cover and/or forest cover per capita), precipitation, elevation, and physical slope[11] were collected for each of the 66 administrative zones for the period 2003/2004-2015/2016.

Following the econometric modelling approach in ELD and UNEP (2015) and Tilahun et al. (2018) and based on literature on the drivers of land degradation, the econometric model of nutrient depletion and/or nutrient loss from agricultural ecosystems in Ethiopia can be modelled as:

$$NPK_{it}=\alpha_0 + \alpha_1 X_{1it} + \alpha_2 X_{2it} + \varepsilon_{it} \qquad (2.1)$$

Where:

- NPK_{it} is the annual soil NPK nutrient loss depletion and/or NPK loss both in 1,000s tons per year, as indicators of degradation of supporting agricultural ecosystem services, for administrative zone i in Ethiopia over the time period t where t = 2003/2004, 2004/2005… 2015/2016;
- X_{1it} is a vector of administrative zone level socioeconomic factors (livestock density in 1,000s of tropical livestock units per hectare of agricultural land, human population in millions, and composites of night-time lights as proxies of urbanisation) for administrative zone i in Ethiopia over time period t where t = 2003/2004, 2004/2005… 2015/2016;
- X_{2it} is a vector of administrative zone level biophysical factors (sparse vegetation cover in hectares, grassland cover in millions of hectares, forest cover in hectare per capita, elevation, slope, and precipitation) for administrative zone i in Ethiopia over time period t where t = 2003/2004, 2004/2005… 2015/2016;
- α_0 to α_3 are parameters to be estimated from empirical data; and ε_{it} is the error or stochastic term that captures the effect of unobserved factors in country i over time period t where t = 2003/2004, 2004/2005 … 2015/2016.

8 *Central Statistical Agency of the Federal Democratic Republic of Ethiopia: www.csa.gov.et*

9 *Central Statistical Agency of the Federal Democratic Republic of Ethiopia: www.csa.gov.et*

10 *Goodman, S., BenYishay, A., Lv, Z., & Runfola, D. (2019). GeoQuery: Integrating HPC systems and public web-based geospatial data tools. Computers & Geosciences, 122, 103-112.*

11 *Goodman, S., BenYishay, A., Runfola, D., 2016. Overview of the geo Framework. AidData. Available online at geo.aiddata.org. DOI: 10.13140/RG.2.2.28363.59686.*

The study includes the above socioeconomic and biophysical factors in the econometric modelling of NPK depletion and NPK loss with the anticipation that the socioeconomic factors will have a significant correlation with both NPK depletion and NPK loss, but we did not set prior expectation or hypotheses on the directions of the correlations. However, in the case of the biophysical factors, our first hypothesis was that administrative zones with relatively larger land areas covered with sparse vegetation and grasslands, and with higher forestland per capita will have a relatively lower level of NPK depletion in their cultivated lands as well as lower levels of NPK losses from their cultivated land areas. In addition, we anticipated positive and statistically significant correlations between precipitation and NPK depletion, and precipitation and NPK loss. We also expected that both elevation and slope would be positively and significantly correlated with NPK depletion as well as NPK loss.

Based on Equation 2.1, the data on the biophysical and socioeconomic factors, and some of the hypotheses indicated in the above paragraph, we did model specification tests for variants of econometric models that ranged from simple OLS to panel data fixed effect and random effect regression models. Table 2.2 shows the results for the soil NPK depletion model whereas Table 2.3 shows the model for NPK loss.

TABLE 2.2:

Models of soil NPK depletion

	OLS (Robust SE)	Fixed effect	Random effect	Restricted fixed effect
Ln-NPK_depletionin1000sTonc				
Ln-LivstkDensity1000sT-LUpHaAgriL	-0.05(0.01) [-3.58]a	-0.07(0.03) [-2.34]b	-0.05(0.03) [-1.65]c	-0.07(0.03) [-2.93]a
Ln-PopulationinMillions	0.27(0.02) [11.68]a	0.25(0.05) [4.75]a	0.27(0.05) [5.16]a	0.26(0.03) [8.54]a
Ln-PopulationinMillionSqr	0.07(0.02) [4.41]a	0.07(0.02) [3.90]a	0.07(0.02) [4.19]a	0.07(0.01) [4.85]a
v4composites_calibrated_count	7.97E-06 (1.42E-06) [5.62]a	8.98E-06 (2.78E-06) [3.23]a	7.97E-06 (2.76E-06) [2.88]a	6.95E-06 (1.98E-06) [3.35]a
v4composites_calibrated_mean	-0.09(0.05) [-1.79]c	-0.08(0.09) [-0.88]	-0.09(0.09) [-0.97]	
v4composites_calibrated_max	0.01(0.01) [0.98]	0.01(0.003) [4.09]a	0.01(0.003) [3.76]a	0.01(0.002) [4.46]a
v4composites_calibrated_min	(omitted)	(omitted)	(omitted)	
v4composites_calibrated_sum	-1.09E-04 (1.38E-04) [-0.80]	-1.24E-04 (1.85E-05) [-6.73]a	-1.09E-04(1.82E-05) [-6.00]a	-1.24E-04 (1.69E-05) [-7.35]a
Ln-sparsevegetationHa	-0.01(0.001) [-4.13]a	-0.01(0.002) [-1.94]c	-0.01(0.002) [-2.19]b	-0.004(0.002) [-2.09]b
grasslandMillionssHa	0.04(0.09) [0.44]	-0.002(0.21) [0.01]	0.04(0.20) [0.200]	
Ln-forestHapercapita	0.02(0.02) [0.98]	0.03(0.03) [1.02]	0.02(0.03) [0.71]	
srtm_elevation_500mnonemean	3.61E-05 (1.14E-04) [0.32]	9.75E-05 (1.10E-04) [0.89]	3.61E-05(1.09E-04) [0.33]	

	OLS (Robust SE)	Fixed effect	Random effect	Restricted fixed effect
srtm_elevation_500mnonemax	-4.02E-05 (2.63E-05) [-1.53]	-4.93E-05 (5.97E-05) [-0.83]	-4.02E-05(5.98E-05) [-0.67]	
srtm_elevation_500mnonemin	6.74E-05 (8.44E-05) [0.80]	5.03E-05 (1.16E-04) [0.44]	6.74E-05(1.15E-04) [0.59]	
udel_precip_mean2002mean	0.01(0.001) [4.90]a	0.01(0.002) [3.19]a	0.01(0.002) [3.26]a	0.01(0.001) [3.92]a
udel_precip_mean2002max	-0.01(0.001) [-5.80]a	-0.01(0.002) [-3.76]a	-0.01(0.002) [-3.53]a	-0.01(0.001) [-3.63]a
udel_precip_mean2002min	-3.39E-04(0.001) [-0.58]	-0.001(0.002) [-0.60]	-3.39E-04(0.002) [-0.22]	
Ln-srtm_slope_500mnonemean	0.02(0.02) [0.75]	0.04(0.06) [0.64]	0.02(0.06) [0.30]	
srtm_slope_500mnonemax	-0.004(0.003) [-1.53]d	-0.01(0.005) [-1.39]	-0.004(0.01) [-0.88]	
srtm_slope_500mnonemin	-0.024(0.826) [-0.030]	-0.41(0.85) [-0.48]a	-0.02(0.85) [-0.03]	
_cons	3.57(0.19) [18.91]a	3.55(0.34) [10.54]a	3.57(0.33) [10.92]a	3.27(0.16) [20.55]a
N	756	756	756	756
F(df, N)	59.04a	10.46a		
R2	0.21	0.20	0.21	0.20
Adj.R2				
Root MSE	0.51			
Mean VIF	5.12			
No. of groups (Year: 2003/4 to 2015/16)		12	12	12
Wald chi2			190.22a	21.37a
Log_L				
R2 within		0.22	0.21	0.21
R2 between		0.17	0.001	0.03
Corr(u_i, xb)		-0.07		-0.04
F test u_i=0, F(df,N)		2.26b		2.03b
Hausman Test (chi2)			23.82a	20.96a

Values in () are standard errors, values in [] are t-statics for the OLS and fixed effect models, and z-statistics for the other models. Significance levels: a < 1 %, b < 5 %, c < 10 %, d < 15 %.

TABLE 2.3:

Models of soil NPK loss

	OLS (Robust SE)	Fixed effect	Random effect	Restricted fixed effect
Ln-NPK_Lossin1000sTonnc				
TLUin1000s	-0.003(0.001) [-2.45]b	-0.003(0.001) [-3.62]a	-0.003(0.001) [-2.88]a	-0.003(0.001) [-4.19]a
squaredTLUin1000s	4.86E-07 (1.87E-07) [2.60]a	4.91E-07(1.94E-07) [2.53]b	4.86E-07 (1.98E-07) [2.45]b	5.32E-07 (1.83E-07) [2.92]a
Ln-PopulationinMillions	1.83(0.61) [2.98]a	2.03(0.55) [3.68]a	1.83(0.55) [3.30]a	1.75(0.46) [3.82]a
Ln-PopulationinMillionSqr	-0.63(0.24) [-2.65]a	-0.49(0.18) [-2.77]a	-0.63(0.18) [-3.52]a	-0.51(0.17) [-3.10]a
v4composites_calibrated_mean	-0.45(0.59) [-0.76]	-0.14(0.80) [-0.17]	-0.45(0.81) [-0.55]	
v4composites_calibrated_count	8.45E-05 (2.44E-05) [3.47]a	8.97E-05(2.54E-05) [3.53]a	8.45E-05 (2.57E-05) [3.29]a	8.00E-05 (2.22E-05) [3.60]a
v4composites_calibrated_max	0.03(0.01) [2.35]b	0.04(0.03) [1.49]d	0.031(0.03) [1.26]	0.04(0.02) [2.47]b
v4composites_calibrated_min	(omitted)	(omitted)	(omitted)	
v4composites_calibrated_sum	1.22E-04 (7.20E-05)[1.70] c	5.53E-06 (1.66E-04) [0.03]	1.22E-04(1.67E-04) [0.73]	
Ln-sparsevegetationHa	-0.02(0.02) [-1.02]	0.01(0.02) [0.29]	-0.02(0.02) [-1.02]	
Ln-forestHapercapita	-0.48(0.25) [-1.94]c	-0.38(0.21) [-1.82]c	-0.48(0.21) [-2.33]b	-0.58(0.15) [-3.82]a
grasslandMillionssHa	-3.10(2.50) [-1.24]	-4.36(1.91) [-2.29]b	-3.10(1.90) [-1.63]d	-4.63(1.58) [-2.92]b
srtm_elevation_500mnonemean	-0.001(0.001) [-0.94]	-8.82E-06 (9.82E-06) [-0.01]	-0.001(0.001) [-0.71]	
srtm_elevation_500mnonemax	-0.001(0.001) [-1.21]	-0.001(0.001) [-1.12]	-0.001(0.001) [-1.13]	
srtm_elevation_500mnonemin	0.001(0.001) [1.18]	0.001(0.001) [1.28]	0.001(0.001) [1.23]	
Ln-udel_precip_mean2002mean	2.72(2.11) [1.29]	2.87(1.33) [2.15]b	2.72(1.35) [2.01]b	2.27(0.72) [3.14]a
udel_precip_mean2002max	-0.01(0.01) [-0.81]	-0.02(0.01) [-1.29]	-0.01(0.01) [-0.95]	
udel_precip_mean2002min	0.01(0.02) [0.93]	0.01(0.01) [0.46]	0.01(0.01) [1.01]	
srtm_slope_500mnonemean	0.34(0.14) [2.37]b	0.35(0.16) [2.20]b	0.34(0.16) [2.19]b	0.30(0.11) [2.62]a

	OLS (Robust SE)	Fixed effect	Random effect	Restricted fixed effect
srtm_slope_500mnonemax	0.09(0.05) [1.92]c	0.10(0.04) [2.37]b	0.09(0.04) [2.19]b	0.08(0.04) [2.24]b
srtm_slope_500mnonemin	6.36(7.003) [0.91]	-0.19(8.25) [-0.02]	6.36(8.35) [0.76]	
_cons	-13.89(8.03) [-1.73]c	-13.37(5.02) [-2.67]a	-13.89(5.09) [-2.73]a	-12.79(3.96) [-3.23]a
N	756	756	756	756
F(df, N)	29.52a	18.31a		
R2	0.33	0.33	0.33	0.33
Adj.R2				
Root MSE	4.63			
Mean VIF	6.80			
No. of groups (Year: 2003/4 to 2015/16)		12	12	12
Wald chi2			367.05a	
Log_L				
R2 within		0.34	0.33	0.33
R2 between		0.33	0.76	0.39
Corr(u_i, xb)		0.03		
F test u_i=0, F(df,N)		3.93a		
Hausman Test (chi2)			41.01a	43.41a

Values in () are standard errors, values in [] are t-statics for the OLS and fixed effect models, and z-statistics for the other models. Significance levels: a < 1 %, b < 5 %, c < 10 %, d < 15 %.

The results in all econometric models consistently indicate that the NPK depletion as well as NPK loss are significantly correlated with the socioeconomic factors (livestock population and/or livestock density, human population, and urbanisation measured in terms of composites of night-time lights). Among the biophysical factors, land cover variables (forest cover per capita, grassland area), precipitation, and physical slope are significantly correlated with NPK loss and only sparse vegetation cover and precipitation are significantly correlated with NPK depletion.

Following Tilahun et al. (2018), we report results of the OLS model with robust standard errors, as well as the fixed and random effect models. Our data set consists of a panel of all the responses and right-hand side variables of Equation 2.1 for the period 2003-2016. As a result, a panel data econometric model that controls the effects of each individual year in the panel is appropriate. In a panel model, the individual effect terms can be modelled as either random or fixed effects. If the individual effects are correlated with the other explanatory variables in the model, the fixed effect model is consistent, and the random effects model is inconsistent. On the other hand, if the individual effects are not correlated with the other national level explanatory variables in the model, both random and fixed effects are consistent and random effects are efficient. The Hausman test statistics for the NPK depletion model (Table 2.2) as well as the NPK loss model (Table 2.3) are significant at p-value<1 per cent, indicating that the fixed effect model is efficient. We further dropped insignificant variables from the fixed effect models in both the NPK depletion and

NPK loss models and ran a Hausman specification test for the restricted fixed models with only significant national level explanatory variables. This means that the restricted fixed effect models in both the NPK depletion and NPK loss models are efficient for estimating the NPK loss and NPK depletion.

Socioeconomic factors and land degradation

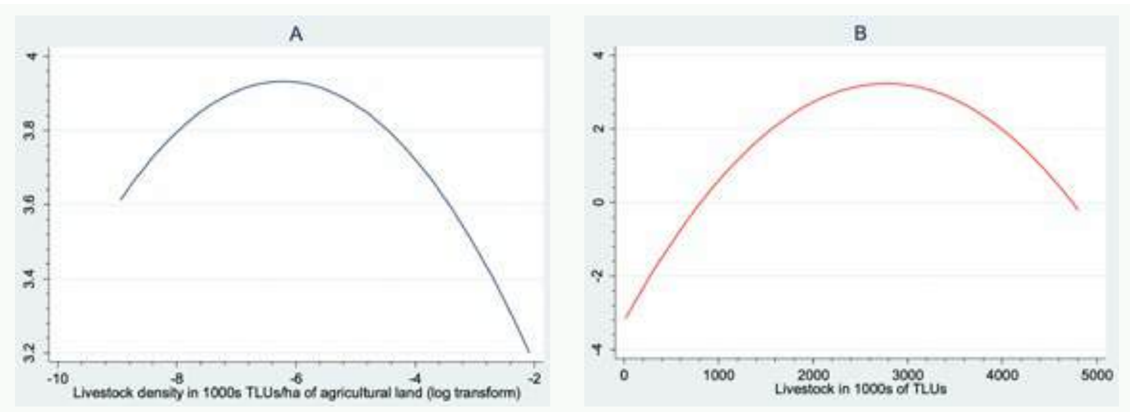
The coefficients for livestock density in 1,000s of TLU per hectare of agricultural land in the restricted fixed effect NPK depletion model (Table 2.2) and the coefficient for livestock population in 1,000s of TLU in the restricted fixed effect NPK loss model (Table 2.3) are significant at p-value<1 per cent. The direction of the effect is negative in both cases. In the case of the NPK loss model, the squared value of livestock population in 1,000s of TLUs showed a positive and statistically significant correlation with log-transformed NPK loss in 1,000s of tons. We had no expectation a priori about the direction of the effects.

Figures 2.8A and 2.8B confirm the directional relationship between log-transformed aggregate NPK depletion and log-transformed livestock density, and the relationship between log-transformed aggregate NPK loss and livestock population. In the restricted fixed effect models, the dependent variables NPK depletion in 1,000s of tons and the livestock density in 1,000s of TLUs per hectare of agricultural land are in log forms. Hence, the coefficients for the log-transformed livestock density can be interpreted as follows: keeping all other factors constant (ceteris paribus), each one-unit increase in the log-transformed livestock population density increases log-transformed NPK loss by 0.072 units. In percentage terms, ceteris paribus, a 1 per cent increase in livestock density would cause NPK depletion to decrease by about 0.07 per cent. In the case of the restricted fixed effect NPK loss model, livestock population is in linear form and therefore we have a log-linear model. In such a case, the interpretation is that a one-unit increase in livestock population causes the log-transformed NPK loss to decrease by 0.003 units. In percentage terms, 1 per cent increase in livestock population would cause NPK loss to decrease by about 0.3 per cent.

The figures below show that both NPK depletion and NPK loss increase with increasing livestock density and livestock population respectively up to a certain point at which NPK depletion and NPK loss reach maximum. Beyond these maximum levels, increases in livestock density and livestock population are associated with decline in log-transformed NPK depletion and NPK loss.

FIGURE 2.8:

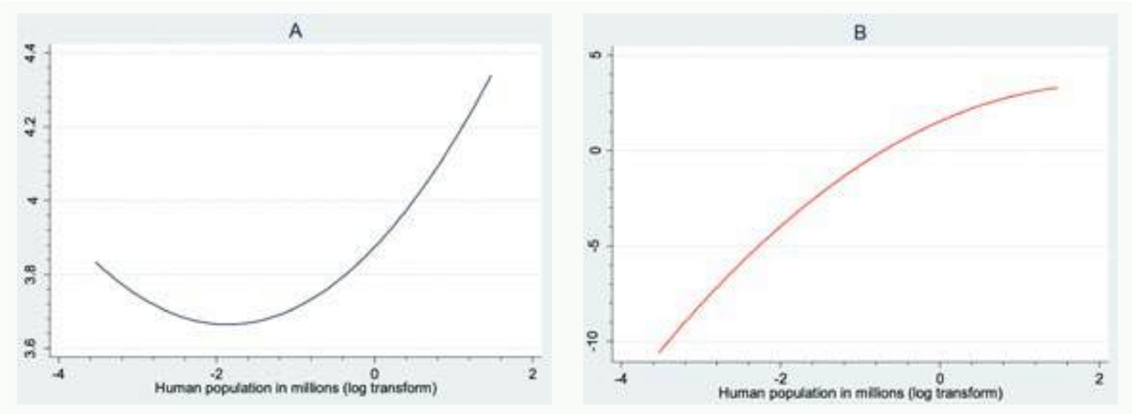
Relationship between soil NPK depletion and livestock density (A) and between NPK loss and livestock population (B).



The coefficients of log-transformed human population in millions are positive in both the NPK depletion and NPK loss models (Tables 2.2 and 2.3). This indicates that an increase in population size increases soil NPK depletion and NPK loss, and therefore exacerbates agricultural land degradation. Figures 2.9A and 2.9B show the directional relationships that human population size has with NPK depletion and NPK loss. The results of the restricted fixed effect NPK depletion and NPK loss models indicate that keeping all other factors constant (ceteris paribus), each one-unit increase in the log-transformed human population density increases log-transformed NPK depletion by 0.257 units and log-transformed NPK loss by 1.526 units. In percentage terms, ceteris paribus, a 1 per cent increase in transformed human population density would cause NPK depletion to increase by about 0.26 per cent and NPK loss to increase by 1.53 per cent.

FIGURE 2.9:

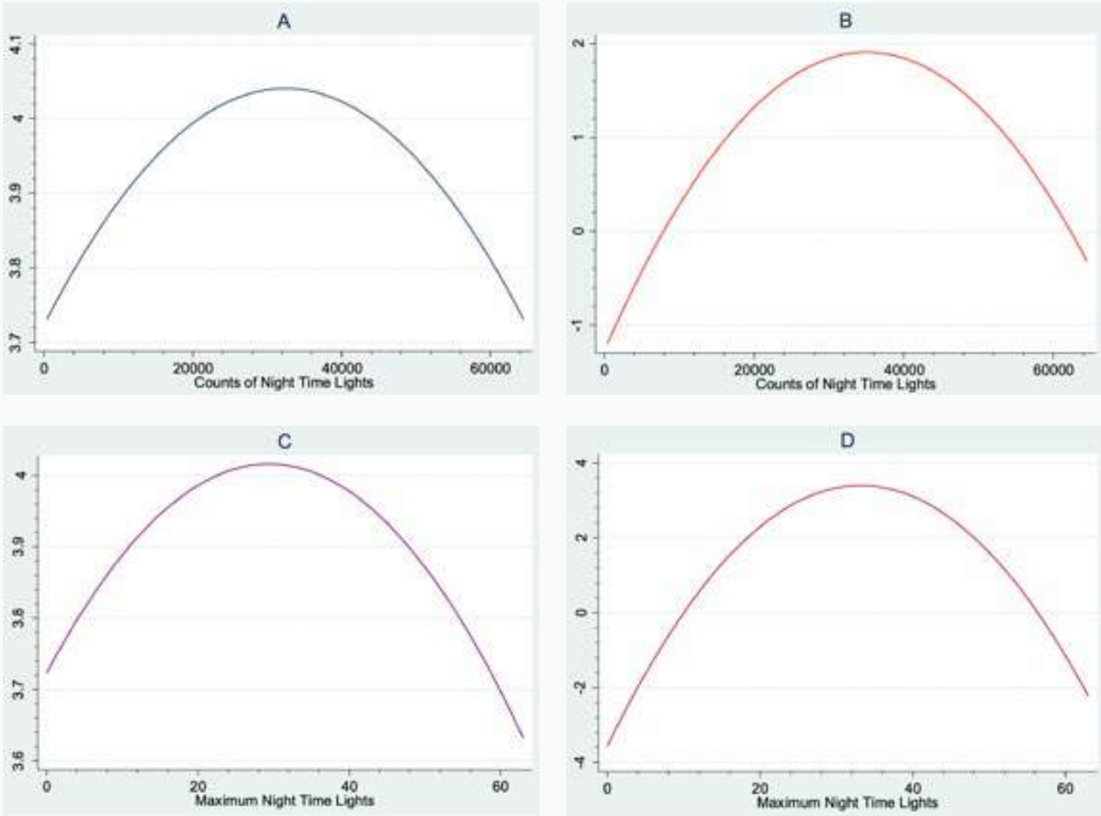
Relationship between soil NPK depletion and human population (A) and between NPK loss and human population (B).



The coefficients for the variables of night-light times, which are used as proxies of the level of urbanisation, are positive and significant especially for the counts and maximum night-light times in both the NPK depletion and NPK loss restricted fixed effect models. This implies that urbanisation to a certain extent is positively correlated with NPK depletion and NPK loss on croplands, and thus exacerbates agricultural land degradation. The concave down parabolic shapes of the Figures 2.10A to 2.10D show the directional relationship that each of the night-light times variables have with log-transformed NPK depletion and NPK loss. The figures show that both NPK loss and NPK depletion increase with increasing night-light times variables up to a certain point at which NPK depletion and NPK loss reach maximum. Beyond these maximum levels, there is a decline in log-transformed NPK depletion and NPK loss. For example, a one-unit increase in the maximum night-light times would increase the log-transformed NPK depletion by 0.01 units and the log-transformed NPK loss by 0.04 units. In percentage terms, a 1 per cent increase in the maximum night-light times would increase NPK depletion by 0.01 per cent and NPK loss by 0.04 per cent.

FIGURE 2.10:

Relationship between soil NPK depletion and counts of night-light times (A) ; between NPK loss and counts of night-light times (B); between soil NPK depletion and maximum night-light times (C); and NPK loss and maximum night-light times (D).



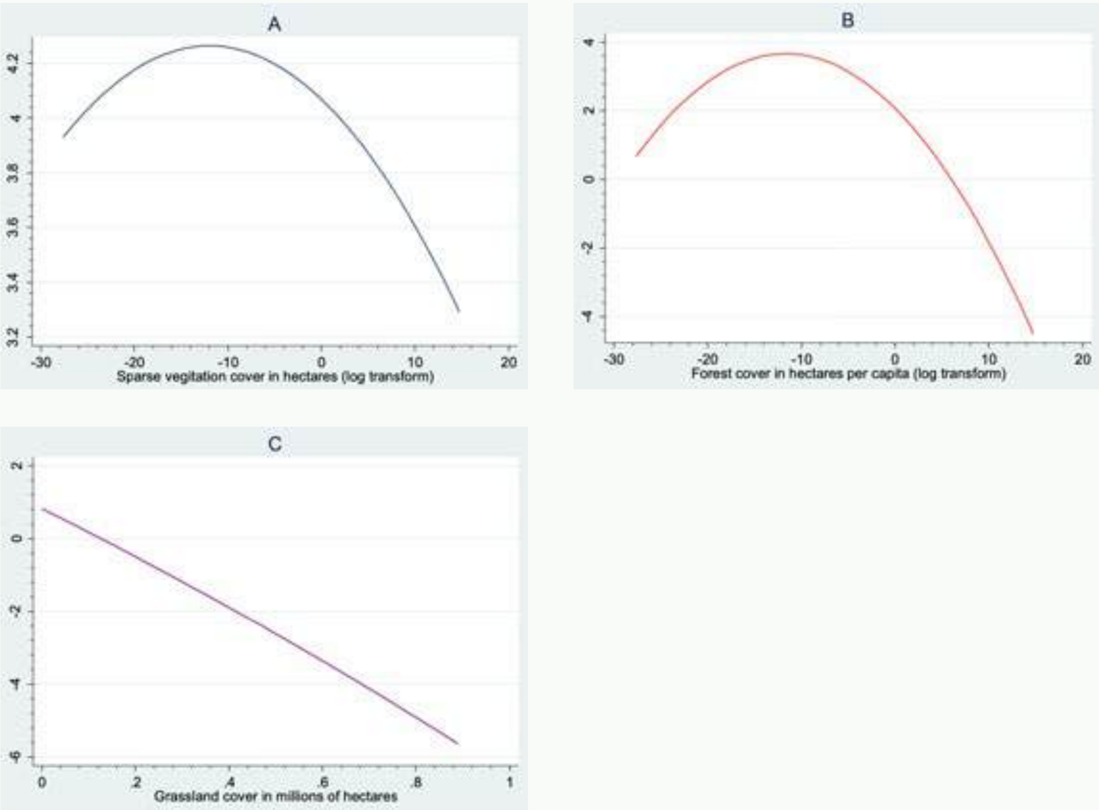
Biophysical factors and land degradation

The coefficients for log-transformed sparse vegetation cover in hectares and log-transformed forest land in hectares per capita are negative and statistically significant in the restricted fixed effect NPK depletion and NPK loss models, respectively. The directions of the effects are consistent with our hypotheses that sparse vegetation cover and forest cover are negatively and significantly correlated with NPK depletion and NPK loss, respectively. Figures 2.11A and 2.11B confirm the directional relationships between sparse vegetation cover and NPK depletion and forest land area per capita and NPK loss. Since in both models the dependent and independent variables are both in log forms, the coefficients indicate that a 1 per cent increase in sparse vegetation cover would decrease NPK depletion by 0.004 per cent whereas a 1 per cent increase in forest cover in hectare per capita would decrease NPK loss by 0.62 per cent. The restricted fixed effect NPK loss model also indicates a negative and statistically significant correlation between grassland cover in millions of hectares and log-transformed NPK loss (Figure 2.11C).

The coefficients for mean annual precipitation and its log-transform are statistically significant and positively correlated with log-transformed NPK depletion and NPK loss, respectively (Tables 2.2 and 2.3). The results are consistent with our hypotheses that high precipitation would lead to higher levels of NPK depletion and NPK loss, mainly through the effect of water erosion

FIGURE 2.11:

Relationship between soil NPK depletion and sparse vegetation cover (A) ; between NPK loss and forest cover per capita (B); between NPK loss and grassland cover (C).

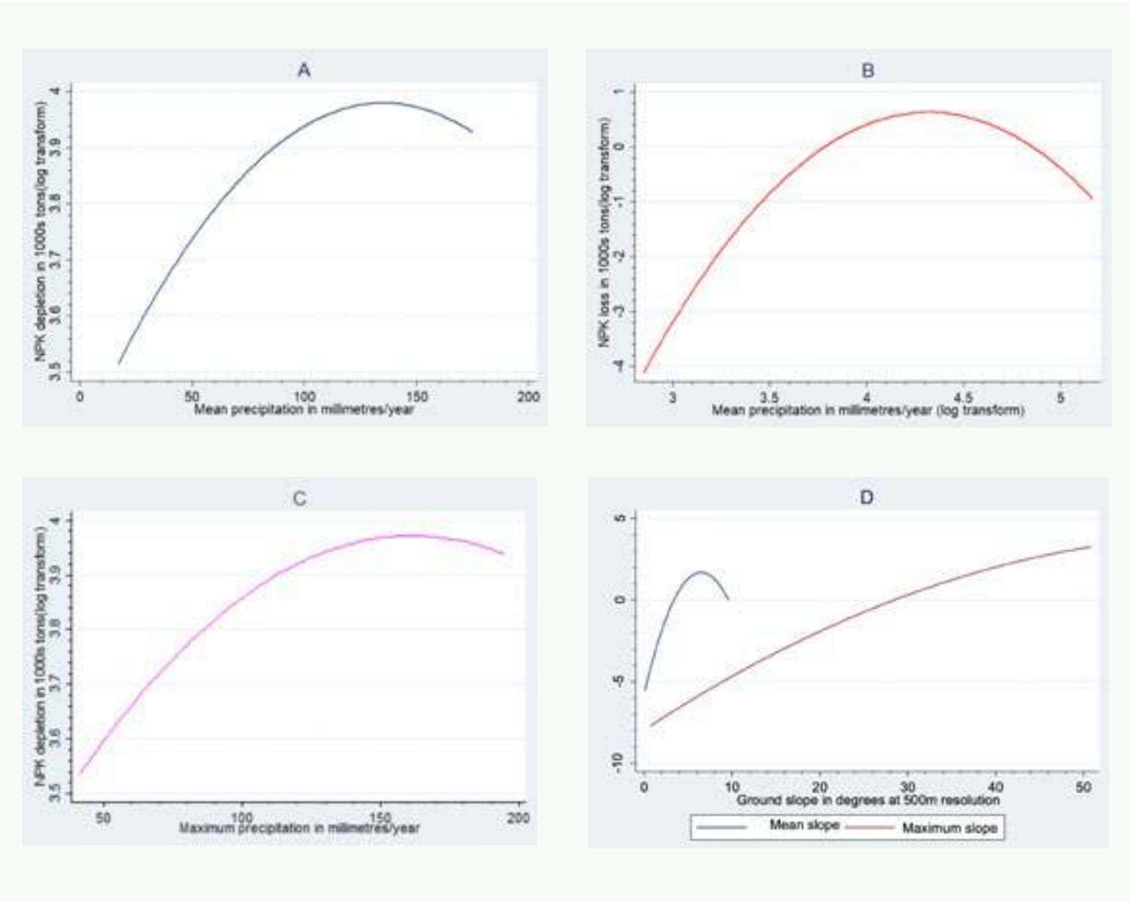


associated with high rainfall. Figures 2.12A and 2.12B confirm the presence of a positive correlation between precipitation and the agricultural land degradation. The coefficients indicate that a 1 per cent increase in the mean annual precipitation would increase NPK depletion by 0.54 per cent and NPK loss by 2.82 per cent. However, the coefficient for maximum annual precipitation is negative and statistically significant in the fixed effect NPK depletion model; Figure 2.12C confirms that this is true after a certain level of maximum precipitation below which there exists a positive correlation consistent with that of the effect of mean annual rainfall on NPK depletion.

In the case of the restricted fixed effect NPK loss model, the coefficients for physical slope variables (mean and maximum slopes) are positive and statistically significant indicating positive correlation with log-transformed NPK loss. This is consistent with our expectation that areas with higher physical slope are likely to have high levels of NPK losses from their agricultural land and this could be because erosion rates are higher with increasing slope of landscapes. Figure 2.12D shows the directional relationship that mean and maximum slopes have with log-transformed NPK loss. A 1 per cent increase in the mean ground slope would increase NPK loss by 36.6 per cent whereas a 1 per cent increase in the maximum ground slope increases NPK loss by 6.67 per cent.

FIGURE 2.12:

Relationship between soil NPK depletion and mean precipitation (A) ; between NPK loss and mean precipitation (B); between soil NPK depletion and maximum precipitation (C); and between NPK loss and mean and maximum ground slope (D).



2.3.4. Econometric modelling of crop production losses induced by land degradation

2.3.4.1. Data, empirical model of agricultural production function, and results

Following the econometric modelling approaches in ELD and UNEP (2015) and Tilahun et al. (2018), the relationship between agricultural land degradation and crop production in agricultural ecosystems of Ethiopia can be specified as in Equation 2.2 below. The model takes into account the effect of land degradation on crop yield and the economic theory of production as a function of factor inputs.

$$Y_{it}=\beta_0 + \beta_1 ALD_{1it} + \beta_2 FI_{2it}+\theta_{it} \quad (2.2)$$

Where:

- Y_{it} represents actual aggregate crop yield (in kg/ha/year) as a provisioning agricultural ecosystem service, for administrative zone i in Ethiopia over time period t where t= 2003/2004,..., 2015/2016;
- ALD_{it} represents the vector of agricultural land degradation indicators (soil NPK depletion in 1,000s tons per year and NPK loss in 1,000s of tons per year) for administrative zone i in Ethiopia ove r time period t= 2003/2004,..., 2015/2016;
- FI_{it} is a vector of national level agricultural factor inputs (labour measured in terms of human population in 1,000s, agricultural land area in hectares, and zonal level consumption of commercial fertiliser in tons of NPK nutrients, and minimum, maximum and mean annual precipitation in millimetres) used by administrative zone i

in Ethiopia over time period t= 2003/2004,..., 2015/2016;

- β represents the coefficients and qit is the error or stochastic term that captures the effect of unobserved factors in administrative zone i over time period t.

To obtain unbiased estimators for β_1 as a coefficient of the treatment variable or our variable of interest ALDit, which captures the impact of land degradation on crop yield, ALDit should fulfil the exogeneity assumption. In other words, the NPK loss and NPK depletion should not be correlated with unobserved factors that affect the response variable (crop yield). Technically, the covariance between ALDit and qit should be zero. However, unobserved factors that affect aggregate crop yield may correlate with either NPK loss or NPK depletion or both, and this violates the exogeneity of ALDit. Thus, unlike the modelling approach in ELD and UNEP (2015) and Tilahun et al. (2018) which did not test for the endogeneity of the agricultural land degradation variables (NPK loss and NPK depletion), this study tested exogeneity of these variables using the Instrumental Variable (IV) method.
In order to deal with possible bias due to unobserved heterogeneity, the effect of ALD_{it} on Y_{it} in the structural Equation 2.2 above can be estimated using IV using *xtivreg* in STATA, which estimates the treatment variable as first stage Equation 2.3 specified below.

$$ALD_{it}=\varphi +\omega FI_{it}+\delta Z_{it}+\mu_{it} \qquad (2.3)$$

where the variable Z_i is an instrument for ALD_{it} in the first-stage equation 2.2 and FI_{it} is the same vector of covariates as in Equation 2.2.

The instrument needs to fulfil two basic requirements: a) instrument relevance which means that the covariance between the instrument and the treatment variable should be different from zero, and b) instrument exogeneity that states the instrument is uncorrelated with the error term of the structural Equation 2.2 (Wooldridge 2002). In the context of omitted variables, instrument exogeneity refers to the assumption of the exclusion restriction, which states that the instrumental variable has no partial effect on the outcome variable after the observed and omitted variables are controlled for, and the instrument should be uncorrelated with the omitted variables. In other words, the exclusion restriction is a strong assumption and requires that the effect of the instrumental variable on the outcome variable is indirect and only through its effect on the treatment variable. Furthermore, consistency of the IV estimator also depends on the assumptions that the assignment to treatment is "ignorable" (i.e. unobserved factors that affect the instrument variable are not related to unobserved factors that affect the outcome variable after controlling for observables). In other words, it assumes that treatment is randomly assigned conditional on the observable covariates. Moreover, Imbens and Angrist (1994) and later Angrist, Imbens and Rubins (1996) argued that the standard interpretation of instrumental variable estimation as impact estimator applies only under unrealistic cases where the treatment effect is constant within the population. In the more realistic case of a heterogeneous causal effect, and under the above two assumptions on instruments, the instrumental variable estimator estimates the local average treatment effect, which is the average effect of the treatment for the subsamples of the population.

We set the following hypotheses on the relationship between each of the factors on the right-hand side of Equation 2.2 and the response variable aggregate crop yield. Our first hypothesis is that both NPK loss and soil NPK depletion as indicators of agricultural land degradation are negatively and significantly correlated with aggregate crop yield. Secondly, we anticipated that administrative level human population as a proxy for labour and administrative level consumption of commercial fertiliser are positively and significantly correlated with aggregate crop yield. Third, we anticipated a significant correlation between land area (arable and permanent cropland area) and aggregate crop yield but we did not have a prior expectation about the direction of the relationship. This is because based on the theory of production, either positive or negative correlations could be anticipated. At early stage of production that starts with small land area, increasing land size would lead to increasing in yield per hectare, but there will be a point at which the marginal effect of change land size will be zero, beyond which increasing land size will lead to decline in productivity.

