The Amhara National Regional State Greenhouse Gas Inventory Report

By

College of Agriculture and Environmental Sciences,

Bahir Dar University

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The Environment and Forest Protection Authority

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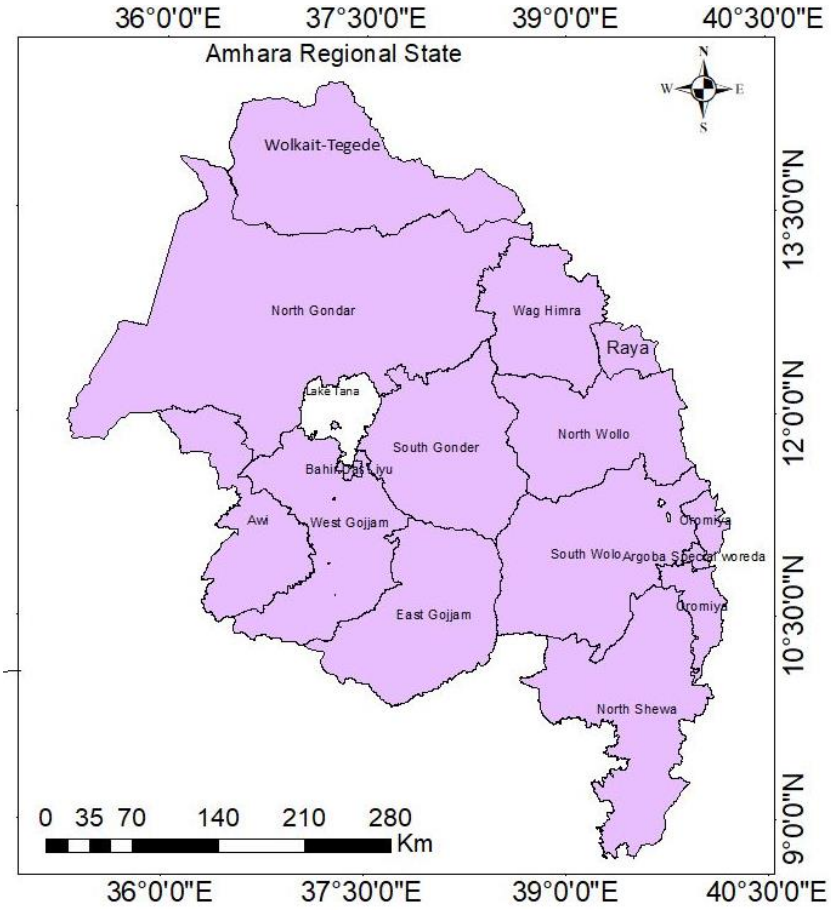






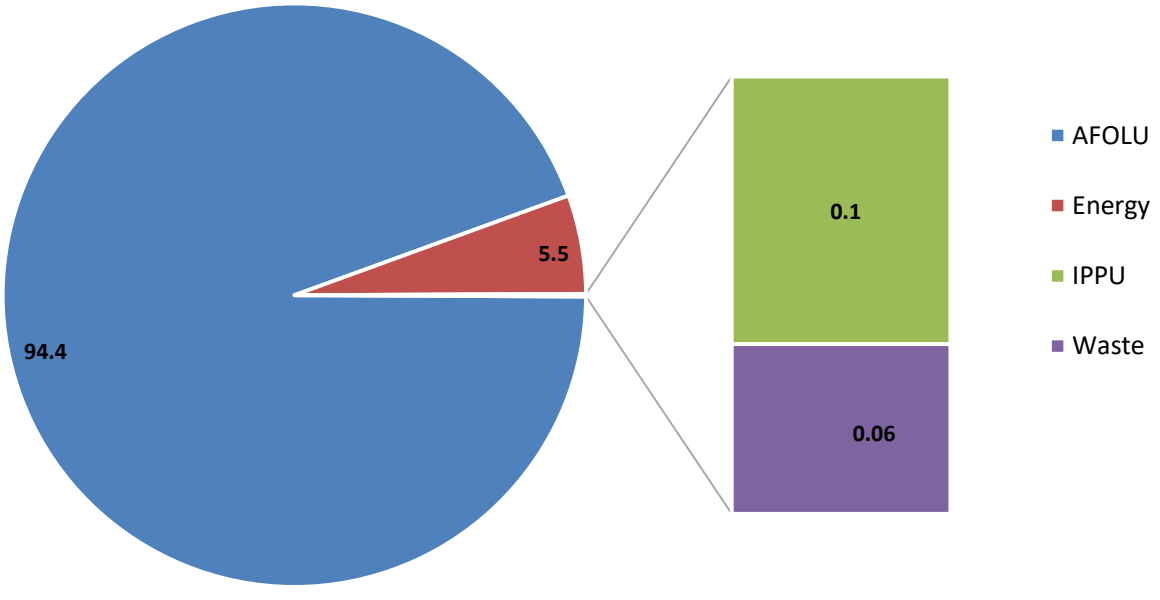

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Total GHG emmison in year 2020: 79,829,885tCO_2e

GHG emssion by sectors (%)



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LIST OF ABBREVIATIONS/ACRONYMS

AD	Activity Data
ANRS	Amhara National Regional State
AFOLU	Agriculture, Forestry, and Other Land Use
CAES	College of Agriculture and Environmental Sciences
CO_2-eq	CO_2 equivalent
CSA	Central Statistical Agency
EF	Emission Factor
EFPA	Environment and Forest Protection Authority
Gg	Gega Gram
GHG	Greenhouse Gas
GPC	Global Protocol for Community-Scale GHG Emission Inventories
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
Kg gas/TJ	Kilogram of gas per terra joule
Kwh	Kilowatt-hours
LULCC	Land Use Land Cover Class
QA/QC	Quality Assurance/Quality Control
tCO2/kWh	Tone of CO2 per Kilowatt-hour
TJ	Terra Joule
UNFCCC	United Nations Framework Convention on Climate Change
BAU	Bussiness as Usual
CRGE	Climate Resilient Green Economy
YDP	Year Development Plan

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Executive Summary

Ethiopia as a country and Amhara National Regional State (ANRS) in particular is strongly affected by the impacts of the changing climate, despite its insignificant contribution to the global greenhouse gas (GHG) emission. Therefore, this study was conducted by Bahir Dar University, College of Agriculture and Environmental Sciences (CAES) in close collaboration with the Environment and Forest Protection Authority of the ANRS to prepare a baseline GHG emission inventory report (regional reference emission level) for the year 2020 and produce projections for the year 2030, and to identify and quantify the major sources of greenhouse gas sources in the region.

The inventory covers emissions from key economic sectors in Amhara Region. The sectors are Agriculture, Forestry and Other Land Use (AFOLU), Energy, Industrial Process and Product Use (IPPU), and Waste. Estimating the GHG emissions in all sectors considered in this study is carried out following the default methodology of the "Revised 2006 IPCC Guidelines for National Greenhouse Gas Inventories" (IPCC, 2006) and the "Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories" (IPCC, 2006) and employed the Tier 1 sectorial technique. The 2019 refinement to the IPCC 2006 guideline was considered when necessary.

In 2020, the Amhara Region's total GHG emission was estimated to be 79,829,885tCO_2e. The AFOLU sector was the largest source of GHG emissions in the region, accounting for 94.34% of the overall regional emissions (75,341,476tCO_2e). With a total of 4,369,800tCO_2e, the energy sector was the next leading source contributing 5.5% of the regional emissions. This was followed by the IPPU sector with 72,609.0tCO_2e (0.1%) and then by the waste sector with 46,000 tCO_2e (0.06%) emissions.

Carbon dioxide remained the dominant GHG in the Amhara Region during the inventory period. CO_2 contributes about 72% of the total GHG emissions (79,829,885tCO2e). The AFOLU and the energy sectors were the two largest sources of CO_2 emissions responsible for the majority of the emissions. AFOLU was the leading source of CO_2 emission. The second source of GHG emission in the region was methane. The majority of the total methane gas was emitted from the AFOLU sector, particularly from livestock.

Ethiopia has envisioned a green development path that keeps the emissions by 2030 at the level of 2010 (CRGE, 2011) while boosting its economy to a middle-income status (GTP2). Accordingly, Ethiopia has submitted its revised Nationally Determined Contribution (NDC),

in which the country has committed a GHG emissions reduction target of 68.8% by 2030 from the BAU levels projected from 2020. This study is therefore imperative to realize the commitment of the country in general and to support the Amhara region to achieve the above ambitious goal, by targeting mitigation actions proposed for all the sectors of energy, IPPU, AFOLU, and Waste sectors.