We used six instrumental variables (forest cover, physical elevation, ground slope and count, mean and sums night-light times) as instruments for NPK loss, NPK depletion and the square of NPK depletion. This choice was based on the intuition that these biophysical factors could affect NPK loss and NPK depletion and with the hypothesis that they fulfil the requirements of the instrument relevance and the exclusion restriction. Our selection of instruments has also been supported with the results of the land degradation model in Equation 2.1 above.

The results of the OLS estimation, fixed effects, random effects and fixed effect IV models in Table 2.4 indicate that the coefficients for the agricultural land degradation variables (log-transformed NPK loss in 1,000s tons, log-transformed NPK depletion in 1,000s tons, and the square of log-transformed NPK depletion in 1,000s tons) are negative and statistically significant. This indicates that an increase in NPK loss and NPK depletion would lead to decline in aggregate crop yield. Figure 2.13 below shows the directional relationship between aggregate crop yield and the three agricultural land degradation variables.

FIGURE 2.13:

Relationship between aggregate crop yield and agricultural land degradation (NPK loss and soil NPK depletion).

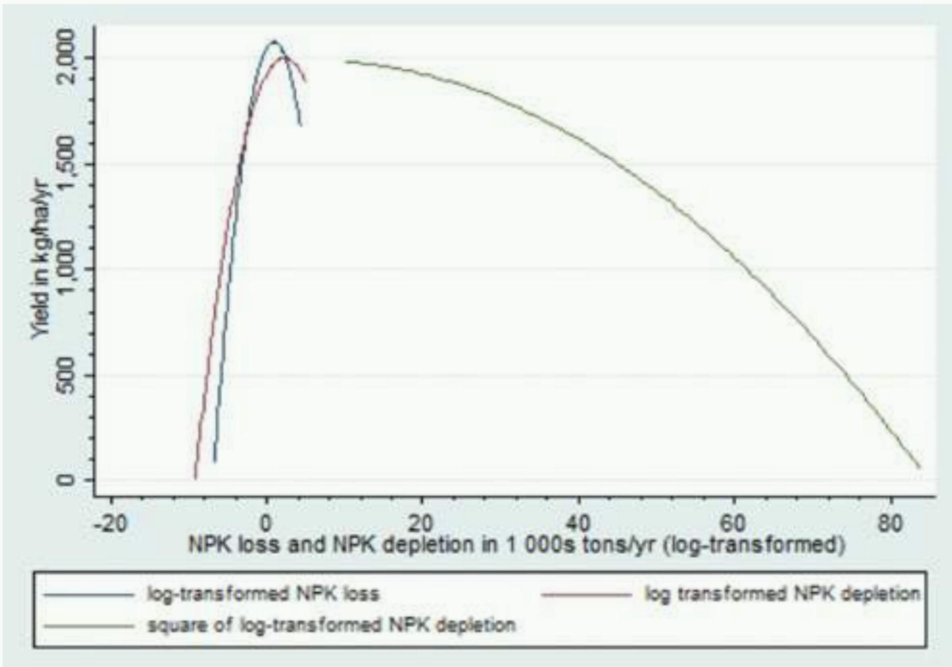


TABLE 2.4:

Aggregate crop yield model

	OLS (Robust SE)	Fixed effects	Random effects	Fixed effects IV
Yield in kg perha				
Ln-NPK_Lossin1000sTonnc	69.62(43.61) [1.58]d	-13.89(44.77) [-0.31]	69.62(46.46) [1.50]d	-526.51(142.72) [-3.69]a
Ln-NPK_depeletionin1000sTonc	-168.23(64.96) [-2.50]b	-234.23(76.88) [-3.05]a	-168.23(80.25) [-2.10]b	-1,194.51(338.37) [-3.53]a
Ln-NPK_depel1000sToncSqure	-50.88(12.33) [-3.76]a	-72.55(12.17) [-5.96]a	-50.88(12.53) [-4.06]a	-134.63(40.17) [-3.35]a
Ln-AgriLandHa	-325.91(56.66) [-5.81]a	-183.14(53.97) [-3.39]a	-325.91(54.47) [-5.98]a	359.03(120.25) [2.99]a
Populationin1000s	0.31(0.07) [4.40]a	0.28(0.06) [4.98]a	0.31(0.06) [5.24]a	0.61(0.09) [6.44]a
Ln-NPK_ InputfromChemFerzerTonc	16.53(2.95) [5.58]a	14.64(3.56) [4.12]a	16.53(3.66) [4.52]a	34.86(6.30) [5.53]a
udel_precip_mean2002max	8.90(2.25) [3.94]a	8.25(1.88) [4.38]a	8.90(1.96) [4.53]a	4.72(2.53) [1.86]c
Ln-udel_precip_mean2002mean	-565.72(313.65) [-1.80]c	-483.57(227.36) [-2.13]b	-565.72(238.24) [-2.37]b	249.64(318.33) [0.78]
udel_precip_mean2002min	5.54(2.31) [2.41]b	6.08(2.11) [2.88]a	5.54(2.21) [2.51]b	7.70(2.85) [2.70]a
_cons	8,033.29(1,154,94) [6.95]a	6,647.93(1,031.80) [6.44]a	8,022.29(1,073.52) [7.47]a	2,130.01(2,253.94) [0.95]
N	718	718	718	718
F(df, N)	16.30a	15.80a		
R2	0.18	0.16	0.18	0.03
Root MSE	922.64			
Mean VIF	3.65			
No. of groups (Year: 2003/4 to 2015/16)		12	12	12
Wald chi2			150.87a	2,252.53a
R2 within		0.17	0.16	.
R2 between		0.17	0.59	0.53
Corr(u_i, xb)		0.04		-0.17
F test u_i=0, F(df,N)		8.28a		7.34a
Hausman Test (chi2) (Fixed Vs Random effects)			79.51a	
Hausman IV Test (chi2) (Fixed effects IV Vs Fixed effects)				34.55a
Wu-Hausman F test: Tests of endogeneity †				27.65a

	OLS (Robust SE)	Fixed effects	Random effects	Fixed effects IV
Tests for validity instruments				
Weak identification test (Cragg–Donald Wald F statistic)				10.49b
Under identification test (Anderson canon. corr. LM stat.)				49.52a
Over identification test (Sargan statistics)				1.68
Tests of endogeneity of: Ln-NPK_Lossin1000sTonnc, Ln-NPK_depeletionin1000sTonc, Ln-NPK_depel1000sToncSqure				
Wu-Hausman F test: F(3,705)	27.65a			
Durbin-Wu-Hausman chi-sq test: Chi-sq(3)	75.58a			

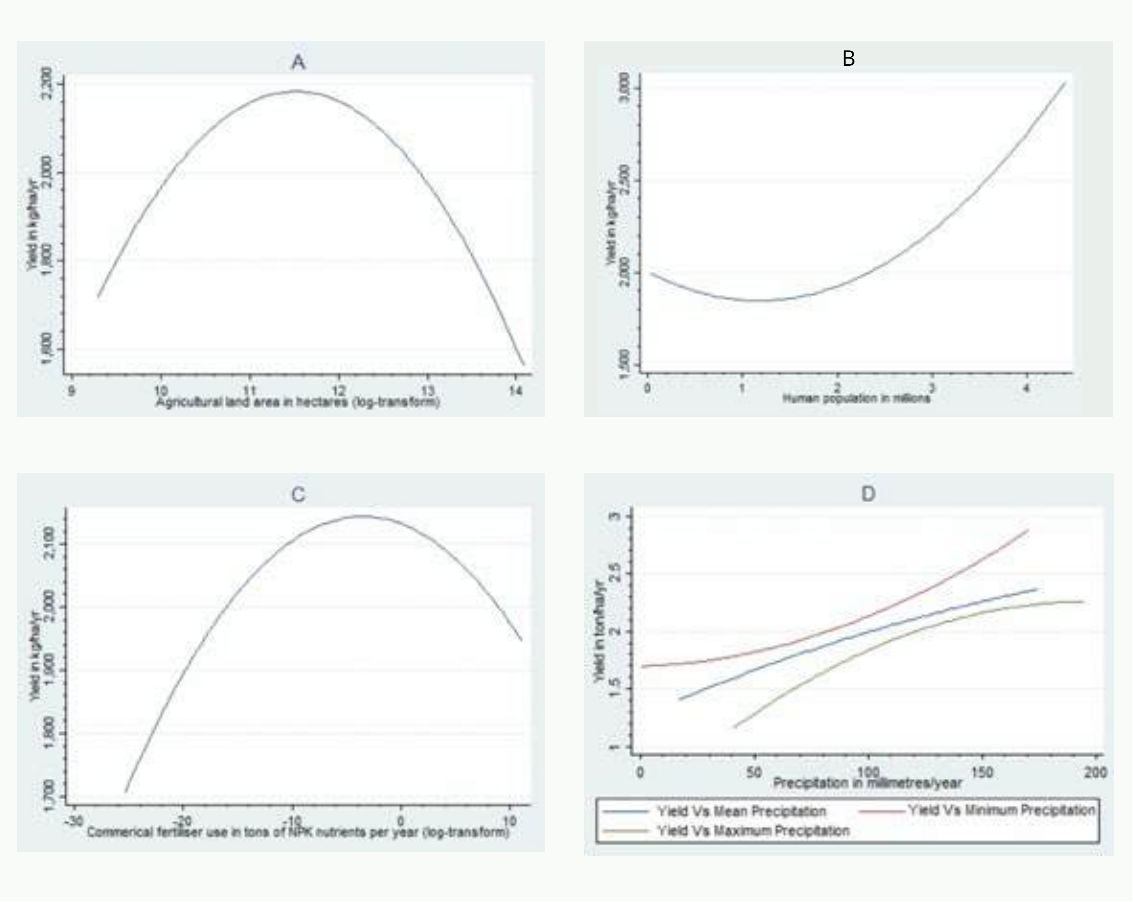
Values in () are standard errors, values in [] are t-statics for the OLS and fixed effect models, and z-statistics for the other models. Significance levels: a < 1 %, b < 5 %, c < 10 %, d < 15 %.
†Test for endogeneity of Ln-NPK_depletion1000sTons, Ln-NPK_depletion1000sTonsqare, Ln-NPK_Losses1000sTons. The test was done using ivreg2.
§ Instrumental variables: Ln-forestHa, srtm_elevation_500mnonemin, lnsrtm_slope_500mnonemean, v4composites_calibrated_sum, v4composites_calibrated_count.

The endogeneity tests after Ivreg2 indicate that the land degradation variables are endogenous (both Wu-Hausman F-statistics and Durbin-Wu-Hausman chi-sq test statistics are significant at 1 per cent) and hence the OLS estimates are biased. However, the fixed effect IV model controls the endogeneity problem as evidenced by the tests on the instruments used for controlling endogeneity (i.e. our instrument variables satisfy all the three identification restrictions). The Sargan statistics for over-identification restriction is insignificant (p=0.432 and Sargan statistics = 1.68) indicating that the instrumental variables used in the model are valid instruments and uncorrelated with the error term of structural equation 2.2, and that they were correctly excluded from the estimated equations. The Anderson Lagrange Multiplier statistic for the under-identification test is also significant (at p-value < 1 per cent) indicating that the IV model was correctly identified. In addition, the Cragg-Donald Wald F-statistics is larger than the critical value of the Stock and Yogo (2002) weak identification test, which equals 9.53 for 5 per cent maximal IV relative bias in the case of six instruments and three endogenous variables, indicating the rejection of the null hypothesis that the instruments are weak (at p-value < 1 per cent).

In addition to the land degradation variables (NPK loss and NPK depletion), the fixed effect IV model for aggregate crop yield also shows that the coefficients for the factor inputs variables (agricultural land, labour, commercial fertiliser use, and rainfall variables) are positive and statistically significant (Figures 2.14A to 2.14D). This indicates that an increase in most of the factor input variables will increase aggregate crop yield up to a certain maximum point beyond which an increase in factor inputs leads to decline in yield per hectare. Figure 2.14 below shows the directional relationship between yield and the factor input variables.

FIGURE 2.14:

Relationship between aggregate crop yield and agricultural land area (A); between aggregate crop yield and human population (labour) (B); between aggregate crop yield and commercial fertiliser use (C); and between aggregate crop yield and precipitation (D).



2.4. Estimation and valuation of benefits from preventing agricultural land degradation

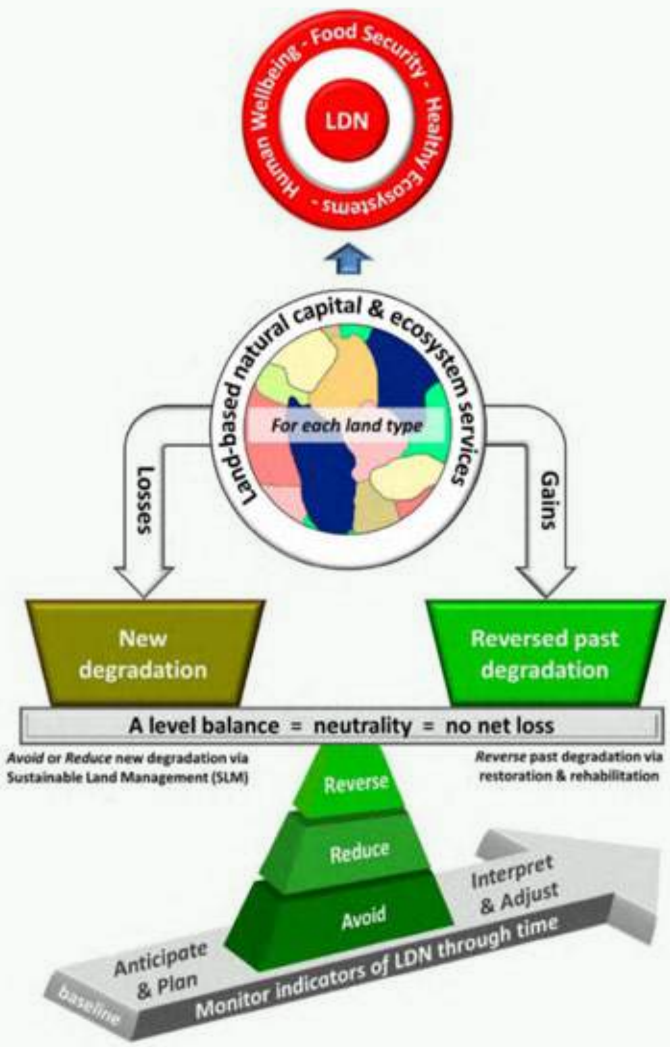
2.4.1. Assumptions and links to SDG targets

In the above sections, the study has provided details on the econometric modelling approaches used to develop the models of agricultural land degradation using NPK depletion and NPK loss as proxies of agricultural land degradation. In the modelling, we related each of these proxies with socioeconomic and biophysical factors. Furthermore, this study developed an aggregate crop yield model as a function of the land degradation proxies and factor inputs.

In this section, the results from land degradation and aggregate crop yield modelling are used to estimate the erosion-induced soil NPK depletion and NPK losses. This time, we use rainfall variables as proxies of water erosion and then estimate the associated aggregate crop productivity losses due to erosion-induced NPK depletion and NPK losses.

FIGURE 2.15:

The key elements of the scientific conceptual framework for LDN and their interrelationships (adapted from: Orr et al. 2017 and Tilahun et al. 2018).



"The target at the top of the figure expresses the vision of LDN, emphasizing the link between human prosperity and the natural capital of land – the stock of natural resources that provides flows of valuable goods and services. The balance scale in the center illustrates the mechanism for achieving neutrality: ensuring that future land degradation (losses) is counterbalanced through planned positive actions elsewhere (gains) within the same land type (same ecosystem and land potential). The fulcrum of the scale depicts the hierarchy of responses: avoiding degradation is the highest priority, followed by reducing degradation and finally reversing past degradation. The arrow at the bottom of the diagram illustrates that neutrality is assessed by monitoring the LDN indicators relative to a fixed baseline. The arrow also shows that neutrality needs to be maintained over time, through land use planning that anticipates losses and plans gains. Adaptive management applies learning from interim monitoring to inform mid-course adjustments to help ensure neutrality is achieved, and maintained in the future".

The estimations of topsoil loss-induced national level NPK loss and soil NPK depletion as well as the associated aggregate crop production losses are based on the assumptions in *Box 2*. The assumptions are based on econometric model results of sections *2.3.3* and *2.3.4* above, which allow us to make consistent application of the concept of LDN (Figure 2.15) and link our results to SDGs 15.3, 15.2, 15.1, 2.4, and 2.3 and other targets.

Based on the assumptions in *Box 2*, we estimate the baseline erosion-induced agricultural land degradation indicators used in this study (NPK loss and soil NPK depletion) and the associated baseline aggregate food production losses. Furthermore, we apply the replacement cost method for valuation of the nutrients and market price method for valuation of the crop production losses. In the following section we will show how the conceptual framework of LDN is used to assess the economic value of losses in the baseline scenario, the cost and benefits of avoiding future (new) degradation, and the CBA and socioeconomic implications of achieving LDN in agricultural ecosystems and its complementarity with other SDGs.

BOX 2.

Assumptions for the estimation of NPK losses, soil NPK depletion, and crop losses

In estimating the effect of NPK loss and soil NPK depletion on aggregate crop production loss using the yield model in *Table 2.4*, we assumed the following:

1. The average annual changes in NPK depletion and NPK loss that occurred over the period 2003-2016 as a baseline. The nutrient auditing allows us to estimate the NPK loss and soil NPK depletion that were taking place in the indicated period. Unless measures are taken, these estimated results are likely to happen again in the future.
2. Business-as-usual is compared to avoiding NPK depletion, avoiding NPK loss, and avoiding both NPK depletion and NPK loss. The business-as-usual assumption allows us to estimate the cost of doing nothing and the assumption of avoiding both NPK loss and NPK depletion in its strictest sense implies the highest priority of LDN as well as the need for investment on sustainable land management.
3. All factor variables used in the NPK loss and NPK depletion models remain constant (Tables 2.2 and 2.3). The implication of this assumption is consistent with the principle of "one-out, all-out". For example, among the biophysical factors in the models, we assume no change in forest cover, grassland cover, sparse vegetation cover, and cultivated land area. All should remain at the 2015/2016 state in each administrative zone. These indicators are also consistent with sub-indicators of SDG 15.3.1.
4. The estimated average annual NPK loss and soil NPK depletion from the nutrient auditing for the base period are considered as baseline indicators of zonal, regional, and country level agricultural land and soil quality. This is consistent with SGD Target 2.4.
5. Based on the assumptions 1-4 and the estimated results, the level of factor inputs in the aggregate crop yield econometric model (*Table 2.4*) remains constant in estimating the effect of the changes in NPK loss and soil NPK depletion on aggregate crop production loss. Here, the estimated crop production loss for the base year is considered an indicator of the level of agricultural productivity loss. If actions to avoid the NPK loss and NPK depletion are implemented in the future, the loss could be converted into benefit and can thus be used as an indicator of improvement in agricultural land productivity. In other words, the crop productivity loss/gain is an alternative sub-indicator of SDG 15.3.
6. Our models imply that efforts aimed at improving forest cover and sparse vegetation cover, for instance, would reduce NPK loss and soil NPK depletion and thus increase aggregate crop yields. Therefore, the estimations based on the assumptions 1-5 provide lower bound results.

2.4.2. Quantity and value of preventing NPK losses and soil NPK depletion

Table 2.5 provides details on the mean annual NPK loss and NPK depletion in the 66 administrative zones over the study period. The table also provides the corresponding monetary value of NPK loss, NPK depletion and the replacement cost price of commercial fertiliser (weighted average price USD 0.43 per kg of NPK nutrients from 2012 prices).

The results show that the monetary value of the average annual NPK loss and soil NPK depletion as a supporting ecosystem service for the country amounts to USD 659 million, of which the value of soil NPK depletion accounts for 52.2 per cent or USD 344 million per year and the remaining is the value of NPK loss. The monetary value of annual NPK loss and NPK depletion in Oromia regional state was USD 334.26 million and accounts for 50.72 per cent of the country level monetary value of the annual NPK loss and NPK depletion. The monetary value of NPK depletion and loss in the Amhara regional state was USD 202.84 million and accounts for 30.78 per cent of the country level monetary value of the annual NPK loss and NPK depletion. The monetary value of NPK loss and NPK depletion in the other seven regional states and Dire Dawa city administration all together amounts to USD 121.90 million or 18.5 per cent of the country level monetary value of NPK depletion and NPK loss.

TABLE 2.5:

Quantity and replacement cost values of mean annual NPK loss and soil NPK depletion by administrative zones over the period 2003/2004-2015/2016.

	NPK loss		**NPK depletion**		**Total replacement cost value of NPK loss and NPK depletion in million USD**
	Quantity in 1,000s tons	Replacement cost value in million USD	Quantity in 1,000s tons	Replacement cost value in million USD	
North West Tigra	16.35(1.84)	6.81(0.78)	10.99(2.03)	5.10(0.71)	11.91(1.40)
Central Tigray	12.24(1.08)	4.90(0.43)	7.22(1.35)	3.35(0.48)	8.25(0.89)
Eastern Tigray	4.10(0.37)	1.63(0.15)	-0.68(0.68)	0.54(0.12)	2.17(0.26)
Southern Tigray	12.47(0.62)	4.91(0.24)	9.45(1.19)	4.02(0.51)	8.93(0.68)
Western Tigray	11.31(1.54)	4.79(0.63)	12.41(1.74)	5.62(0.77)	10.40(1.38)
Tigray	**56.47**	**23.03**	**39.38**	**18.63**	**41.66**
Afar Zone 1	1.09(0.15)	0.46(0.07)	0.21(0.64)	0.41(0.20)	0.86(0.26)
Afar Zone 3	0.17(0.05)	0.07(0.02)	-3.64(0.37)		0.07(0.02)
Afar	**1.27**	**0.53**	**-3.43**	**0.41**	**0.93**
North Gondar	49.85(4.96)	20.25(2.05)	55.30(6.29)	23.85(2.65)	44.10(4.65)
South Gondar	26.03(2.47)	10.33(0.98)	27.89(3.60)	11.61(1.43)	21.95(2.38)
North Wollo	14.77(0.83)	5.80(0.33)	10.70(1.06)	4.85(0.42)	10.65(0.74)
South Wollo	25.54(1.37)	9.95(0.54)	15.83(1.78)	7.27(0.68)	17.22(1.13)
North Shewa	34.84(2.81)	13.64(1.10)	33.99(3.34)	13.88(1.33)	27.52(2.39)
East Gojam	36.15(3.49)	14.06(1.36)	32.95(4.86)	13.80(1.72)	27.86(2.98)
West Gojam	39.26(3.89)	16.10(1.61)	41.76(5.54)	16.65(2.01)	32.75(3.54)
Waghimra	5.09(0.47)	2.00(0.19)	2.91(0.57)	1.51(0.20)	3.52(0.38)
Agwawi	16.67(1.92)	6.94(0.81)	18.42(2.65)	6.84(0.96)	13.78(1.74)
Oromia Zone	4.51(0.29)	1.82(0.12)	3.12(0.34)	1.45(0.14)	3.27(0.26)
Argoba s.w.	0.30(0.07)	0.12(0.03)	0.14(0.10)	0.11(0.03)	0.23(0.06)
Amhara	**253.01**	**101.02**	**243.01**	**101.82**	**202.84**
West Wellega	22.02(1.81)	9.29(0.78)	42.28(3.90)	17.64(1.62)	26.94(2.38)
East Wellega	26.52(2.14)	10.92(0.89)	44.89(5.62)	18.06(2.33)	28.97(3.21)
Illobabor	19.37(1.76)	7.99(0.73)	37.86(4.06)	15.64(1.63)	23.63(2.36)
Jimma	34.01(2.67)	13.87(1.09)	60.31(6.57)	23.88(2.58)	37.75(3.62)
West Shewa	40.99(3.74)	16.25(1.49)	42.00(5.20)	16.37(2.11)	32.62(3.55)
North Shewa	23.47(2.25)	9.09(0.87)	16.27(2.96)	6.80(0.99)	15.89(1.84)
East Shewa	28.93(2.98)	11.36(1.16)	33.70(7.74)	13.64(1.96)	25.01(3.03)
Arsi	38.56(3.06)	15.24(1.20)	30.20(4.97)	11.25(1.57)	26.49(2.77)
West Harerghe	19.65(1.75)	8.05(0.72)	20.32(2.43)	8.89(1.01)	16.94(1.71)
East Hareghe	21.41(2.09)	8.98(0.92)	17.38(3.39)	8.05(1.39)	17.03(2.30)
Bale	20.59(1.51)	8.17(0.59)	19.44(3.24)	7.88(1.19)	16.05(1.76)
Borena	1.96(0.16)	0.83(0.07)	-7.48(0.66)	0.02(0.01)	0.85(0.07)
South West Shewa	23.08(4.65)	8.90(1.80)	24.21(8.14)	10.62(3.01)	19.51(4.78)
Guji	7.61(0.93)	3.13(0.38)	5.52(2.57)	3.26(0.95)	6.39(1.31)
West Arsi	19.19(3.66)	7.74(1.47)	10.70(5.95)	5.87(1.31)	13.61(2.76)

Kelem Wellega	11.89(2.27)	4.97(0.95)	23.32(5.16)	10.42(1.99)	15.39(2.94)
Horoguduru Welle	11.76(2.25)	4.69(0.90)	15.70(4.68)	6.51(1.37)	11.20(2.25)
Oromia	**370.99**	**149.46**	**436.60**	**184.79**	**334.26**
Shinele	0.14(0.03)	0.06(0.01)	-0.57(0.13)	0.002(0.001)	0.06(0.01)
Jijiga	5.51(0.74)	2.25(0.30)	2.65(1.21)	1.61(0.45)	3.86(0.75)
Liben	0.26(0.06)	0.11(0.03)	-4.10(0.40)		0.11(0.03)
Somalie	**5.91**	**2.41**	**-2.92**	**1.62**	**4.03**
Metekel	8.01(0.88)	3.37(0.37)	11.58(1.42)	5.07(0.62)	8.43(0.99)
Asosa	3.35(0.22)	1.38(0.09)	5.35(0.44)	2.36(0.19)	3.74(0.28)
Kemeshi	2.44(0.16)	1.01(0.07)	4.45(0.39)	1.96(0.17)	2.98(0.24)
Mao Komo	0.48(0.11)	0.20(0.05)	0.79(0.24)	0.39(0.09)	0.58(0.14)
Benishangul Gumuz	**14.27**	**5.96**	**22.16**	**9.77**	**15.73**
Gurage	6.77(0.50)	2.73(0.20)	-0.004(1.10)	1.23(0.29)	3.96(0.48)
Hadiya	8.56(0.62)	3.44(0.25)	3.61(0.66)	2.19(0.21)	5.63(0.46)
Kembata Tembaro	2.79(0.23)	1.14(0.09)	0.10(0.34)	0.58(0.09)	1.72(0.18)
Sidama	8.60(0.71)	3.72(0.32)	4.53(1.98)	2.83(0.65)	6.55(0.94)
Gedio	1.38(0.07)	0.62(0.04)	4.81(0.85)	2.03(0.31)	2.65(0.34)
Wolayita	7.20(0.98)	3.09(0.42)	4.66(1.58)	2.27(0.54)	5.37(0.95)
South Omo	3.09(0.44)	1.27(0.18)	-7.94(0.87)		1.27(0.18)
Shaka	1.51(0.16)	0.65(0.07)	4.03(0.66)	1.66(0.27)	2.31(0.34)
Kaffa	7.39(0.66)	2.96(0.27)	6.46(1.25)	3.07(0.46)	6.03(0.72)
Gamo Gofa	8.96(1.14)	3.70(0.48)	4.94(1.93)	2.88(0.68)	6.58(1.16)
Bench Maji	3.45(0.42)	1.44(0.18)	5.25(1.36)	2.29(0.53)	3.73(0.70)
Yem s.w	0.94(0.09)	0.37(0.04)	0.71(0.10)	0.30(0.04)	0.67(0.07)
Dawro	2.26(0.33)	0.91(0.13)	0.08(0.54)	0.59(0.17)	1.50(0.29)
Basketo s.w.	.0.32(0.04)	0.14(0.02)	0.27(0.07)	0.13(0.03)	0.26(0.04)
Konta s.w.	0.90(0.09)	0.36(0.04)	0.78(0.15)	0.36(0.06)	0.72(0.09)
Silte	7.64(1.04)	3.13(0.43)	5.08(1.88)	2.41(0.52)	5.53(0.91)
Alaba s.w.	2.86(0.35)	1.18(0.14)	2.15(0.60)	1.11(0.15)	2.30(0.29)
Segen People	2.04(0.74)	0.83(0.30)	-2.01(1.35)	0.79(0.34)	1.62(0.63)
SNNP	**76.67**	**31.65**	**37.48**	**26.73**	**58.38**
Agnuwak	0.23(0.11)	0.10(0.04)	0.21(0.26)	0.18(0.10)	0.27(0.14)
Nuware	0.08(0.02)	0.03(0.01)	-1.55(0.17)		0.03(0.01)
Mezhenger	0.20(0.05)	0.08(0.02)	0.02(0.06)	0.05(0.01)	0.13(0.03)
Itang s.w.	0.05(0.01)	0.02(0.01)	-0.28(0.09)	0.01(0.01)	0.03(0.01)
Gambella	**0.56**	**0.23**	**-1.60**	**0.24**	**0.47**
Hundene	0.80(0.10)	0.32(0.04)	-2.56(0.14)	0.001(0.001)	0.32(0.04)
Dire Dawa	0.73(0.07)	0.29(0.03)	-0.07(0.08)	0.08(0.02)	0.37(0.05)
ETHIOPIA	**780.67**	**314.92**	**768.04**	**344.08**	**658.99**

2.4.3. Quantity and value of preventing crop production losses induced by land degradation

Table 2.6 below shows the average annual yield losses due to NPK depletion and NPK loss and the corresponding value of these production losses at the weighted average aggregate crop price of 2016 (USD 464.10 per ton for the 52 crop types included in this study). The table provides details for each of the administrative zones covered in the study. At country level, the average annual agricultural land degradation-induced aggregate crop production loss is estimated at about 104 million tons of which 67.56 per cent was due to NPK loss and the remaining 32.44 per cent was due to NPK depletion. The monetary value of this aggregate crop production loss at weighted average crop prices of 2016 was estimated at about USD 48.35 billion.

At regional states level, the sum of agricultural land degradation-induced aggregate crop production losses in Oromia, Amhara, and SNNP was 94.42 million tons with a value of USD 44.26 billion. This figure accounts for 90.64 per cent of the country level annual aggregate crop production loss and 91.54 per cent of the monetary value of the loss induced by NPK loss and NPK depletion. The six regional states and Dire Dawa city administration account for the remaining 9.36 per cent of the aggregate crop loss and 8.46 per cent of the monetary value.

TABLE 2.6:

Quantity and market value of average aggregate crop production loss induced by NPK loss and soil NPK depletion by administrative zones in the period 2003-2016.

	Production loss induced by NPK loss		Production loss induced by NPK depletion		Market value of production gain from prevented land degradation in million USD
	Quantity in million tons	Market value in million USD	Quantity in million tons	Market value in million USD	
North West Tigray	1.06(0.05)	402.50(18.99)	0.51(0.02)	193.24(9.12)	595.74(28.11)
Central Tigray	1.12(0.04)	509.83(19.22)	0.54(0.02)	244.78(9.23)	754.61(28.45)
Eastern Tigray	0.47(0.03)	199.26(10.52)	0.23(0.01)	95.67(5.05)	294.92(15.57)
Southern Tigray	1.23(0.03)	562.13(14.11)	0.59(0.02)	269.89(6.77)	832.01(20.88)
Western Tigray	0.73(0.07)	294.57(27.29)	0.35(0.03)	141.43(13.10)	436.00(40.39)
Tigray	**4.61**	1,968.29	2.22	945.00	2,913.29
Afar Zone 1	0.06(0.01)	11.11(1.33)	0.03(0.003)	5.33(0.64)	16.44(1.97)
Afar Zone 3	0.02(0.01)	8.04(1.89)	0.01(0.003)	3.86(0.91)	11.89(2.80)
Afar	**0.08**	**19.15**	**0.04**	**9.19**	**28.34**
North Gondar	4.08(0.21)	1,792.33(91.81)	1.96(0.10)	860.52(44.08)	2,652.85(135.89)
South Gondar	3.03(0.23)	1,440.99(107.55)	1.45(0.11)	691.83(51.64)	2,132.82(159.19)
North Wollo	1.44(0.04)	720.90(20.16)	0.69(0.02)	346.11(9.68)	1,067.02(29.84)
South Wollo	2.44(0.04)	1,317.97(22.65)	1.17(0.02)	632.77(10.87)	1,950.75(33.52)
North Shewa	2.84(0.11)	1,422.89(54.88)	1.36(0.05)	683.14(26.35)	2,106.03(81.23)
East Gojam	3.20(0.13)	1,659.05(67.06)	1.54(0.06)	796.53(32.20)	2,455.58(99.25)
West Gojam	3.22(0.14)	1,235.80(55.13)	1.55(0.07)	593.32(26.47)	1,829.12(81.60)
Waghimra	0.62(0.05)	294.34(22.82)	0.30(0.02)	141.32(10.96)	435.66(33.78)
Agwawi	1.40(0.06)	531.82(24.30)	0.67(0.03)	255.33(11.67)	787.15(35.96)
Oromia Zone	0.33(0.01)	123.17(2.02)	0.16(0.003)	59.14(0.97)	182.30(2.99)
Argoba s.w.	0.03(0.001)	10.62(0.47)	0.02(0.001)	5.10(0.23)	15.72(0.70)
Amhara	**22.61**	**10,549.89**	**10.86**	**5,065.11**	**15,615.00**
West Wellega	1.88(0.09)	890.99(44.63)	0.90(0.05)	427.77(21.43)	1,318.77(66.06)
East Wellega	2.11(0.08)	798.04(31.93)	1.01(0.04)	383.15(15.33)	1,181.18(47.26)
Illobabor	1.68(0.10)	879.57(50.003)	0.81(0.05)	422.29(24.01)	1,301.86(74.01)
Jimma	3.34(0.16)	1,861.99(86.65)	1.60(0.08)	893.96(41.60)	2,755.94(128.26)
West Shewa	3.09(0.10)	1,320.49(40.93)	1.49(0.05)	633.98(19.65)	1,954.46(60.58)
North Shewa	2.19(0.06)	1,159.11(32.06)	1.05(0.03)	556.50(15.39)	1,715.62(47.45)
East Shewa	2.66(0.14)	1,265.00(67.93)	1.28(0.07)	607.34(32.61)	1,872.33(100.54)

Arsi	3.39(0.17)	1,530.63(76.22)	1.63(0.08)	734.87(36.59)	2,265.50(112.81)
West Hareghe	1.53(0.05)	703.94(24.00)	0.73(0.03)	337.97(11.52)	1,041.91(35.52)
East Hareghe	1.85(0.14)	951.01(71.45)	0.89(0.07)	456.59(34.31)	1,407.59(105.76)
Bale	2.09(0.14)	991.71(66.07)	1.004(0.07)	476.13(31.72)	1,467.84(97.79)
Borena	0.23(0.01)	162.22(9.10)	0.11(0.01)	77.88(4.37)	240.11(13.47)
South West Shewa	2.04(0.30)	1,189.50(176.84)	0.98(0.15)	571.09(84.90)	1,760.59(261.74)
Guji	0.70(0.04)	363.22(18.92)	0.34(0.02)	174.39(9.08)	537.61(28.00)
West Arsi	1.92(0.09)	636.15(29.96)	0.92(0.04)	305.42(14.38)	941.58(44.34)
Kelem Wellega	1.08(0.05)	490.94(21.04)	0.52(0.02)	235.71(10.10)	726.65(31.14)
Horoguduru Welle	1.53(0.13)	741.12(61.28)	0.74(0.06)	355.82(29.42)	1,096.94(90.70)
Oromia	**33.31**	**15,935.62**	**15.99**	**7,650.86**	**23,586.48**
Shinele	0.03(0.01)	10.12(4.75)	0.01(0.01)	4.86(2.28)	14.97(7.03)
Jijiga	0.37(0.01)	162.48(3.74)	0.18(0.004)	78.01(1.79)	240.49(5.53)
Liben	0.03(0.002)	6.23(0.45)	0.02(0.001)	2.99(0.22)	9.22(0.66)
Somalie	**0.42**	**178.83**	**0.20**	**85.86**	**264.68**
Metekel	0.65(0.07)	269.44(29.12)	0.31(0.03)	129.36(13.98)	398.80(43.10)
Asosa	0.32(0.01)	97.94(2.14)	0.15(0.003)	47.02(1.03)	144.96(3.16)
Kemeshi	0.20(0.02)	58.06(6.44)	0.10(0.01)	27.88(3.09)	85.94(9.53)
Mao Komo	0.06(0.002)	24.52(1.004)	0.03(0.001)	11.77(0.48)	36.29(1.49)
Benishangul Gumuz	**1.22**	**449.96**	**0.59**	**216.03**	**665.99**
Gurage	0.92(0.27)	415.39(124.58)	0.44(0.13)	199.43(59.81)	614.82(184.39)
Hadiya	0.75(0.02)	284.88(7.47)	0.36(0.01)	136.77(3.59)	421.65(11.06)
Kembata Tembaro	0.24(0.01)	83.12(2.36)	0.12(0.003)	39.91(1.13)	123.03(3.50)
Sidama	0.90(0.06)	454.06(31.34)	0.43(0.03)	218.00(15.05)	672.06(46.39)
Gedio	0.37(0.17)	294.54(135.24)	0.18(0.08)	141.41(64.93)	435.95(200.17)
Wolayita	0.55(0.03)	169.61(9.41)	0.26(0.02)	81.43(4.52)	251.04(13.93)
South Omo	0.28(0.02)	95.36(6.57)	0.13(0.01)	45.78(3.15)	141.15(9.72)
Shaka	0.15(0.01)	128.85(11.44)	0.07(0.01)	61.86(5.49)	190.71(16.93)
Kaffa	0.75(0.04)	354.95(17.03)	0.36(0.02)	170.41(8.18)	525.36(25.21)
Gamo Gofa	1.05(0.28)	321.93(85.50)	0.50(0.13)	154.56(41.05)	476.49(126.55)
Bench Maji	0.31(0.02)	165.14(9.74)	0.15(0.01)	79.28(4.68)	244.42(14.42)
Yem s.w.	0.11(0.01)	50.82(2.65)	0.05(0.003)	24.40(1.27)	75.21(3.92)
Dawro	0.23(0.02)	100.28(7.62)	0.11(0.01)	48.15(3.66)	148.43(11.28)
Basketo s.w.	0.03(0.001)	9.13(0.41)	0.01(0.001)	4.39(0.20)	13.52(0.60)
Konta s.w.	0.08(0.01)	36.63(3.43)	0.04(0.004)	17.59(1.65)	54.22(5.08)
Silte	0.54(0.05)	200.05(18.04)	0.26(0.02)	96.05(8.66)	296.10(26.71)
Alaba s.w.	0.22(0.02)	89.38(7.57)	0.11(0.01)	42.91(3.63)	132.30(11.20)
Segen People	0.40(0.05)	163.92(19.54)	0.19(0.02)	78.70(9.38)	242.62(28.93)
SNNP	**7.88**	**3,418.03**	**3.78**	**1,641.03**	**5,059.06**
Agnuwak	0.03(0.02)	9.21(4.92)	0.02(0.01)	4.42(2.36)	13.63(7.28)
Nuware	0.01(0.001)	1.87(0.24)	0.01(0.001)	0.90(0.12)	2.77(0.36)
Mezhenger	0.05(0.01)	15.04(1.80)	0.02(0.003)	7.22(0.86)	22.26(2.66)
Itang s.w.	0.01(2.19E-04)	1.16(0.04)	0.003(1.05E-04)	0.56(0.02)	1.72(0.06)
Gambella	**0.10**	**27.28**	**0.05**	**13.10**	**40.37**
Hundene	0.09(0.01)	90.52(10.36)	0.04(0.01)	43.46(4.97)	133.97(15.34)
Dire Dawa	0.07(0.01)	29.04(3.11)	0.03(0.003)	13.94(1.49)	42.98(4.60)
ETHIOPIA	**70.39**	**32,666.58**	**33.79**	**15,683.57**	**48,350.15**

s.w. refers special wereda.

2.5. Summary

Soil fertility is one of the key production factors for most farmers in developing countries. Soil nutrient depletion and nutrient losses, which are the major problems of soil degradation, are the focus of this study. The study covers nutrient auditing for 66 administrative zones in 9 regional states and 1 city administration of Ethiopia, which all together have cultivated 52 crop types on 12.77 million hectares per year in the main production season from 2003-2016. This cropland amounts close to 13 per cent of the total land area of the country. Agricultural land cultivated with cereal crops account for 70 per cent of the 12.77 million hectares of cultivated land followed by pulses (14 per cent) and oil crops (7 per cent). The remaining 9 per cent of the land was cultivated with coffee (3 per cent), vegetables (2 per cent), root crops (2 per cent), fruits (1 per cent) and other crops (1 per cent).

Our study indicates that there was an increasing trend in agricultural land degradation in Ethiopia over the study period. The average country level soil NPK nutrient depletion was 768 thousand tons per year for the period 2003-2016. In 2003/2004, the soil NPK depletion at country level was 194 thousand tons (21.12 kg/ha) and it considerably increased to 1.25 million tons (76.7 kg/ha) in 2015/2016. This indicates an increasing trend in the annual depletion of NPK nutrients from the soil nutrient reserves of the agricultural land of Ethiopia during the study period.

There were variations across regions both in terms of the share of regional level soil NPK depletion to country level soil NPK depletion and the per hectare level rates of depletion. The sum of average annual NPK depletion in the four regional states (Oromia, Amhara, SNNP, and Tigray) accounted for 98.49 per cent of the 768 thousand tons of country level annual NPK depletion, with Oromia accounting for the largest share (56.85 per cent) followed by Amhara (31.64 per cent), Tigray (5.13 per cent), and SNNP (4.88 per cent). The other five regions (Benishangul Gumuz, Somalie, Afar, Harari, Gambella) and the Dire Dawa city administration together accounted for only 1.51 per cent of the annual country level NPK depletion. On a per hectare level, the NPK depletion at country level was 60.13 kg per hectare per year, and the three highest depletion rates on per hectare level were in Benishangul Gumuz (99.97 kg/ha/yr) followed by Oromia (72.23 kg/ha/yr) and Amhara (59.22 kg/ha/yr).

On the other hand, the average country level NPK loss was 781 thousand tons per year (61.12 kg/ha/yr) over the period 2003-2016. NPK loss was 0.430 million tons or 46.82 kg/ha in the production year of 2003/2004 whereas the figures increased to 1.15 million tons or 70.85 kg/ha in 2015/2016. Close to 48 per cent of the national level average annual NPK loss was in Oromia, followed by Amhara (32.41 per cent), SNNP (9.82 per cent) and Tigray (7.23 per cent). The per hectare level NPK loss was the highest in Afar (86.73 kg/ha/yr) followed by Somalie (77.08 kg/ha/yr), Tigray (67.46 kg/ha/yr), and Benishangul Gumuz (64.25 kg/ha/yr) whereas the lowest was in Gambella (30.72 kg/ha/yr).

The econometric models of land degradation consistently indicate that the soil NPK depletion and NPK loss are significantly correlated with socioeconomic factors. They are also significantly correlated with biophysical covariates. This indicates that the models can be used for estimation and prediction of the level of soil nutrient depletion and total soil nutrient losses in Ethiopia for each of its administrative zones and regions using zonal level statistics on the indicated biophysical and socioeconomic factors. This is simpler than using only the biophysical approach of auditing soil nutrient balances. Moreover, the econometric modelling approach allows policy analysis because it shows the correlation with the socioeconomic and biophysical factors and it relates nutrient losses and soil nutrient depletion in agriculture to other land uses (e.g., forest cover, grassland cover, and sparse vegetation cover). Moreover, the econometric models of aggregate crop yields consistently indicate that aggregate crop yield is negatively and significantly correlated with NPK loss as well as soil NPK depletion, meaning that land degradation reduces productivity in agriculture in Ethiopia.
Using the nutrient auditing approach, the econometric models, and the market-based valuation approaches, and based on plausible assumptions consistent with the concept of land degradation neutrality, results of this study indicate that:

1. The monetary value of the sum of country level average annual NPK loss and soil NPK depletion as a supporting ecosystem service for

the country amounts to USD 659 million (at weighted average price of USD 0.43 per kg of NPK nutrients from 2012 prices). Out of this, the value of soil NPK depletion accounts for 52.2 per cent or USD 344 million per year. The remaining is the value of NPK loss.

2. The monetary value of the sum of annual NPK loss and NPK depletion in Oromia regional state was USD 334.26 million and accounts for 50.72 per cent of the country level monetary value of the annual NPK loss and NPK depletion. The monetary value of NPK depletion and loss in the Amhara regional state was USD 202.84 million and accounts for 30.78 per cent of the country level monetary value of the annual NPK loss and NPK depletion. The monetary value of NPK loss and NPK depletion in the other seven regional states and Dire Dawa city administration all together amounts to USD 121.90 million or 18.5 per cent of the country level monetary value of NPK depletion and NPK loss.
3. At country level, the average annual aggregate crop production loss induced by agricultural land degradation is estimated at about 104 million tons of crops, of which 67.56 per cent was due to NPK loss and the remaining 32.44 per cent was due to NPK depletion. The monetary value of this aggregate crop production loss at weighted average aggregate crop price of 2016 (which was USD 464.10 per ton) is estimated at about USD 48.35 billion per year.
4. The sum of agricultural land degradation-induced aggregate crop production losses in Oromia, Amhara, and SNNP was 94.42 million tons with a value of USD 44.26 billion. This represents close to 91 per cent of the national annual aggregate crop production loss and about 92per cent of its monetary value.

Thus, Ethiopia as well as regional and global stakeholders need to take action against soil nutrient depletion and nutrient losses that are aggravating agricultural land degradation and loss of crop productivity in the country. This may require investment in SLM technologies on agricultural land in each of the 66 administrative zones of Ethiopia. The first step to make such interventions is to assess the cost of investing in SLM technologies. The next chapter tackles this issue.

PHOTO

03 The costs of sustainable land management in Ethiopia

3.1. Introduction

In Chapter 2, we looked at the levels and trends of NPK depletion and NPK loss from agricultural land in the 66 administrative zones of Ethiopia. We also looked at the level and monetary value of aggregate crop production losses associated with agricultural land degradation. Therefore, preventing agricultural land degradation could enable Ethiopia to increase agricultural productivity without going to the extensive margin that may otherwise require conversion of other land uses. In order to increase agricultural productivity, investing in SLM technologies is important. The objective of this chapter is to develop a meta-transfer function for costs of SLM technologies using econometric methods and based on available data from World Overview on Conservation Approaches and Technologies (WOCAT) database on the establishment and maintenance costs of SLM technologies in Ethiopia.

The next sections of the chapter provide descriptions of the WOCAT database on costs of SLM technologies, the available data for Ethiopia, and the econometric methods used to develop country level meta-transfer functions for the establishment and maintenance costs of SLM technologies in Ethiopia.

3.2. WOCAT data on costs of SLM technologies in Ethiopia

The WOCAT database collects site-specific background biophysical and socioeconomic data on SLM technologies, and their perceived benefits and costs. The database classifies SLM technologies into four broad classes, which are also described and reported in Giger et al. (2015) as:

- Agronomic measures: measures that improve soil cover (e.g. green cover, mulch), measures that enhance organic matter/soil fertility (e.g. manuring), soil surface treatment (e.g. conservation tillage), and sub-surface treatment (e.g. deep ripping).
- Structural measures: terraces (bench, forward/backward slopping), bunds, banks (level, graded), dams, pans, ditches (level, graded), walls, barriers and palisades.
- Vegetative measures: plantation/reseeding of tree and shrub species (e.g. live fences, tree crowns), grasses, and perennial herbaceous plants (e.g. grass strips).
- Management measures: change of land use types (e.g. area enclosure), change of management intensity level (e.g. from grazing to cut and carry), major change in timing of activities, and controlling/change of species composition.

In the database, a specific technology may also include a combination of two or more of the above measures. For the purpose of this study, such a technology is termed as mixed SLM technology.

Until April 2019, the WOCAT network reported, documented, and assessed 55 SLM technologies for the period 2002-2014 in Ethiopia. Annex Table A3.1 summarises 44 of these technologies for which data on per hectare level establishment cost and/or annual maintenance costs were reported in the database. Out of these 44 SLM technologies, 29 of them were classified as structural SLM technologies, 10 were mixed types, 3 were management technologies and the other 2 were agronomic SLM technologies. Agronomic practices that improve soil cover (e.g., green cover, mulch), measures that enhance organic matter/soil fertility (e.g., manuring), soil surface treatment (e.g., conservation tillage or minimum tillage), sub-surface treatment (e.g., deep ripping), intercropping and precision agriculture are effective measures in addressing and/or reducing soil nutrient depletion. However, the data available for agronomic measures in the WOCAT database for Ethiopia is very limited. In this study, we take the average costs of all these SLM technologies for which data is available.

In terms of location from which the technologies were reported, 13 were reported from SNNP; 11 were from Amhara, 10 were from Oromia, 8 were from Tigray and the remaining 3 were from Dire Dawa city administration.

TABLE 3.1:

Mean values of establishment and maintenance costs as reported in the WOCAT database.

Type of SLM tecnology	Stats.	Establishment cost in USD/ha		% of land users contri-bution to establish-ment cost	Maintenance cost in USD/ha/yr		% of land users contri-bution to mainte-nance cost
		Labour	Total		Labour	Total	
Agronomic	Mean	252.90	432.69	78.48	159.00	413.60	54.12
	semean	252.90	361.69	21.53	159.00	324.91	45.89
	N	2.00	2.00	2.00	2.00	2.00	2.00
Structural	Mean	748.88	1,158.26	57.16	272.06	312.19	74.12
	semean	247.65	437.62	6.90	179.27	179.13	7.83
	N	29.00	29.00	29.00	28.00	28.00	27.00
Management	Mean	4,713.67	6,920.17	38.79	3,137.23	4,708.77	57.60
	semean	4,443.68	6,615.25	13.22	3,106.40	4,650.68	27.80
	N	3.00	3.00	3.00	3.00	3.00	3.00
Mixed	Mean	1,258.03	2,115.85	74.54	298.13	428.54	78.03
	semean	803.49	1,050.05	7.69	117.76	148.14	11.31
	N	10.00	10.00	10.00	8.00	8.00	8.00
Total	Mean	1,112.38	1,735.77	60.83	481.28	661.54	72.66
	semean	378.42	569.08	5.16	254.10	356.63	6.24
	N	44.00	44.00	44.00	41.00	41.00	41.00

Note: Semean refers to standard error of the mean; N refers to number of SLM technologies.

The mean total establishment cost for the 44 reported technologies was USD 1,112.38 per hectare with a standard error of USD 378.42 per hectare (Table 3.1). Labour cost accounted for 60.83 per cent of the establishment cost and the remaining 39.17 per cent was for material, equipment and other costs. In the case of annual maintenance costs, data was available for 41 of the technologies and the mean annual maintenance cost for these technologies was USD 661.54 per hectare of which 72.66 per cent was for labour costs.

3.3. Econometric approach to estimate country level meta-analytical transfer function of costs of SLM technologies

As indicated in the above sub-section, the WOCAT database provides important information on establishment and maintenance costs of different SLM technologies. However, it is not possible to apply theses observed costs directly to this study because they are site-specific and may not be representative at country and even regional levels. Also, the cost information for the 55 technologies are reported between 2002 and 2014 but vary across time. Lastly, the data suffers from missing data problem and thus, one has to address these constraints before using the data directly for any kind of cost estimation. This is possible through developing a meta-analytical transfer function using econometric modelling approaches. In this regard, following Tilahun et al. (2018), we developed variants of econometric models for the establishment and maintenance costs of SLM technologies based on the following hypotheses that are guided by economic theory.

First, we hypothesised that costs of SLM are correlated with the site-specific biophysical factors like climate, slope, landform, rainfall, soil fertility and soil depth. The reason for establishing this relationship is due to the assumption that costs are higher when biophysical conditions are more difficult, meaning more robust under higher precipitation and more difficult at slopes. However, we anticipated that site-specific socioeconomic factors like relative wealth of residents or national level economic indicators like GDP per capita would have positive and statistically significant effects on both establishment and maintenance costs. Furthermore, costs may also depend on unobserved regional fixed effects and on the type of SLM technology.

Based on the above hypotheses, we developed variants of econometric models for the establishment and maintenance costs of SLM technologies based on the data in Annex Table A3.1 and data on GDP per capita for 2002-2014 for the hypothesised dependent and explanatory variables from FAOSTAT and World Bank databases. The relationship between costs of the SLM technologies and the hypothesised explanatory variable are specified in Equation 3.1 below:

$$C_{it}=\partial_0 + \partial_1 B_{it} + \partial_2 S_{it} + \partial_3 R_i + \partial_4 T_i + \mu_{it} \qquad (3.1)$$

Where:

- C_{it} refers either to the establishment or the maintenance costs of a specific SLM technology measure in the WOCAT database reported for regional state i of Ethiopia (i = 1, 2, ..., 5) at time t (t = 2002, 2003, ...,2014);
- B_{it} is the vector of site-specific biophysical factors (climate, slope, landform, rainfall, soil fertility, and soil depth) as additional information about the natural environment at which the technology was adopted, and reported for regional state i of Ethiopia at time t;
- S_{it} is a vector of socioeconomic factors (relative wealth of residents living at the sites from which the information costs for the SLM technologies were reported, GDP per capita for Ethiopia) for region i at time t;
- R_i is vector of time invariant regional dummies for controlling regional fixed effects ;
- T_i is a time invariant dummy to control for the variation effect in the measures of the SLM technologies;
- ∂ represents the coefficients; and m_{it} is the error or stochastic term that captures the effect of unobserved factors in regional state i at time t.

TABLE 3.2:

Models for establishment costs of SLM technologies in USD per hectare

Ln-totalESTcost	OLS (Robust SE)	Fixed effect	Random effect	Restricted random effects
Climate	-0.84(0.45) [-1.85]c	-0.89(0.33) [-2.68]b	-0.84(0.35) [-2.38]b	-0.82(0.25) [-3.24]a
Rainfal1	-1.07(0.21) [-5.13]a	-1.14(0.34) [-3.35]a	-1.07(0.30) [-3.62]a	-1.02(0.26) [-3.99]a
Landform1	0.32(0.10) [3.06]a	0.42(0.13) [3.14]a	0.32(0.13) [2.38]b	0.24(0.11) [2.15]b
Slope1	-0.36(0.23) [-1.53]d	-0.23(0.19) [-1.25]	-0.36(0.19) [-1.86]c	
soildepth1	0.12(0.26) [0.45]	0.04(0.25) [0.16]	0.12(0.26) [0.44]	
Soilfertility	-1.06(0.37) [-2.86]a	-0.87(0.34) [-2.55]b	-1.06(0.38) [-2.80]a	-0.41(0.24) [-1.72]c
Relativewealth	-0.41(0.26) [-1.60]d	0.002(0.23) [0.01]	-0.41(0.25) [-1.67]c	

Ln-totalESTcost	OLS (Robust SE)	Fixed effect	Random effect	Restricted random effects
Ln-GDPpercapitaCurUSD	1.21(0.43) [2.78]b	(omitted)	1.21(0.44) [2.72]a	0.92(0.43) [2.15]b
Regiondummy1	(omitted)	(omitted)	-1.86(0.79) [-2.38]b	-2.18(0.69) [-3.15]a
Regiondummy3	2.58(0.66) [3.90]a	-0.99(0.73) [-1.36]	0.72(0.49) [1.47]d	
Regiondummy4	0.04(0.71) [0.05]	-2.13(0.53) [-4.02]a	-1.83(0.49) [-3.75]a	-1.347(0.37) [-3.64]a
Regiondummy7	1.86(0.68) [2.76]b	(omitted)	(omitted)	
consTechdummy1	-0.24(0.67) [-0.36]	-0.71(0.91) [-0.78]	1.06(0.97) [1.10]	
consTechdummy3	-0.31(0.32) [-0.95]	-0.18(0.65) [-0.28]	1.00(0.54) [1.85]c	
consTechdummy4	(omitted)	(omitted)	1.31(0.9) [1.45]d	
consTechdummy5	-1.31(0.87) [-1.50]d	-1.63(0.84) [-1.95]c	(omitted)	
_cons	7.04(3.15) [2.23]b	14.65(2.47) [5.93]a	7.600(3.08) [2.37]b	7.66(2.76) [2.77]a
N	38	38	38	38
F(df, N)	3.31a	2.79b		
R2	0.61	0.10	0.61	0.39
Adj.R2				
Root MSE	0.88			
Mean VIF	3.67			
No. of groups (Year: 2002 to 2014)		11	11	11
Wald chi2			35.74a	30.25a
Log_L				
R2 within		0.69	0.49	0.46
R2 between		0.05	0.85	0.69
Corr(u_i, xb)		-0.80		
F test u_i=0, F(df,N)		2.88b		
Hausman Test (chi2)			12.58	4.40

Values in () are standard errors, values in [] are t-statics for the OLS and fixed effect models, and z-statistics for the other models. Significance levels: a < 1 %, b < 5 %, c < 10 %, d < 15 %.

Based on the above specifications in Equation 3.1, we did model specification tests for various econometric models - i.e ., Ordinary Least Squares (OLS), Ordinary least squares with robust standard errors, Generalised Least Squares (GLS), Fixed Effect and Random Effect – for each of the establishment and maintenance costs. In the modelling, we dropped outliers in the data of the 44 SLM technologies. The results for the establishment cost models are presented in Table 3.2 and the results for the maintenance costs are presented in Table 3.3.

TABLE 3.3:

Models for annual maintenance costs of SLM technologies in USD per hectare

Ln-totalMNTcost	OLS (Robust SE)	Fixed effect	Random effect	Restricted random effects
Climate	-0.002(0.40) [-0.01]	0.23(0.57) [0.41]	-0.002(0.46) [0.00]	
Rainfal1	-0.98(0.32) [-3.08]a	-0.83(0.58) [-1.43]	-0.98(0.42) [-2.34]b	-0.62(0.26) [-2.36]b
Landform1	0.08(0.17) [0.47]	0.12(0.22) [0.53]	0.08(0.18) [0.46]	
Slope1	-0.11(0.35) [-0.31]	0.05(0.32) [0.15]	-0.11(0.27) [-0.41]	
soildepth1	0.25(0.34) [0.75]	0.24(0.437) [0.55]	0.25(0.36) [0.71]	
Soilfertility	0.02(0.47) [0.05]	0.20(0.57) [0.34]	0.02(0.48) [0.050]	
Relativewealth	-0.53(0.28) [-1.89]c	-0.40(0.40) [-0.99]	-0.53(0.32) [-1.69]c	-0.45(0.27) [-1.66]c
Ln-GDPpercapitaCurUSD	1.60(0.55) [2.90]a	(omitted)	1.60(0.62) [2.57]b	1.92(0.44) [4.36]a
Regiondummy1	(omitted)	(omitted)	-2.72(1.17) [-2.32]b	-1.50(0.71) [-2.11]b
Regiondummy3	3.88(0.73) [5.32]a	0.77(1.30) [0.59]	1.16(0.65) [1.79]c	1.43(0.45) [3.19]a
Regiondummy4	1.93(0.76) [2.53]b	-0.69(0.92) [-0.75]	-0.79(0.72) [-1.09]	
Regiondummy7	2.72(0.86) [3.15]a	(omitted)	(omitted)	
consTechdummy1	(omitted)	(omitted)	0.17(1.42) [0.12]	
consTechdummy3	-0.31(0.64) [-0.48]	-0.11(1.29) [-0.08]	-0.14(0.82) [-0.17]	
consTechdummy4	-0.03(0.92) [-0.03]	0.26(1.53) [0.17]	0.14(1.25) [0.11]	
consTechdummy5	-0.17(1.30) [-0.13]	-0.18(1.62) [-0.11]	(omitted)	
_cons	-2.47(4.85) [-0.51]	6.22(4.63) [1.34]	0.09(4.50) [0.02]	-3.45(2.61) [-1.33]
N	35	35	35	35
F(df, N)	8.65a	0.37		
R2	0.64	0.001	0.64	0.56
Adj.R2				
Root MSE	1.12			
Mean VIF	3.97			
No. of groups (Year: 2002 to 2014)		9	9	9
Wald chi2			34.82a	37.04a
Log_L				

Ln-totalMNTcost	OLS (Robust SE)	Fixed effect	Random effect	Restricted random effects
R2 within		0.24	0.21	0.09
R2 between		0.0002	0.91	0.87
Corr(u_i, xb)		-0.68		
F test u_i=0, F(df,N)		0.97		
Hausman Test (chi2)			2.85	2.45

Values in () are standard errors, values in [] are t-statics for the OLS and fixed effect models, and z-statistics for the other models. Significance levels: a < 1 %, b < 5 %, c < 10 %, d < 15 %.

The results from the different econometric models consistently indicate that the establishment cost is significantly correlated with four of the biophysical covariates (climate, rainfall, land form, and soil fertility) at p-value < 10 per cent and log-transformed GDP per capita is consistently and significantly correlated with establishment costs in three of the four models at p-value < 10 per cent (Table 3.2). In the case of the maintenance costs models, only rainfall, relative wealth of residents, and log-transformed GDP per capita are consistently significant in at least three of the four models (Table 3.3) at p-value < 10 per cent. Moreover, at significance levels between 1 and 10 per cent, regional fixed effects affect both establishment and maintenance costs whereas the dummies for the technology type are not significant in both models. We reported results of the OLS model with robust standard errors as well as the fixed and random effect models. Our data set consists of a panel of establishment and maintenance costs information for the period 2002-2014.

As a result, panel data econometric model specifications that control the effects of each individual year is appropriate. In a panel model, the individual effect terms can be modelled as either random or fixed effects. If the individual effects are correlated with the other explanatory variables in the model, the fixed effect model is consistent, and the random effects model becomes inconsistent. On the other hand, if the individual effects are not correlated with the other explanatory variables in the model, both random and fixed effects are consistent and random effects is efficient. The Hausman test statistics in both establishment and maintenance costs models (Tables 3.2 and 3.3) are not significant, indicating that the random effect model is efficient. We further dropped insignificant variables from the random effect model and ran Hausman specification tests for the fixed and random effect models with only significant explanatory variables. This consistently proved that the restricted random effect model is efficient for estimating both the establishment and maintenance costs.

3.4. Results

Based on the above econometric model results, we used the restricted random effect models as meta-transfer functions to estimate the establishment and maintenance costs at national level of SLM technologies for the year 2016. We used GDP per capita for the year 2016 and assumed the other factors remained constant. Table 3.4 shows that the estimated average total establishment costs for the year 2016 was USD 1,749.19 per hectare, of which USD 1,073.86 (61 per cent) was labour costs. The estimated average establishment costs for the year 2016 were higher by USD 636.81 per hectare (or 57.25 per cent higher) compared to the mean establishment costs of USD 1,112.38 per hectare for the 44 SLM technologies reported in the period 2002-2014.

For their part, the annual maintenance costs for the year 2016 were estimated using the restricted random effect model in Table 3.4 and GDP per capita for the year 2016. The estimate average maintenance costs amounted to USD 609.38 per hectare. The estimated labour costs were USD 427.75 per hectare (or 70 per cent of the total maintenance costs) for the year 2016. This is lower by USD 52.16 per hectare (or 7.89 per cent lower) than the average maintenance costs for the 41 SLM technologies reported in the period 2002-2014 (Annex Table 3.1). Table 3.4 also provides estimates of average maintenance and establishment costs by technology type. This was partly because we dropped outliers in the process of the econometric modelling.

TABLE 3.4:

Estimated average establishment and maintenance costs of SLM technologies in USD per hectare adjusted to 2016 prices.

Conservation measure	Costs in USD per ha			Ratio labour cost to total cost	Ratio non-labour to total cost	Land users' share in %
	Labour	non-labour	Total			
Establishment costs						
Agronomic	392.37 (392.37)	311.05 (136.66)	703.42 (529.03)	0.56 (0.32)	0.44 (0.32)	78.48 (21.53)
Structural	1,143.63 (262.83)	589.99 (130.29)	1,733.62 (293.69)	0.66 (0.05)	0.34 (0.05)	57.16 (6.90)
Management	798.43 (216.76)	112.22 (25.65)	910.65 (191.11)	0.88 (0.07)	012 (0.07)	38.79 (13.22)
Mixed	1,068.90 (152.51)	1,205.85 (189.50)	2,274.75 (188.61)	0.51 (0.06)	0.49 (0.06)	74.54 (7.69)
Total establishment costs	1,073.86 (188.02)	675.33 (108.12)	**1,749.19 (217.27)**	0.61 (0.04)	0.39 (0.04)	60.83 (5.16)
N	40	40	40	44	44	44
Maintenance costs						
Agronomic	164.13 (164.13)	308.28 (125.78)	472.41 (289.91)	0.35 (0.22)	0.65 (0.22)	54.12 (45.89)
Structural	458.63 (143.92)	180.43 (48.11)	639.06 (147.78)	0.72 (0.08)	0.28 (0.08)	74.12 (7.83)
Management	187.75 (32.13)	90.98 (90.98)	278.73 (58.85)	0.67 (0.16)	0.33 (0.16)	57.60 (27.80)
Mixed	471.09 (159.06)	171.72 (48.19)	642.80 (131.18)	0.73 (0.09)	0.27 (0.09)	78.03 (11.31)
Total maintenance costs	427.75 (112.97)	181.63 (38.34)	**609.38 (115.95)**	0.70 (0.06)	0.30 (0.06)	72.66 (6.24)
N	35	35	35	41	41	40

Values in () are standard errors

3.5. Summary

The results of this chapter indicate that the R^2-values for the restricted establishment and maintenance costs models are 0.385 and 0.561, respectively. This means that the variations in the explanatory variables can explain 38.5 and 56.1 per cent of the variations in the log-transformed establishment costs per hectare and log-transformed maintenance costs per hectare. This is partly because the data points and number of regional states in the country from which such cost information was reported to the WOCAT database are relatively small. As sample size increases, it is likely that the explanatory power of the models will also improve. In the future, as more data from more regional states in Ethiopia become available in the WOCAT database, it will be possible to update and improve the models by including more data points. Despite this, the explanatory powers of the models are sufficient, and the coefficients of the explanatory variables are both consistent and efficient as indicated by the Hausman specification test statistics. Moreover, in addition to the input data available in the WOCAT database itself, the

PHOTO

models require only GDP per capita for both estimation and adjusting of costs to current prices of the required study year.

Thus, the estimated establishment and maintenance costs at national level of SLM technologies could be used as an important input in further CBAs of possible actions to prevent land degradation and the associated losses of provisioning ecosystem services to agricultural ecosystems in Ethiopia. It could also be used at the regional states and administrative zones levels.

04 Cost-benefit analysis and benefit-cost ratios of sustainable management in Ethiopia

4.1. Introduction

The analyses and results in the earlier chapters provide insights on the extent of agricultural land degradation caused by soil NPK depletion and NPK loss on close to 13 million hectares of cultivated land in Ethiopia. They also provide details on the extent of the associated crop production losses both in quantity and value terms that the country and each of the 66 administrative zones experienced over the period 2003-2016. There is a need for interventions against agricultural land degradation and this, among other things, requires updated information on the costs of sustainable management technologies that could be applied as remedies. In this regard, Chapter 3 provides both the methods used and the results of the national average costs of establishing and maintaining SLM technologies in Ethiopia for the base year 2016.

Based on the results of the previous chapters, the objective of this chapter is to perform a cost-benefit analysis (CBA) of preventing soil NPK depletion and NPK loss through investing in SLM technologies on cultivated lands in the country as a whole, in its regional states, and in its administrative zones. This chapter specifically aims to assess:

- How much will it cost for each of the 66 administrative zone, the regional states, and Ethiopia to prevent soil NPK depletion and NPK loss from the cultivated lands in the next 11 to 21 years (2020 to 2030 and 2020 to 2040);
- What are the present values (PV) of the flows of benefits from preventing soil NPK depletion and NPK loss over the next 11 to 21 years (2020-2030 and 2020-2040), and;
- Compare the benefits and costs of preventing soil NPK depletion and NPK loss at administrative zone, regional state, and country levels.

Thus, the next sections of the chapter discuss how the net present value and benefit-cost ratios are calculated. The section also provided the assumptions on the flows of future benefits and costs. We also present the results of the CBA, which is followed by the results of the sensitivity analysis and chapter summary.

4.2. The net present value and benefit-cost ratio

We applied the net present value (NPV) as a main decision criterion to evaluate the economic returns of preventing soil NPK depletion and NPK loss on agricultural land of Ethiopia. NPV sums up the discounted annual flows of net benefits, which is the difference of discounted benefits and discounted costs of preventing NPK losses and soil NPK depletion, over the lifespan of the project. The NPV of a project is the amount by which it increases net worth in PV terms. Therefore, the decision rule is to accept a project (in this case a SLM project aimed at preventing soil NPK depletion and NPK loss on agricultural land) with non-negative NPV and reject otherwise:

$$NPV_i = \sum_{(t=1)}^{T} \left[\frac{(B_{it}-C_{it})}{(1+r)^t} \right] \qquad (4.1)$$

Where,

- NPV_i is Net Present Value (in USD) of preventing soil NPK depletion and NPK loss on agricultural land for administrative zone i in Ethiopia;
- B_{it} is benefit (in USD) of preventing soil NPK depletion and NPK loss on agricultural land of administrative zone i at time t;
- C_{it} is the cost (in USD) of preventing soil NPK depletion and NPK loss on agricultural land for administrative zone i at time t;
- r is average real discount rate at country level;
- t is time in years (t = 0, 1, 2, ...T) where t=0 in year 2020, t=1 in year 2021, ..., and T= 10 in year 2030 and T=20 in year 2040;
- i is a subscript for administrative zone.

Calculating NPV requires decisions on three important parameters that may necessitate making some plausible and policy-relevant assumptions. These are the discounting period, the flows of costs and benefits over the discount period, and the discount rate.

Discounting period: The first is to determine a reasonable period over which a country or

BOX 3:

Assumptions on the flows of costs and benefits

In addition to the assumptions 1-6 in *Box 2* and the results of the estimations in chapters 2 and 3, we assumed the following when deriving the flows of benefits and costs of interventions to prevent soil NPK depletion and NPK loss and the associated crop production/productivity losses:

1. We assumed that each administrative zone would establish and apply all the sustainable land management technologies on 20 per cent of the cropland area per year (see column two of *Annex Table A2* for the cultivated land area for each zone) and all the croplands will have these SLM technologies by the end of the first five years.
2. The per hectare investment costs for the establishment and annual maintenance of SLM structures and technologies are based on the results of Chapter 3 (Table 3.5). In addition to these costs, we take into account additional operational costs amounting to 15 per cent of the establishment costs and 10 per cent of the maintenance costs in the first 5 years, and only 10 per cent of the maintenance from the 6th year onwards as planning and implementation. We also considered another 10 to 20 per cent of the investment costs for monitoring and evaluation. The planning and implementation costs are for each year over the project period whereas the monitoring and evaluation costs are for 2022, 2026, 2030, 2035, and 2040.
3. We assumed that maintenance costs start from the second year onwards.
4. In the case of flows of benefits of preventing soil NPK depletion and NPK loss, we assumed zero benefits at t=0. Benefits start to flow from 2021 onwards in terms of prevented NPK losses and depletion as well as prevented crop production losses, or in other words increased productivity. These benefits are based on results of Chapter 2.
5. Sustainable land management technologies vary in their effectiveness in reducing soil erosion due to different factors. Bench terraces, for example, are reported to have more than 75 per cent effectiveness in reducing soil erosion (Tegne et al. 2011). In this study, given that preventing degradation has the highest priority in the LDN concept, we assumed the prevention of soil NPK depletion and NPK loss to have the maximum possible (100 per cent reduction in topsoil loss).

decisionmaker can accomplish proper planning, implementation, as well as monitoring and evaluation of investments in SLM technologies on agricultural land that could prevent soil NPK depletion and NPK loss. When determining the discount period, it is also important to consider national and global scale development goals and the time set to achieve such goals so that the results of the study can be integrated to national and global scale development goals. In this regard, we have selected a period of 11 years (2020 to 2030), which is also the remaining time for the countries who have agreed to achieve the SDGs after taking lessons from the last 15 years of efforts to achieve the past Millennium Development Goals. We further take into account 10 more years after 2030 to provide more insights on the net benefits of investing in SLM interventions over a longer time horizon.

Rate of discount: In the evaluation of public projects in the framework of CBA, the choice of discount rate has been a continuous debate in the literature. Some economists defend the use of the market interest rate, which is based on individual time preference, while others argue that we need to take into account intergenerational equity, although market rates of interest may be too high and inappropriate. So far, there is no one-fit-for-all method of choosing the discount rate. Therefore, this analysis uses the real interest rates of Ethiopia for discounting, as reported in the World Bank database. We were able to get data on the real interest rates of Ethiopia for the period 1991-2017. We took the geometric mean of the available data to determine the real interest rate. We found the geometric mean of the real discount rates for 1991-2017 to be 0.59 per cent, and we used this in discounting the future flows of costs and benefits.

Flow of costs and benefits: Once the project period is determined, the next step is to estimate the flows of costs and benefits for each year of the discounting period. The following plausible assumptions were made in determining the flows of costs and benefits (see Box 3).

Benefit-cost ratio (BCR) and annuity: As a second decision criterion, we also calculated the BCR. Moreover, for each administrative zone, the annuity values of the PV of costs, the PV of benefits, and the NPV were calculated and compared with the average country level GDP and agricultural GDP. All values in USD are based on 2016 prices.

Sensitivity analysis: We conducted a sensitivity analysis to observe the sensitivity of NPVs and BCR to changes in important parameters used in the cost-benefit analysis. These include changes in the discount rates, weighted average prices of crops, establishment and maintenance costs of SLM technologies, and their effectiveness in preventing soil NPK depletion and NPK loss.

4.3. Present value of costs of sustainable land management in Ethiopia

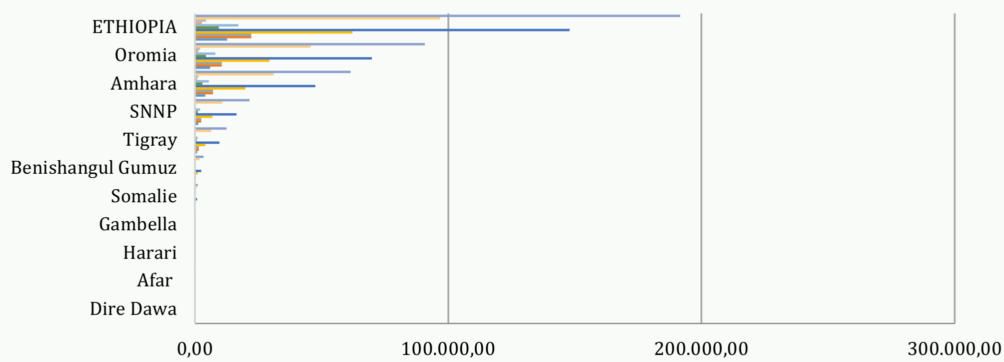
4.3.1. Present value of costs at country level

The PV of investments in SLM interventions on 12.77 million hectares of agricultural land in Ethiopia from 2020-2030 is estimated at USD 96.74 billion (USD 7,434 per hectare); whereas the present value of total costs over the period 2020-2040 is about USD 192 billion (USD 15,008 per hectare) (Figure 4.1).