1. INTRODUCTION

1.1. Background

It is globally accepted that excessive emission of Greenhouse gases is the reason for climate change. Greenhouse gases are gaseous substances that are found abundantly in the atmosphere and trap reflected long-wave radiation and hence regulate the temperature of our planet. Without greenhouse gases, our planet would be too cold as most of the radiation reflected from the surface of the earth would pass through and leave the atmosphere easily. On the contrary, increased concentration of greenhouse gases in the atmosphere increases the average atmospheric temperature. Therefore an optimum amount of GHG concentration is needed to maintain the optimum range of climate conditions that sustains existing life forms including human beings. However, rigorous recent human activity has led to an increased greenhouse gas concentration in the atmosphere. This affects the natural system in which the atmosphere regulates the temperature of the earth. Due to increased greenhouse gas emissions induced by human beings, the planet is now facing global warming.

Consequently, global warming has become one of the major environmental challenges that the world has faced. Among the greenhouse gases, carbon dioxide, nitrous oxide, methane, and hydrofluorocarbons (HFCs) are the major ones. They have contributed more than 76% of the globally increased greenhouse effects (IPCC, 2001). The total greenhouse gas including Land Use Land Cover Change and Forestry (LULCCF) increases gradually. During the 1990s, it was 22219.63Mt CO_2e. However, toward the turn of 2000, the total greenhouse emission including land use-land use change and forestry was around 27205.08 Mt CO_2e. In the year 2013, the total greenhouse gas emission, including LULUCF, was reduced to 18739.21 Mt CO_2e. From 1990 - 2013 the average growth of world greenhouse gas emissions was around 1.544% (CAIT 2017). On the other hand, the total GHG emission excluding LULCCF was around 22866.8 Mt- CO2e. From 1990-2013 the average growth of global GHG emissions, excluding LULUCF, was around 2.05%. This statistical data has proved that the global greenhouse gas emissions with and without LULUCF have increased on average at 1.54 and 2.05% per year respectively (UNFC- CC 2017). As a result of this, greenhouse gas emission has become a global, national, and local policy issue that many countries around the world are trying to address as a common issue.

Although developing countries have a small share of global greenhouse gas emissions, they have shown increasing trends and patterns. However, they are highly exposed and vulnerable to climate variability and climate-related events (Sarkodie and Strezov, 2019). Developing countries have shown 271% of average growth in 2013 as compared to the 1990s net total greenhouse gas emissions. Therefore, Ethiopia is not an exception as there have been increased trends in greenhouse gas emissions.

There are several causes for greenhouse gas emissions, but the major causes are fossil fuel burning, forest harvest and land-use change, agricultural activities, and industrial processes. In developed countries, the energy sector (fossil fuel) and the industrial sector are the main sources of greenhouse gases. However, in developing nations, like Ethiopia, land-use change and the forestry (LULUCF) and the agricultural sector are the main sources of greenhouse gas emissions. In Ethiopia, the agricultural sector, land-use change, and forestry contributed a huge share of greenhouse gas emissions (FDREMoEF 2015; USAID 2015). Other sectors like manufacturing, industry, energy, and waste have insignificant contributions to greenhouse gas emissions. However, in terms of average annual growth rates some sectors like industrial sectors and waste have shown despicable increments in their contribution to greenhouse gas emissions (USAID 2015).

Ethiopia is the second most populous country in Africa with a population of over 120 million (MoPD, 2022). The country has designed and endorsed a climate-resilient green economy strategy since 2011 and registered notable economic growth and considerable poverty reduction in the past two decades. Ethiopia's real GDP has increased from $ 8.24 billion in 2000 to $84.3 billion in 2018 (MoPD, 2022). In terms of sectoral contribution, the service sector takes the lion's share of GDP (40%) and has overtaken the agriculture sector which has been the dominant sector for millennia. The service sector is closely followed by agriculture (37%), and then industry (23%).

Ethiopia's economy is vulnerable to climate risks. Although Ethiopia has a long history of coping with climate variability and extreme weather events, including drought and intense precipitation, it is most vulnerable to climate change and extremes mainly due to its location, dependency of the economy on climate change-sensitive sectors, and low adaptive capacity (MoPD, 2022). The impacts of climate change and extremes such as drought, flood, and temperature extremes, delay of rainfall onset, early rainfall cessation, high rainfall intensity, and frost are being reflected in the performance of the sector as well as the entire economy.

There is considerable evidence about the impacts of climate change in Ethiopia over the last fifty years (FDRE, 2021).

The vast majority of Ethiopia's population (78%) subsists on rain-fed agriculture (FDRE, 2021), and thus the performance and welfare of the economy are linked to the volatile climatic conditions, particularly rain. The correlation between rainfall and the overall GDP of the country is strong (World Bank, 2006) and estimates suggest that climate change may reduce Ethiopia's GDP by up to 10 percent by 2045 (World Bank, 2010). The impact of rainfall can be felt not only on agricultural output but also on the environment, electricity where 90% of it is hydropower, manufactured goods, income and consumption, and prices of goods and services. Overall, the cumulative effects of climate change are bound to worsen poverty and food insecurity which in turn would further erode the adaptive capacity of the nation and its people (MoPD, 2022).

Ethiopia has shown increasing trends of emission in most sectors, except land use-land cover change, and forestry. Having an average emission of 50739.73 Gg CO_2e, land use land cover change, and forestry is the largest sector that contributes to greenhouse gas emissions in Ethiopia. The agricultural sector played the second largest role with an average emission level of 47093.63 Gg CO_2e. Following the above two sectors, the energy sector, ranked third, has contributed an emission of 17670.13 Gg CO_2e. Other sectors like waste, industrial, and international bunkers have contributed a trivial amount to the country's greenhouse gas emissions, with average greenhouse gas emissions of 3081.21 Gg CO_2e, 881.21 Gg CO_2e, and 458.65 Gg CO_2, respectively. However, the annual emissions growth rate of the bunker sector is very high accounting for 57.53%. The industrial sector has shown a 20.05% average annual growth rate followed by land use- land use change and forestry with an annual emission growth rate of 19.76%. The energy sector and waste sector have 9.45% and 7.4% average annual growth rates. The agricultural sector has a 3.11% average annual growth rate (Engdaw, 2020); summarized in Figure 1.

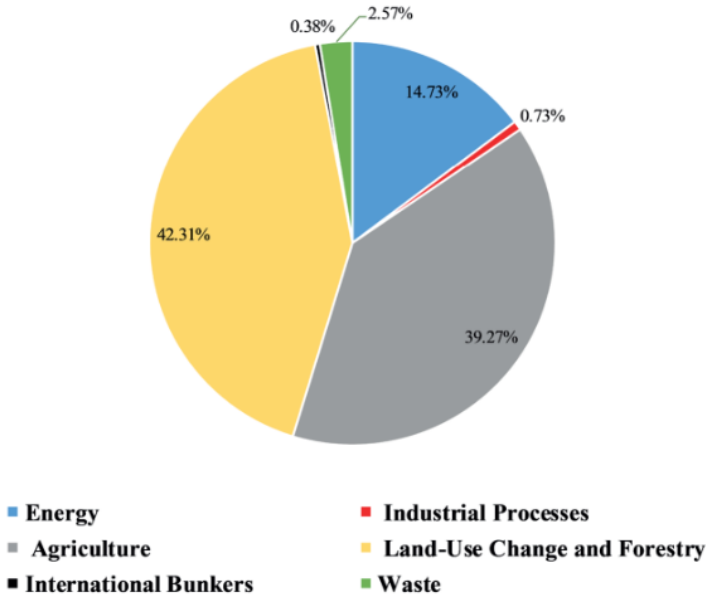


Figure 1. Annual GHG Emissions of Ethiopia by Sector (UNFCCC)

Despite its insignificant contribution to the global GHG emission (0.04%) (Crippa, 2019) and being one of the most affected countries in the world by the impacts of the changing climate, Ethiopia is willing to reduce GHG emissions. It is envisaged that the country will achieve this by taking advantage of opportunities provided by low-carbon development pathways. In this sense, as outlined in the IPCC documents, the energy, IPPU, AFOLU, and waste management sectors are recognized as being catalysts for the shift to low-carbon growth paths and a green economy (MoPD, 2022). The nation takes mitigation measures in the context of sustainable development and aims to strike a balance between the need to address socio-economic, environmental, and development issues and the nation's commitment and contribution to the global agenda laid out by the UNFCCC and the Paris Agreement. Thus, inventorying and monitoring greenhouse gas emissions by different sectors in the country is deemed necessary. Accordingly, a GHG inventory report has been prepared for the country for the period ranging between 2010 and 2030 and now, akin to the national report, a GHG emission inventory report is being prepared for the Amhara National Regional State for the same period.