The cost components include establishment costs of USD 22.34 billion in PV, which has to be invested in the first 5 years until 2024, and maintenance costs are estimated at USD 62.27 billion in PV over the period 2021-2030 or USD 147.89 billion in PV over the period 2021-2040. The PV of establishment costs accounts for 23.09 per cent of the PV of the total costs if the project period is 2020-2030. If the project period is from 2020 to 2040, it accounts for only 11.65 per cent of the PV of the total costs.

FIGURE 4.1:

Country and regional level PV of the total costs (in millions of USD) of SLM.



	Dire Dawa	Afar	Harari	Gambella	Somalie	Benishangul Gumuz	Tigray	SNNP	Amhara	Oromia	ETHIOPIA
PV of total costs_2020-2040	180,28	218,83	231,64	273,29	1.151,24	3.333,28	12.563,72	21.448,04	61.585,93	90.715,97	191.702,22
PV of total costs _2020-2030	90,98	110,43	116,90	137,92	580,97	1.682,14	6.340,28	10.823,75	31.079,34	45.779,82	96.742,53
PV of monitoring & evaluation costs_2020-2040	4,06	4,92	5,21	6,15	25,90	75,00	282,68	482,57	1.385,67	2.041,08	4.313,24
PV of monitoring & evaluation costs_2020-2030	2,59	3,15	3,33	3,93	16,55	47,93	180,66	308,41	885,56	1.304,42	2.756,53
PV of planning & implementation costs_2020-2040	16,14	19,59	20,73	24,46	103,04	298,35	1.124,53	1.919,73	5.512,33	8.119,65	17.158,55
PV of planning & implementation costs_2020-2030	8,82	10,70	11,33	13,36	56,30	163,01	614,41	1.048,89	3.011,79	4.436,36	9.374,97
PV of maintenance costs_2020-2040	139,08	168,81	178,70	210,83	888,12	2.571,45	9.692,24	16.546,02	47.510,26	69.982,53	147.888,03
PV of maintenance costs_2020-2030	58,56	71,08	75,24	88,77	373,95	1.082,71	4.080,94	6.966,74	20.004,32	29.466,33	62.268,64
PV of establishment costs_2020-2040	21,01	25,50	27,00	31,85	134,17	388,48	1.464,27	2.499,71	7.177,68	10.572,71	22.342,39
PV of establishment costs_2020-2030	21,01	25,50	27,00	31,85	134,17	388,48	1.464,27	2.499,71	7.177,68	10.572,71	22.342,39
Harvested area 1000s ha	12,01	14,58	15,43	18,21	76,71	222,09	837,11	1.429,07	4.103,43	6.044,35	12.773,01

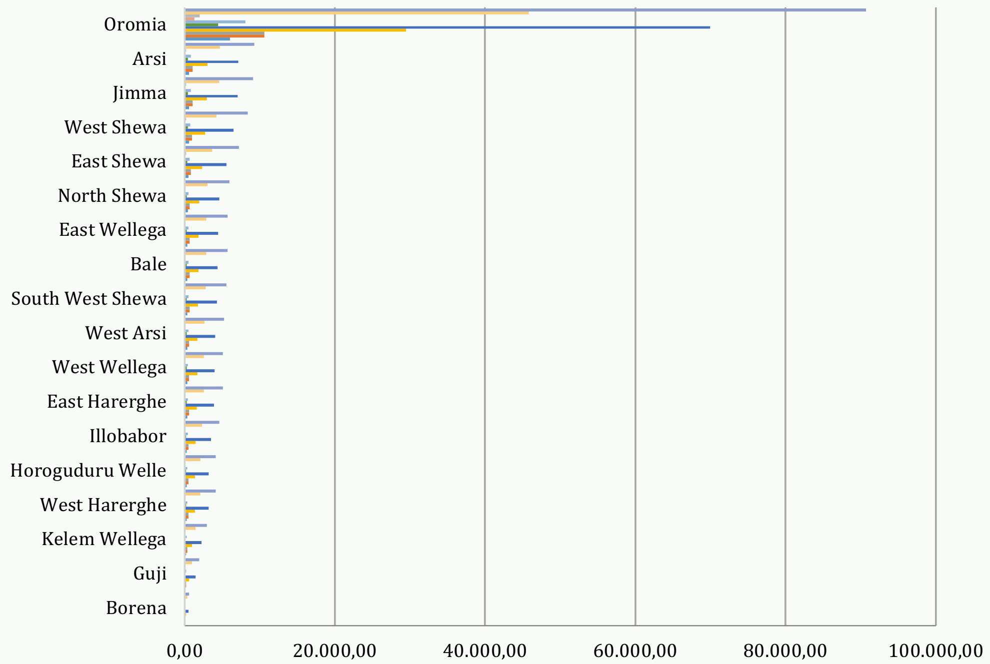
The PV of maintenance costs, which are annual costs for maintaining established SLM structures, accounts for 64.37 per cent of the PV of the total costs over the period 2020-2030 and 77.14 per cent of the total costs over the period 2020-2040.

As shown in Figure 4.1, the PV of annual planning and implementation costs are USD 9.38 billion (9.69 per cent of the PV of the total costs for 2020-2030) and USD 17.16 billion (8.69 per cent of the PV of the total costs for 2020-2040) for their respective project periods. The PV of the costs for monitoring and evaluation are estimated at about USD 2.78 billion (2.85 per cent of the PV of the total costs for 2020-2030) and USD 4.31 billion (2.25 per cent of the PV of the total costs for 2020-2040).

On a per hectare level, the PV of establishment costs for both the periods 2020-2030 and 2020-2040 are estimated at about USD 1,749 per hectare. For annual maintenance costs, the PV is USD 4,875 per hectare for the period 2020-2030 and USD 11,578 per hectare for 2020-2040. The PV of annual planning and implementation costs are USD 734 per hectare and USD 1,343 per hectare for the project periods 2020-2030 and 2020-2040, respectively. The PV of monitoring and evaluation costs are USD 216 per hectare for the 2020-2030 project period and USD 338 per hectare for 2020-2040.

FIGURE 4.2:

PV of the total costs (in millions of USD) of SLM in Oromia.



	Borena	Guji	Kelem Wellega	West Hareghe	Horoguduru Welle	Illobabor	East Hareghe	West Wellega	West Arsi	South West Shewa	Bale	East Wellega	North Shewa	East Shewa	West Shewa	Jimma	Arsi	Oromia
PV of total costs_2020-2040	620,96	1.905,70	2.952,80	4.152,92	4.172,95	4.570,79	5.047,43	5.116,07	5.232,20	5.543,96	5.698,18	5.741,34	5.971,64	7.235,91	8.425,22	9.100,36	9.227,57	90.715,97
PV of total costs _2020-2030	313,37	961,71	1.490,13	2.095,77	2.105,88	2.306,65	2.547,19	2.581,82	2.640,43	2.797,76	2.875,58	2.897,37	3.013,59	3.651,60	4.251,79	4.592,50	4.656,70	45.779,82
PV of monitoring & evaluation costs_2020-2040	13,97	42,88	66,44	93,44	93,89	102,84	113,57	115,11	117,72	124,74	128,21	129,18	134,36	162,81	189,56	204,76	207,62	2.041,08
PV of monitoring & evaluation costs_2020-2030	8,93	27,40	42,46	59,72	60,00	65,72	72,58	73,57	75,23	79,72	81,94	82,56	85,87	104,05	121,15	130,86	132,69	1.304,42
PV of planning & implementation costs_2020-2040	55,58	170,57	264,29	371,71	373,51	409,11	451,78	457,92	468,31	496,22	510,02	513,89	534,50	647,66	754,11	814,54	825,93	8.119,65
PV of planning & implementation costs_2020-2030	30,37	93,20	144,40	203,09	204,07	223,53	246,84	250,20	255,87	271,12	278,66	280,77	292,04	353,86	412,03	445,04	451,26	4.436,36
PV of maintenance costs_2020-2040	479,03	1.470,15	2.277,92	3.203,76	3.219,21	3.526,12	3.893,82	3.946,77	4.036,37	4.276,87	4.395,84	4.429,14	4.606,80	5.582,12	6.499,60	7.020,44	7.118,58	69.982,53
PV of maintenance costs_2020-2030	201,70	619,01	959,13	1.348,95	1.355,46	1.484,68	1.639,50	1.661,80	1.699,52	1.800,79	1.850,88	1.864,90	1.939,71	2.350,37	2.736,68	2.955,98	2.997,30	29.466,33
PV of establishment costs_2020-2040	72,37	222,10	344,14	484,01	486,35	532,71	588,26	596,26	609,80	646,13	664,11	669,14	695,98	843,33	981,94	1.060,62	1.075,45	10.572,71
PV of establishment costs_2020-2030	72,37	222,10	344,14	484,01	486,35	532,71	588,26	596,26	609,80	646,13	664,11	669,14	695,98	843,33	981,94	1.060,62	1.075,45	10.572,71
Harvested area 1000s ha	41,37	126,98	196,74	276,71	278,04	304,55	336,31	340,88	348,62	369,39	379,67	382,54	397,89	482,12	561,37	606,35	614,83	6.044,35

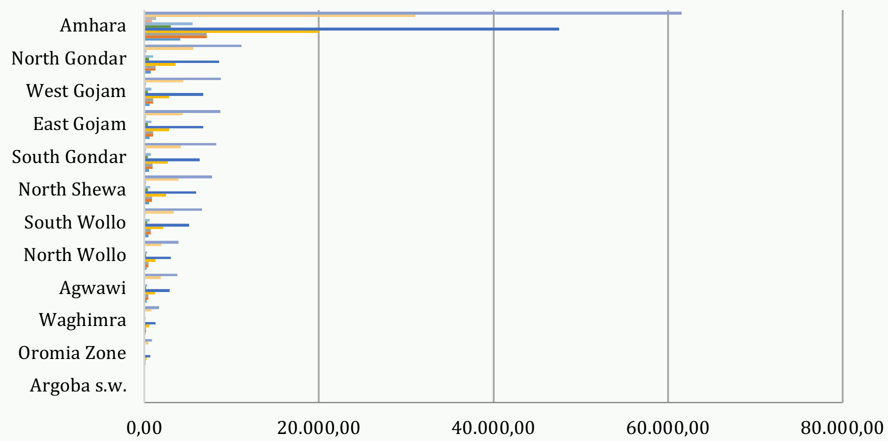
4.3.2. Present values of costs at regional and zonal levels

Each of the following sections shows the present value of the total costs of SLM interventions in the selected regional states. The figures also show the establishment, maintenance, planning and implementation, as well as monitoring and evaluation costs.

Oromia regional state: The PV of total costs of SLM intervention on 6.04 million hectares of agricultural land in Oromia is estimated at about USD 45.78 billion for the 2020-2030 project period and USD 90.72 billion for the project period 2020-2040 (Figure 4.2).

FIGURE 4.3:

The PV of the total costs (in millions of USD) of SLM in Amhara.



	Argoba s.w.	Oromia Zone	Waghimra	Agwawi	North Wollo	South Wollo	North Shewa	South Gondar	East Gojam	West Gojam	North Gondar	Amhara
PV of total costs_2020-2040	83,74	894,01	1.673,67	3.800,32	3.908,60	6.638,18	7.735,65	8.248,54	8.709,54	8.777,31	11.116,39	61.585,93
PV of total costs _2020-2030	42,26	451,16	844,62	1.917,83	1.972,47	3.349,96	3.903,79	4.162,63	4.395,27	4.429,47	5.609,89	31.079,34
PV of monitoring & evaluation costs_2020-2040	1,88	20,12	37,66	85,51	87,94	149,36	174,05	185,59	195,96	197,49	250,12	1.385,67
PV of monitoring & evaluation costs_2020-2030	1,20	12,86	24,07	54,65	56,20	95,45	111,23	118,61	125,24	126,21	159,85	885,56
PV of planning & implementation costs_2020-2040	7,50	80,02	149,80	340,15	349,84	594,16	692,39	738,30	779,56	785,62	994,99	5.512,33
PV of planning & implementation costs_2020-2030	4,10	43,72	81,85	185,85	191,15	324,63	378,30	403,38	425,93	429,24	543,63	3.011,79
PV of maintenance costs_2020-2040	64,60	689,68	1.291,14	2.931,74	3.015,27	5.121,00	5.967,64	6.363,31	6.718,95	6.771,22	8.575,70	47.510,26
PV of maintenance costs_2020-2030	27,20	290,39	543,64	1.234,42	1.269,59	2.156,21	2.512,69	2.679,29	2.829,03	2.851,04	3.610,82	20.004,32
PV of establishment costs_2020-2040	9,76	104,19	195,06	442,92	455,54	773,66	901,57	961,35	1.015,07	1.022,97	1.295,59	7.177,68
PV of establishment costs_2020-2030	9,76	104,19	195,06	442,92	455,54	773,66	901,57	961,35	1.015,07	1.022,97	1.295,59	7.177,68
Harvested area 1000s ha	5,58	59,57	111,52	253,21	260,43	442,30	515,42	549,60	580,31	584,83	740,68	4.103,43

Amhara regional state: Figure 4.3 shows the PV of total costs of SLM intervention on 4.1 million hectares of agricultural land in Amhara. It is estimated at about USD 31.08 billion for the 2020-2030 project period and USD 61.59 billion for the project period 2020-2040.

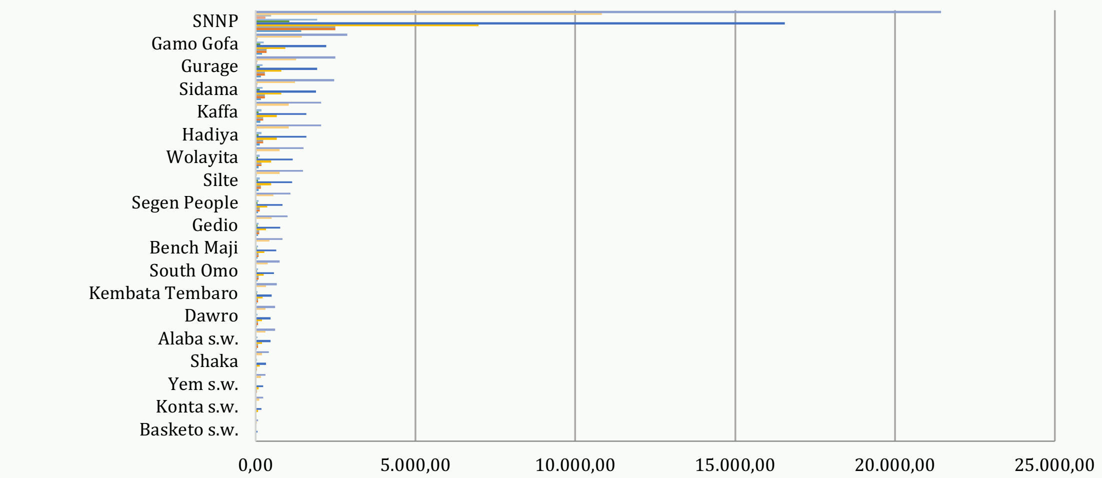
Southern Nations Nationalities and Peoples (SNNP) regional state: Figure 4.4 shows the present value of total costs of SLM intervention on 1.43 million hectares of agricultural land in SNPP. It is estimated at about USD 10.82 billion for the 2020-2030 project period and USD 21.45 billion for the project period 2020-2040.

Tigray regional state: Figure 4.5 shows the PV of total costs of SLM intervention on 0.837 million hectares of agricultural land in Tigray. It is estimated at about USD 6.34 billion for the 2020-2030 project period and USD 12.56 billion for the project period 2020-2040.

Benishangul Gumuz regional state: Figure 4.6 shows the PV of total costs of SLM intervention on 0.222 million hectares of agricultural land in Benishangul Gumuz. It is estimated at about USD 1.68 billion for the 2020-2030 project period and USD 3.33 billion for the project period 2020-2040.

FIGURE 4.4:

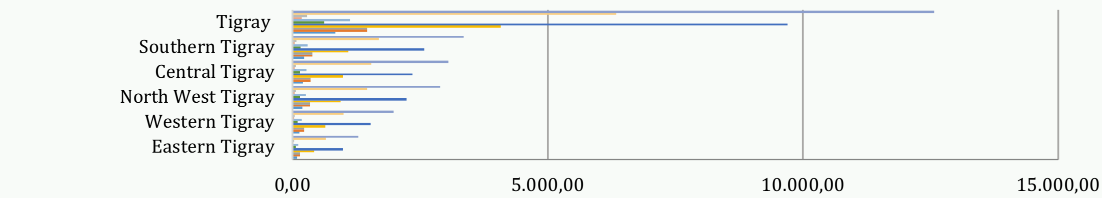
The PV of the total costs (in millions of USD) of SLM in SNNP.



	Basketo s.w.	Konta s.w.	Yem s.w.	Shaka	Alaba s.w.	Dawro	Kembata Tembaro	South Omo	Bench Maji	Gedio	Segen People	Silte	Wolayita	Hadiya	Kaffa	Sidama	Gurage	Gamo Gofa	SNNP
PV of total costs_2020-2040	79,51	228,08	308,79	408,13	599,87	612,62	658,40	752,74	834,68	995,01	1.095,37	1.473,71	1.491,20	2.050,89	2.054,28	2.450,72	2.492,61	2.861,44	21.448,04
PV of total costs _2020-2030	40,13	115,10	155,83	205,97	302,72	309,16	332,26	379,87	421,22	502,13	552,78	743,71	752,53	1.034,98	1.036,69	1.236,76	1.257,89	1.444,03	10.823,75
PV of monitoring & evaluation costs_2020-2040	1,79	5,13	6,95	9,18	13,50	13,78	14,81	16,94	18,78	22,39	24,65	33,16	33,55	46,14	46,22	55,14	56,08	64,38	482,57
PV of monitoring & evaluation costs_2020-2030	1,14	3,28	4,44	5,87	8,63	8,81	9,47	10,82	12,00	14,31	15,75	21,19	21,44	29,49	29,54	35,24	35,84	41,15	308,41
PV of planning & implementation costs_2020-2040	7,12	20,41	27,64	36,53	53,69	54,83	58,93	67,38	74,71	89,06	98,04	131,91	133,47	183,57	183,87	219,35	223,10	256,12	1.919,73
PV of planning & implementation costs_2020-2030	3,89	11,15	15,10	19,96	29,34	29,96	32,20	36,81	40,82	48,66	53,57	72,07	72,93	100,30	100,46	119,85	121,90	139,94	1.048,89
PV of maintenance costs_2020-2040	61,34	175,95	238,21	314,85	462,76	472,60	507,92	580,70	643,91	767,60	845,02	1.136,89	1.150,38	1.582,15	1.584,77	1.890,60	1.922,91	2.207,45	16.546,02
PV of maintenance costs_2020-2030	25,83	74,08	100,30	132,57	194,85	198,99	213,86	244,51	271,12	323,20	355,80	478,69	484,37	666,17	667,27	796,04	809,65	929,45	6.966,74
PV of establishment costs_2020-2040	9,27	26,58	35,99	47,57	69,91	71,40	76,73	87,73	97,28	115,97	127,66	171,76	173,80	239,03	239,42	285,62	290,51	333,49	2.499,71
PV of establishment costs_2020-2030	9,27	26,58	35,99	47,57	69,91	71,40	76,73	87,73	97,28	115,97	127,66	171,76	173,80	239,03	239,42	285,62	290,51	333,49	2.499,71
Harvested area 1000s ha	5,30	15,20	20,57	27,19	39,97	40,82	43,87	50,15	55,61	66,30	72,98	98,19	99,36	136,65	136,88	163,29	166,08	190,66	1.429,07

FIGURE 4.5:

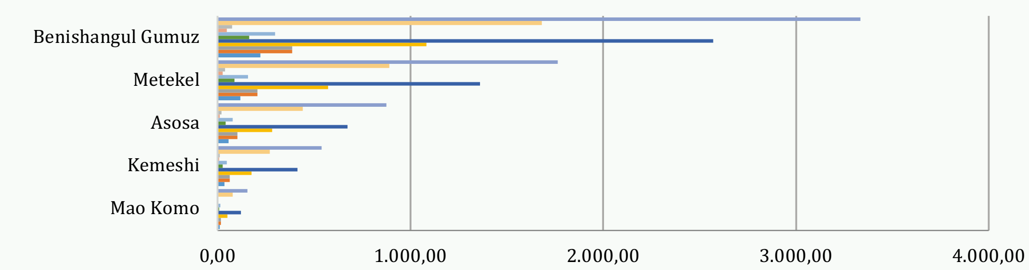
The PV of the total costs (in millions of USD) of SLM in Tigray.



	Eastern Tigray	Western Tigray	North West Tigray	Central Tigray	Southern Tigray	Tigray
PV of total costs_2020-2040	1.288,21	1.978,45	2.894,99	3.053,00	3.349,06	12.563,72
PV of total costs _2020-2030	650,10	998,43	1.460,96	1.540,70	1.690,11	6.340,28
PV of monitoring & evaluation costs_2020-2040	28,98	44,51	65,14	68,69	75,35	282,68
PV of monitoring & evaluation costs_2020-2030	18,52	28,45	41,63	43,90	48,16	180,66
PV of planning & implementation costs_2020-2040	115,30	177,08	259,12	273,26	299,76	1.124,53
PV of planning & implementation costs_2020-2030	63,00	96,75	141,58	149,30	163,78	614,41
PV of maintenance costs_2020-2040	993,79	1.526,27	2.233,33	2.355,23	2.583,62	9.692,24
PV of maintenance costs_2020-2030	418,44	642,64	940,35	991,67	1.087,84	4.080,94
PV of establishment costs_2020-2040	150,14	230,58	337,40	355,82	390,32	1.464,27
PV of establishment costs_2020-2030	150,14	230,58	337,40	355,82	390,32	1.464,27
Harvested area 1000s ha	85,83	131,82	192,89	203,42	223,15	837,11

FIGURE 4.6:

The PV of the total costs (in millions of USD) of SLM in Benishangul Gumuz.



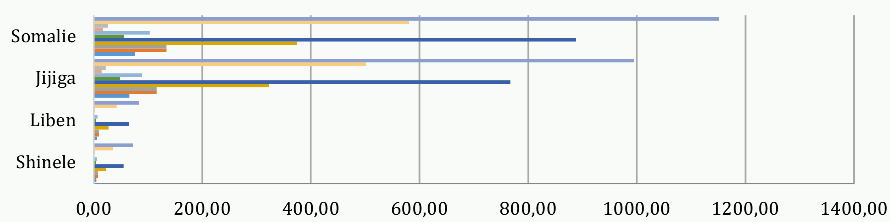
	Mao Komo	Kemeshi	Asosa	Metekel	Benishangul Gumuz
PV of total costs_2020-2040	155,68	538,28	874,70	1.764,61	3.333,28
PV of total costs _2020-2030	78,57	271,64	441,42	890,51	1.682,14
PV of monitoring & evaluation costs_2020-2040	3,50	12,11	19,68	39,70	75,00
PV of monitoring & evaluation costs_2020-2030	2,24	7,74	12,58	25,37	47,93
PV of planning & implementation costs_2020-2040	13,93	48,18	78,29	157,94	298,35
PV of planning & implementation costs_2020-2030	7,61	26,32	42,78	86,30	163,01
PV of maintenance costs_2020-2040	120,10	415,25	674,79	1.361,30	2.571,45
PV of maintenance costs_2020-2030	50,57	174,84	284,12	573,18	1.082,71
PV of establishment costs_2020-2040	18,14	62,74	101,94	205,66	388,48
PV of establishment costs_2020-2030	18,14	62,74	101,94	205,66	388,48
Harvested area 1000s ha	10,37	35,87	58,28	117,58	222,09

Somalie regional state: Figure 4.7 shows the PV of total costs of SLM intervention on 0.077 million hectares of agricultural land in Somalie. It is estimated at about USD 0.581 billion for the 2020-2030 project period and USD 1.15 billion for the project period 2020-2040.

Gambella regional state: Figure 4.8 shows the PV of total costs of SLM intervention on 0.018 million hectares of agricultural land in Gambella. It is estimated at about USD 0.138 billion for the 2020-2030 project period and USD 0.273 billion for the project period 2020-2040.

FIGURE 4.7:

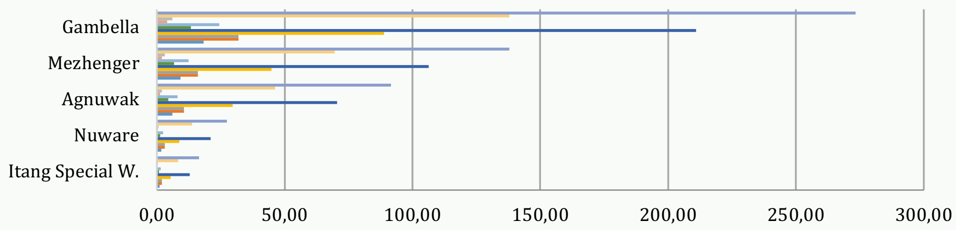
The PV of the total costs (in millions of USD) of SLM in Somalie.



	Shinele	Liben	Jijiga	Somalie
PV of total costs_2020-2040	72,16	84,29	994,79	1151,24
PV of total costs _2020-2030	36,42	42,54	502,02	580,97
PV of monitoring & evaluation costs_2020-2040	1,62	1,90	22,38	25,90
PV of monitoring & evaluation costs_2020-2030	1,04	1,21	14,30	16,55
PV of planning & implementation costs_2020-2040	6,46	7,54	89,04	103,04
PV of planning & implementation costs_2020-2030	3,53	4,12	48,65	56,30
PV of maintenance costs_2020-2040	55,67	65,02	767,43	888,12
PV of maintenance costs_2020-2030	23,44	27,38	323,13	373,95
PV of establishment costs_2020-2040	8,41	9,82	115,94	134,17
PV of establishment costs_2020-2030	8,41	9,82	115,94	134,17
Harvested area 1000s ha	4,81	5,62	66,28	76,71

FIGURE 4.8:

The PV of the total costs (in millions of USD) of SLM in Gambella.



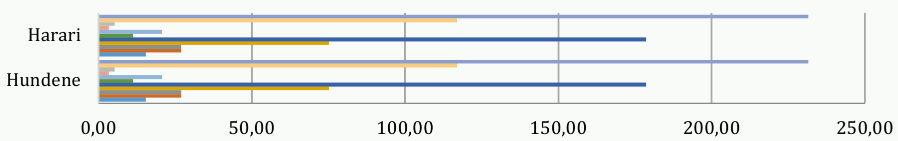
	Itang Special W.	Nuware	Agnuwak	Mezhenger	Gambella
PV of total costs_2020-2040	16,55	27,36	91,53	137,86	273,29
PV of total costs _2020-2030	8,35	13,80	46,19	69,57	137,92
PV of monitoring & evaluation costs_2020-2040	0,37	0,62	2,06	3,10	6,15
PV of monitoring & evaluation costs_2020-2030	0,24	0,39	1,32	1,98	3,93
PV of planning & implementation costs_2020-2040	1,48	2,45	8,19	12,34	24,46
PV of planning & implementation costs_2020-2030	0,81	1,34	4,48	6,74	13,36
PV of maintenance costs_2020-2040	12,77	21,10	70,61	106,35	210,83
PV of maintenance costs_2020-2030	5,38	8,89	29,73	44,78	88,77
PV of establishment costs_2020-2040	1,93	3,19	10,67	16,07	31,85
PV of establishment costs_2020-2030	1,93	3,19	10,67	16,07	31,85
Harvested area 1000s ha	1,10	1,82	6,10	9,19	18,21

Harari regional state: Figure 4.9 shows the PV of total costs of SLM intervention on 0.015 million hectares of agricultural land in Harari. It is estimated at about USD 0.117 billion for the 2020-2030 project period and USD 0.232 billion for the project period 2020-2040.

Afar regional state: Figure 4.10 shows the PV of total costs of SLM intervention on 0.015 million hectares of agricultural land in Afar. It is estimated at about USD 0.110 billion for the 2020-2030 project period and USD 0.219 billion for the project period 2020-2040.

FIGURE 4.9:

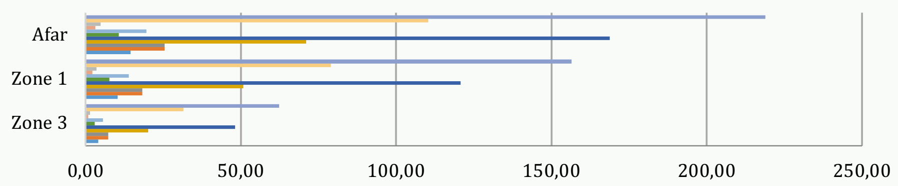
The PV of the total costs (in millions of USD) of SLM in Harari.



	Hundene	Harari
PV of total costs_2020-2040	231,64	231,64
PV of total costs _2020-2030	116,90	116,90
PV of monitoring & evaluation costs_2020-2040	5,21	5,21
PV of monitoring & evaluation costs_2020-2030	3,33	3,33
PV of planning & implementation costs_2020-2040	20,73	20,73
PV of planning & implementation costs_2020-2030	11,33	11,33
PV of maintenance costs_2020-2040	178,70	178,70
PV of maintenance costs_2020-2030	75,24	75,24
PV of establishment costs_2020-2040	27,00	27,00
PV of establishment costs_2020-2030	27,00	27,00
Harvested area 1000s ha	15,43	15,43

FIGURE 4.10:

The PV of the total costs (in millions of USD) of SLM in Afar.

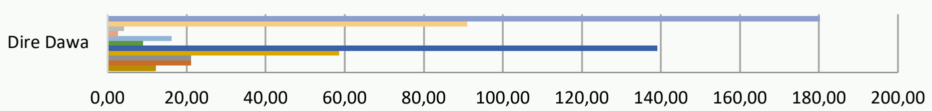


	Zone 3	Zone 1	Afar
PV of total costs_2020-2040	62,36	156,47	218,83
PV of total costs _2020-2030	31,47	78,96	110,43
PV of monitoring & evaluation costs_2020-2040	1,40	3,52	4,92
PV of monitoring & evaluation costs_2020-2030	0,90	2,25	3,15
PV of planning & implementation costs_2020-2040	5,58	14,01	19,59
PV of planning & implementation costs_2020-2030	3,05	7,65	10,70
PV of maintenance costs_2020-2040	48,10	120,71	168,81
PV of maintenance costs_2020-2030	20,25	50,83	71,08
PV of establishment costs_2020-2040	7,27	18,24	25,50
PV of establishment costs_2020-2030	7,27	18,24	25,50
Harvested area 1000s ha	4,15	10,43	14,58

Dire Dawa city administration: Figure 4.11 shows the PV of total costs of SLM intervention on 0.012 million hectares of agricultural land in Dire Dawa. It is estimated at about USD 0.091 billion for the 2020-2030 project period and USD 0.180 billion for the project period 2020-2040.

FIGURE 4.11:

The PV of the total costs (in millions of USD) of SLM in Dire Dawa.



	Dire Dawa
PV of total costs_2020-2040	180,28
PV of total costs _2020-2030	90,98
PV of monitoring & evaluation costs_2020-2040	4,06
PV of monitoring & evaluation costs_2020-2030	2,59
PV of planning & implementation costs_2020-2040	16,14
PV of planning & implementation costs_2020-2030	8,82
PV of maintenance costs_2020-2040	139,08
PV of maintenance costs_2020-2030	58,56
PV of establishment costs_2020-2040	21,01
PV of establishment costs_2020-2030	21,01
Harvested area 1000s ha	12,01

4.4. Present value of benefits of sustainable land management in Ethiopia

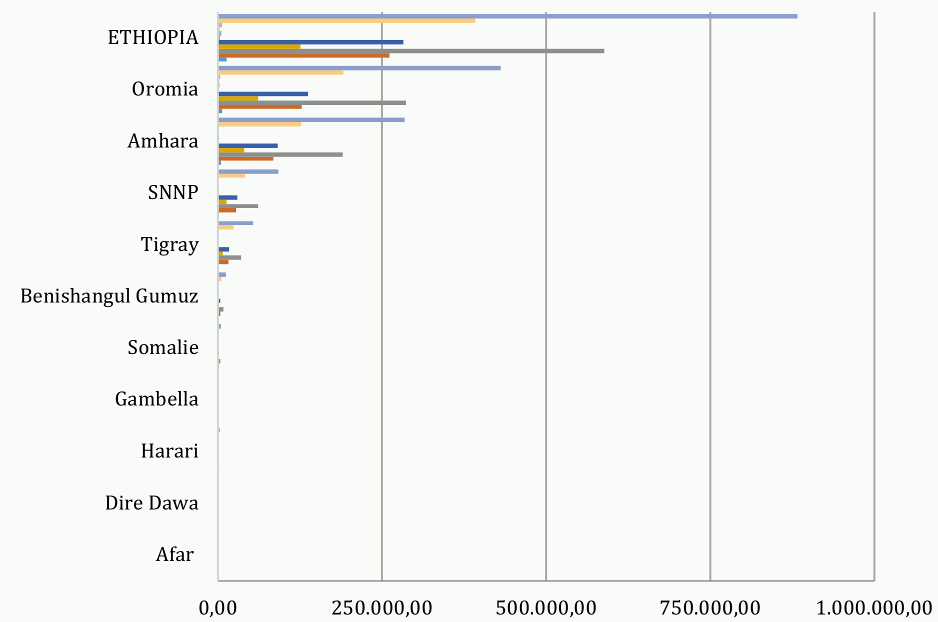
4.4.1. Present value of benefits at country level

The PV of total benefits of SLM interventions to prevent soil NPK depletion and NPK losses in the next 11 years (2020-2030) on 12.77 million hectares of agricultural land in Ethiopia is estimated at about USD 392.22 billion (USD 30,706 per hectare) (Figure 4.12).

For the period 2020-2040, the PV of total benefits is about USD 882.46 billion (USD 69,088 per hectare). Close to 67 per cent of the PV of the total benefits is composed of the PV of yield gains from preventing NPK losses, whereas close to 32per cent per cent of the benefits consists of the PV of yield gains from preventing soil NPK depletion through investments in SLM technologies. The PV of the replacement costs of prevented NPK depletion and NPK loss accounts only for 1.34 per cent of the country-level PV of total benefits in the periods 20202030 and 2020-2040 through SLM interventions.

FIGURE 4.12:

Country and regional level PVs of the total benefits (in millions of USD) of SLM.



	Afar	Dire Dawa	Harari	Gambella	Somalie	Benishang ul Gumuz	Tigray	SNNP	Amhara	Oromia	ETHIOPIA
PVTB from preventing NPK loss & NPK depletion_2020-2040	526,84	780,36	2.417,31	738,59	4.836,73	12.276,32	53.189,11	92.154,60	284.723,14	430.814,41	882.457,40
PVTB from preventing NPK loss & NPK depletion_2020-2030	234,15	346,83	1.074,36	328,26	2.149,66	5.456,14	23.639,60	40.957,60	126.543,62	191.473,06	392.203,28
PVB as replacement cost savings from preventing NPK depletion_2020-2040	7,33	1,40	0,01	4,27	29,08	175,94	335,33	481,04	1.832,68	3.326,29	6.193,37
PVB as replacement cost savings from preventing NPK depletion_2020-2030	3,26	0,62	0,00	1,90	12,92	78,19	149,04	213,80	814,52	1.478,35	2.752,61
PVB as replacement cost savings from preventing NPK loss_2020-2040	9,45	5,28	5,81	4,17	43,40	107,26	414,58	569,78	1.818,41	2.690,34	5.668,48
PVB as replacement cost savings from preventing NPK loss_2020-2030	4,20	2,34	2,58	1,85	19,29	47,67	184,26	253,23	808,18	1.195,71	2.519,32
PVB as yield gains from preventing NPK depletion_2020-2040	165,45	250,96	782,23	235,73	1.545,40	3.888,56	17.009,95	29.538,55	91.172,03	137.715,45	282.304,32
PVB as yield gains from preventing NPK depletion_2020-2030	73,53	111,54	347,66	104,77	686,85	1.728,25	7.559,98	13.128,24	40.520,90	61.206,87	125.468,59
PVB as yield gains from preventing NPK loss_2020-2040	344,61	522,72	1.629,26	491,00	3.218,85	8.099,31	35.429,24	61.524,46	189.897,95	286.841,12	587.998,51
PVB as yield gains from preventing NPK loss_2020-2030	153,16	232,32	724,12	218,22	1.430,60	3.599,69	15.746,33	27.344,21	84.399,09	127.484,92	261.332,66
Harvested area in 1000s ha	14,58	12,01	15,43	18,21	76,71	222,09	837,11	1.429,07	4.103,43	6.044,35	12.773,01

On a per hectare level, the PV of benefits of yield gains from preventing NPK loss for the periods 202020230 and 2020-2040 are estimated at about USD 204,060 per hectare and USD 46,034 per hectare, respectively. From prevented soil NPK depletion, the PV of benefits of yield gains are USD 9,823 per hectare for the period 2020-2030 and USD 22,102 per hectare for 2020-2040. The PV of benefits in terms of savings of the replacement cost value of prevented NPK loss are USD 197 per hectare and USD 444 per hectare for the project periods 2020-2030 and 2020-2040, respectively. From prevented soil NPK depletion, the PV of benefits in terms of savings of the replacement cost value are USD 216 per hectare for the 20202030 project period and USD 485 per hectare for 20202040.