1.2. Amhara National Regional State Background

Amhara Regional State is one of the Regions in the country; located in north-western Ethiopia between 9°20' and 14°20' North latitude and 36° 20' and 40° 20' East longitude (Figure 2). The Amhara Region has an estimated land area of more than 170, 000 km^2. The region borders Eritrea and Tigray Region in the North, Afar Region in the East, Oromiya

Region in the South, Benishangul-Gumiz Region in the Southwest, and the country of Sudan to the West.

According to MoPD (2022), the Ethiopian population has reached over 120 million, of these the Amhara region population is believed to be more than 40 million, including the areas of Raya and Wolkait Tsegede Setit Humera zone. Currently, Amhara region is divided into 22 zones (Figure 2). "Decision-making power has recently been decentralized to Weredas and thus the Weredas are responsible for all development activities in their areas." The Amhara Region contains much of the highland plateaus above 1500 meters with rugged formations, gorges and valleys, and millions of settlements for Amhara villages surrounded by subsistence farms and grazing fields. In this Region are located, the renowned Abay River and its source, Lake Tana, as well as historic sites including Gonder, and Lalibela. "Interspersed on the landscape are higher mountain ranges and cratered cones, the highest of which, at 4,620 meters, is Mount Ras Dashen northeast of Gondar. Millennia of erosion has produced steep valleys, in places 1,600 meters deep and several kilometers wide. In these valleys flow rapid streams that are unsuitable for navigation, but [with great potentials] as sources of hydroelectric power and water for irrigation".

The Amhara region is one of the regions in Ethiopia seriously affected by the impacts of climate change and mitigation and adaptation efforts are being made. Taking effective measures to attenuate the vagaries of climate change, in part, requires knowledge of the Region's GHG emission levels and its relative contribution to the national GHG emissions. However, such a comprehensive study has never been conducted and information regarding the regional and sectoral emission levels and the appropriate mitigation actions to be taken has been scant. Therefore, this study was initiated and commissioned by the Environment and Forest Protection Authority of the Amhara National Regional State in collaboration with Bahir Dar University, College of Agriculture and Environmental Sciences (CAES), to conduct a regional greenhouse gas inventory and produce a standard report following the IPPC's guideline.

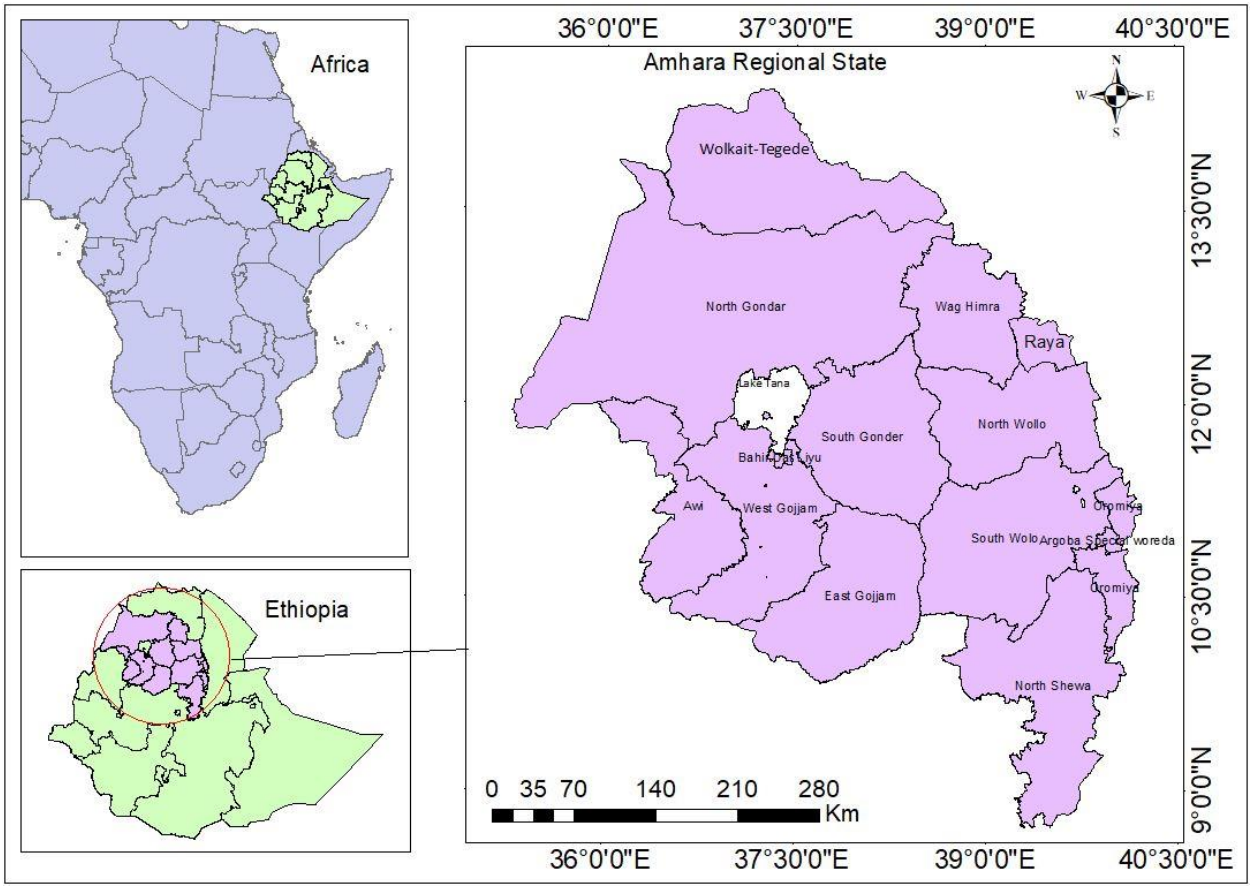


Figure 2. Location map of the study area

1.3. Objectives of the study

The objectives of this study were to:

- To conduct an inventory and prepare a baseline or reference GHG emissions of the Amhara region for the year 2020;
- To estimate the GHG emissions of the Amhara region for the year 2030
- To identify the major sources of greenhouse gas sources and quantify their respective emissions.

1.4. Scope of the GHG Inventory (Geography and Thematic areas)

Greenhouse gas emissions inventory was conducted within the whole boundaries of the Amhara region. Thematic areas are grouped as Agriculture, forestry, and other land use (AFOLU); Energy; Industrial process and product use (IPPU); and the Waste sectors.

2. METHODOLOGY

2.1. The General Methodology of the Analysis

The most common, simple methodological approach used in the IPCC guidelines is to combine information on the extent to which human activity takes place (called activity data, AD) with coefficients that quantify the emissions or removals per unit of activity (called emission factors, EF). The basic equation is (Equation1):

$$\text{Emissions} = \text{AD} * \text{EF} \quad (1)$$

Where: AD is activity data, and EF is emission factors

The guidelines also contain mass balance methods, for example, the stock difference methods used in the agriculture, forestry, and other land-use (AFOLU) sector estimates CO_2 emissions from changes over time in the carbon content of living biomass and dead organic matter pools (IPCC, 2006).

Accordingly, the methodology and procedures used in preparing this inventory were drawn from the IPCC's 2006 guideline. The base year for this inventory process was 2020 and the projection year will be 2030 to align the national greenhouse inventory. Activity data were collected and applied in the development of the inventory. By multiplying activity data (AD) by an emission factor (EF) related to the activity, emissions are determined. The amount of an activity that generates GHG emissions over a specific period is represented by activity data (for instance, the number of kWh of energy used annually). The amount of GHG emissions produced for each unit of a certain activity is calculated using emission factors (for instance, tonnes of CO2 emissions from electricity use are expressed as t CO2/kWh).