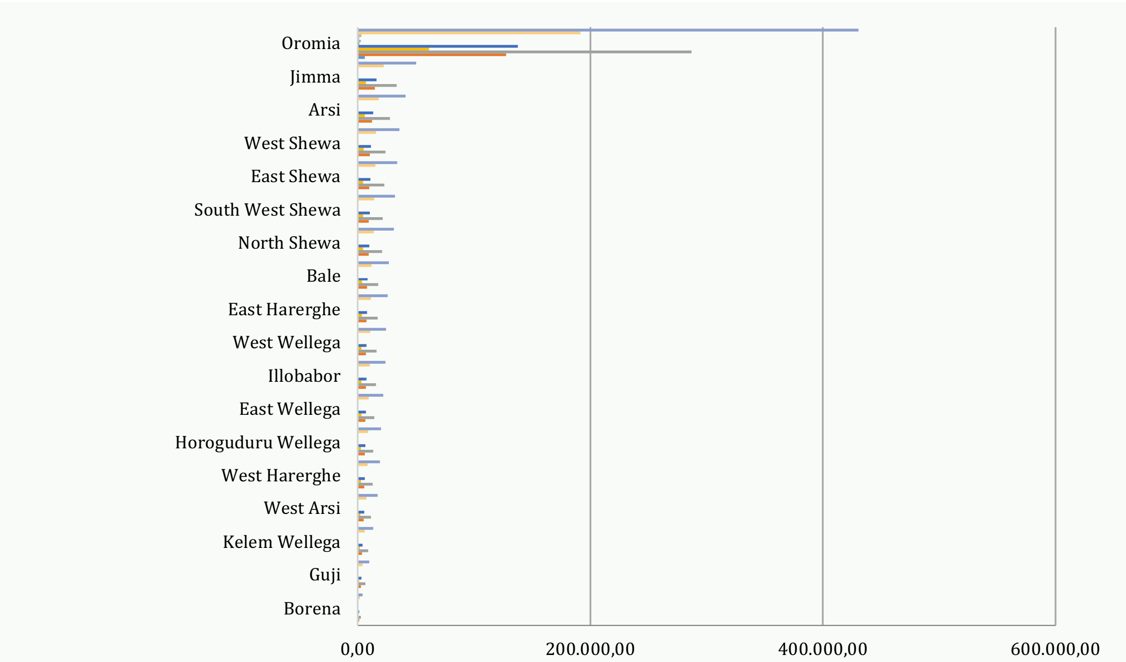
The PV of total benefits of SLM interventions in Oromia amounts close to 49 per cent of the countrylevel PV of total benefits for both the project periods. In the state of Amhara, the PV of total benefits accounts for 32.26 per cent of the country-level PV of total benefits for both periods. The PV of total benefits in SNNP and Tigray account for 10.44 per cent and 6.03 per cent, respectively. The four regional states together account for 97.55 per cent of the country-level PV of total benefits of SLM interventions. The other four regional states (Benishangul Gumuz, Somalie, Gambella, Harari, Afar) and Dire Dawa city administration amount only to the remaining 2.45 per cent. Such a difference is mainly due to differences in cultivated land areas among regions.

4.4.2. Present values of benefits at regional and zonal levels

The following section shows the PV of benefits of SLM intervention in the selected regional states in Ethiopia. Each figure provides further details on the present values of benefits as yield gains and as replacement cost savings from prevented NPK loss and NPK depletion.

FIGURE 4.13:

The present values of the total benefits (in millions of USD) of SLM in Oromia.

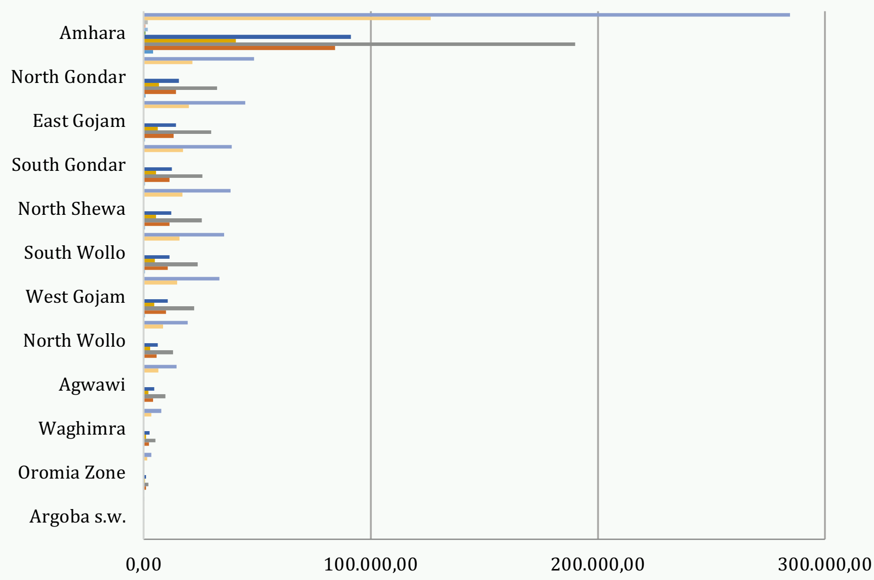


	Borena	Guji	Kelem Wellega	West Arsi	West Hareghe	Horoguduru Wellega	East Wellega	Illobabor	West Wellega	East Hareghe	Bale	North Shewa	South West Shewa	East Shewa	West Shewa	Arsi	Jimma	Oromia
PVTB from preventing NPK loss & NPK depletion_2020-2040	4.337,17	9.792,08	13.449,03	17.275,09	19.059,24	20.013,70	21.782,75	23.858,89	24.222,59	25.643,12	26.709,92	31.167,10	32.041,84	34.152,12	35.767,57	41.255,80	50.286,40	430.814,41
PVTB from preventing NPK loss & NPK depletion_2020-2030	1.927,63	4.352,04	5.977,35	7.677,82	8.470,77	8.894,98	9.681,22	10.603,95	10.765,59	11.396,94	11.871,08	13.852,04	14.240,82	15.178,72	15.896,70	18.335,91	22.349,51	191.473,06
PVB as replacement cost savings from preventing NPK depletion_2020-2040	0,28	58,74	187,49	105,70	159,96	117,23	325,00	281,53	317,58	144,90	141,79	122,39	191,11	245,59	294,69	202,49	429,80	3.326,29
PVB as replacement cost savings from preventing NPK depletion_2020-2030	0,12	26,11	83,33	46,98	71,09	52,10	144,45	125,13	141,15	64,40	63,02	54,40	84,94	109,15	130,98	90,00	191,02	1.478,35
PVB as replacement cost savings from preventing NPK loss_2020-2040	14,99	56,35	89,53	139,33	144,90	84,35	196,49	143,81	167,24	161,56	147,01	163,63	160,13	204,53	292,52	274,38	249,60	2.690,34
PVB as replacement cost savings from preventing NPK loss_2020-2030	6,66	25,04	39,79	61,92	64,40	37,49	87,33	63,91	74,33	71,80	65,34	72,73	71,17	90,90	130,01	121,94	110,93	1.195,71
PVB as yield gains from preventing NPK depletion_2020-2040	1.401,92	3.138,97	4.242,72	5.497,63	6.083,45	6.404,76	6.896,62	7.601,25	7.699,93	8.218,57	8.570,35	10.017,04	10.279,63	10.932,08	11.411,62	13.227,66	16.091,26	137.715,45
PVB as yield gains from preventing NPK depletion_2020-2030	623,07	1.395,10	1.885,65	2.443,39	2.703,75	2.846,56	3.065,16	3.378,34	3.422,19	3.652,70	3.809,04	4.452,02	4.568,73	4.858,70	5.071,83	5.878,96	7.151,67	61.206,87
PVB as yield gains from preventing NPK loss_2020-2040	2.919,99	6.538,02	8.836,95	11.450,76	12.670,93	13.340,17	14.364,64	15.832,30	16.037,83	17.118,09	17.850,77	20.864,03	21.410,97	22.769,92	23.768,74	27.551,27	33.515,74	286.841,12
PVB as yield gains from preventing NPK loss_2020-2030	1.297,77	2.905,79	3.927,53	5.089,23	5.631,52	5.928,96	6.384,28	7.036,58	7.127,93	7.608,04	7.933,68	9.272,90	9.515,99	10.119,96	10.563,88	12.245,01	14.895,88	127.484,92
Harvested area in 1000s ha	41,37	126,98	196,74	348,62	276,71	278,04	382,54	304,55	340,88	336,31	379,67	397,89	369,39	482,12	561,37	614,83	606,35	6.044,35

Oromia regional state: Figure 4.13 shows the PV of total benefits of SLM intervention on 6.04 million hectares of agricultural land in Oromia. It is estimated at about USD 191.47 billion for the 2020-2030 project period and USD 430.81 billion for the project period 2020-2040.

FIGURE 4.14:

The present values of the total benefits (in millions of USD) of SLM in Amhara.



	Argoba s.w.	Oromia Zone	Waghimra	Agwawi	North Wollo	West Gojam	South Wollo	North Shewa	South Gondar	East Gojam	North Gondar	Amhara
PVTB from preventing NPK loss & NPK depletion_2020-2040	289,20	3.340,26	7.905,15	14.416,77	19.398,03	33.513,68	35.423,32	38.403,92	38.785,79	44.701,89	48.545,13	284.723,14
PVTB from preventing NPK loss & NPK depletion_2020-2030	128,53	1.484,56	3.513,40	6.407,45	8.621,35	14.894,97	15.743,70	17.068,41	17.238,13	19.867,50	21.575,61	126.543,62
PVB as replacement cost savings from preventing NPK depletion_2020-2040	1,96	26,10	27,23	123,12	87,30	299,67	130,85	249,82	209,02	248,38	429,24	1.832,68
PVB as replacement cost savings from preventing NPK depletion_2020-2030	0,87	11,60	12,10	54,72	38,80	133,19	58,15	111,03	92,90	110,39	190,77	814,52
PVB as replacement cost savings from preventing NPK loss_2020-2040	2,19	32,70	36,05	124,90	104,45	289,87	179,02	245,55	186,00	253,10	364,58	1.818,41
PVB as replacement cost savings from preventing NPK loss_2020-2030	0,97	14,53	16,02	55,51	46,42	128,83	79,56	109,13	82,67	112,49	162,03	808,18
PVB as yield gains from preventing NPK depletion_2020-2040	91,79	1.064,43	2.543,70	4.595,99	6.230,04	10.679,76	11.389,92	12.296,58	12.453,00	14.337,50	15.489,32	91.172,03
PVB as yield gains from preventing NPK depletion_2020-2030	40,80	473,08	1.130,54	2.042,66	2.768,91	4.746,56	5.062,19	5.465,15	5.534,67	6.372,22	6.884,14	40.520,90
PVB as yield gains from preventing NPK loss_2020-2040	191,19	2.217,04	5.298,16	9.572,77	12.976,25	22.244,38	23.723,53	25.611,97	25.937,77	29.862,91	32.261,98	189.897,95
PVB as yield gains from preventing NPK loss_2020-2030	84,97	985,35	2.354,74	4.254,56	5.767,22	9.886,39	10.543,79	11.383,10	11.527,90	13.272,40	14.338,66	84.399,09
Harvested area in 1000s ha	5,58	59,57	111,52	253,21	260,43	584,83	442,30	515,42	549,60	580,31	740,68	4.103,43

Amhara regional state: Figure 4.14 shows the PV of total benefits of SLM intervention on 4.1 million hectares of agricultural land in Amhara. It is estimated at about USD 126.54 billion for the 2020-2030 project period and USD 284.72 billion for the project period 2020-2040.

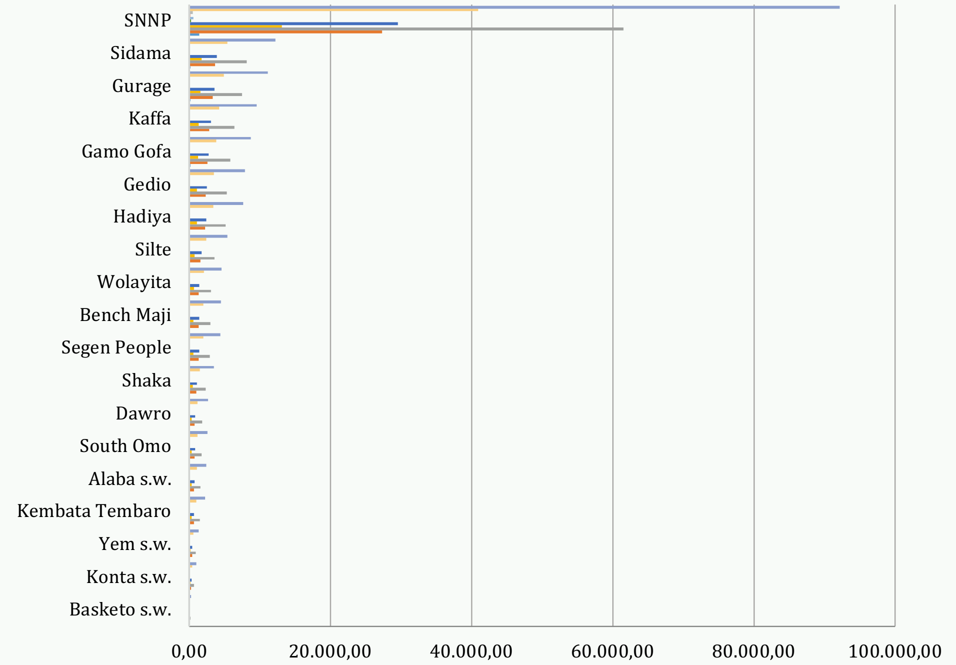
Southern Nations Nationalities and Peoples (SNNP) regional state: Figure 4.15 shows the PV of total benefits of SLM intervention on 1.43 million hectares of agricultural land in SNNP. It is estimated at about USD 40.96 billion for the 2020-2030 project period and USD 92.16 billion for the project period 2020-2040.

Tigray regional state: Figure 4.16 shows the PV of total benefits of SLM intervention on 0.837 million hectares of agricultural land in Tigray. It is estimated at about USD 23.64 billion for the 2020-2030 project period and USD 53.19 billion for the project period 2020-2040.

Benishangul Gumuz regional state: Figure 4.17 shows the PV of total benefits of SLM intervention on 0.222 million hectares of agricultural land in Benishangul Gumuz. It is estimated at about USD 5.46 billion for the 2020-2030 project period and USD 12.28 billion for the project period 2020-2040.

FIGURE 4.15:

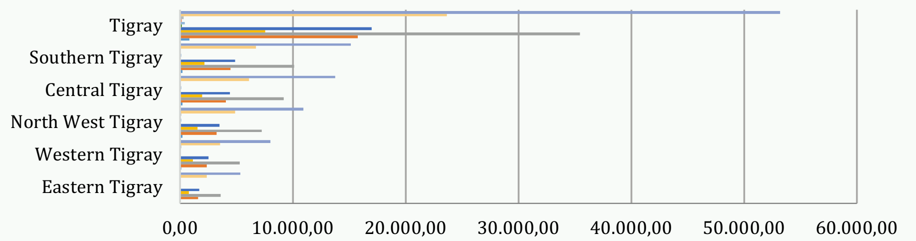
The present values of the total benefits (in millions of USD) of SLM in SNNP.



	Basketo s.w.	Konta s.w.	Yem s.w.	Kembata Tembaro	Alaba s.w.	South Omo	Dawro	Shaka	Segen People	Bench Maji	Wolayita	Silte	Hadiya	Gedio	Gamo Gofa	Kaffa	Gurage	Sidama	SNNP
PVTB from preventing NPK loss & NPK depletion_2020-2040	248,12	988,90	1.365,88	2.245,48	2.422,67	2.563,44	2.698,70	3.474,25	4.437,04	4.466,60	4.615,27	5.429,39	7.690,92	7.894,73	8.695,29	9.565,01	11.138,03	12.214,90	92.154,60
PVTB from preventing NPK loss & NPK depletion_2020-2030	110,27	439,51	607,06	997,99	1.076,74	1.139,31	1.199,42	1.544,11	1.972,02	1.985,16	2.051,23	2.413,06	3.418,19	3.508,77	3.864,57	4.251,11	4.950,24	5.428,84	40.957,60
PVB as replacement cost savings from preventing NPK depletion_2020-2040	2,32	6,51	5,36	10,50	20,04	0,00	10,66	29,89	14,24	41,19	40,93	43,34	39,39	36,51	51,89	55,19	22,15	50,95	481,04
PVB as replacement cost savings from preventing NPK depletion_2020-2030	1,03	2,89	2,38	4,67	8,91	0,00	4,74	13,28	6,33	18,31	18,19	19,26	17,51	16,23	23,06	24,53	9,84	22,64	213,80
PVB as replacement cost savings from preventing NPK loss_2020-2040	2,44	6,44	6,69	20,43	21,29	22,82	16,31	11,61	14,89	25,89	55,68	56,25	61,88	11,13	66,55	53,34	49,20	66,94	569,78
PVB as replacement cost savings from preventing NPK loss_2020-2030	1,08	2,86	2,97	9,08	9,46	10,14	7,25	5,16	6,62	11,51	24,75	25,00	27,50	4,95	29,58	23,71	21,87	29,75	253,23
PVB as yield gains from preventing NPK depletion_2020-2040	78,94	316,58	439,15	718,35	772,45	824,11	866,64	1.113,50	1.416,59	1.427,09	1.465,74	1.728,85	2.461,89	2.545,40	2.782,12	3.067,44	3.589,75	3.923,97	29.538,55
PVB as yield gains from preventing NPK depletion_2020-2030	35,08	140,70	195,18	319,26	343,31	366,27	385,17	494,89	629,60	634,26	651,44	768,38	1.094,17	1.131,29	1.236,50	1.363,31	1.595,45	1.743,99	13.128,24
PVB as yield gains from preventing NPK loss_2020-2040	164,42	659,38	914,69	1.496,21	1.608,89	1.716,51	1.805,09	2.319,25	2.950,55	2.972,42	3.052,92	3.600,94	5.127,75	5.301,70	5.794,74	6.389,03	7.476,93	8.173,05	61.524,46
PVB as yield gains from preventing NPK loss_2020-2030	73,08	293,06	406,53	664,98	715,06	762,89	802,26	1.030,78	1.311,36	1.321,08	1.356,85	1.600,42	2.279,00	2.356,31	2.575,44	2.839,57	3.323,08	3.632,47	27.344,21
Harvested area in 1000s ha	5,30	15,20	20,57	43,87	39,97	50,15	40,82	27,19	72,98	55,61	99,36	98,19	136,65	66,30	190,66	136,88	166,08	163,29	1.429,07

FIGURE 4.16:

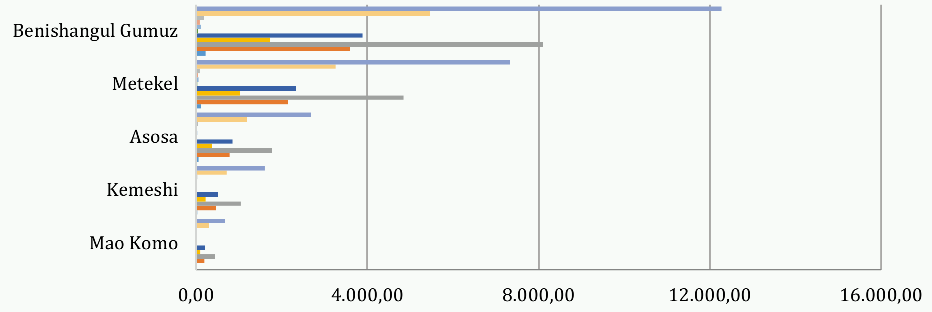
The present values of the total benefits (in millions of USD) of SLM in Tigray.



	Eastern Tigray	Western Tigray	North West Tigray	Central Tigray	Southern Tigray	Tigray
PVTB from preventing NPK loss & NPK depletion_2020-2040	5.347,72	8.035,24	10.937,72	13.731,49	15.136,94	53.189,11
PVTB from preventing NPK loss & NPK depletion_2020-2030	2.376,76	3.571,22	4.861,21	6.102,88	6.727,53	23.639,60
PVB as replacement cost savings from preventing NPK depletion_2020-2040	9,74	101,13	91,85	60,33	72,28	335,33
PVB as replacement cost savings from preventing NPK depletion_2020-2030	4,33	44,95	40,82	26,81	32,13	149,04
PVB as replacement cost savings from preventing NPK loss_2020-2040	29,34	86,15	122,49	88,21	88,40	414,58
PVB as replacement cost savings from preventing NPK loss_2020-2030	13,04	38,29	54,44	39,20	39,29	184,26
PVB as yield gains from preventing NPK depletion_2020-2040	1.721,99	2.545,68	3.478,40	4.405,97	4.857,92	17.009,95
PVB as yield gains from preventing NPK depletion_2020-2030	765,33	1.131,41	1.545,95	1.958,21	2.159,08	7.559,98
PVB as yield gains from preventing NPK loss_2020-2040	3.586,65	5.302,28	7.244,99	9.176,98	10.118,34	35.429,24
PVB as yield gains from preventing NPK loss_2020-2030	1.594,07	2.356,57	3.220,00	4.078,66	4.497,04	15.746,33
Harvested area in 1000s ha	85,83	131,82	192,89	203,42	223,15	837,11

FIGURE 4.17:

The present values of the total benefits (in millions of USD) of SLM in Benishangul Gumuz.

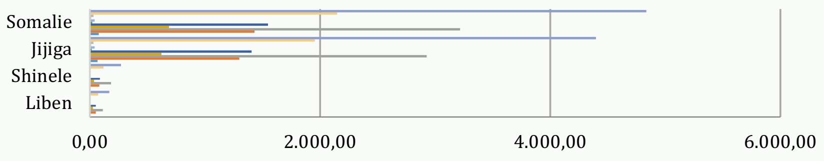


	Mao Komo	Kemeshi	Asosa	Metekel	Benishangul Gumuz
PVTB from preventing NPK loss & NPK depletion_2020-2040	669,00	1.600,50	2.676,59	7.330,23	12.276,32
PVTB from preventing NPK loss & NPK depletion_2020-2030	297,33	711,33	1.189,60	3.257,88	5.456,14
PVB as replacement cost savings from preventing NPK depletion_2020-2040	6,93	35,33	42,47	91,21	175,94
PVB as replacement cost savings from preventing NPK depletion_2020-2030	3,08	15,70	18,87	40,54	78,19
PVB as replacement cost savings from preventing NPK loss_2020-2040	3,57	18,26	24,86	60,58	107,26
PVB as replacement cost savings from preventing NPK loss_2020-2030	1,58	8,11	11,05	26,92	47,67
PVB as yield gains from preventing NPK depletion_2020-2040	211,90	501,78	846,38	2.328,50	3.888,56
PVB as yield gains from preventing NPK depletion_2020-2030	94,18	223,01	376,17	1.034,89	1.728,25
PVB as yield gains from preventing NPK loss_2020-2040	441,35	1.045,14	1.762,89	4.849,93	8.099,31
PVB as yield gains from preventing NPK loss_2020-2030	196,16	464,50	783,51	2.155,53	3.599,69
Harvested area in 1000s ha	10,37	35,87	58,28	117,58	222,09

Somalie regional state: Figure 4.18 shows the PV of total benefits of SLM intervention on 0.077 million hectares of agricultural land in Somalie. It is estimated at about USD 2.15 billion for the 2020-2030 project period and USD 4.84 billion for the project period 2020-2040.

FIGURE 4.18:

The present values of the total benefits (in millions of USD) of SLM in Somalie.

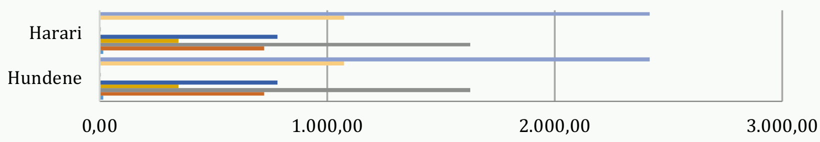


	Liben	Shinele	Jijiga	Somalie
PVTB from preventing NPK loss & NPK depletion_2020-2040	167,81	270,54	4.398,37	4.836,73
PVTB from preventing NPK loss & NPK depletion_2020-2030	74,58	120,24	1.954,83	2.149,66
PVB as replacement cost savings from preventing NPK depletion_2020-2040	0,00	0,03	29,04	29,08
PVB as replacement cost savings from preventing NPK depletion_2020-2030	0,00	0,01	12,91	12,92
PVB as replacement cost savings from preventing NPK loss_2020-2040	1,95	1,02	40,44	43,40
PVB as replacement cost savings from preventing NPK loss_2020-2030	0,87	0,45	17,97	19,29
PVB as yield gains from preventing NPK depletion_2020-2040	53,80	87,42	1.404,18	1.545,40
PVB as yield gains from preventing NPK depletion_2020-2030	23,91	38,85	624,08	686,85
PVB as yield gains from preventing NPK loss_2020-2040	112,06	182,08	2.924,71	3.218,85
PVB as yield gains from preventing NPK loss_2020-2030	49,80	80,92	1.299,87	1.430,60
Harvested area in 1000s ha	5,62	4,81	66,28	76,71

Harari regional state: Figure 4.19 shows the PV of total benefits of SLM intervention on 0.015 million hectares of agricultural land in Harari regional state of Ethiopia. It is estimated at about USD 1.07 billion for the 2020-2030 project period and USD 2.42 billion for the project period 2020-2040.

FIGURE 4.19:

The present values of the total benefits (in millions of USD) of SLM in Harari.

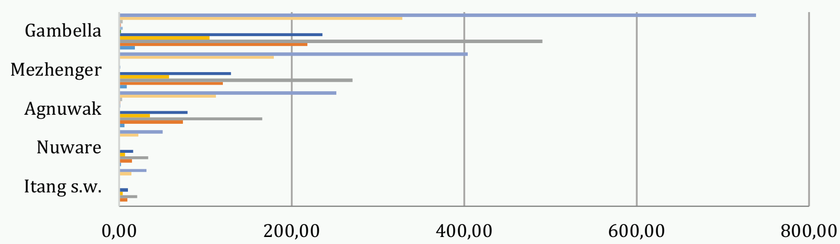


	Hundene	Harari
PVTB from preventing NPK loss & NPK depletion_2020-2040	2.417,31	2.417,31
PVTB from preventing NPK loss & NPK depletion_2020-2030	1.074,36	1.074,36
PVB as replacement cost savings from preventing NPK depletion_2020-2040	0,01	0,01
PVB as replacement cost savings from preventing NPK depletion_2020-2030	0,00	0,00
PVB as replacement cost savings from preventing NPK loss_2020-2040	5,81	5,81
PVB as replacement cost savings from preventing NPK loss_2020-2030	2,58	2,58
PVB as yield gains from preventing NPK depletion_2020-2040	782,23	782,23
PVB as yield gains from preventing NPK depletion_2020-2030	347,66	347,66
PVB as yield gains from preventing NPK loss_2020-2040	1.629,26	1.629,26
PVB as yield gains from preventing NPK loss_2020-2030	724,12	724,12
Harvested area in 1000s ha	15,43	15,43

Gambella regional state: Figure 4.20 shows the PV of total benefits of SLM intervention on 0.018 million hectares of agricultural land in Gambella regional state of Ethiopia. It is estimated at about USD 0.328 billion for the 2020-2030 project period and USD 0.739 billion for the project period 2020-2040.

FIGURE 4.20:

The present values of the total benefits (in millions of USD) of SLM in Gambella.

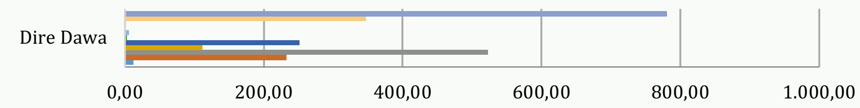


	Itang s.w.	Nuware	Agnuwak	Mezhenger	Gambella
PVTB from preventing NPK loss & NPK depletion_2020-2040	31,81	50,68	251,89	404,20	738,59
PVTB from preventing NPK loss & NPK depletion_2020-2030	14,14	22,52	111,95	179,64	328,26
PVB as replacement cost savings from preventing NPK depletion_2020-2040	0,18	0,00	3,17	0,92	4,27
PVB as replacement cost savings from preventing NPK depletion_2020-2030	0,08	0,00	1,41	0,41	1,90
PVB as replacement cost savings from preventing NPK loss_2020-2040	0,39	0,60	1,71	1,46	4,17
PVB as replacement cost savings from preventing NPK loss_2020-2030	0,18	0,27	0,76	0,65	1,85
PVB as yield gains from preventing NPK depletion_2020-2040	10,04	16,14	79,60	129,95	235,73
PVB as yield gains from preventing NPK depletion_2020-2030	4,46	7,18	35,38	57,76	104,77
PVB as yield gains from preventing NPK loss_2020-2040	20,91	33,63	165,79	270,67	491,00
PVB as yield gains from preventing NPK loss_2020-2030	9,29	14,95	73,68	120,30	218,22
Harvested area in 1000s ha	1,10	1,82	6,10	9,19	18,21

Dire Dawa city administration: Figure 4.21 shows the PV of total benefits of SLM intervention on 0.012 million hectares of agricultural land in Dire Dawa. It is estimated at about USD 0.347 billion for the 2020-2030 project period and USD 0.780 billion for the project period 2020-2040.

FIGURE 4.21:

The present values of the total benefits (in millions of USD) of SLM in Dire Dawa.

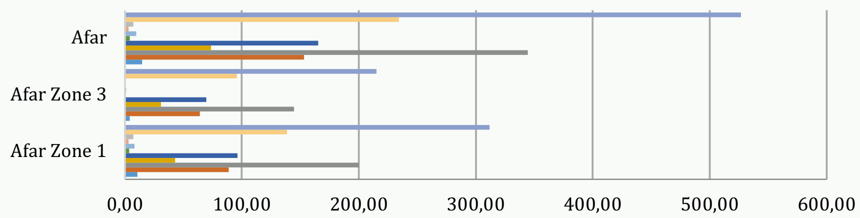


	Dire Dawa
PVTB from preventing NPK loss & NPK depletion_2020-2040	780,36
PVTB from preventing NPK loss & NPK depletion_2020-2030	346,83
PVB as replacement cost savings from preventing NPK depletion_2020-2040	1,40
PVB as replacement cost savings from preventing NPK depletion_2020-2030	0,62
PVB as replacement cost savings from preventing NPK loss_2020-2040	5,28
PVB as replacement cost savings from preventing NPK loss_2020-2030	2,34
PVB as yield gains from preventing NPK depletion_2020-2040	250,96
PVB as yield gains from preventing NPK depletion_2020-2030	111,54
PVB as yield gains from preventing NPK loss_2020-2040	522,72
PVB as yield gains from preventing NPK loss_2020-2030	232,32
Harvested area in 1000s ha	12,01

Afar regional state: Figure 4.22 shows the PV of total benefits of SLM intervention on 0.015 million hectares of agricultural land in Afar. It is estimated at about USD 0.234 billion for the 2020-2030 project period and USD 0.527 billion for the project period 2020-2040.

FIGURE 4.22:

The present values of the total benefits (in millions of USD) of SLM in Afar.



	Afar Zone 1	Afar Zone 3	Afar
PVTB from preventing NPK loss & NPK depletion_2020-2040	311,55	215,29	526,84
PVTB from preventing NPK loss & NPK depletion_2020-2030	138,47	95,68	234,15
PVB as replacement cost savings from preventing NPK depletion_2020-2040	7,33	0,00	7,33
PVB as replacement cost savings from preventing NPK depletion_2020-2030	3,26	0,00	3,26
PVB as replacement cost savings from preventing NPK loss_2020-2040	8,23	1,23	9,45
PVB as replacement cost savings from preventing NPK loss_2020-2030	3,66	0,54	4,20
PVB as yield gains from preventing NPK depletion_2020-2040	96,01	69,44	165,45
PVB as yield gains from preventing NPK depletion_2020-2030	42,67	30,86	73,53
PVB as yield gains from preventing NPK loss_2020-2040	199,98	144,63	344,61
PVB as yield gains from preventing NPK loss_2020-2030	88,88	64,28	153,16
Harvested area in 1000s ha	10,43	4,15	14,58

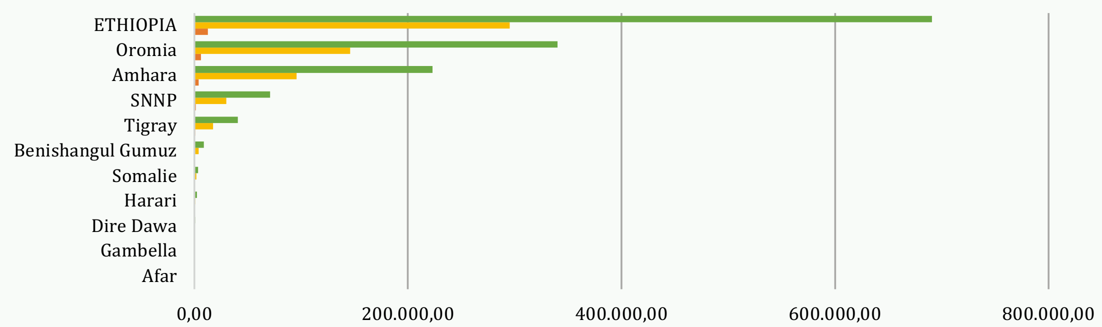
4.5. Net present value and benefit-cost ratios of sustainable land management in Ethiopia

4.5.1. NPVs and BCRs at country level

Figure 4.23 shows net present values (NPVs) of SLM interventions in the periods 2020-2030 and 2020-2040 at country and regional levels. The NPV of SLM interventions for preventing soil NPK depletion and NPK losses in 2020-2030 on 12.77 million hectares of agricultural land in Ethiopia is estimated at about USD 295.46 billion (USD 23,132 per hectare). Over the period 2020-2040, the NPV would be about USD 690.76 billion (USD 54,079 per hectare). The country-level benefit-cost ratios (BCR) are 4.05 and 4.60 for the discounting periods 2020-2030 and 2020-2040 (Figure 4.24), meaning that the PV of total benefits of investment on SLM interventions are more than four times higher than the PV of total costs. The NPVs of SLM interventions in Oromia account for 49.31 per cent and 49.24 per cent of the country-level NPVs for the project periods of 2020-2030 and 2020-2040, respectively. The NPV of SLM interventions in Amhara amounts to nearly 32.3 per cent, while SNNP and Tigray account close to 10.2 per cent and 5.9 per cent, respectively, of the country-level NPVs of SLM interventions in both periods. The four regional states altogether account for nearly 97.7 per cent of the country-level NPVs of SLM interventions in the two intervention periods. The other four regional states (Benishangul Gumuz, Somalie, Harari, Gambella, and Afar) and Dire Dawa city administration account for only 2.3 per cent of the country-level NPVs of SLM interventions in both periods. Again, such a difference is mainly due to differences in cultivated land areas among regions.

FIGURE 4.23:

Country and regional level NPVs (in millions of USD) of SLM in Ethiopia.

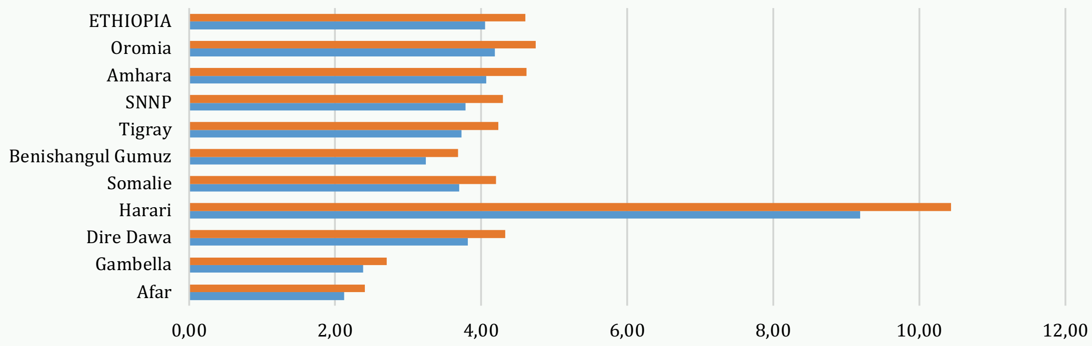


	Afar	Gambella	Dire Dawa	Harari	Somalie	Benishangul Gumuz	Tigray	SNNP	Amhara	Oromia	ETHIOPIA
NPV_2020-2040	308,01	465,30	600,08	2.185,67	3.685,49	8.943,04	40.625,38	70.706,56	223.137,21	340.098,41	690.755,15
NPV_2020-2030	123,72	190,34	255,85	957,46	1.568,68	3.774,00	17.299,32	30.133,85	95.464,26	145.693,25	295.460,74
Harvested area in 1000s ha	14,58	18,21	12,01	15,43	76,71	222,09	837,11	1.429,07	4.103,43	6.044,35	12.773,01

Harari, Oromia, and Amhara are the three regions with the highest BCRs. Except for Afar and Gambella, all other regional states and the Dire Dawa city administration have BCRs higher than three for both project periods (Figure 4.24). This indicates that investment in SLM interventions in all regional states has positive and high returns.

FIGURE 4.24:

Country and regional level BCR of SLM in Ethiopia.



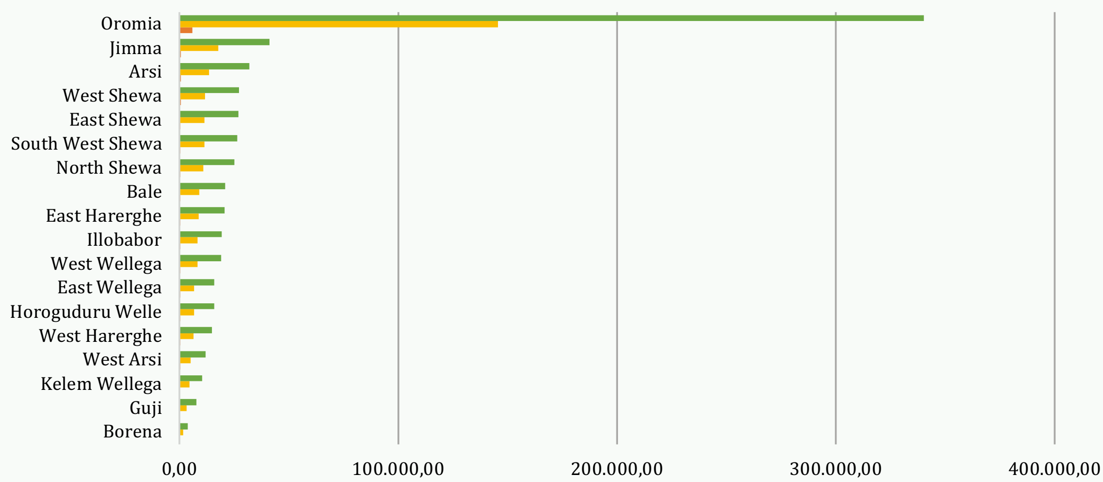
	Afar	Gambella	Dire Dawa	Harari	Somalie	Benishangul Gumuz	Tigray	SNNP	Amhara	Oromia	ETHIOPIA
BCR_2020-2040	2,41	2,70	4,33	10,44	4,20	3,68	4,23	4,30	4,62	4,75	4,60
BCR_2020-2030	2,12	2,38	3,81	9,19	3,70	3,24	3,73	3,78	4,07	4,18	4,05

4.5.2. NPVs and BCRs at regional and zonal levels

Oromia regional state: Figure 4.25 shows the NPVs of SLM intervention in Oromia. It is estimated at about USD 145.69 billion (USD 24,104 per hectare) for 2020-2030 and USD 340.10 billion (USD 56,267 per hectare) for 2020-2040.

FIGURE 4.25:

The NPV (in millions of USD) of SLM in Oromia.

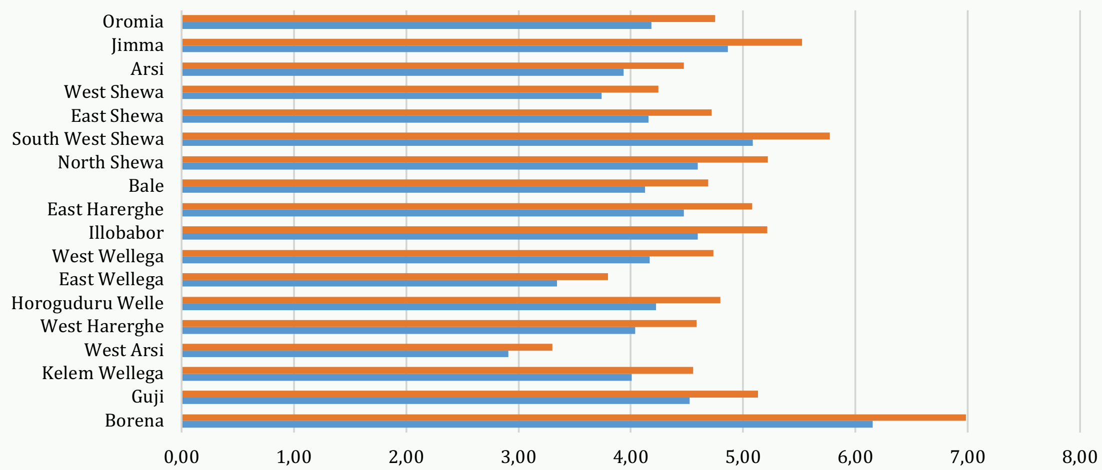


	Borena	Guji	Kelem Wellega	West Arsi	West Hareghe	Horogud uru Welle	East Wellega	West Wellega	Illobabor	East Hareghe	Bale	North Shewa	South West Shewa	East Shewa	West Shewa	Arsi	Jimma	Oromia
NPV_2020-2040	3.716,21	7.886,39	10.496,23	12.042,89	14.906,32	15.840,75	16.041,41	19.106,52	19.288,10	20.595,69	21.011,75	25.195,46	26.497,87	26.916,21	27.342,35	32.028,23	41.186,04	340.098,4
NPV_2020-2030	1.614,26	3.390,33	4.487,22	5.037,39	6.375,00	6.789,10	6.783,86	8.183,77	8.297,30	8.849,76	8.995,49	10.838,46	11.443,06	11.527,12	11.644,91	13.679,22	17.757,01	145.693,2
Harvested area in 1000s ha	41,37	126,98	196,74	348,62	276,71	278,04	382,54	340,88	304,55	336,31	379,67	397,89	369,39	482,12	561,37	614,83	606,35	6.044,35

In terms of BCRs, Borena, South West Shewa, and Jimma are the three administrative zones with the highest benefit-cost ratios, ranging from 4.87 to 6.98 for both project periods. All other 14 administrative zones have benefit-cost ratios ranging from 2.91 to 5.22 (Figure 4.26). This indicates that investments in SLM intervention in all of the 17 administrative zones of the regional state will have positive and high returns.

FIGURE 4.26:

The BCR of SLM in Oromia.

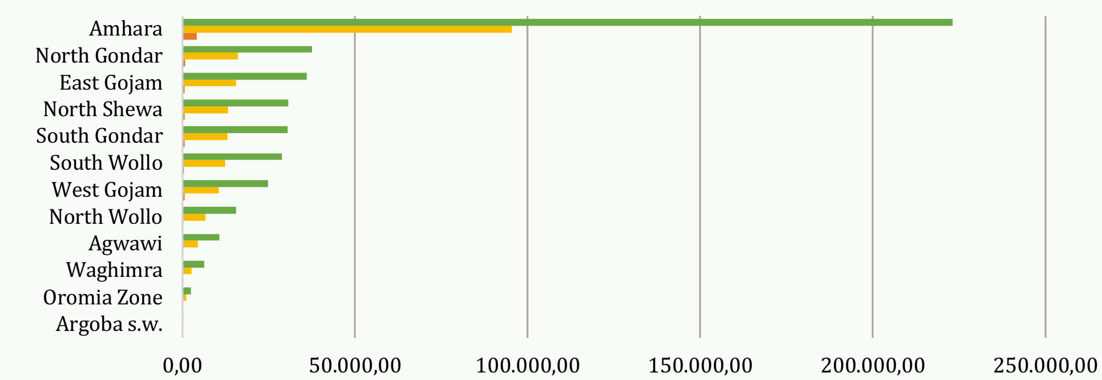


	Borena	Guji	Kelem Wellega	West Arsi	West Hareghe	Horoguduru Welle	East Wellega	West Wellega	Illobabor	East Hareghe	Bale	North Shewa	South West Shewa	East Shewa	West Shewa	Arsi	Jimma	Oromia
BCR_2020-2040	6,98	5,13	4,55	3,30	4,59	4,80	3,79	4,73	5,22	5,08	4,69	5,22	5,77	4,72	4,24	4,47	5,52	4,75
BCR_2020-2030	6,15	4,52	4,01	2,91	4,04	4,22	3,34	4,17	4,59	4,47	4,13	4,60	5,09	4,16	3,74	3,94	4,87	4,18

Amhara regional state: Figure 4.27 shows the NPVs of SLM intervention in Amhara. They are estimated at about USD 95.46 billion (USD 23,264 per hectare) for 2020-2030 and USD 2,23.14 billion (54,378 USD per hectare) for 2020-2040.

FIGURE 4.27:

The NPV (in millions of USD) of SLM in Amhara.



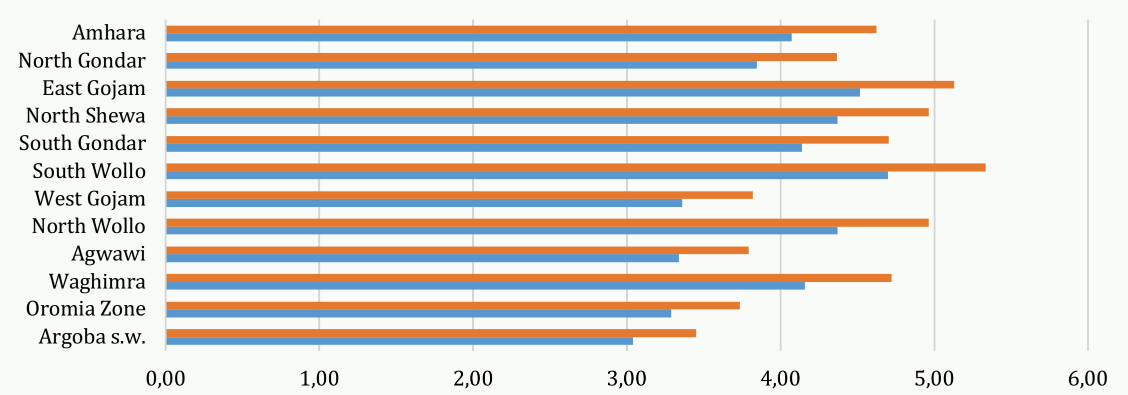
	Argoba s.w.	Oromia Zone	Waghimra	Agwawi	North Wollo	West Gojam	South Wollo	South Gondar	North Shewa	East Gojam	North Gondar	Amhara
NPV_2020-2040	205,46	2.446,25	6.231,48	10.616,46	15.489,44	24.736,38	28.785,14	30.537,25	30.668,27	35.992,34	37.428,74	223.137,21
NPV_2020-2030	86,27	1.033,40	2.668,78	4.489,62	6.648,88	10.465,50	12.393,74	13.075,50	13.164,61	15.472,23	15.965,73	95.464,26
Harvested area in 1000s ha	5,58	59,57	111,52	253,21	260,43	584,83	442,30	549,60	515,42	580,31	740,68	4.103,43

South Wollo, East Gojam, and North Shewa are the three administrative zones with the highest BCRs, ranging from 4.37 to 5.34. All other seven administrative zones and one special wereda have BCRs in the range of 3.04 to 4.96 (Figure 4.28). This indicates that investments in SLM intervention in all of the 10 administrative zones and one special wereda will have positive and high returns.

SNNP regional state: Figure 4.29 shows the NPVs of SLM intervention in SNPP. They are estimated at about USD 30.13 billion (USD 21,086 per hectare) for 2020-2030 and USD 70.71 billion (USD 49,477 per hectare) for 2020-2040.

FIGURE 4.28:

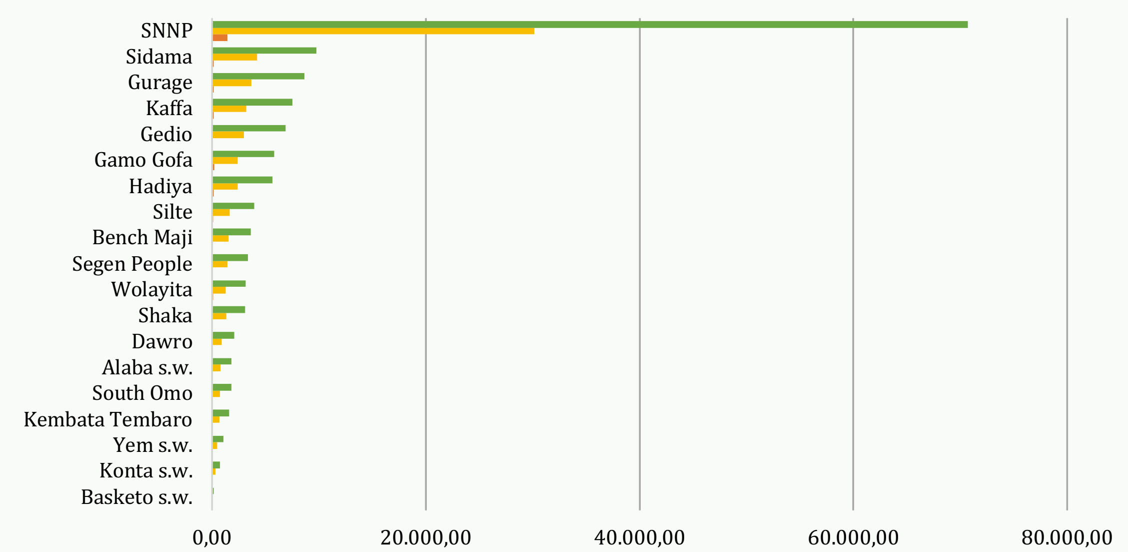
The BCR of SLM in Amhara.



	Argoba s.w.	Oromia Zone	Waghimra	Agwawi	North Wollo	West Gojam	South Wollo	South Gondar	North Shewa	East Gojam	North Gondar	Amhara
BCR_2020-2040	3,45	3,74	4,72	3,79	4,96	3,82	5,34	4,70	4,96	5,13	4,37	4,62
BCR_2020-2030	3,04	3,29	4,16	3,34	4,37	3,36	4,70	4,14	4,37	4,52	3,84	4,07

FIGURE 4.29:

The NPV (in millions of USD) of SLM in SNNP.

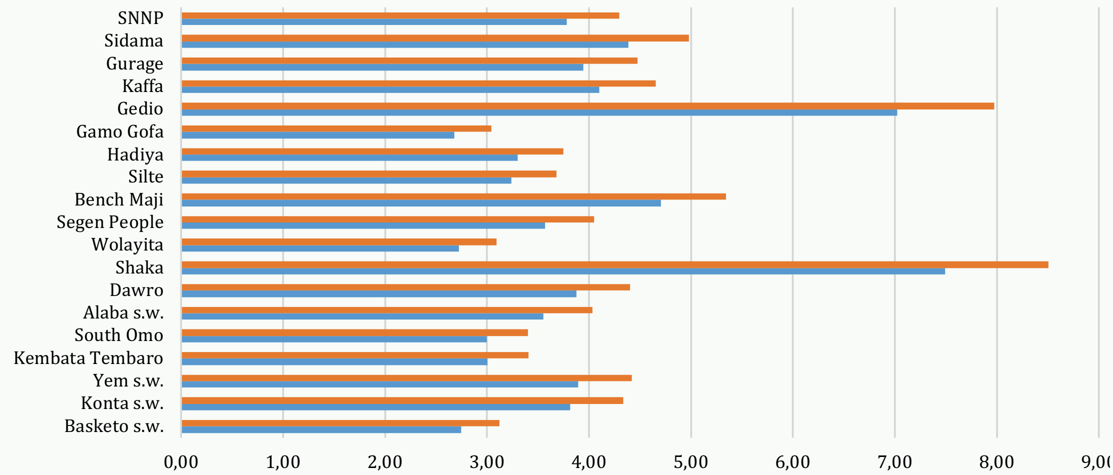


	Basketo s.w.	Konta s.w.	Yem s.w.	Kembata Tembaro	South Omo	Alaba s.w.	Dawro	Shaka	Wolayita	Segen People	Bench Maji	Silte	Hadiya	Gamo Gofa	Gedio	Kaffa	Gurage	Sidama	SNNP
NPV_2020-2040	168,61	760,83	1.057,09	1.587,08	1.810,70	1.822,80	2.086,08	3.066,11	3.124,07	3.341,67	3.631,92	3.955,68	5.640,03	5.833,84	6.899,72	7.510,72	8.645,43	9.764,18	70.706,5
NPV_2020-2030	70,15	324,41	451,23	665,73	759,44	774,02	890,26	1.338,14	1.298,70	1.419,24	1.563,93	1.669,35	2.383,21	2.420,55	3.006,64	3.214,42	3.692,34	4.192,09	30.133,8
Harvested area in 1000s ha	5,30	15,20	20,57	43,87	50,15	39,97	40,82	27,19	99,36	72,98	55,61	98,19	136,65	190,66	66,30	136,88	166,08	163,29	1.429,07

Shaka, Gedio, and Bench Maji are the three administrative zones with the highest BCRs, ranging from 4.71 to 8.51 for the project periods. All other 11 administrative zones and 4 special weredas have BCRs in the range of 2.68 to 4.98 (Figure 4.30). This indicates that investments in SLM in all of the 14 administrative zones and four special weredas will have positive and high returns.

FIGURE 4.30:

The BCR of SLM in SNNP.

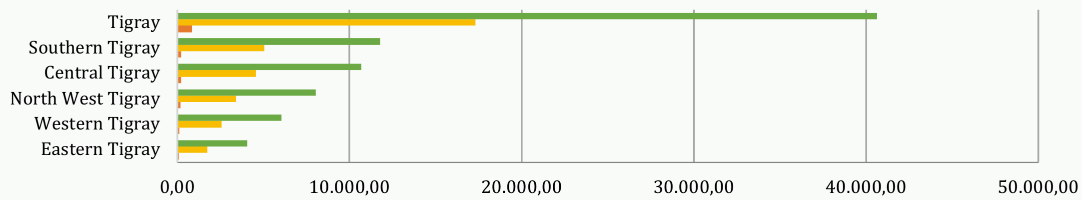


	Basketo s.w.	Konta s.w.	Yem s.w.	Kembata Tembaro	South Omo	Alaba s.w.	Dawro	Shaka	Wolayita	Segen People	Bench Maji	Silte	Hadiya	Gamo Gofa	Gedio	Kaffa	Gurage	Sidama	SNNP
BCR_2020-2040	3,12	4,34	4,42	3,41	3,40	4,03	4,40	8,51	3,09	4,05	5,35	3,68	3,75	3,04	7,97	4,65	4,48	4,98	4,30
BCR_2020-2030	2,75	3,82	3,89	3,00	3,00	3,55	3,88	7,49	2,72	3,57	4,71	3,24	3,30	2,68	7,02	4,10	3,94	4,39	3,78

Tigray regional state: Figure 4.31 shows the NPVs of SLM intervention in Tigray. They are estimated at about USD 17.3 billion (USD 20,665 per hectare) for 2020-2030 and USD 40.63 billion (USD 48,530 per hectare) for 2020-2040.

FIGURE 4.31:

The NPV (in millions of USD) of SLM in Tigray.

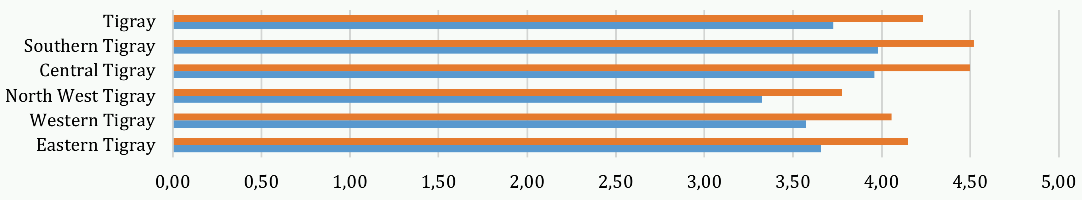


	Eastern Tigray	Western Tigray	North West Tigray	Central Tigray	Southern Tigray	Tigray
NPV_2020-2040	4.059,51	6.056,79	8.042,74	10.678,48	11.787,87	40.625,38
NPV_2020-2030	1.726,67	2.572,79	3.400,25	4.562,19	5.037,42	17.299,32
Harvested area in 1000s ha	85,83	131,82	192,89	203,42	223,15	837,11

Southern Tigray, Central Tigray, and Eastern Tigray are the three administrative zones with the highest BCRs, ranging from 3.66 to 4.52 for both project periods. The other two administrative zones have BCRs in the range of 3.33 to 4.06 (Figure 4.32). This indicates that investments in SLM interventions in all five administrative zones of the regional state will have positive and high returns.

FIGURE 4.32:

The BCR of SLM in Tigray.

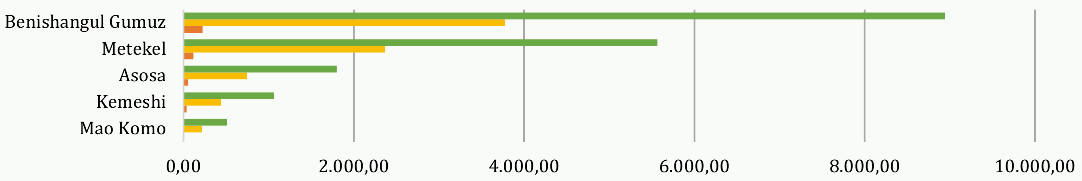


	Eastern Tigray	Western Tigray	North West Tigray	Central Tigray	Southern Tigray	Tigray
BCR_2020-2040	4,15	4,06	3,78	4,50	4,52	4,23
BCR_2020-2030	3,66	3,57	3,33	3,96	3,98	3,73

Benishangul Gumuz regional state: Figure 4.33 shows the NPVs of SLM intervention in Benishangul Gumuz. They are estimated at about USD 3.77 billion (USD 16,993 per hectare) for 20202030 and USD 8.94 billion (USD 40,267 per hectare) for 2020-2040. The NPVs of SLM in the Metekel zone alone account for 62.73 per cent and 62.23 per cent of the regional-level NPVs of SLM interventions in the periods 2020-2030 and 2020-2040, respectively.

FIGURE 4.33:

The NPV (in millions of USD) of SLM in Benishangul Gumuz.

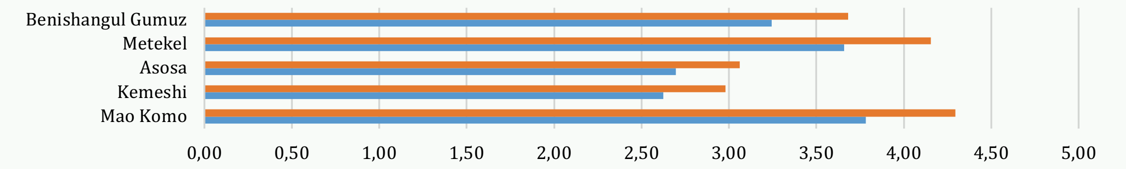


	Mao Komo	Kemeshi	Asosa	Metekel	Benishangul Gumuz
NPV_2020-2040	513,32	1.062,22	1.801,89	5.565,62	8.943,04
NPV_2020-2030	218,77	439,69	748,18	2.367,37	3.774,00
Harvested area in 1000s ha	10,37	35,87	58,28	117,58	222,09

Mao Komo, Metekel, and Asosa are the three administrative zones with the highest BCRs ranging from 2.7 to 4.3 for both projection periods. Kemeshi has a BCR of 2.62 and 2.98 for the projection periods 2020-2030 and 2020-2040 (Figure 4.34). This indicates that investments in SLM in all four administrative zones will have positive and high returns.

FIGURE 4.34:

The BCR of SLM in Benishangul Gumuz.

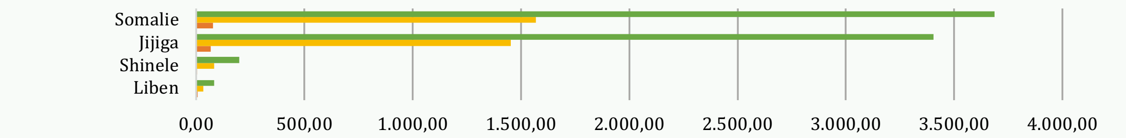


	Mao Komo	Kemeshi	Asosa	Metekel	Benishangul Gumuz
BCR_2020-2040	4,30	2,98	3,06	4,15	3,68
BCR_2020-2030	3,78	2,62	2,70	3,66	3,24

Somalie regional state: Figure 4.35 shows the NPVs of SLM intervention in Somalie. They are estimated at about USD 1.57 billion (USD 20,450 per hectare) for 2020-2030 and USD 3.69 billion (USD 48,047 per hectare) for 2020-2040. The NPVs of SLM interventions in Jijiga zone alone account for 92.61 per cent and 92.35 per cent of the regional level NPVs of SLM interventions in the periods 2020-2030 and 2020-2040, respectively.

FIGURE 4.35:

The NPV (in millions of USD) of SLM in Somalie.

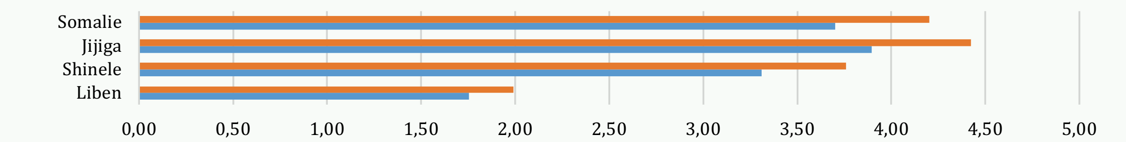


	Liben	Shinele	Jijiga	Somalie
NPV_2020-2040	83,52	198,38	3.403,58	3.685,49
NPV_2020-2030	32,05	83,83	1.452,81	1.568,68
Harvested area in 1000s ha	5,62	4,81	66,28	76,71

In terms of BCR, Jijiga zone has the highest, followed by Shinele and Liben. The BCR of the three administrative zones are in the range of 1.75 to 4.42 for both prject periods (Figure 4.36). This indicates that investments in SLM intervention in all three administrative zones of the regional state will have positive and high returns.

FIGURE 4.36:

The BCR of SLM in Somalie.

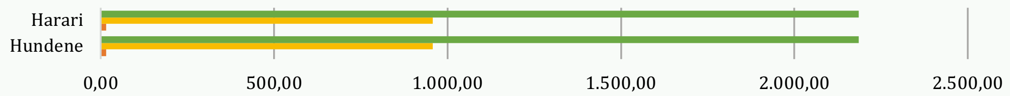


	Liben	Shinele	Jijiga	Somalie
BCR_2020-2040	1,99	3,76	4,42	4,20
BCR_2020-2030	1,75	3,31	3,90	3,70

Harari regional state: Figure 4.37 shows the NPVs of SLM intervention in Harari. They are estimated at about USD 0.957 billion (USD 62,035 per hectare) for 2020-2030 and USD 2.19 billion (141,611 USD per ha) for 2020-2040.

FIGURE 4.37:

The NPV (in millions of USD) of SLM in Harari.

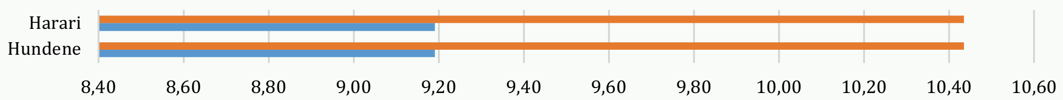


	Hundene	Harari
NPV_2020-2040	2.185,67	2.185,67
NPV_2020-2030	957,46	957,46
Harvested area in 1000s ha	15,43	15,43

In terms of BCR, the region has the highest of all regions, with values 9.19 and 10.44 for the projection periods 2020-2030 and 2020-2040, respectively (Figure 4.38). This indicates that investments in SLM intervention the region will have positive and high returns.

FIGURE 4.38:

The BCR of SLM in Harari.



	Hundene	Harari
BCR_2020-2040	10,44	10,44
BCR_2020-2030	9,19	9,19

Dire Dawa city administration: Figure 4.39 shows the NPVs of SLM intervention in Dire Dawa. They are estimated at about USD 0.256 billion (USD 21,301 per hectare) for 2020-2030 and USD 0.600 billion (USD 49,960 per hectare) for 2020-2040.

FIGURE 4.39:

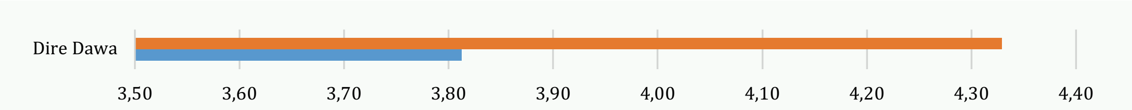
The NPV (in millions of USD) of SLM in Dire Dawa.

	Dire Dawa
NPV_2020-2040	600,08
NPV_2020-2030	255,85
Harvested area in 1000s ha	12,01

The BCR for the city administration are 3.81 and 4.33 for the projection periods 2020-2030 and 20202040, respectively (Figure 4.40). This indicates that investments in SLM intervention will have positive and high returns.

FIGURE 4.40:

The BCR of SLM in Dire Dawa.

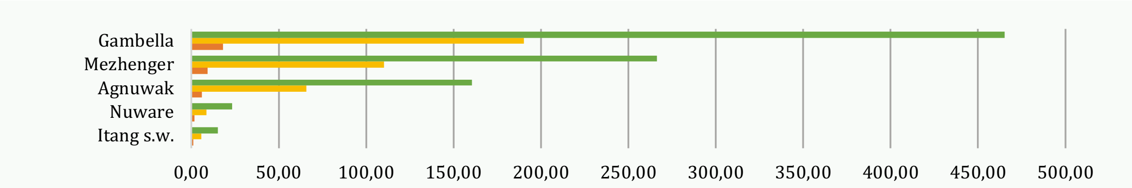


	Dire Dawa
BCR_2020-2040	4,33
BCR_2020-2030	3,81

Gambella regional state: Figure 4.41 shows the NPVs of SLM intervention in Gambella. They are estimated at about USD 0.190 billion (USD 10,453 per hectare) for 2020-2030 and USD 0.465 billion (USD 25,553 per hectare) for 2020-2040. The NPV in the Mezhenger zone alone accounts for 57.83 per cent and 57.24 per cent of the regional-level NPVs of SLM interventions for the periods 20202030 and 2020-2040, respectively.

FIGURE 4.41:

The NPV (in millions of USD) of SLM in Gambella.

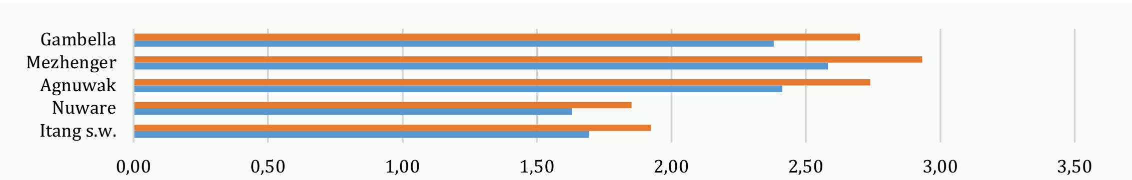


	Itang s.w.	Nuware	Agnuwak	Mezhenger	Gambella
NPV_2020-2040	15,26	23,32	160,37	266,34	465,30
NPV_2020-2030	5,79	8,72	65,76	110,08	190,34
Harvested area in 1000s ha	1,10	1,82	6,10	9,19	18,21

Mezhenger and Agnuwak zones and Itang special wereda rank from first to third with BCRs that are in the range of 1.69 to 2.93. Nuware zone has the lowest BCR of 1.63 and 1.85 for the projection periods 2020-2030 and 2020-2040 (Figure 4.42). This indicates that investments in SLM intervention in all three administrative zones and one special wereda will have positive and high returns.

FIGURE 4.42:

The BCR of SLM in Gambella.

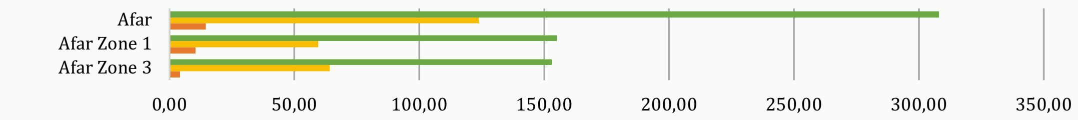


	Itang s.w.	Nuware	Agnuwak	Mezhenger	Gambella
BCR_2020-2040	1,92	1,85	2,74	2,93	2,70
BCR_2020-2030	1,69	1,63	2,41	2,58	2,38

Afar regional state: Figure 4.43 shows the NPVs of SLM intervention in Afar. They are estimated at about USD 0.124 billion (USD 8,485 per hectare) for 2020-2030 and USD 0.527 billion (USD 21,125 per hectare) for 2020-2040. Afar Zone 3 account for 51.9 per cent and 49.65 per cent of the regionallevel NPV of SLM interventions in the periods 2020-2030 and 2020-2040, respectively. Zone 1 accounts for the remaining 48.10 per cent and 50.35 per cent.

FIGURE 4.43:

The NPV (in millions of USD) of SLM in Afar.

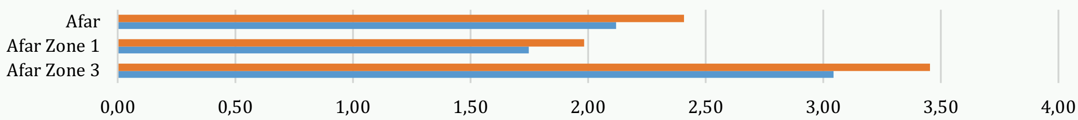


	Afar Zone 3	Afar Zone 1	Afar
NPV_2020-2040	152,93	155,08	308,01
NPV_2020-2030	64,22	59,50	123,72
Harvested area in 1000s ha	4,15	10,43	14,58

The BCRs for Zone 3 are 3.04 and 3.45, and 1.75 and 1.98 for Zone 1 for the projection periods (Figure 4.44). This indicates that investments in SLM intervention in both administrative zones will have positive and high returns.

FIGURE 4.44:

The BCR of SLM in Afar.



	Afar Zone 3	Afar Zone 1	Afar
BCR_2020-2040	3,45	1,98	2,41
BCR_2020-2030	3,04	1,75	2,12

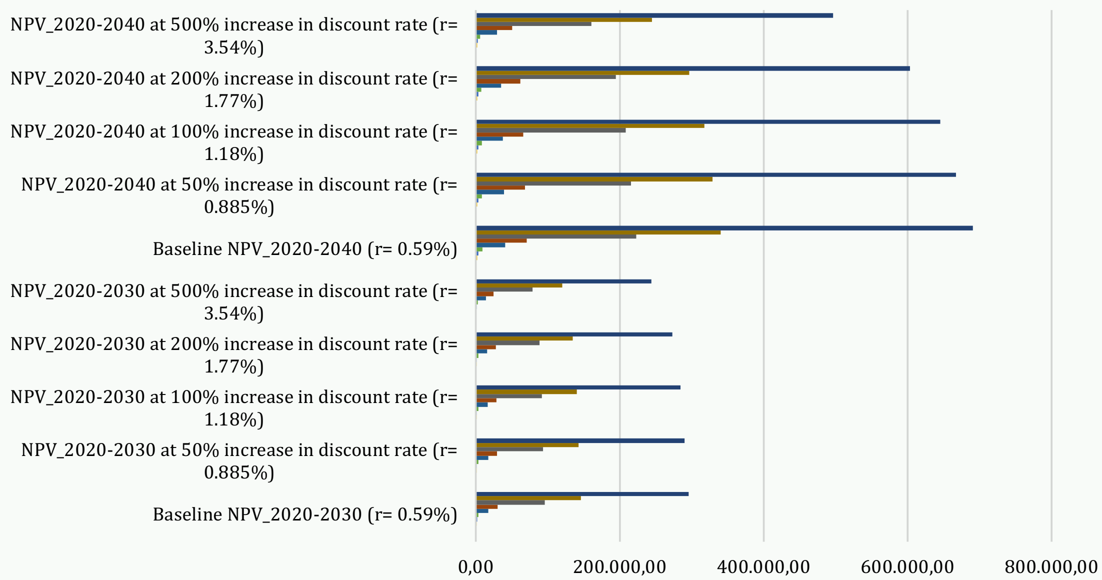
4.6. Sensitivity analysis

4.6.1. Sensitivity of NPV and BCR to changes in the real discount rate

The results of the sensitivity analysis indicate that both NPV and BCR are less sensitive to changes in the discount rate, implying that a given percentage change in the real discount rate causes an opposite and relatively small proportional changes in both NPV and BCR. For example, a 500 per cent increase in the real discount rate (i.e. change from r=0.59 per cent to r=3.54 per cent for the discounting period 2020-2030) will cause the country-level NPV to change only by 17.69 per cent and the BCR to decline from 4.05 to 3.92, which is only a 3.41 per cent decline (Figures 4.45 and 4.46). For the discounting period 2020-2040, the 500 per cent increase in the real discount rate will cause the country-level NPV to change only by 28.11 per cent and the BCR to decline from 4.60 to 4.42, which is only a 3.89 per cent decline. Moreover, when increasing the real discount rate from the baseline rate of 0.59 per cent to 3.54 per cent, the sensitivity analyses indicate that the NPVs for all administrative zones remain positive and benefit-cost ratios are greater than one.

F I G U R E 4 . 4 5 :

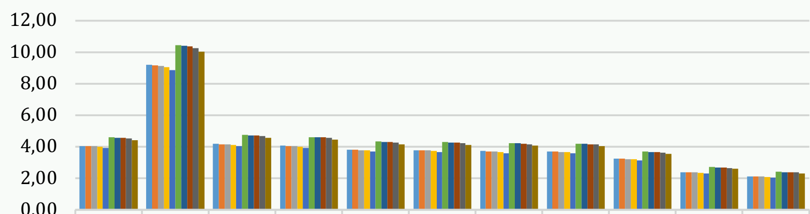
Sensitivity of NPV (in millions of USD) to changes in real discount rate.



	Baseline NPV_2020-2030 (r= 0.59%)	NPV_2020-2030 at 50% increase in discount rate (r= 0.885%)	NPV_2020-2030 at 100% increase in discount rate (r= 1.18%)	NPV_2020-2030 at 200% increase in discount rate (r= 1.77%)	NPV_2020-2030 at 500% increase in discount rate (r= 3.54%)	Baseline NPV_2020-2040 (r= 0.59%)	NPV_2020-2040 at 50% increase in discount rate (r= 0.885%)	NPV_2020-2040 at 100% increase in discount rate (r= 1.18%)	NPV_2020-2040 at 200% increase in discount rate (r= 1.77%)	NPV_2020-2040 at 500% increase in discount rate (r= 3.54%)
ETHIOPIA	295.460,74	289.678,92	284.038,20	273.164,08	243.534,05	690.755,15	667.353,68	644.951,32	602.949,99	496.580,88
Oromia	145.693,25	142.848,66	140.073,46	134.723,36	120.144,58	340.098,41	328.590,14	317.573,08	296.917,28	244.609,73
Amhara	95.464,26	93.596,75	91.774,79	88.262,45	78.691,85	223.137,21	215.579,05	208.343,57	194.778,02	160.416,97
SNNP	30.133,85	29.540,95	28.962,54	27.847,53	24.809,70	70.706,56	68.304,39	66.004,84	61.693,67	50.773,40
Tigray	17.299,32	16.958,52	16.626,05	15.985,16	14.239,09	40.625,38	39.244,27	37.922,17	35.443,53	29.167,85
Benishangul Gumuz	3.774,00	3.698,65	3.625,15	3.483,47	3.097,58	8.943,04	8.636,88	8.343,82	7.794,45	6.406,48
Somalie	1.568,68	1.537,76	1.507,59	1.449,44	1.291,01	3.685,49	3.560,15	3.440,17	3.215,23	2.645,82
Harari	957,46	939,39	921,75	887,73	794,98	2.185,67	2.113,02	2.043,46	1.913,02	1.581,74
Dire Dawa	255,85	250,82	245,91	236,45	210,67	600,08	579,70	560,19	523,61	430,91
Gambella	190,34	186,37	182,49	175,01	154,67	465,30	449,00	433,40	404,16	330,29
Afar	123,72	121,06	118,47	113,48	99,92	308,01	297,08	286,61	267,01	217,70

F I G U R E 4 . 4 6 :

Sensitivity of BCR to changes in real discount rate.