The IPCC has adopted guidelines that include methods for estimating GHG emissions that are generally accepted as well as advice on how to guarantee quality throughout every stage of inventory compilation in this inventory study. The methodologies outlined in the 2006 IPCC Guidelines (IPCC, 2006) are used in this inventory to guarantee consistency with all sector reports for the region in particular and the country in general. Although the methodologies employed in this inventory report adhere to the 2006 IPCC Guidelines, default coefficients, and emission factors were obtained from the 2019 Refinement to the 2006 IPCC Guidelines (IPCC 2019), which reflects the most recent scientific findings. The 2019 Refinement to 2006 IPCC Guidelines for National GHG Inventories (IPCC, 2019) is a recent

update to the 2006 IPCC Guidelines that takes into account the most recent developments in research and methodology on emission estimation.

As indicated in the IPCC guideline (2006), the greenhouse gas protocol, reporting standard covers the accounting and reporting of six greenhouse gases: Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Sulpherhexaflouride (SF_6). Therefore, for this particular study, we considered the first three greenhouse gases **(**carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) which are believed to be pertinent to the context of Amhara Region. This is because the sources of fluorinate groups in the region in particular and in the country, in general, are considered to be insignificant.

2.2. Sectorial GHG Measurement

The Amhara National Regional State, Environment and Forest Protection Authority (EFPA) took the lead on this GHG Emission Inventory project. Various organizations in the region provided inventory activity data. Based on the sorts of data types to conduct the inventory, the institutions were divided into four categories.

2.2.1. Agriculture, Forestry, and Other Land Use (AFOLU)

2.2.1.1. Livestock

According to the MEF (2015) report in Ethiopia, the agriculture sector accounts for about 74% of total national GHG emissions, with more than 60% coming from livestock. Ethiopia's Nationally Determined Contribution (NDC) states the intention to reduce GHG emissions from the livestock sub-sector. This can be achieved by reducing GHG emissions from different livestock production systems with various levels of intensification. The current GHG inventory is one of the main tools through which the Amhara region can measure and report livestock sub-sector GHG emissions. This GHG inventory was compiled using recommended international guidelines and represents a unique opportunity to assess the effectiveness of policies and measures in addressing climate change. This GHG inventory strengthens regional capacities to identify livestock GHG mitigation options and to track the effects of policies and measures, such as the livestock mitigation measures set out in Ethiopia's Climate Resilient Green Economy (CRGE) Strategy (FDRE, 2011).

In this report, emissions are estimated from dairy cattle, other cattle, sheep, goats, camels, horses, mules, donkeys, and poultry for the main livestock emission sources:

- Methane emissions from enteric fermentation and manure management
- Direct N_2O emissions from manure management systems

- Indirect N2O emissions from manure management systems.

The detailed methodology adopted for the livestock sector is described below.

i) Estimation of Livestock Population

This report's reference year is 2020. The livestock sub-sector activity data present the head of the various species of farm animals in the Amhara region, Ethiopia is based on data obtained from the Central Statistics Agency (CSA) and the Amhara Region Livestock Development and Promotion Office (ARLDPO) for rural areas. For urban and pre-urban areas, data was obtained from the Amhara Region Livestock Development and Promotion Office. Cattle (dairy cows and other cattle), sheep, goats, camels, horses, mules, donkeys, and poultry are among the livestock species found in the region. The livestock population projections for 2030 were calculated using two different scenarios: business as usual and interventions. The annual growth rate (%) of 2010-2020 was used to estimate the livestock population for the business-as-usual scenario (Table 1). On the other hand, the annual growth rate for the intervention scenario is calculated by considering the Ethiopia 2030, Ministry of Agriculture, and Amhara Region Livestock Development and Promotion Office 10-year plans and Ethiopia's Climate Resilient Green Economy (CRGE) Strategy.

Table 1. The past, present, and projected livestock population of the Amhara region

Livestock Species	**2010**	**2020**	**Annual Growth Rate (%), 2010-2020 (Business as Usual)**	**Annual Growth Rate (%), (With Interventions)**	**Livestock Population Projections, 2030**	
					Business-as-Usual	**With Interventions**
Dairy Cows	396,049	609,915	5.4	3	1,031,990	902,823
Other Cattle	12,889,465	17,014,094	3.2	-4	23,313,410	11,229,302
Sheep	8,705,139	10,533,218	2.1	2.42	12,966,372	13,378,542
Goats	5,144,521	7,047,994	3.7	4.0	10,135,685	10,432,753
Camels	36,440	50,287	3.8	0.1	73,018	50,792
Horses	363,016	468,290	2.9	0.1	623,259	472,994
Mules and Donkeys	2,426,939	3,664,678	5.1	0.1	6,026,470	3,701,490
Poultry	13,330,923	17,966,746	3.5	4.0	23,343870	26,595,173

Sources: ARLDPO, 2020; CSA, 2010, 2020

ii) Methane Emissions from Enteric Fermentation

Methane (CH4) emissions from enteric fermentation of livestock were calculated by using Tier 1 methodology following the method of 2006 revised IPCC guidelines which is cited in the 3A1 worksheet of IPCC Inventory Software. To estimate total emission, the selected emission factors are

multiplied by the associated animal population and summed (Equation2): Enteric fermentation emissions from a livestock category:

$$\text{Emissions} = EF(T) * (NT/106) \quad (2)$$

Where:

- Emissions = methane emissions from Enteric Fermentation, Gg CH_4 yr^{-1}
- $EF_{(T)}$ = emission factor for the defined livestock population, Kg CH_4 $head^{-1}$ yr^{-1}
- $N_{(T)}$ = the number of heads of livestock species/category T in the region
- T = species/category of livestock

Total emissions from livestock enteric fermentation (Equation 3):

$$\text{Total CH4Enteric} = \sum iEi \quad (3)$$

Where:

- Total CH_4Enteric = total methane emissions from Enteric Fermentation, Gg CH4 yr-1
- E_i = is the emissions for the i^{th} livestock categories and subcategories

iii) Estimation of the Average Annual Population

The following equation (Equation 4) was used to calculate the average annual population for each livestock species/category T

$$AAP = \text{Days alive} * (NAPA/365) \quad (4)$$

Where:

- AAP = annual average population
- NAPA = the number of animals produced annually for each species/category.

Emissions factors for different livestock species were used based on the Revised 2006 IPCC Greenhouse Gas Inventory Guidelines to calculate methane emissions from livestock enteric fermentation proposed for development (Table 2).

Table 2. Enteric fermentation emissions factors for different livestock species

Livestock Species	**Enteric Fermentation Emission Factors for Tier 1 Method (Kg CH_4 $head^{-1}$ $year^{-1}$)**
Dairy Cows	46
Other Cattle	31
Sheep	5
Goats	5
Camels	46
Horses	18
Mules and Donkeys	10

Source: IPCC, 2006

iv) Methane Emissions from Manure Management

This section describes how to estimate CH4 produced during the storage and treatment of manure and from manure deposited on pasture. The term 'manure' is used here collectively to include both dung and urine (i.e., the solids and the liquids) produced by livestock. Tier 1 method, a simplified method that only requires livestock population data by animal species/category and climate region or temperature, in combination with IPCC default emission factors, to estimate emissions (Table 3). Because some emissions from manure management systems are highly temperature dependent, it is good practice to estimate the average annual temperature associated with the locations where manure is managed. Methane (CH_4) emissions from manure management of different livestock species were calculated by using the following formula with the Tier 1 method which is cited in the 3A2 worksheet of IPCC Inventory Software and emission factors based on the Revised 2006 IPCC Greenhouse Gas Inventory Guidelines (Equation5).

$$CH_{4Manure} = \sum (EF_{(T)} * N_{(T)})/_{10}{}^{6} \quad (5)$$

Where: $CH_{4Manure}$ - CH_4 emissions from manure management, for a defined population, Gg CH_4 yr^{-1}; $EF_{(T)}$ - emission factor for the defined livestock population, kg CH4 head-1 yr^{-1}; $N_{(T)}$ - the number of heads of livestock species/category T in the country; T - species/category of livestock

Table 3. Manure management emission factors for different livestock species

Livestock Species	Emission Factors For Manure Management (Kg CH_4 $head^{-1}$ $year^{-1}$)
Dairy Cows	1
Other Cattle	1
Sheep	0.15
Goats	0.17
Camels	1.92
Horses	1.64
Mules and Donkeys	0.9
Poultry	0.03

Source: IPCC, 2006

v) Nitrous Oxide (N2O) Emissions from Manure

a) Direct nitrous oxide (N_2O) emissions from manure management

Direct nitrous oxide (N_2O) emissions from manure management systems were calculated based on the IPCC 2006 Guidelines Tier 1 method which is cited in the 3A2 worksheet of IPCC Inventory

Software. The direct nitrous oxide (N_2O) emissions from manure management were calculated by the following equation which is derived from IPCC 2006 guidelines (Equation 6):

$$N_2O_{D(mm)} = \left[\sum_S\left[\sum_T^n\left(N_T \times Nex_T \times MS_{T,S}\right)\right] \times EF_{3(S)}\right] \times \frac{44}{28} \quad (6)$$

Where: $N_2O_{D\ (mm)}$ is direct N_2O emissions from manure management in the region, kg N_2O $year^{-1}$; N_T is the number of head of livestock species/category T in the region; Nex_T is average nitrogen excretion per head of livestock species/category T in the region, kg N $head^{-1}$ $year^{-1}$; $MS_{T,S}$ is the fraction of total annual nitrogen excretion for livestock species/category T that is managed in manure management system *S*; EF_{3S} is emission factor for direct N_2O emissions from manure management system Sin the region, kg N_2O-N/kg N; S -Manure management system; T - Species/category of livestock 44/28 is the conversion of N_2O-N emissions (mm) to N_2O emissions (mm) (Table 4).

Annual nitrogen excretion rates were determined for each livestock category defined by the livestock population number and nitrogen excretion rate emission factor which is expressed in nitrogen excreted per 1000 kg of animal per day. The annual nitrogen excretion rate was calculated by the following Equation which is derived from IPCC 2006 guidelines (Equation7):

$$Nex_{(T)} = N_{rate\ (T)} * TAM(T) \ / 1000 * 365 \quad (7)$$

Where: $Nex_{(T)}$ - annual N excretion from livestock category T, (kg N/animal/yr); $N_{rate\ (T)}$ - default value N excretion rate, Kg N/(1000 kg animal mass)/day); $TAM_{(T)}$ =-typical animal mass for livestock category T, (kg/animal)

Table 4. Default values for nitrogen excretion rate (kg N/ (1000 kg animal mass)/day**)**

Livestock Species	**N Excretion Rate (kg N/ (1000 kg animal mass)/day)**
Dairy Cows	0.6
Other Cattle	0.63
Sheep	1.17
Goats	1.37
Camels	0.46
Horses	0.46
Mules and Asses	0.46
Poultry	0.82

Source: IPCC, 2006

Table 5. EF for direct N_2O emissions from manure management system S in the region

System	Definition	EF (kg N_2O-N/kg Nitrogen excreted)
Pasture/Range/Pad dock	The manure from pasture and range grazing animals is allowed to lie as is and is not managed.	0.02
Daily Spread	Manure is routinely removed from a confinement facility and is applied to cropland or pasture within 24 hours of excretion.	0
Solid storage	The storage of manure, typically for several months, in unconfined piles or stacks.	0.005
Burned for fuel or as waste	The dung is excreted on the field. The sun-dried dung cakes are burned for fuel.	
Composting – Passive Windrow	Composting in windrows with infrequent turning for mixing and aeration.	0.01
Poultry manure	With litter	0.001
	Without litter	0.001

Source: IPCC, 2006

b) Indirect nitrous oxide (N_2O) emissions from manure management

The calculation of N volatilization of NH_3 and NO_x from manure management systems is based on the multiplication of the amount of nitrogen excreted (from all livestock categories) and managed in each manure management system by a fraction of volatilized nitrogen. N losses are then summed over all manure management systems (Table 6). The Tier 1 method is applied using default nitrogen excretion data, default manure management system data, and default fractions of N losses from manure management systems due to volatilization. Nitrous oxide emissions due to volatilization were calculated using IPCC (Equation 8):

$$N_{volatilization-MMS} = \left[\sum_S \left[\sum_T^n \left(N_T \times Nex_T \times MS_{T,S}\right)\right] \times \frac{Frac_{GasMS}}{100}_{(T,S)}\right] \quad (8)$$

Where: $N_{volatilization\ -\ MMS}$ - amount of manure nitrogen lost due to volatilization of NH_3 and NO_x, kg N $year^{-1}$; N_T - number of head of cattle sub-category T in the region; Nex_T - average nitrogen excretion per head of species/category T in the region, kg N $head^{-1}$ $year^{-1}$; $MS_{T,S}$ - fraction of total annual nitrogen excretion for species/category T that is managed in manure management system *S* in the region, dimensionless; $Frac_{GasMS}$ - percent of managed manure nitrogen for each sub-category that volatilizes as NH_3 and NO_x in manure management system *S*, %.

The indirect N2O emissions from volatilisation of N in forms of NH_3 and NO_x ($N_2OG_{(mm)}$) are estimated using (Equation 9):

$$N_2O_{G(mm)} = (N_{volatilization-MMS} \times EF_4) \times \frac{44}{28} \quad (9)$$

Where: $N_2O_{G(mm)}$ - indirect N_2O emissions due to volatilization of N from manure management in the region, kg N_2O year^{-1}; EF_4 - emission factor for N_2O emissions from atmospheric deposition of nitrogen on soils and water surfaces, kg N_2O-N (kg NH_3-N + NO_x-N volatilized) $^{-1}$; the default value is 0.01 kg N_2O-N (kg NH_3-N + NO_x-N volatilized) $^{-1}$.

Table 6. Default values for nitrogen loss due to volatilization of NH_3 and NO_x from manure management

Livestock Species	**Manure management system (MMS)**	**N loss from MMS due to volatilisation of N-NH_3 and N-NO_x (%) $Frac_{GasMS}$**
Dairy Cows	Solid storage	30
Other Cattle	Solid storage	45
Poultry	Poultry without litter	55
	Poultry with litter	40
Others*	Solid storage	12

Source: IPCC, 2006; * Includes sheep, horses, and fur-bearing animals.

2.2.1.2. Land use Land cover

Climate change has appeared to be a bottleneck for sustainable development, and hence it has necessitated that human development efforts must consider the climate footprint. It has been proven that increasing Greenhouse gas concentration in the atmosphere is the major cause of global warming. While it is the developed nations (the so-called annex one countries in the IPCC 2006), who emit most of the greenhouse gases mainly from fossil fuel burning, developing countries like Ethiopia have also their share. Since climate change affects all global communities, so does its mitigation. Therefore, all countries have a responsibility to align development efforts with climate change mitigation measures. Ethiopia has pioneered to design of a climate-resilient green economy strategy, which has identified four pillars where climate change mitigation measures can be realized. Of these four pillars, the forestry and agriculture sectors take the biggest share of emissions (about 87% of the total emissions of the country) (CRGE). However, these two sectors have also the biggest abatement potential. The forest sector alone has more than 50% of the abatement potential.

Amhara region is known for its strong dependence on agriculture and over 80% of the population lives in rural areas where fuel wood is the main means of energy supply. Hence, agricultural area expansion and deforestation are also major challenges.

As per the IPCC methodological framework, the determination of emission reference level/reference level for land use change in the AFOLU (Agriculture Forestry and other Land Uses) sector can be done in three approaches. These approaches offer more detailed information while moving from approach 1 to approach 3. They are: approach 1) use of total land use area data, but no data on

conversion between different land uses, approach 2) using total land use area including changes between categories and approach 3) using spatially explicit land use conversion data. In this assessment of the carbon emission reference level, the third approach was followed, and spatially explicit data with a 10m * 10 m resolution was used.