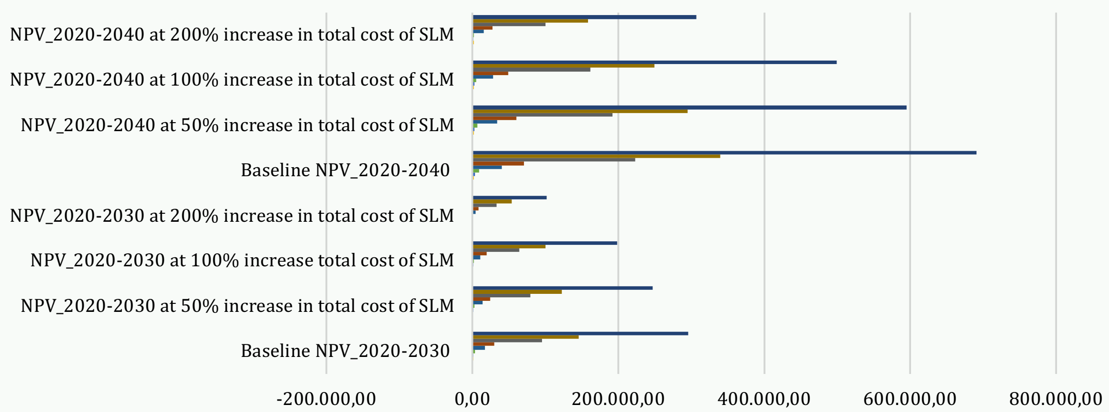
	ETHIOPIA	Harari	Oromia	Amhara	Dire Dawa	SNNP	Tigray	Somalie	Benishangul Gumuz	Gambella	Afar
Baseline BCR_2020-2030 (r= 0.59%)	4,05	9,19	4,18	4,07	3,81	3,78	3,73	3,70	3,24	2,38	2,12
BCR_2020-2030 at 50% increase in discount rate (r= 0.885%)	4,04	9,16	4,17	4,06	3,80	3,77	3,72	3,69	3,23	2,37	2,11
BCR_2020-2030 at 100% increase in discount rate (r= 1.18%)	4,03	9,13	4,15	4,04	3,79	3,76	3,70	3,67	3,22	2,36	2,11
BCR_2020-2030 at 200% increase in discount rate (r= 1.77%)	4,00	9,07	4,13	4,02	3,76	3,73	3,68	3,65	3,20	2,35	2,09
BCR_2020-2030 at 500% increase in discount rate (r= 3.54%)	3,92	8,88	4,04	3,93	3,68	3,66	3,60	3,57	3,13	2,30	2,05
Baseline BCR_2020-2040 (r= 0.59%)	4,60	10,44	4,75	4,62	4,33	4,30	4,23	4,20	3,68	2,70	2,41
BCR_2020-2040 at 50% increase in discount rate (r= 0.885%)	4,59	10,40	4,73	4,61	4,31	4,28	4,22	4,19	3,67	2,69	2,40
BCR_2020-2040 at 100% increase in discount rate (r= 1.18%)	4,57	10,36	4,71	4,59	4,30	4,26	4,20	4,17	3,65	2,68	2,39
BCR_2020-2040 at 200% increase in discount rate (r= 1.77%)	4,53	10,27	4,68	4,55	4,26	4,23	4,17	4,14	3,63	2,66	2,37
BCR_2020-2040 at 500% increase in discount rate (r= 3.54%)	4,42	10,03	4,56	4,44	4,16	4,13	4,07	4,04	3,54	2,60	2,32

4.6.2. Sensitivity of NPV and BCR to changes in total costs of sustainable land management

The results of the sensitivity analysis to changes in total cost of SLM technologies indicate that both NPV and BCR are less sensitive to changes in the total costs of SLM interventions. For example, a 200 per cent increase in the total cost of SLM interventions will cause the country-level NPV to change only by 65.5 per cent and the BCR to decline from 4.05 to 1.35, which is a 66.67 per cent decline (Figures 4.47 and 4.48). For the discounting period 2020-2040, a 200 per cent increase in the total cost of SLM interventions will cause the country-level NPV to change by 55.51 per cent and BCR to decline from 4.05 to 1.53, which is a 66.67 per cent decline. Moreover, for the 200 per cent increase in the total cost of SLM technologies, the sensitivity analyses indicate that for most of the administrative zones and all regional states – except for Afar and Gambella – the NPVs remain positive and benefit-cost ratios stay greater than one.

FIGURE 4.47:

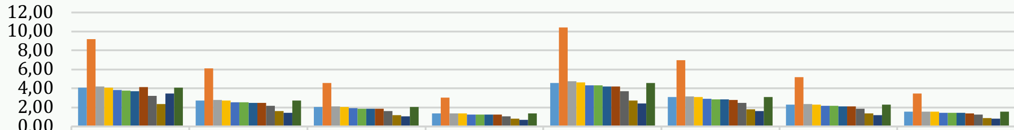
Sensitivity of NPV (in millions of USD) to changes in total costs of SLM.



	Baseline NPV_2020-2030	NPV_2020-2030 at 50% increase in total cost of SLM	NPV_2020-2030 at 100% increase total cost of SLM	NPV_2020-2030 at 200% increase in total cost of SLM	Baseline NPV_2020-2040	NPV_2020-2040 at 50% increase in total cost of SLM	NPV_2020-2040 at 100% increase in total cost of SLM	NPV_2020-2040 at 200% increase in total cost of SLM
ETHIOPIA	295.460,74	247.089,48	198.718,22	101.975,69	690.755,15	594.904,05	499.052,94	307.350,73
Oromia	145.693,25	122.803,34	99.913,43	54.133,61	340.098,41	294.740,44	249.382,45	158.666,47
Amhara	95.464,26	79.924,60	64.384,93	33.305,59	223.137,21	192.344,24	161.551,27	99.965,35
SNNP	30.133,85	24.721,97	19.310,09	8.486,34	70.706,56	59.982,55	49.258,53	27.810,49
Tigray	17.299,32	14.129,18	10.959,04	4.618,76	40.625,38	34.343,53	28.061,67	15.497,95
Benishangul Gumuz	3.774,00	2.932,93	2.091,86	409,72	8.943,04	7.276,40	5.609,76	2.276,48
Somalie	1.568,68	1.278,20	987,71	406,74	3.685,49	3.109,87	2.534,25	1.383,01
Harari	957,46	899,01	840,57	723,67	2.185,67	2.069,85	1.954,03	1.722,39
Dire Dawa	255,85	210,36	164,87	73,89	600,08	509,94	419,80	239,52
Gambella	190,34	121,39	52,43	-85,49	465,30	328,65	192,01	-81,29
Afar	123,72	68,50	13,29	-97,15	308,01	198,59	89,18	-129,65

FIGURE 4.48:

Sensitivity of BCR to changes in total costs of SLM.



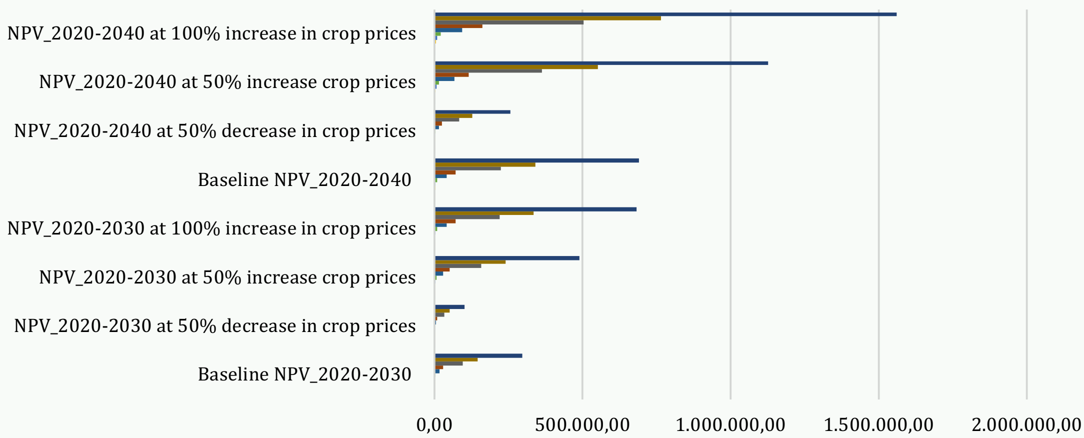
	Baseline NPV_2020-2030	BCR_2020-2030 at 50% increase in total cost of SLM	BCR_2020-2030 at 100% increase total cost of SLM	BCR_2020-2030 at 200% increase in total cost of SLM	Baseline BCR_2020-2040	BCR_2020-2040 at 50% increase in total cost of SLM	BCR_2020-2040 at 100% increase in total cost of SLM	BCR_2020-2040 at 200% increase in total cost of SLM
ETHIOPIA	4,05	2,70	2,03	1,35	4,60	3,07	2,30	1,53
Harari	9,19	6,13	4,60	3,06	10,44	6,96	5,22	3,48
Oromia	4,18	2,79	2,09	1,39	4,75	3,17	2,37	1,58
Amhara	4,07	2,71	2,04	1,36	4,62	3,08	2,31	1,54
Dire Dawa	3,81	2,54	1,91	1,27	4,33	2,89	2,16	1,44
SNNP	3,78	2,52	1,89	1,26	4,30	2,86	2,15	1,43
Tigray	3,73	2,49	1,86	1,24	4,23	2,82	2,12	1,41
Somalie	4,15	2,47	1,85	1,23	4,20	2,80	2,10	1,40
Benishangul Gumuz	3,24	2,16	1,62	1,08	3,68	2,46	1,84	1,23
Gambella	2,38	1,59	1,19	0,79	2,70	1,80	1,35	0,90
Afar	3,44	1,41	1,06	0,71	2,41	1,61	1,20	0,80
ETHIOPIA	4,05	2,70	2,03	1,35	4,60	3,07	2,30	1,53

4.6.3. Sensitivity of NPV and BCR to changes in weighted average aggregate crop price

NPV is more sensitive to changes in the weighted average aggregate crop price whereas BCR is almost proportionally sensitive to changes in crop prices. For example, a 50 per cent decrease in the weighted average aggregate crop price will cause the country-level NPV to decrease by 65.5 per cent and the BCR to decrease from 4.05 to 2.05, which is a 49.31 per cent increase (Figures 4.49 and 4.50). For the discounting

FIGURE 4.49:

Sensitivity of NPV (in millions of USD) to changes in total crop prices.

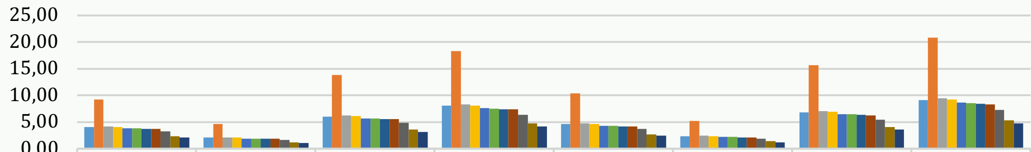


	Baseline NPV_2020-2030	NPV_2020-2030 at 50% decrease in crop prices	NPV_2020-2030 at 50% increase crop prices	NPV_2020-2030 at 100% increase in crop prices	Baseline NPV_2020-2040	NPV_2020-2040 at 50% decrease in crop prices	NPV_2020-2040 at 50% increase crop prices	NPV_2020-2040 at 100% increase in crop prices
ETHIOPIA	295.460,74	102.060,12	488.861,38	682.262,00	690.755,15	255.603,76	1.125.906,56	1.561.057,97
Oromia	145.693,25	51.347,35	240.039,15	334.385,05	340.098,41	127.820,14	552.376,69	764.654,99
Amhara	95.464,26	33.004,28	157.924,27	220.384,26	223.137,21	82.602,23	363.672,19	504.207,17
SNNP	30.133,85	9.897,62	50.370,07	70.606,30	70.706,56	25.175,06	116.238,08	161.769,58
Tigray	17.299,32	5.646,17	28.952,48	40.605,63	40.625,38	14.405,79	66.844,98	93.064,58
Benishangul Gumuz	3.774,00	1.110,03	6.437,97	9.101,95	8.943,04	2.949,10	14.936,98	20.930,91
Somalie	1.568,68	509,96	2.627,40	3.686,13	3.685,49	1.303,36	6.067,61	8.449,73
Harari	957,46	421,58	1.493,35	2.029,24	2.185,67	979,92	3.391,41	4.597,16
Dire Dawa	255,85	83,92	427,78	599,71	600,08	213,24	986,92	1.373,76
Gambella	190,34	28,85	351,84	513,34	465,30	101,93	828,66	1.192,03
Afar	123,72	10,37	237,06	350,41	308,01	52,98	563,04	818,07

period 2020-2040, the 50 per cent decrease in the weighted average aggregate crop price will cause the country-level NPV to decrease by 63 per cent and the BCR to decrease from 4.05 to 2.33, which is a 49.31 per cent decrease. Moreover, for the 50 per cent decrease in the weighted average crop price, the sensitivity analyses indicate that for 62 of the 66 administrative zones and all regional states, the NPVs remain positive and BCR stay greater than one.

FIGURE 4.50:

Sensitivity of BCR to changes in total crop prices.



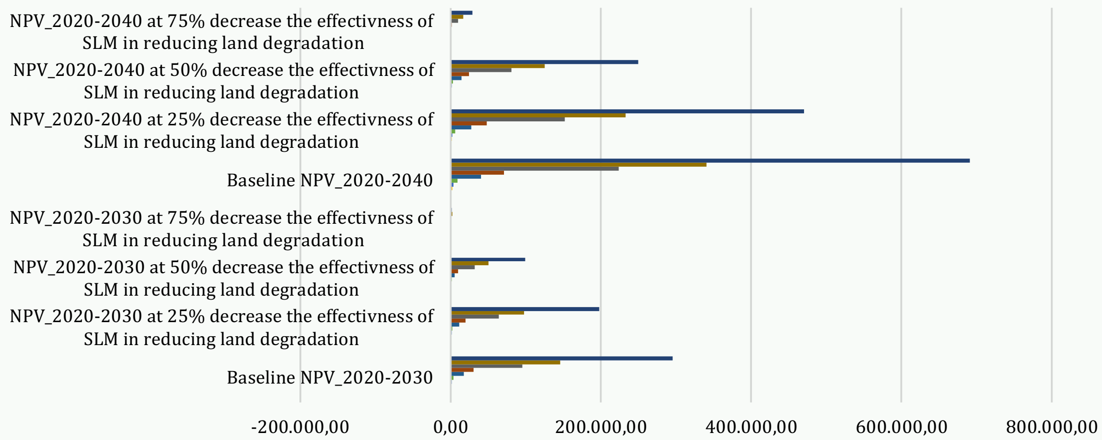
	Baseline BCR_2020-2030	BCR_2020-2030 at 50% decrease in crop prices	BCR_2020-2030 at 50% increase crop prices	BCR_2020-2030 at 100% increase in crop prices	Baseline BCR_2020-2040	BCR_2020-2040 at 50% decrease in crop prices	BCR_2020-2040 at 50% increase crop prices	BCR_2020-2040 at 100% increase in crop prices
ETHIOPIA	4,05	2,05	6,05	8,05	4,60	2,33	6,87	9,14
Harari	9,19	4,61	13,78	18,36	10,44	5,23	15,64	20,85
Oromia	4,18	2,12	6,24	8,30	4,75	2,41	7,09	9,43
Amhara	4,07	2,06	6,08	8,09	4,62	2,34	6,91	9,19
Dire Dawa	3,81	1,92	5,70	7,59	4,33	2,18	6,47	8,62
SNNP	3,78	1,91	5,65	7,52	4,30	2,17	6,42	8,54
Tigray	3,73	1,89	5,57	7,40	4,23	2,15	6,32	8,41
Somalie	3,70	1,88	5,52	7,34	4,20	2,13	6,27	8,34
Benishangul Gumuz	3,24	1,66	4,83	6,41	3,68	1,88	5,48	7,28
Gambella	2,38	1,21	3,55	4,72	2,70	1,37	4,03	5,36
Afar	2,12	1,09	3,15	4,17	2,41	1,24	3,57	4,74

4.6.4. Sensitivity of NPV and BCR to changes in the effectiveness of SLM technologies

NPV is more sensitive to changes in the effectiveness of SLM technologies in reducing agricultural land degradation whereas BCR is almost proportionally sensitive to changes in the effectiveness of SLM technologies. For example, a 50 per cent decrease in the effectiveness of SLM interventions in reducing agricultural land degradation will cause the country-level NPV to decrease by 66.37 per cent and the BCR to decrease from 4.05 to 2.03, which is a 50 per cent decrease (Figures 4.51 and 4.52). For the discounting period 2020-2040, the 50 per cent decrease in the effectiveness of SLM interventions in reducing agricultural land degradation will cause the country-level NPV to decrease by 63.88 per cent and the BCR to decrease from 4.05 to 2.3, which is a 50 per cent decrease. Moreover, for a 50 per cent decrease in the effectiveness of SLM technologies, the sensitivity analyses indicate that for 62 of the 66 administrative zones and all regional states, the NPVs remain positive and BCRs stay greater than one.

FIGURE 4.51:

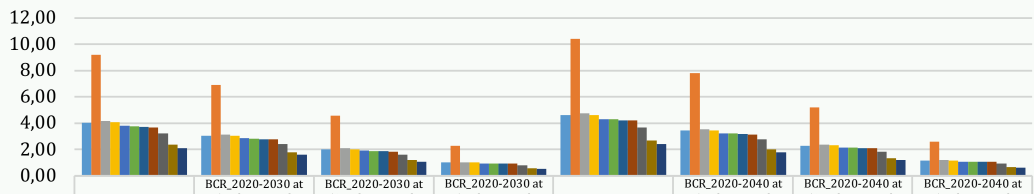
Sensitivity of NPV (in millions of USD) to changes in the effectiveness of SLM in reducing land degradation.



	Baseline NPV_2020-2030	NPV_2020-2030 at 25% decrease the effectivness of SLM in reducing land degradation	NPV_2020-2030 at 50% decrease the effectivness of SLM in reducing land degradation	NPV_2020-2030 at 75% decrease the effectivness of SLM in reducing land degradation	Baseline NPV_2020-2040	NPV_2020-2040 at 25% decrease the effectivness of SLM in reducing land degradation	NPV_2020-2040 at 50% decrease the effectivness of SLM in reducing land degradation	NPV_2020-2040 at 75% decrease the effectivness of SLM in reducing land degradation
ETHIOPIA	295.460,74	197.409,93	99.359,11	1.308,29	690.755,15	470.140,82	249.526,48	28.912,13
Oromia	145.693,25	97.824,98	49.956,71	2.088,45	340.098,41	232.394,83	124.691,24	16.987,63
Amhara	95.464,26	63.828,37	32.192,46	556,56	223.137,21	151.956,42	80.775,63	9.594,85
SNNP	30.133,85	19.894,45	9.655,05	-584,35	70.706,56	47.667,91	24.629,26	1.590,61
Tigray	17.299,32	11.389,42	5.479,52	-430,38	40.625,38	27.328,11	14.030,84	733,56
Benishangul Gumuz	3.774,00	2.409,97	1.045,93	-318,10	8.943,04	5.873,96	2.804,88	-264,20
Somalie	1.568,68	1.031,27	493,85	-43,56	3.685,49	2.476,30	1.267,12	57,94
Harari	957,46	688,87	420,28	151,69	2.185,67	1.581,34	977,01	372,69
Dire Dawa	255,85	169,14	82,44	-4,27	600,08	404,99	209,90	14,81
Gambella	190,34	108,28	26,21	-55,85	465,30	280,65	96,00	-88,64
Afar	123,72	65,18	6,64	-51,89	308,01	176,30	44,59	-87,12

FIGURE 4.52:

Sensitivity of BCR to changes in the effectiveness of SLM in reducing land degradation.



	Baseline BCR_2020-2030	BCR_2020-2030 at 25% decrease the effectivness of SLM in reducing land degradation	BCR_2020-2030 at 50% decrease the effectivness of SLM in reducing land degradation	BCR_2020-2030 at 75% decrease the effectivness of SLM in reducing land degradation	Baseline BCR_2020-2040	BCR_2020-2040 at 25% decrease the effectivness of SLM in reducing land degradation	BCR_2020-2040 at 50% decrease the effectivness of SLM in reducing land degradation	BCR_2020-2040 at 75% decrease the effectivness of SLM in reducing land degradation
ETHIOPIA	4,05	3,04	2,03	1,01	4,60	3,45	2,30	1,15
Harari	9,19	6,89	4,60	2,30	10,44	7,83	5,22	2,61
Oromia	4,18	3,14	2,09	1,05	4,75	3,56	2,37	1,19
Amhara	4,07	3,05	2,04	1,02	4,62	3,47	2,31	1,16
Dire Dawa	3,81	2,86	1,91	0,95	4,33	3,25	2,16	1,08
SNNP	3,78	2,84	1,89	0,95	4,30	3,22	2,15	1,07
Tigray	3,73	2,80	1,86	0,93	4,23	3,18	2,12	1,06
Somalie	3,70	2,78	1,85	0,93	4,20	3,15	2,10	1,05
Benishangul Gumuz	3,24	2,43	1,62	0,81	3,68	2,76	1,84	0,92
Gambella	2,38	1,79	1,19	0,60	2,70	2,03	1,35	0,68
Afar	2,12	1,59	1,06	0,53	2,41	1,81	1,20	0,60

4.7. Summary

The analyses in this chapter show the profitability of investments in SLM technologies on agricultural land in Ethiopia in the next 11 to 21 years. The PV of the total costs of investing in SLM technologies from 2020-2030 on 12.77 million hectares of agricultural land in Ethiopia is estimated at about USD 97 billion (USD 7,434 per hectare). For the 2020-2040 period, the PV of total costs over is about USD 192 billion (USD 15,008 per hectare). The PV of the establishment costs amounts to 23.09 per cent and 11.65 per cent of the PV of the total costs for the project periods 2020-2030 and 2020-2040, respectively. Maintenance costs, which are annual costs for maintaining established SLM structures, account for 64.37 per cent of the PV of the total costs over the period 2020-2030, and 77.14 per cent of the total costs over the period 2020-2040. Planning, implementation, as well as monitoring and evaluation costs together account for the remaining 12.54 per cent and 11.21 per cent of the present value of the country-level total costs of investment in sustainable land management technologies over the periods 2020-2030 and 2020-2040, respectively.

The four largest producers (Oromia, Amhara, SNNP and Tigray) account for 97.2 per cent of the country-level PV of total costs. The other four regional states (Benishangul Gumuz, Somalie, Gambella, Harari, Afar) and the Dire Dawa city administration account for only 2.8 per cent. Such a difference is mainly due to differences in cultivated land areas among regions; the largest four producers account for 81.5 per cent of the country-level average cultivated land area from 20032016.

The PV of total benefits of SLM interventions for preventing soil NPK depletion and NPK losses on 12.77 million hectares of agricultural land in Ethiopia are estimated at about USD 392 billion (USD 30,706 per hectare) for 2020-2030, and USD 882.46 billion (USD 69,088 per hectare) for 2020-2040. For both discounting periods, close to 67 per cent of the PV of the total benefits are due to the PV of yield gains from prevented NPK losses whereas 32 per cent of the benefits are accounted by the PV of yield gains from prevented soil NPK depletion through investment in SLM technologies. The remaining 1.34 per cent of the present values of total benefits is accounted by the present value of the replacement cost value of prevented NPK depletion and losses. The four main regional states (Oromia, Amhara, SNNP, and Tigray) account for 97.55 per cent of the country-level PV of total benefits of SLM interventions.

The NPVs of SLM interventions to prevent soil NPK depletion and NPK losses on 12.77 million hectares of agricultural land in Ethiopia are estimated at about USD 295 billion (USD 23,132 per hectare) for 2020-2030 and close to USD 691 billion (USD 54,079 per hectare) for 20202040. The country-level BCRs are 4.05 and 4.60 for the discounting periods 2020-2030 and 2020-2040, respectively. This indicates that the PV of total benefits of investment in SLM interventions are more than four times higher than the PV of total costs. The four main regional states (Oromia, Amhara, SNNP, and Tigray) account for 97.7 per cent of the country-level NPVs whereas the other four regional states (Benishangul Gumuz, Somalie, Harari, Gambella, and Afar) and the Dire Dawa city administration account for only 2.3 per cent.

The results of the sensitivity analyses show that NPVs and BCR are more sensitive to changes in prices and changes in the effectiveness of SLM technologies, in which the latter has important implications for policy and decision-making in terms of planning and institutional capacities for implementation of the SLM technologies. In general, the sensitivity analyses indicate that the results of the NPV and BCR are robust to changes in the different parameters used in the analyses. Thus, investing in SLM technologies on agricultural land to prevent soil nutrient depletion and nutrient losses will be a profitable intervention for Ethiopia in the regional states and administrative zones covered in this study. Moreover, such an investment not only enables the country to increase its agricultural productivity and achieve SDG 15.3 by achieving LDN, but it also has cobenefits and implications for other associated targets of the SDGs as discussed in the next chapter.

05 Policy implications

5.1. Introduction

This chapter focuses on how investing in SLM technologies to prevent NPK loss and soil NPK depletion on agricultural land in Ethiopia and thus achieving LDN in agriculture would be profitable for the country by providing co-benefits with policy implications in achieving related SDGs. The objective of this chapter is to assess further implications for achieving other SDGs.

Thus, the next sections of the chapter discuss the policy implications of investing in SLM technologies to achieve agricultural LDN (SDG 15.3) in Ethiopia and how these policies would help achieve a number of related SDGs as co-benefits.

5.2. Co-benefits and policy implications for SDGs

5.2.1. Economic growth (SDG 8.1)

Following Tilahun et al. (2018), we assessed the implications of achieving agricultural LDN in Ethiopia for SDG 8, which aims at "promoting sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all" (UN 2017). We developed an indicator that measures the contribution of real annuity of the NPV to the growth of real GDP per capita, as described below.

1. First, we estimated the annuity value of the NPV in Table 5.1 for Ethiopia, its administrative regions, and the 66 administrative zones covered in the study.
2. Based on World Bank database on GDP deflator, we deflated the annuity by the GDP deflator to convert it into real prices.
3. We calculated the real annuity as a percentage of the real 2016 GDP as well as the real agricultural 2016 GDP. The results indicate by how many percent the real GDP and real agricultural GDP of the country would grow on average over the period 2020-2030 and 2020-2040 if all the administrative zones in the nine regional states and the Dire Dawa city administration invested in SLM technologies on their agricultural land.
4. Furthermore, we calculated the annual geometric mean population growth for Ethiopia for the periods 2020-2030 and 2020-2040 based on projected population data from the FAO database. Economists estimate real GDP per capita growth as the difference between real GDP growth rate and human population growth rate. Accordingly, we estimated the contribution of real annuity of the NPV to real GDP per capita growth as the difference between real annuity as a percentage of real 2016 GDP and the estimated annual geometric mean of the population growth.

This indicator is consistent with indicator 8.1.1 "annual growth rate of real GDP per capita" set to measure target 8.1 of SDG 8. Target 8.1 states "sustain per capita economic growth in accordance with national circumstances and, in particular, at least 7 per cent gross domestic product growth per annum in the least developed countries" (UN 2017).

Table 5.1 shows that the annuity of NPV of investing in SLM interventions in Ethiopia amounts to USD 25.2 billion at constant prices for the discounting period of 2020-2030 and USD 31.77 billion at constant prices for the period 2020-2040. These annuity values account for 38 per cent and 48 per cent of the country-level real 2016 GDP and 110 per cent and 138 per cent of the real agricultural 2016 GDP, respectively (Figure 5.1). The annuities of NPV for the period 2020-2030 and 2020-2040 for the regional state of Oromia alone account for 19 per cent and 24 per cent of the real 2016 GDP and 54 per cent and 68 per cent of the real agricultural 2016 GDP, respectively. The share of real annuity of NPV to real GDP and real agricultural GDP for the other regions and the Dire Dawa city administration can be found in Figure 5.1. The results in Figure 5.1 indicate that investing in SLM technologies to prevent NPK losses and soil NPK depletion and the associated losses in aggregate crop yield would enable the economy of Ethiopia and its agricultural sector to grow by the indicated rates over the periods 2020-2030 and 2020-2040.

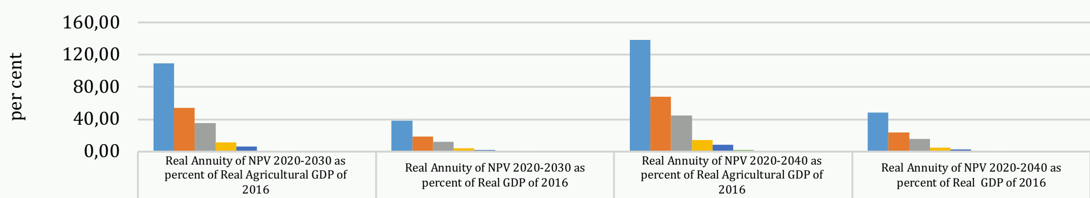
TABLE 5.1:

Annuities of NPV in current and constant prices for the discounting periods of 2020-2030 and 2020-2040.

	2020-2030			2020-2040		
	NPV in millions of USD	Annuity of NPV in millions of USD at current prices	Annuity of NPV in millions of USD at constant prices	NPV in millions of USD	Annuity of NPV in millions of USD at current prices	Annuity of NPV in millions of USD at constant prices
ETHIOPIA	295,460.74	27,820.23	25,199.97	690,755.15	35,069.72	31,766.65
Tigray	17,299.32	1,628.88	1,475.47	40,625.38	2,062.56	18,68.29
Afar	123.72	11.65	10.55	308.01	15.64	14.16
Amhara	95,464.26	8,988.80	8,142.19	223,137.21	11,328.70	10,261.70
Oromia	145,693.25	13,718.30	12,426.24	340,098.41	17,266.84	15,640.55
Somalie	1,568.68	147.71	133.79	3,685.49	187.11	169.49
Benishangul Gumuz	3,774.00	355.36	321.89	8,943.04	454.04	411.28
SNNP	30,133.85	2,837.37	2,570.13	70,706.56	3,589.78	3,251.67
Gambella	190.34	17.92	16.23	465.30	23.62	21.40
Harari	957.46	90.15	81.66	2,185.67	1,10.97	100.52
Dire Dawa	255.85	24.09	21.82	600.08	30.47	27.60

FIGURE 5.1:

Real annuity of NPV of preventing agricultural land degradation as percentage of real agricultural 2016 GDP and real 2016 GDP.



	Real Annuity of NPV 2020-2030 as percent of Real Agricultural GDP of 2016	Real Annuity of NPV 2020-2030 as percent of Real GDP of 2016	Real Annuity of NPV 2020-2040 as percent of Real Agricultural GDP of 2016	Real Annuity of NPV 2020-2040 as percent of Real GDP of 2016
ETHIOPIA	109,65	38,11	138,22	48,04
Oromia	54,07	18,79	68,06	23,65
Amhara	35,43	12,31	44,65	15,52
SNNP	11,18	3,89	14,15	4,92
Tigray	6,42	2,23	8,13	2,83
Benishangul Gumuz	1,40	0,49	1,79	0,62
Somalie	0,58	0,20	0,74	0,26
Harari	0,36	0,12	0,44	0,15
Dire Dawa	0,09	0,03	0,12	0,04
Gambella	0,07	0,02	0,09	0,03

Our analysis also indicates that Ethiopia's population will grow by an average of 2.15 per cent over the period 2020-2030 and will reach 138.3 million by 2030. The growth rate for the period 20202040 is projected at a rate of 1.94 per cent per annum and the population will reach 164.3 million by 2040. If the country and all of its administrative regions and zones are going to invest in SLM technologies to prevent agricultural land degradation, the gains from such investments in terms of annuities of NPV would lead to high rates of growth in the per capita income of the country. The results indicate that per capita GDP would grow by an average of 35.96 per cent over the period 2020230 and by an average of 46.1 per cent over the period 2020-2040.

5.2.2. Rural employment (SDG 8.5)

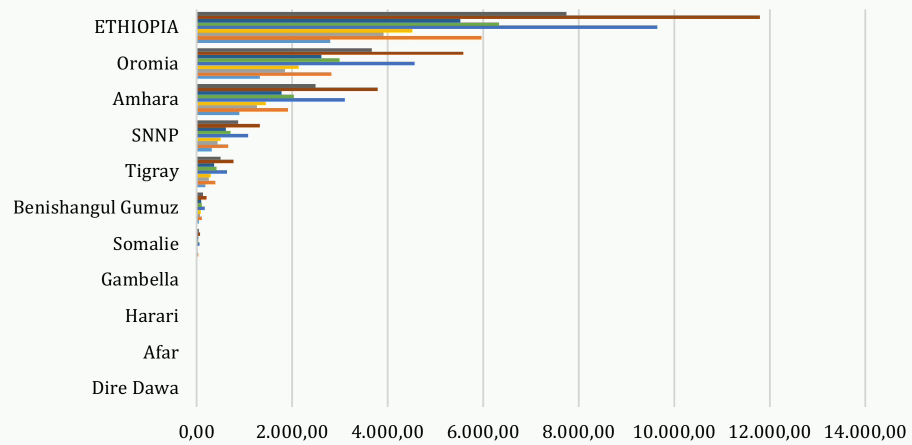
In the list of the SDGs, target 8.5 of SDG number 8 states: "By 2030, achieve full and productive employment and decent work for all women and men, including for young people and persons with disabilities, and equal pay for work of equal value" (UN 2017). The corresponding indicator 8.5.1 considers "the average hourly earnings of female and male employees, by occupation, age and persons with disabilities". In order to assess the implication of achieving agricultural LDN for SDG 8.5, specifically "achieving full productive employment" in Ethiopia, we estimated the number of rural employment opportunities that investment in the SLM technologies on agricultural land of the country could generate over the periods 2020-2030 and 2020-2040, as described in Tilahun et al. (2018) and presented below.

1. First, we estimated the annuity values of the total costs of SLM technologies, which is the sum of the present values of establishment and maintenance cost of SLM technologies, for the 2020-2030 and 2020-2040 discounting periods (Figure 5.2).
2. Based on the WOCAT data that we used for developing econometric models of establishment and maintenance costs, labour costs on average are 60.83 per cent of the establishment costs and 72.66 per cent of the maintenance costs (Table 3.2 in chapter 3). We applied these ratios to calculate the annuity values of the PV of labour costs for establishment and maintenance of SLM technologies.
3. We estimated the number of rural job opportunities that the annuity of the PV of labour cost estimated in step 2 above could generate at two alternative wage rates (lower-bound and upper-bound wage rates). We divided the annuity of the PV of total labour costs by the upper-bound wage rate to get the minimum number of job opportunities, and we divided the PV of total labour costs by the lower-bound wage rate to get the maximum number of job opportunities. We considered the lower-bound wage rate as the international poverty line per capital daily income set as USD 3.2 at Purchasing Power Parity (PPP) from the World Bank database. Here we calculated the corresponding annual lower- and upper-bound wage rates at current USD using the following formula:
   - Lower-bound wage rate in USD/person/year = (USD 3.20 in PPP/day * 365.25 days/yr)/(Official Exchange Rate/ PPP conversion factor). We got the PPP conversion factor from the World Bank database. This resulted in USD 468.21 per person per year as the lower-bound wage rate.
   - Upper bound wage rate = per capita GDP of 2016 = 712.88 USD per person per year.

The results in Figure 5.2 show that the annuity of the PV establishment cost of SLM technologies over the period 2020-2024 on a total of 12.77 million hectares of agricultural land is USD 2.79 billion per year. This could generate a maximum of 5.96 million rural job opportunities for the five-year period at annual wage rate of USD 468.21 per person per year and a minimum of 3.92 million rural jobs at an annual wage rate of USD 712.88 per person per year. In addition to this, the annuity of the PV of labour costs for annual maintenance of the established SLM structures amounts to USD 4.52 billion per year for the discounting period of 2020-2030 and USD 5.52 billion per year for the discounting period of 2020-2040. These annuities of PV of maintenance cost of labour could generate a maximum of 9.65 million rural jobs for the period 2021-2030 or a maximum of 11.79 million rural jobs for the period 2021-2040, and a minimum of 6.34 million jobs for the period 2020-2030 or a minimum of 7.74 million jobs for the period 2021-2040. Details on the regional states' maximum and minimum numbers of rural job opportunities that the annuities of the PV establishment and maintenance labour costs could generate can be found in Figure 5.2.

FIGURE 5.2:

Rural job opportunities that could be created in 2020-2030 and 2020-2040.



	Dire Dawa	Afar	Harari	Gambella	Somalie	Benishangul Gumuz	Tigray	SNNP	Amhara	Oromia	ETHIOPIA
Rural jobs in 1000s that annuity of PV of maintenance costs of labor could create at wage=USD 712.88/yr in 2021-2040	7,28	8,84	9,36	11,04	46,50	134,63	507,45	866,28	2.487,44	3.664,00	7.742,81
Rural jobs in 1000s that annuity of PV of maintenance costs of labor could create at wage=USD 468.21/yr in 2021-2040	11,09	13,46	14,24	16,81	70,80	204,98	772,62	1.318,96	3.787,28	5.578,65	11.788,88
Annuity of PV of maintenance labor costs of SLM in millions of USD 2021_2040	5,19	6,30	6,67	7,87	33,15	95,98	361,75	617,55	1.773,24	2.611,98	5.519,68
Rural jobs in 1000s that annuity of PV of maintenance costs of labor could create at wage=USD 712.88/yr in 2021-2030	5,96	7,23	7,66	9,03	38,05	110,18	415,29	708,96	2.035,72	2.998,62	6.336,72
Rural jobs in 1000s that annuity of PV of maintenance costs of labor could create at wage=USD 468.21/yr in 2021-2030	9,07	11,01	11,66	13,75	57,94	167,76	632,31	1.079,44	3.099,51	4.565,57	9.648,02
Annuity of PV of maintenance labor costs of SLM in millions of USD 2021_2030	4,25	5,16	5,46	6,44	27,13	78,55	296,05	505,41	1.451,22	2.137,65	4.517,31
Rural jobs in 1000s that annuity of PV of establishment costs of labor could create at wage=USD 712.88/yr in 2020-2024	3,68	4,47	4,73	5,58	23,52	68,10	256,68	438,19	1.258,23	1.853,37	3.916,57
Rural jobs in 1000s that annuity of PV of establishment costs of labor could create at wage=USD 468.21/yr in 2020-2024	5,61	6,81	7,21	8,50	35,81	103,69	390,81	667,18	1.915,73	2.821,87	5.963,21
Annuity of PV of establishment labor costs of SLM in miliions of USD 2020_2024	2,63	3,19	3,37	3,98	16,77	48,55	182,98	312,38	896,96	1.321,23	2.792,04

5.2.3. Poverty reduction (SDG 1.1 and SDG 1.2)

SDG 1 aims at "Ending poverty in all its forms everywhere" (UN 2017). The goal's target 1.1 states: "By 2030, eradicate extreme poverty for all people everywhere, currently measured as people living on less than USD 1.25 a day". Whereas target 1.2 reads: "By 2030, reducing at least by half the proportion of men, women and children of all ages living in poverty in all its dimensions according to national definitions" (UN 2017). In order to assess the implication of achieving agricultural LDN for SDG 1, we assessed how the annuity of the NPV would contribute to poverty reduction for Ethiopia with national poverty gap data and the results of NPV from this study following Tilahun et al. (2018) and as described below.

1. First, we used data on poverty gap index at USD 3.2 PPP of international poverty line from the World Bank database for Ethiopia. The poverty gap for Ethiopia at USD 3.2 PPP a day was 23.1 per cent.
2. We calculated the annual poverty gap reduction rate by dividing the poverty gap by 11, where 11 indicates the number of years from 2020 to 2030 where flows of benefits from SLM intervention will realise. The cumulative of the annual poverty reduction rate = 23.1 per cent for the year 2030 and years from 2031-2040.
3. We calculated the total cost of poverty gap reduction for the country and each of the regional states for the periods 2020-2030 and 2020-2040 as a product of the international poverty line per capita annual income, the cumulative annual poverty gap reduction rate, and the projected total population of the year.
4. We estimated the PV of this total cost of poverty reduction and annuity of the cost using the same real discount rate used for the NPV analysis in Chapter 4.

5. We calculated the ratio of annuity of the NPV in Chapter 4 to annuity of the cost of poverty reduction and used it as an indicator of how the annuity of the NPV of investing in SLM on agricultural land of the country would enhance national income that could be possibly used to reduce poverty and achieve SDG 1.1 and 1.2.

The results in Table 5.2 indicate that the number of Ethiopians living with income below 3.2 USD PPP a day in Ethiopia will be 69.65 million, ceteris paribus, assuming the current poverty head count ratio of 62.2 per cent at USD 3.20 PPP daily per capita income. Taking into account the 23.1 per cent of poverty gap at USD 3.20 PPP daily per capita income, the country has to work hard to lift 31.95 million people out of poverty and enable this many people to have a daily per capita income of USD 3.20 PPP, or in other words a per capita annual income of USD 468.21. The number will be higher if we consider a planning period up to 2040, by which the country needs to lift close to 38 million people out of poverty.

The PV of the cost of poverty gap reduction for the period 2020-2030 at a real discount rate of 0.59 per cent is estimated at about USD 84.02 billion, with an annuity value of USD 7.91 billion. The figures are higher if we consider the planning period of 2020-2040, by which the PV of the cost of poverty gap reduction for the country will be close to USD 269 billion with an annuity value of USD 13.63 billion per year. This implies that Ethiopia needs to enhance its capacity and increase the per capita income level of its growing population. One possible way of doing this is through increasing the productivity of the agricultural sector with investments in SLM technologies. The results in this study indicate that the annuities of the NPV of investment in SLM technologies amount to USD 27.82 billion for the discounting period of 2020-2030. This amounts to 3.5 times the PV of the cost of lifting 31.95 million people out of poverty by 2030. The ratio of the annuity of the NPV of preventing NPK loss and NPK depletion to that of the annuity of the PV of the cost of poverty gap reduction over the period 2020-2040 is 2.6. Thus, the results indicate that by 2030, investing in SLM technologies and achieving agricultural LDN in Ethiopia would enable the country to have the financial resources needed to reduce the poverty gap to zero and maintain this zero poverty gap until 2040 (Figure 5.3). Further details at regional level can be found in Table 5.2 and Figure 5.3.

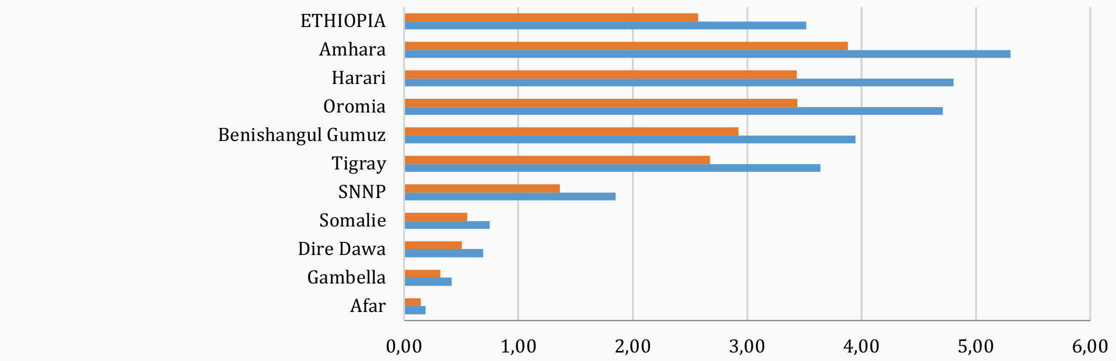
TABLE 5.2:

PV of costs of reducing poverty gap to zero by 2030 and 2040 and annuities of NPV of preventing land degradation.

Zone	Population in 1,000s with income below 3.2 USD PPP a day in 2020	Population in 1,000s to be lifted out of poverty by 2030	Population in 1,000s to be lifted out of poverty by 2040	PV cost of poverty gap reduction in million USD		Annuity of PV of cost of poverty gap reduction		Annuity of NPV of preventing land degradation	
				2020 to 2030	2020 to 2040	2020 to 2030	2020 to 2040	2020 to 2030	2020 to 2040
ETHIOPIA	69,645.99	31,946.58	37,946.43	84,020.11	268,540.14	7,911.24	13,633.81	27,820.23	35,069.72
Tigray	3,935.49	1,805.21	2,144.24	4,747.73	15,174.41	447.04	770.41	1,628.88	2,062.56
Afar	544.12	249.59	296.46	656.42	2,098.02	61.81	106.52	11.65	15.64
Amhara	14,917.82	6,842.79	8,127.93	17,996.68	57,519.93	1,694.55	2,920.29	8,988.80	11,328.70
Oromia	25,647.94	11,764.70	13,974.21	30941.38	98,893.02	2,913.40	5,020.81	13,718.30	17,266.84
Somalie	1,731.68	794.32	943.50	2,089.07	6,676.98	196.70	338.99	147.71	187.11
Benishangul Gumuz	792.63	363.58	431.86	956.22	3,056.20	90.04	155.16	355.36	454.04
SNNP	13,494.40	6,189.87	7,352.39	16,279.49	52,031.54	1,532.86	2,641.65	2,837.37	3,589.78
Gambella	377.73	173.26	205.81	455.69	1,456.45	42.91	73.94	17.92	23.62
Harari	165.21	75.78	90.01	199.31	637.01	18.77	32.34	90.15	110.97
Dire Dawa	307.60	141.09	167.59	371.08	1,186.02	34.94	60.21	24.09	30.47

FIGURE 5.3:

Ratio of annuity of NPV of preventing agricultural land degradation to annuity of PV of cost of reducing poverty gap to zero by 2030 and 2040.



	Afar	Gambella	Dire Dawa	Somalie	SNNP	Tigray	Benishangul Gumuz	Oromia	Harari	Amhara	ETHIOPIA
Raio of Annuity of NPV to Annuity of cost of poverty gap reduction to zero by 2040	0,15	0,32	0,51	0,55	1,36	2,68	2,93	3,44	3,43	3,88	2,57
Raio of Annuity of NPV to Annuity of cost of poverty gap reductionto zero by 2030	0,19	0,42	0,69	0,75	1,85	3,64	3,95	4,71	4,80	5,30	3,52

5.2.4. Food security (SDG 2.3 and SDG 2.4)

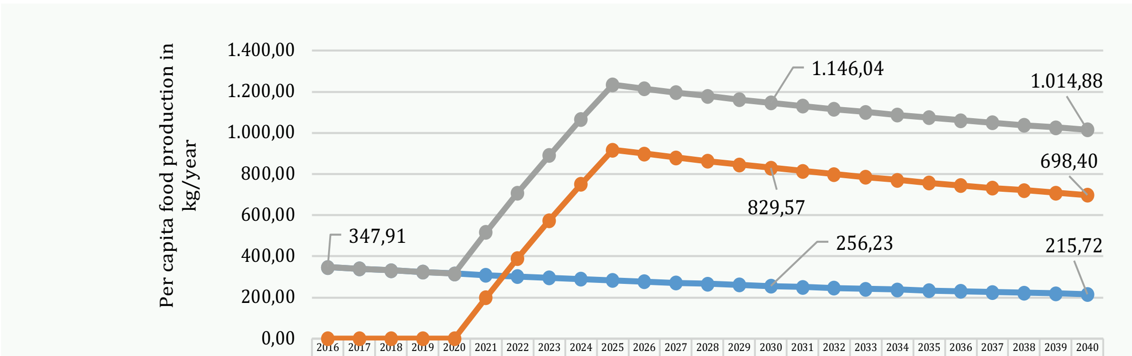
SDG 2 aims at "ending hunger, achieve food security and improved nutrition and promote sustainable agriculture by 2030" (UN 2017). Specifically, target 2.3 requires countries to "double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment by 2030". Target SDG 2.4 requires countries to "ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality by 2030" (UN 2017). In order to assess the implication of achieving agricultural LDN for SDG 2, we developed an indicator which is the domestic per capita food crop production with and without investment in SLM technologies in the next 11 to 21 years following Tilahun et al. (2018) and as described below.

1. Based on the results in Table 2.6 and the proportion of food crops to total aggregate crop production data from CSA, we estimated the baseline aggregate food crop production of each administrative zone from 2003-2016. We assumed the average as a baseline in the case of BAU, where there will not be investment in SLM technologies and the same food crop production levels will continue over the period 2020-2030 and 2020-2040.
2. We calculated the per capita food crop production for each administrative zone, each region, and for the entire country for the periods 2020-2030 and 2020-2040 by dividing the aggregate domestic food crop production data from step 1 above by the projected human population data for 2020-2030 and 2020-2040 from the databases of World Bank and AidData.
3. We also calculated the food gains due to prevented crop production losses from both prevented NPK losses and NPK depletion by multiplying the proportion of food crops to total aggregate crop production.
4. The gains in food crop per capita due to prevented production losses from NPK losses and depletion is calculated by dividing the result in step 3 with projected human population of 2020-2030 and 2020-2040.

The results in Figure 5.4 show that the baseline per capita domestic food crop production at a national level was 348 kg in 2016 and this will decline to 316 kg by 2020. The figure will drop to 256 kg by 2030 under the business-as usual-case, which assumes no investment in SLM to prevent NPK loss and soil NPK depletion and the associated crop losses. However, if Ethiopia invests in SLM technologies the gain in per capita domestic food crop production will be about 200 kg by 2021, 830 kg by 2030 and 698 kg by 2040. This implies that investments in SLM to prevent production losses induced by NPK loss and soil NPK depletion will increase the total per capita domestic food crop production to 1146 kg at by 2030 and to 1015 kg by 2040. This implies that through investment in SLM technologies to achieve LDN in agriculture or SDG 15.3, it is also possible to increase per capita domestic food production and agricultural productivity and hence simultaneously achieve some of the elements of SDG 2.3 and 2.4.

FIGURE 5.4:

National trends of per capita domestic food crops production in kilograms (2016-2040) under BAU and SLM interventions to prevent NPK loss and soil NPK depletion in Ethiopia.



	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Business as usual percapita food production in kg	347,91	339,60	331,60	323,89	316,47	309,33	302,46	295,85	289,50	283,39	277,51	271,87	266,44
Percapita food production gain under SLM	0,00	0,00	0,00	0,00	0,00	200,37	391,68	574,87	750,15	917,49	898,48	880,20	862,64
Percapita food production under SLM	347,91	339,60	331,60	323,89	316,47	516,84	708,16	891,34	1.066,	1.233,	1.214,	1.196,	1.179,

	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Business as usual percapita food production in kg	261,23	256,23	251,42	246,81	242,37	238,11	234,01	230,06	226,27	222,61	219,10	215,72
Percapita food production gain under SLM	845,77	829,57	814,01	799,06	784,70	770,90	757,62	744,85	732,56	720,74	709,36	698,40
Percapita food production under SLM	1.162,	1.146,	1.130,	1.115,	1.101,	1.087,	1.074,	1.061,	1.049,	1.037,	1.025,	1.014,

Furthermore, the study also has implications for natural capital accounting (SDG 15.9) and for certain elements of SDG 12 ("Ensuring sustainable consumption and production patterns") in the sense that investment in SLM is one way of achieving sustainable production patterns in agriculture. In addition, our analysis and results – for example, the econometric modelling of agricultural land degradation – take into account the other land uses like forest cover, grasslands, and sparse vegetation cover as covariates. Thus, such analysis assumes that these factors remain constant. For example, a decline in the forest or sparse vegetation cover of the country will cause agricultural land degradation to increase and vice versa. In other words, other development interventions for mitigation and adaptation to climate change impacts in Ethiopia will in one way or another affect production and productivity of the agricultural sector as a whole. Moreover, our analysis implicitly assumes increasing agricultural productivity through enhancing the productive capacity of the current agricultural land through SLM interventions. These all have positive implications for taking actions to combat climate change (SDG 13).

5.3. Conclusions

This chapter highlights that investment in SLM technologies on 12.77 million hectares of agricultural land in Ethiopia to achieve SDG 15.3 would contribute towards a number of other related SDGs as cobenefits to the country in the next 11 years and beyond.

Economics Growth (SDG 8.1): Investing in SLM technologies to prevent NPK losses and soil NPK depletion and the associated losses in aggregate crop yield would enable the economy of Ethiopia to grow by an average rate of 38 per cent of the 2016 GDP per year until 2030 and 48 per cent of the 2016 GDP over the period 2020-2040.

Rural Employment (SDG 8.5): Close to USD 2.8 billion per year in PV is required as labour costs to establish SLM in five years starting in 2020 and another USD 4.52 billion for maintenance of the established SLM technologies on agricultural land of Ethiopia over the period 2021-2030 or USD 5.52 billion per year for the period 2021-2040. At a lower-bound average wage rate of USD 468.21 per person per year, which corresponds to USD

3.20 PPP per day at the international poverty line for Ethiopia, the country could generate close to 6 million rural jobs for the period 2020-2024 with the annuity of the PV establishment costs of labour. Moreover, at the same annual wage rate, an additional 9.65 to 11.79 million rural jobs could be created with the annuity of the present value of maintenance costs of labour over the periods 2021-2030 and 2021-2040, respectively.

Poverty reduction (SDGs 1.1 and 1.2): The sum annuity of NPV of investing in SLM technologies to prevent NPK loss and soil NPK depletion and thus preventing the corresponding crop production losses in Ethiopia is about USD 27.82 billion for the discounting period of 2020-2030 and USD 35.07 billion per year for the period 2020-2040. The annuity of NPV for the period 2020-2030 is 3.5 times the annuity of the PV of costs of reducing the poverty gap to zero by 2030 and lifting close to 32 million people up to a daily income level of USD 3.20 PPP or annual per capita income of 468.21 USD. For the period 2020-2040, the annuity of NPV is 2.6 times the annuity of the PV of costs of reducing the poverty gap to zero by 2030 and maintaining this up to 2040 and by lifting close to 38 million people up to the annual per capita income of 468.21 USD.

Food Security (SDGs 2.3 and 2.4): Investment in SLM to prevent NPK loss and soil NPK depletion and the corresponding crop production losses will increase the total per capita domestic food crop production from 348 to 1146 kg by 2030 when the country's population is projected to reach 138.3 million. Per capita domestic food production will grow to 1015 kg by 2040 when the country's population is expected to be 164.3 million. This implies that with the growing population, it is still possible to increase per capita domestic food production and agricultural productivity through sustainable land management and hence simultaneously achieve some of the elements SDG 2.3 and 2.4.

Other co-benefits: The methods applied in this study highlighted soil and its nutrients as natural capital could be accounted in the national accounting system of country. The depreciations in such natural capital can be estimated and deducted from the conventional GDP and hence land degradation adjusted GDP can be estimated. Moreover, the study also highlighted the other co-benefits of the results in relation to achieving certain elements of SDG 12 (ensuring sustainable consumption and production patterns (SDG 12)) and the positive implication for taking climate action (SDG 13).

PHOTO:

Agricultural land in Ethiopia (ICRAF)

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Appendices

ANNEX TABLE A2.1:

Main season average production of agricultural crops in Ethiopia (2003/2004-2015/2016). N=12 years)

		No. holders in millions	Area in millions ha/yr	Production in million tons/yr	Yield in tons/ha/yr
Cereals	Teff	5.84(0.21)	2.41(0.13)	3.32(0.31)	1.37
	Barley	4.03(0.09)	1.03(0.13)	1.59(0.09)	1.54
	Wheat	4.30(0.12)	1.83(0.51)	3.58(0.77)	1.95
	Maize	7.96(0.32)	1.74(0.14)	4.78(0.50)	2.75
	Sorghum	4.48(0.16)	1.46(0.08)	3.11(0.28)	2.11
	Fingermillet	1.16(0.15)	0.37(0.02)	0.50(0.07)	1.36
	Oat	0.22(0.02)	0.05(0.01)	0.04(0.002)	0.77
	Rice	0.05(0.03)	0.03(0.01)	0.04(0.02)	1.21
Pulses	Fababean	3.46(0.14)	0.54(0.10)	0.83(0.13)	1.54
	Fieldpea	1.59(0.06)	0.21(0.01)	0.29(0.04)	1.41
	White Haricotbean	1.94(0.20)	0.19(0.02)	0.21(0.03)	1.08
	Red Haricotbean	0.56(0.28)	0.05(0.03)	0.07(0.03)	1.35
	Chickpea	0.87(0.05)	0.37(0.21)	0.31(0.04)	0.85
	Lentil	0.72(0.04)	0.13(0.04)	0.11(0.01)	0.80
	Grasspea	0.66(0.05)	0.27(0.17)	0.45(0.26)	1.66
	Soya bean	0.05(0.01)	0.01(0.01)	0.01(0.003)	0.86
	Fenugreek	0.52(0.04)	0.02(0.002)	0.01(0.002)	0.78
	Mungbeans	0.02(0.01)	0.002(0.001)	0.002(0.001)	0.99
	Gibto	0.12(0.02)	0.02(0.004)	0.02(0.01)	0.98
Oil seeds	Neug	1.01(0.04)	0.32(0.07)	0.22(0.05)	0.68
	Linseed	1.04(0.06)	0.18(0.07)	0.14(0.05)	0.78
	Groundnuts	0.21(0.02)	0.04(0.01)	0.05(0.01)	1.28
	Safflower	0.12(0.02)	0.01(0.001)	0.01(0.001)	1.004
	Sesame	0.57(0.04)	0.20(0.03)	0.14(0.02)	0.70
	Rapeseed	0.65(0.07)	0.11(0.02)	0.05(0.01)	0.45
Vegetables	Lettuce	0.004(0.002)	0.03(0.02)	0.002(0.001)	0.07
	Head Cabbage	0.32(0.04)	0.06(0.05)	0.01(0.002)	0.19
	Eth. Cabbage	3.00(0.15)	0.03(0.01)	0.31(0.04)	9.94
	Tomato	0.16(0.02)	0.001(0.001)	0.01(0.003)	5.18
	Green Pepper	1.02(0.07)	0.01(0.003)	0.05(0.02)	5.04
	Red Pepper	1.86(0.10)	0.07(0.01)	0.14(0.02)	2.18
	Swisschard	0.07(0.02)	0.001(0.001)	0.01(0.01)	6.49
Root and tuber crops	Beetroot	0.34(0.03)	0.003(0.002)	0.02(0.01)	7.05
	Carrot	0.13(0.01)	3.25E-04(1.59E-04)	0.003(0.002)	9.85
	Onion	0.76(0.03)	0.06(0.05)	0.10(0.01)	1.73
	Potato	1.24(0.05)	0.11(0.07)	0.56(0.05)	4.92
	Yam	0.10(0.05)	0.001(0.001)	0.01(0.01)	7.62
	Garlic	1.75(0.15)	0.01(0.002)	0.12(0.02)	10.93
	Taro	1.29(0.11)	0.03(0.002)	0.57(0.14)	17.64
	Sweet Potato	1.35(0.07)	0.04(0.003)	0.86(0.21)	19.65
Fruits	Avocado	0.89(0.11)	0.01(0.001)	0.04(0.01)	5.62
	Banana	1.90(0.14)	0.03(0.003)	0.21(0.02)	7.92
	Guava	0.21(0.02)	0.002(0.001)	0.001(1.57E-04)	0.45
	Lemon	0.13(0.01)	0.001(0.001)	0.003(0.001)	2.31
	Mango	0.71(0.09)	0.02(0.01)	0.05(0.01)	2.99
	Orange	0.36(0.02)	0.01(0.002)	0.02(0.004)	4.76
	Papaya	0.48(0.03)	0.003(0.001)	0.03(0.01)	10.77
	Pineapple	0.01(0.003)	4.75E-04(4.43E-04)	0.002(0.002)	4.34
Other crops	Khat	2.30(0.13)	0.17(0.02)	0.17(0.02)	1.02
	Coffee	3.61(0.27)	0.40(0.05)	0.28(0.03)	0.71
	Hops	1.84(0.09)	0.03(0.01)	0.04(0.02)	1.48
	Sugar Cane	0.96(0.06)	0.07(0.06)	0.74(0.14)	11.01
	Total		12.77	24.21	1.90

Values in () are standard errors of the means. Source: Own calculation based on data from Central Statistical Agency of FDRE.

ANNEX TABLE A2.2:

Average annual cultivated land area, NPK nutrients depletion and NPK losses in kilos per hectare by administrative zone (N= 12 main production seasons from 2003/2004 to 2015/2016).

	Area in 1,000s ha	NPK_depletionkgperhac	NPK_LossKgperhac
Tigray			
North West Tigray	192.89(9.10)	56.44(9.51)	82.69(6.27)
Central Tigray	203.42(7.67)	33.88(6.15)	59.18(3.91)
Eastern Tigray	85.83(4.53)	-9.03(7.76)	47.15(2.91)
Southern Tigray	223.15(5.60)	42.05(5.04)	55.85(2.46)
Western Tigray	131.82(12.21)	88.05(8.03)	82.16(4.88)
Afar			
Afar Zone 1	10.43(1.25)	19.79(61.34)	105.76(13.05)
Afar Zone 3	4.15(0.98)	-875.54(660.31)	45.12(9.34)
Amhara			
North Gondar	740.68(37.94)	72.81(6.28)	65.86(4.31)
South Gondar	549.60(41.02)	50.46(6.07)	47.43(3.68)
North Wollo	260.43(7.28)	40.43(3.21)	56.34(2.01)
South Wollo	442.30(7.60)	35.29(3.46)	57.37(2.20)
North Shewa	515.42(19.88)	64.44(4.81)	66.53(3.36)
East Gojam	580.31(23.46)	54.52(6.37)	60.83(3.73)
West Gojam	584.83(26.09)	70.70(8.18)	66.31(5.10)
Waghimra	111.52(8.65)	25.81(5.38)	46.19(3.97)
Agwawi	253.21(11.57)	70.26(7.67)	64.22(5.02)
Oromia Zone	59.57(0.98)	51.86(5.25)	75.29(4.25)
Argoba s.w.	5.58(0.25)	60.99(9.21)	79.83(5.32)
Oromia			
West Wellega	340.88(17.07)	123.20(8.52)	64.10(3.55)
East Wellega	382.54(15.30)	117.11(13.69)	69.48(5.05)
Illobabor	304.55(17.31)	120.27(7.60)	62.20(2.66)
Jimma	606.35(28.22)	96.62(7.03)	55.28(2.16)
West Shewa	561.37(17.40)	72.93(7.96)	71.91(5.18)
North Shewa	397.89(11.00)	39.21(6.62)	57.96(4.40)
East Shewa	482.12(25.89)	71.36(15.28)	60.96(5.89)
Arsi	614.83(30.62)	48.01(7.53)	62.74(4.31)
West Harerghe	276.71(9.43)	71.55(6.94)	69.71(4.44)
East Harerghe	336.31(25.27)	49.12(9.35)	63.66(4.75)
Bale	379.67(25.29)	49.61(8.24)	54.41(2.62)
Borena	41.37(2.32)	-191.05(24.76)	47.55(3.37)
South West Shewa	369.39(54.92)	54.55(8.78)	59.13(3.38)
Guji	126.98(6.61)	35.45(17.68)	57.80(4.66)
West Arsi	348.62(16.42)	60.57(8.05)	73.64(5.57)
Kelem Wellega	196.74(8.43)	163.34(8.22)	79.87(3.60)
Horoguduru Welle	278.04(22.99)	83.64(7.68)	56.74(2.70)
Ethiopian Somalie			
Shinele	4.81(2.26)	-254.47(61.55)	47.95(6.08)
Jijiga	66.28(1.52)	44.38(19.18)	86.33(13.09)
Liben	5.62(0.40)	-938.18(101.76)	46.66(9.50)
Benishangul Gumuz			
Metekel	117.58(12.71)	97.10(6.19)	68.10(3.12)
Asosa	58.28(1.27)	92.06(7.56)	57.64(3.80)
Kemeshi	35.87(3.98)	131.02(12.88)	71.99(5.62)
Mao Komo	10.37(0.42)	125.67(10.41)	68.47(4.23)
SNNP			
Gurage	166.08(49.81)	-3.53(8.86)	52.88(5.12)
Hadiya	136.65(3.58)	25.60(4.26)	62.23(3.65)
Kembata Tembaro	43.87(1.25)	0.87(7.87)	62.70(3.87)
Sidama	163.29(11.27)	21.25(11.12)	52.18(1.61)
Gedio	66.30(30.44)	134.61(17.92)	35.61(3.16)
Wolayita	99.36(5.51)	40.81(13.07)	69.88(5.96)
South Omo	50.15(3.45)	-156.99(11.87)	58.34(5.27)
Shaka	27.19(2.41)	139.52(11.69)	54.83(2.12)
Kaffa	136.88(6.57)	43.92(7.30)	52.87(2.55)
Gamo Gofa	190.66(50.63)	24.84(11.34)	55.07(6.06)
Bench Maji	55.61(3.28)	84.41(20.78)	59.68(4.47)
Yem s.w.	20.57(1.07)	32.33(3.75)	44.47(2.36)
Dawro	40.82(3.10)	-14.49(22.12)	52.34(5.12)
Basketo s.w.	5.30(0.24)	48.14(11.81)	59.95(5.99)
Konta s.w.	15.20(1.42)	48.82(8.30)	60.04(5.25)
Silte	98.19(8.86)	-95.22(153.07)	73.90(6.75)
Alaba s.w.	39.97(3.38)	47.27(15.19)	68.55(3.74)
Segen People	72.98(8.70)	27.41(23.88)	68.15(3.11)
Gambella			
Agnuwak	6.10(3.26)	-28.82(50.78)	56.19(7.75)
Nuware	1.82(0.24)	-1,028.58(118.41)	64.09(3.36)
Mezhenger	9.19(1.10)	16.59(3.64)	34.73(3.66)
Itang s.w.	1.10(0.04)	-69.30(48.79)	72.11(6.88)
Harari			
Hundene	15.43(1.77)	-189.69(23.35)	51.09(3.35)
Dire Dawa City Administration			
Dire Dawa	12.01(1.29)	-10.89(6.79)	62.59(4.64)

Values in () are standard errors: s.w. refers to special wereda.

ANNEX TABLE A3.1:

Establishment and maintenance costs of SLM technologies reported by Ethiopia to the WOCAT database.

Specific title of the technology	Region	WOCAT Reference	Type of Conservation Measure	Year	Establishment cost in USD per ha			Land users' share in % of total establishment cost	Maintenance cost in USD per ha per year			land users' share in % total maintenance cost
					labour	Non labour	Total		labour	Non labour	Total	
Rehabilitation of degraded lands (Area closure) Ethiopia – Kutura	SNNPR	T_ETH42en	Agronomic	2011	505.80	288.57	794.37	56.95	0.00	88.69	88.69	8.23
Teff row planting Ethiopia - Teff bemesmr mezrat (Amharic)	Amhara	T_ETH608en	Agronomic	2014	0.00	71.00	71.00	100.00	318.00	420.50	738.50	100.00
Konso bench terrace Ethiopia - Kawata (Konso)	SNNPR	T_ETH009en	Structural	2002	1650.00	410.00	2060.00	100.00	5000.00	40.00	5040.00	100.00
Stone faced soil bund of Tigray Ethiopia - Emni Getsu hamed zala	Tigray	T_ETH014en	Structural	2003	109.40	120.05	229.45	100.00	10.90	0.00	10.90	100.00
Stone bund of Tigray Ethiopia - Emni Zala (Tigrigna)	Tigray	T_ETH019en	Structural	2003	110.00	15.00	125.00	83.00	11.25	0.00	11.25	83.00
Stone faced trench Ethiopia - Emnigetsu metrebawi zala	Tigray	T_ETH018en	Structural	2003	234.00	145.00	379.00	6.36	4.00	0.00	4.00	100.00
Boreda soil bund Ethiopia	SNNPR	T_ETH20en	Structural	2004	52.50	35.00	87.50	17.14	4.38	0.00	4.38	100.00
Graded soil bund Ethiopia - Yafer Erken (Amharic)	Amhara	T_ETH29en	Structural	2005	99.00	104.00	203.00	100.00	54.00	101.00	155.00	100.00
Stone faced soil bund of South Gonder Ethiopia - Irken (Amharic)	Amhara	T_ETH32en	Structural	2005	183.00	90.00	273.00	92.31	25.00	0.00	25.00	100.00
Dejen stone bund Ethiopia - Gidad, Irken	Amhara	T_ETH28en	Structural	2005	236.00	147.00	383.00	100.00	30.00	42.00	72.00	100.00
DireDawa traditional checkdam Ethiopia – Chiba	Dire Dawa	T_ETH034en	Structural	2005	406.00	23.00	429.00	0.00	40.00	23.00	63.00	
Dawa-Cheffa traditional checkdam Ethiopia – Kiter	Amhara	T_ETH027en	Structural	2005	4625.00	120.00	4745.00	95.00	624.00	30.00	654.00	100.00
Stablized stone faced soil bund Ethiopia - Kirit (Amharic)	Amhara	T_ETH33en	Structural	2005	170.00	909.00	1079.00	100.00	17.00	72.00	89.00	100.00
Stone faced trench bund Ethiopia - Emni Getsel metrebawizala	Tigray	T_ETH015en	Structural	2006	118.00	79.50	197.50	100.00	10.50	0.00	10.50	100.00
Sweet potato ridge Ethiopia	Oromia	T_ETH038en	Structural	2008	73.00	110.00	183.00	100.00				
Homestead development Ethiopia	SNNPR	T_ETH017en	Structural	2009	220.00	194.50	414.50	47.31	31.00	0.00	31.00	100.00
Hararghie stone faced soil bund Ethiopia - Daaga Dhakaa (Oromifa)	Oromia	T_ETH47en	Structural	2011	244.00	78.50	322.50	24.35	25.00	0.00	25.00	100.00
Haraghie stone bund Ethiopia - Duagu ghagaa (Oromiya)	Oromia	T_ETH046en	Structural	2011	169.00	72.00	241.00	28.63	82.80	0.00	82.80	0.00
Vegetated Fanya juu Ethiopia - Ye Masa Erken (Amharic)	SNNPR	T_ETH44en	Structural	2011	140.00	256.00	396.00	35.35	14.00	209.00	223.00	6.28

Soil bund with contour cultivation Ethiopia - Ditchira, Kab (Amharic)	SNNPR	T_ETH43en	Structural	2011	156.00	421.90	577.90	67.88	18.84	81.39	100.23	18.80
Stone faced level bund Ethiopia - Daagd dagaafi Biyye	Oromia	T_ETH024en	Structural	2011	125.00	64.70	189.70	65.89	0.00	64.70	64.70	3.62
Hararghie soil bund Ethiopia - Daga Biyye (Oromigna)	Oromia	T_ETH021en	Structural	2011	89.00	181.10	270.10	41.65	11.75	167.70	179.45	39.04
Microcatchments and ponds Ethiopia - Wuha Masebaseb	SNNPR	T_ETH045en	Structural	2011	83.70	352.00	435.70	0.00	6.97	120.00	126.97	0.00
Sorghum terrace of Diredawa (STD) Ethiopia - Daga (Oromifa)	Dire Dawa	T_ETH36en	Structural	2011	272.00	29.00	301.00	54.82	40.70	0.00	40.70	100.00
Ridge bund Ethiopia - Ketara (Oromigna)	Oromia	T_ETH022en	Structural	2011	200.00	243.50	443.50	100.00	24.00	131.00	155.00	100.00
Stone wall check dam Ethiopia - Yedengay Keter (Amharic)	Amhara	T_ETH604en	Structural	2011	1165.00	5.00	1170.00	50.21	500.00	5.00	505.00	50.50
Soil bund and Fanya Juu combined and vegetated Ethiopia	Oromia	T_ETH049en	Structural	2011	199.00	71.00	270.00	18.87	13.00	0.00	13.00	100.00
Stone-faced soil bund stablized with grass Ethiopia - Dhaga (oromifa)	Oromia	T_ETH048en	Structural	2011	125.00	118.20	243.20	0.00	12.50	36.80	49.30	0.00
Check dam ponds Ethiopia - May me'ekori ketri	Tigray	T_ETH607en	Structural	2012	4678.00	7322.00	12000.00	10.00	56.00	0.00	56.00	100.00
Large semi-circular stone bunds Ethiopia - Abiy nay emni firki werhi	Tigray	T_ETH606en	Structural	2012	3667.00	75.00	3742.00	60.00	117.00	0.00	117.00	100.00
Soil faced deep trench bunds Ethiopia - Nay Hamed Amik Metrebwi Zala	Tigray	T_ETH605en	Structural	2012	2119.00	80.00	2199.00	59.00	833.00	0.00	833.00	100.00
Area closure Ethiopia - Bota Klela (Tigrigna)	Tigray	T_ETH013en	Management	2003	154.00	36.50	190.50	27.24	15.00	0.00	15.00	100.00
Area closure for rehabilitation of degraded Hillsides Ethiopia - Lafa Dangesu	Oromia	T_ETH023en	Management	2011	13600.00	6550.00	20150.00	65.16	9350.00	4660.00	14010.00	67.54
Rehabilitation of degraded lands Ethiopia - Yetegoda Meret Magegem (Amharic)	SNNPR	T_ETH040en	Management	2011	387.00	33.00	420.00	23.96	46.70	54.60	101.30	5.25
Area closure for rehabilitation Ethiopia - Meret mekelel	SNNPR	T_ETH25en	Mixed	2003	175.00	216.00	391.00	29.03	35.00	56.00	91.00	45.05
Improved grazing land management Ethiopia - Gitosh masheshal	SNNPR	T_ETH26en	Mixed	2003	320.00	732.00	1052.00	56.51	35.00	91.00	126.00	100.00
Grazing land improvement Ethiopia	SNNPR	T_ETH016en	Mixed	2007	320.00	732.00	1052.00	56.00	35.00	91.00	126.00	100.00
Desho grass soil bund Ethiopia - Desho Erken (Amharic)	SNNPR	T_ETH041en	Mixed	2011	8.00	6.11	14.11	56.70				
Runoff/floodwater farming Ethiopia - Korbe (Oromifa)	Oromia	T_ETH37en	Mixed	2011	253.00	130.00	383.00	100.00	450.00	364.00	814.00	100.00
Earth checks for gully reclamation Ethiopia	SNNPR	T_ETH039en	Mixed	2011	282.30	388.20	670.50	100.00				
Jatropha curcas hedge Ethiopia - Agulo Keter	Amhara	T_ETH562en	Mixed	2011	30.00	7.00	37.00	100.00	25.00	5.00	30.00	100.00
Gully erosion management Ethiopia - Borebore lemat (Amharic)	Amhara	T_ETH609en	Mixed	2014	8319.00	2557.91	10876.91	91.62	902.00	166.30	1068.30	58.49
Area closure on degraded lands Ethiopia - Yetrakot Meret mekelel (Amharic)	Amhara	T_ETH610en	Mixed	2014	1766.00	2026.20	3792.20	75.50	624.00	250.00	874.00	20.70
Vegetated graded soil bund Ethiopia - Yeafer Erken (Amharic)	Amhara	T_ETH611en	Mixed	2014	1107.00	1782.80	2889.80	80.00	279.00	20.00	299.00	100.00

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