Carbon emission reference level can be determined in two different ways, the process-based (loss and gain) method and the stock-difference method (IPCC 2006). We opted to use the stock-difference method as it is less complicated but provides more reliable information. The stock difference method is the most commonly used in Ethiopia in general (Yitebitu et al., 2010). We have tried our best to comply with the IPCC principles of data adequacy, consistency, completeness, and transparency. Detailed information regarding the data collection and analysis techniques employed to determine the carbon emission reference level for the Amhara Region for the year 2020 is provided below. The values for 2020, the base year, were determined by analyzing the LULC changes between 2017 and 2022 as quality data for 2020 was not available.

i) The Historic Period

The national emission reference level ERL/RL has considered the period between 2000 and 2013 as the historic period since this period is aligned with the FCPF Carbon Fund Methodological Framework (MEFCC, 2017). The availability of satellite data for the years 2000 and 2013 was another reason. That historic period for the emission reference level was also just before Ethiopia started the implementation of REDD+ projects on the ground and hence provides the baseline condition before REDD+. However, the period chosen for determining the emission reference level for the Amhara Region (this report) has been between 2017 and 2022. This is because it gives recent developments related to the tree cover dynamics in the region. It was also because availability of LULC data at a spatial resolution of 10m*10m, which could provide detailed information on the highly fragmented LULCs such as woodlots and church forests.

ii) LULC data acquisition and analysis

Remote sensing and Geographic information systems were used to assess Land use land cover change patterns and change prediction to monitor carbon stocks from existing land use land cover of the region. Classified Sentinel 2 satellite images acquired in the year 2017 and 2022 were used for data analysis. The data which has a 10-meter spatial resolution was acquired from ESRI land use land cover data sources (ESRI 2017, 2022). The image was a subset to delineate the boundary of the area using the shape file of the Amhara region. QGIS 3.34.3 was used for image processing (change detection). The shapefile data for the biome was accessed from the RCMRD Open Data Site (RCMRD, 2020). The biome shape file was rasterized with 10 m resolution.

Accessing LULC data that covers the Amhara Region was a big challenge, and looking at LULC data for different periods of interest was even more difficult. The different LULC data that the group managed to find were not satisfying since they were not fulfilling one or more of the following requirements.

1. The LULC classification categories did not follow the six major categories of the IPCC that are included in the AFOLU (Forest, Cropland, Rangeland, Settlement, Wetland, and Other land)
2. Some of the LULC maps were inclined to specific LULC, mostly more detailed with vegetation cover
3. The resolution of the LULC maps was too course, mostly greater than 30m * 30m
4. Difficult to get two different period spatial data with similar classification of LULC and similar resolution
5. Most LULC maps that we could get were not accessible in softcopy data that can be analyzed in a GIS environment.

There were three options to analyze the LULC changes in the Amhara region. The first was to get a previously classified LULC map specific to the Amhara Region. However, those maps were not feasible for the different reasons listed above. The second option was to download satellite images for the two different periods and undertake the LULC classification. The third option was to use the data we got from the ESRI database. The second option could allow us to analyze longer periods of historical change. However, it is cumbersome to do the LULC classification at the regional scale, and older satellite images that can be accessed freely have coarser resolution. Therefore, we chose to use the LULC data obtained from the ESRI database although it provided only five-year-old historical data. The LULC data obtained from the ESRI database has a 10m * 10m resolution, and it provided annual data starting from 2017. We have got the regional shapefile data and extracted the LULC data of the Amhara Region from the ESRI database for the 2017 and 2022 years.

After extracting the LULC data of the two periods (2017 and 2022), an evaluation was made on the accuracy of the classification, observing the classified data in detail at known places of different LULC. The ESRI LULC data was classified into nine classes. However, the three classes (bare land, afro-alpine, and clouds) can be considered in other land use categories. Therefore, the ESRI LULC category follows the IPCC major LULC category of six classes. Besides, this data can be a potential future source that can be used across different countries and hence provides a better opportunity for data comparability. In addition, consistency of the method in the different periods can be guaranteed.

However, some of the woodland is changed to forest following the new forest classification in Ethiopia. Ethiopia's current definition of a forest is "land occupied with trees (natural and planted, including bamboo) attaining a height of more than 2 meters at maturity, canopy cover of more than

20% and covering an area of more than 0.5 ha, with a minimum width of 20 meters or not more than two-thirds of its length" (MEFCC, 2018). Given this definition of a forest, the major portion of the forest cover of Ethiopia falls under the FAO's "forest" classification which is defined as "Land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10%, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use" (FAO, 2010). The major difference in the definitions lies in the height of the trees intentionally made to include the vast areas of dense woodlands found in Ethiopia.

Table 7. Identified land use land cover class definitions (Venter et al., 2022)

Name	**Description**
Water	Areas where water was predominantly present throughout the year; may not cover areas with sporadic or ephemeral water; contains little to no sparse vegetation, no rock outcrop nor built-up features like docks; examples: rivers, ponds, lakes, oceans, flooded salt plains.
Tree cover/ Forest	Any significant clustering of tall (~5 m or higher) dense vegetation, typically with a closed or dense canopy; examples: wooded vegetation, clusters of dense tall vegetation within savannas, plantations, swamp or mangroves (dense/tall vegetation with ephemeral water or canopy too thick to detect water underneath).
Riparian vegetation	Areas of any type of vegetation with obvious intermixing of water throughout a majority of the year; seasonally flooded area that is a mix of grass/shrub/trees/bare ground; examples: flooded mangroves, emergent vegetation, rice paddies, and other heavily irrigated and inundated agriculture.
Cropland	Humans planted/plotted cereals, grasses, and crops not at tree height; examples: corn, wheat, soy, and fallow plots of structured land.
Built-up Area (Settlement)	Human-made structures; major road and rail networks; large homogenous impervious surfaces including parking structures, office buildings, and residential housing; examples: houses, dense villages/towns/cities, paved roads, and asphalt.
Other land (Bare land)	Areas of rock or soil with very sparse to no vegetation for the entire year; large areas of sand and deserts with no to little vegetation; examples: exposed rock or soil, desert and sand dunes, dry salt flats/pans, dried lake beds, mines.
Afro-alpine	Large homogenous areas of permanent snow typically only in mountain areas or the highest latitudes
Wooded grassland	Open areas covered in homogenous grasses with little to no taller vegetation; wild cereals and grasses with no obvious human plotting (i.e., not a plotted field); examples: natural meadows and fields with sparse to no tree cover, open savanna with few to no trees, parks/golf courses/lawns, pastures. A mix of small clusters of plants or single plants dispersed on a

	landscape that shows exposed soil or rock; scrub-filled clearings within dense forests that are not taller than trees; examples: moderate to sparse cover of bushes, shrubs, and tufts of grass, savannas with very sparse grasses, trees or other plants.

iii) The different levels of LULC Classes

The FAO provided three levels of LULC Classes,

1- FRA Class LULCC (Four classes: Forest, Other Wooded land, Other Land, Water)
2- Major LUCC (Two forest classes, one Other Wooded land, four other land, and two water classes)
3- LUCC; which is a more detailed LULC classification.

For the carbon stock assessment, it was preferred to use the 3rd level of classification when data was available at that level; otherwise, the 2 and 1-level categories were used.

iv) Vegetation classification and stratification

Vegetation classification in Ethiopia is quite complex due to a wide range of determinant variables for plant growth such as topography, elevation, soil type, climate, and anthropogenic influences. Therefore, it is hard to find one consistent way of vegetation classification in the country. Recently, the potential vegetation map of Ethiopia has been classified into 12 vegetation classes (Friis and Sebsebe 2009; Friis, Demissew, and van Breugel 2010). Accordingly, the Amhara region is characterized by the Dry Evergreen Afromontane Forest and Dryland Complex, Cobretum-Terminalia woodland and wooded grassland, Acacia-Commiphora Woodland and Bushland proper, Afro-alpine Belt and Ericaceous Belt.

However, for simplification of the complexity of vegetation types particularly for carbon stock assessment, they have categorized the different vegetation zones into five major biomes by combining different vegetation classes that have similar carbon stock. These biomes are; Acacia-Commiphora, Combretum-Terminalia, Dry Afromontane, Moist Afromontane, and others. This classification assumes that although there are different vegetation types within one biome; the carbon stock is comparable (assumed to be similar). Accordingly, most of the Amhara region is covered by the Dry Afromontane and Combretum-Terminalia biomes. A small fraction of the eastern frontier of the region is covered by Acacia-Commiphora. There is little Moist Afromontane biome in the Amhara Region. The Other Biomes, which mostly are water bodies or marshland areas has also a small portion of coverage. Since the national emission reference level (ERL) submitted to the UNFCCC has used the biome classes for determining the carbon stock of the country, we have adopted that to the Amhara Region as well.

v) The choice of the emission factor

The emission factor can be determined in three different ways (IPCC 2019).

a. Using global default values provided by the IPCC/FAO for the particular ecosystem and LULC,
b. Taking emission factor values of specific LULC in a particular ecosystem as determined by the national greenhouse gas inventory (NGHGI),
c. Taking recommended emission factor values for each LULC and ecosystem from literature/ research

Since the current inventory of greenhouse gas emissions is targeted at a sub-national level (Amhara Region), the first option was not taken into consideration as the global emission factor for such a scale has been assumed to be less accurate than the other options. We also found that there is limited relevant literature/ research that can cover all the different LULC and ecosystem types found in the Amhara Region. Besides, we have observed a wide range of disparities in the emission factor values recommended by the available literature. Using the values from the fragmented literature would raise the issue of data accuracy and may also put the issue of consistency with the NGHGI in question. Finally, the second option was decided to be appropriate at this point. The NGHGI was based on the national forest inventory that was undertaken in 2016 with the support of the FAO. The national forest inventory has been based on 539 accessible sampling units of which 128 were forest. Consequently, there were 94 accessible sampling units (12 were forests) in the Amhara Region. The carbon stock density of the different LULC types was, therefore, obtained from the national forest inventory data that is provided to be appropriate for the Amhara region. The emission factor for the region (also for the country) was determined for different LULC and biome combinations.

vi) Analysis of the carbon stock

The carbon stock for the region is determined by considering three pools (the -above-ground biomass, below-ground biomass, and deadwood) which were determined separately and added together to give the total carbon stock. The emission factor for the LULC classes was obtained from the national forest inventory (FAO 2018). The region was divided into four biomes and the emission factor for each LULC class was determined in each biome.

2.2.1.3. Aggregate Sources and Non-CO_2 Emissions Sources on Land

Aggregate sources and non-CO_2 emission sources on land include emissions from biomass burning, liming, urea application, direct and indirect N_2O emissions from managed soils, and indirect N_2O emissions from manure management. In Ethiopia, farmers traditionally burn grasslands to encourage the sprouting of new vegetation for cattle grazing, and forest fires, both controlled and uncontrolled, occur sporadically. However, data on the occurrence of fire and burnt areas are not systematically

collected and are not thought to be sufficiently reliable for inclusion in formal reporting (MEFCC, 2017). From the limited reports it received, FDRE (2022) attempted to estimate emissions from biomass burning from forest land and found that it was less than 1Gg. Similarly, there is no systematic record of data about burnt areas, both forest and grassland, in the Amhara region. In addition, their contribution to GHG emissions is also thought to be small. Thus, emissions from biomass burning are not included in this report. Direct and indirect N_2O emissions from managed soils as well as indirect N_2O emissions from manure management, which are often associated with livestock rearing are addressed under the livestock sector. Carbon dioxide emissions from liming and urea application and methane emissions from rice cultivation in the region were estimated. The 2006 IPCC guideline was followed and their corresponding CO_2 equivalents were also calculated. The detailed descriptions for each subcategory are given below.

i) CO_2 Emissions from Liming

Lime is applied to "reduce soil acidity and improve plant growth in managed systems, particularly agricultural lands and managed forests" (IPCC, 2006, p. 11.26). The IPCC further states that adding carbonates to soils in the form of lime, which could be calcic limestone ($CaCO_3$), or dolomite ($CaMg(CO_3)_2$), leads to CO_2 emissions as the carbonate limes dissolve and release bicarbonate ($2HCO_3$), which evolves into CO_2 and water (H_2O).

Ethiopia started lime treatment of acidic soils recently in 2016 (FDRE, 2022). Vast areas of the Amhara region, particularly east Gojam, west Gojam, Awi, and south Gondar zones, are covered by acidic soils and require lime treatment to reduce soil acidity levels and improve soil productivity and hence plant growth. Accordingly, the region is using lime and the total amount of lime used annually starting from 2020 was collected from the Bureau of Agriculture. Lime data for the Wolqait Tsegede Setit Humara zone and other newly included districts in Wag Himra, North Wollo, and North Gonder zones were not available and not included in the calculation. The exclusion is partly because soil acidity is not a major problem in these areas and the use of lime and their contribution to CO_2 emission were considered insignificant. Indeed, the contribution of lime to CO_2 emission to date is one of the lowest in the region. It is, however, important to monitor as lime application to treat acidic soils in the region seems to exhibit an increasing trend.

Estimation of CO_2 emissions from lime was made using the Tier 1 approach of the IPCC, as CO_2 emissions from liming are not considered a key emission source category and there were no regionally or nationally developed methods of inventorying. Thus, CO_2 emissions from additions of carbonate limes to soils in the Amhara region were estimated using Equation 10 of the 2006 IPCC guideline as follows.

Annula CO2 emissions from lime application

$$\text{CO2}-\text{C emmission} = (\text{M limestone} * \text{EFlimestone}) + (\text{M dolomite} * \text{EF dolomite}) \qquad (10)$$

Where: CO2–C emmission= annnula CO2 emissions from lime application,tonnes C yr^{-1}; M-annualamount of calcic limestone($CaCO_3$) or dolomite($CaMg(CO_3)_2$),tonnes yr^{-1}; EF- emmision factor ,tonnes of C(tonnes of lime stone or dolomite)$^{-1}$

The procedures followed to estimate emissions from liming were as follows. First, the total amount of carbonate containing lime applied annually to soils in the region was obtained. An attempt was also made to differentiate limestone and dolomite. However, the data we found were all about limestone application. Second, an overall default emission factor (EF) of 0.12 was used for limestone. For dolomite, it was 0.13. Third, the total amount of limestone was multiplied by the respective emission factor to obtain the total CO_2–C emission. Finally, this figure was multiplied by 44/12 to convert CO_2–C emissions into CO_2.

ii) CO_2 Emissions from Urea Fertilization

It is already known that the application of urea fertilizer to soils to increase crop yield adds to CO_2 emissions to the atmosphere. The carbon dioxide that was fixed in the industrial production process will be released into the atmosphere during the fertilization process of urea that was added to the soil. During the fertilization process, urea ($CO(NH_2)_2$) will be converted into ammonium (NH4+), hydroxyl ion (OH-), and bicarbonate (HCO3-) compounds, in the presence of water and urease enzymes (IPCC, 2006). Akin to the soil reaction following the addition of lime, bicarbonate that is formed during the fertilization process evolves into CO_2 and water thereby contributing to CO_2 emissions to the atmosphere.

Nearly half of the total fertilizer used in the Amhara region is urea. The total amount of fertilizer used in the region in 2020, excluding the newly included zone – Wolqait Tsegede Setit Humara zone– and some districts from Wag Himra, North Wollo, and North Gondar zones, was reported to be 5,780,025 quintals, of which 2,648,926 quintals were urea fertilizer. However, as observed from the fertilizer data collected from the Bureau of Agriculture, the use of urea fertilizer seems to slightly decline from year to year. The decline from 2020 to 2021, for example, was estimated to be 0.13%, meaning that more urea fertilizer was used in the former years than the latter ones.

An attempt was also made to include the amount of urea fertilizer used in the newly included areas. Although it was not possible to find the 2020 data, it was possible to get the 2021 data, which was reported to be 18,153.5 quintals. To arrive at the possible use of urea fertilizer in these areas in 2020, an educated guess was made by considering a proportional 0.13% reduction in the following year, parallel to the one witnessed by the region between these years. It is thus estimated to be 18,177 quintals for the newly included areas in 2020, making the regional total 2,667103 quintals.

Akin to the lime estimation, CO_2 emission from urea fertilization was estimated following the IPCC's Tier 1 approach and using the following (Equation 11).

Annual CO2emissions from urea application

$$\text{CO2} - \text{C emission} = \text{M} * \text{EF} \quad (11)$$

Where: CO2–C emission = annual C emissions from urea application, tonnes C yr^{-1}; M- annual amount of urea fertilization, tonnes urea yr^{-1}; EF- emission factor, tonne of C (tonne of urea)$^{-1}$

Once the total amount of urea applied annually is obtained, an overall emission factor (FE) of 0.20 for urea was applied. Then, total CO_2–C emission from urea application was estimated by multiplying the amount of urea applied to the soil by the emission factor (EF). To convert CO_2–C emissions into CO_2 it was multiplied by 44/12.

iii) Methane Emissions from Rice Cultivation

Ethiopia is not known for its rice production. However, rice cultivation has been growing recently. It was started in the Amhara region and has expanded to other regions recently. It was started in the South Gondar Zone of the Amhara national regional state and was limited to it for the vast majority of the rice cultivation era in the region as well as in Ethiopia. Now, it is practiced in more than eight zones of the region albeit the area covered by rice is still relatively small. However, there is a plan to increase the acreage and productivity of rice in the region as well as in Ethiopia.

Nonetheless, rice cultivation has also environmental concerns in that it emits methane to the atmosphere and contributes to global warming. The IPCC reported that "anaerobic decomposition of organic material in flooded rice fields produces methane (CH4), which escapes to the atmosphere primarily by transport through the rice plants". It was further stated that the annual amount of CH4 emitted from a given area of rice is a function of the number and duration of crops grown, water regimes before and during the cultivation period, and organic and inorganic soil amendments. Soil type, temperature, and rice cultivar are also reported to affect CH4 emissions.

While rice production in the region is expanding the main producer is still south Gondar Zone, accounting for more than two-thirds of the total. It is remotely followed by Central Gonder, Awi, and West Gojam Zones. The newly included zone, Wolqait Tsegede and Setit Humera zone is also one of the zones joining the pack in producing rice. The total area covered by rice cultivation in the region in 2020, excluding Wolqait Tsegede and Setit Humera zone, was 52,527 hectares. From the rice data obtained for the years 2022 and 2023 and the projected rate of growth in production over the years, the 2020 rice data for the newly included zone was estimated. Thus, the area covered by rice in 2020 for the newly included zone was estimated to be 1180 hectares. This will in turn give us a regional total of 53,707 hectares.

This study used the basic equation developed by the IPCC to estimate CH4 emissions from rice cultivation as shown in Equation 5.1. According to the 2006 IPCC guideline, CH4 emissions are estimated by multiplying daily emission factors by the cultivation period of rice and annual harvested areas. Natural conditions and agricultural management of rice production may be highly variable

within the region and country. Such variability was taken into account by disaggregating regional total harvested area into sub-units (e.g., harvested areas under different water regimes). As Sass (2002) highlighted, the harvested area for each sub-unit is multiplied by the respective cultivation period and emission factor that is representative of the conditions that define the sub-unit. As described in the guideline, with this disaggregated approach, the total annual emissions of the region from rice cultivation will be equal to the sum of emissions from each sub-unit of the harvested area. CH4 emission from rice cultivation can be calculated as (Equation12):

$$CH4\ \text{Rice} = \sum(\text{EFi,j,k} * \text{Ti,j,k} * \text{Ai,j,k} * 10^{-6}) \quad (12)$$

Where: CH_4 rice - annual methane emission from rice cultivation, Gg CH_4 yr^{-1}; $EF_{i,j,k}$- a daily emission factor for i,j, and k conditions, Kg CH4 ha^{-1} $day^{-}1$; $Ti_{,j,k}$- cultivation periods of rice for i,j, and k conditions, day; $A_{i,j,k}$- an annual harvested area of rice for i,j, and k conditions, ha $yr^{-};^{1}$ i,j, and k = represent different ecosystems, water régimes, type and amount of organic amendments, and other conditions under which CH_4 emissions from rice may vary.

The different conditions considered in the 2006 guideline to estimate emissions from rice cultivation including rice ecosystem types, flooding patterns before and during the cultivation period, and the type and amount of organic amendments were also considered in this study. Other conditions such as soil type, and rice cultivar were not considered for the disaggregation as there was no region or country-specific information about the relationship between these conditions and CH4 emissions. Moreover, the 2006 guideline for analyzing CO_2 emissions from rice cultivation was updated and refined and hence values in the updated version of the guideline, i.e., tables and figures in the 2019 guideline, were used for the analysis.

Approach-wise, Tier 1 of the IPCC was applied as CH4 emissions from rice cultivation were not considered a key category, and country-specific emission factors were not available. The disaggregation of the annual harvest area of rice was also done for the different baseline water regimes (Equation13)

Adjusted daily emission factor (Tier1)

$$EFi = EFc * SFw * SFp * SFo \quad (13)$$

Where: EFi - adjusted daily emission factor for a particular harvested area; EFc- baseline emission factor for continuously flooded fields without organic amendments; SFw- scaling factor to account for the differences in water regime during the cultivation periods; SFp- scaling factor to account for the differences in water regime in the preseason before the cultivation periods; SFo - scaling factor should vary for both type and amount of organic amendments applied which can be calculated as

Adjestued CH4 emission scaling factors for organic amendments (Equation14)

$$SFo = (1 + \sum ROAi * CFOAi)^{0.59} \quad (14)$$

Where: SF_o-is scaling factor should vary for both type and amount of organic amendments applied ROAi- application rate of organic amendments i, in dry weight for straw and fresh weight for others, tonne ha^{-1}; $CFOA_i$ = conversion factor for organic amendments i (in terms of its relative effect with respect to straw applied shortly before cultivation).

Ultimately, CH4 emissions from rice cultivation in the Amhara region were estimated based on the following information. The rice ecosystem was categorized as irrigated; the water regime was categorized as intermittently flooded; the annual harvested area for the year 2020 was found to be 53,707 hectares; and the cultivation period identified was 113 days, as indicated in the IPCC guideline for Africa. In addition, the baseline emission factor for continuously flooded fields without organic amendments was fixed at 1.19; scaling factor to account for the differences in water regime during the cultivation period was fixed at 0.71; scaling factor to account for the differences in water regime in the pre-season before the cultivation period was fixed at 0.89; and scaling factor for both type and amount of organic amendment applied was fixed at 1.

2.2.2. Energy sector

2.2.2.1. Data sources and activities

Institutions at the local, regional, and national levels were the sources of the activity data (AD). A large portion of the AD was gathered from the region's energy consumers and responsible offices. Actual consumptions of energy by the different sub-sectors were gathered using a bottom-up approach. The sub-sectors include transportation, manufacturing, construction, residential, commercial/institutional, and agriculture/forestry. The activity data collected and the sources in the energy sector are tabulated by category in Table 8.

Table 8. Activity data and source in the energy sector.

Activity Data	**Unit**	**Source**
Fuel consumption		
Diesel oil (የ ና ፍጣ ዘ ይት)	Liter	ANRS-BoTMD
Gasoline (petrol) (ቤንዚን)	Liter	ANRS-BoTMD
Electricity consumption		
Residential	KWh	EEU
Commercial/Institutional	KWh	EEU
Industrial	KWh	EEU
Biomass consumption		
Firewood	m^3	CSA
Tree Residues	m^3	ANSR-BoPD
Sawdust	m^3	ANSR-BoPD
Charcoal	m^3	CSA

Activity Data	Unit	Source
Statistical data		
Manufacturing Industries	#	ANSR-BoII
Construction Industries	#	ANSR-BoII
Irrigation motor pumps	#	ANSR-BoA
Motor boats	#	ANSR-BoCT, Tana Water Transport Enterprise
Vehicles per category	#	ANSR-BoTL
Construction machinery	#	AWWCE, ARWE, ARRCA, and ABWCE
Average distance traveled by a car per liter of fuel	Km/liter	ANSR-TLA
Average distance traveled by a car per year	Km	ANSR-TLA
Average fuel consumption of machines per hour	liter/hour	Construction industries

ANRS-BoTMD = ANRS Trade and Market Development Bureau, EEU = Ethiopia Electric Utility, ANSR-BoPD = ANRS Bureau of Pland and Development, ANSR-BoII = ANRS Amhara Industry and Investment Bureau, ANSR-TLA = ANSR- Transport and Logistics Authority, ANSR-BoA = ANSR Bureau of Agriculture, ANSR-BoII = ANSR – Bureau of Industry and Investment, ANSR-BoCT = ANSR- Bureau of Culture and Tourism, AWWCE = Amhara Water Works Construction Enterprise, ARRCA = Amhara Rural Roads Construction Agency, ARWE = Amhara Road Works Enterprise, and ABWCE = Amhara Building Works Construction Enterprise

2.2.2.2. GHG Emission calculation and reporting

The calculation of GHG emissions involves multiplying activity data (AD) by an emission factor (EF) specific to each activity. Activity data is the quantity of an activity that results in the emission of GHG in a specified period (e.g., kilowatt-hours (kWh) of electricity consumed in a year). The amount of GHG emissions resulting from a certain activity is calculated using emission factors (for example, the amount of CO_2 emissions from using electricity is expressed as tCO_2/kWh).

Energy sector activities in the Amhara region mainly depend on the combustion of fossil fuels and the use of electricity to produce mechanical energy for generating power in the various sectors. Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are the GHGs mainly released in the combustion of fuels. There are two ways to estimate CO_2 emissions from fuel combustion: the top-down or reference approach, and the bottom-up or sectorial approach. In this study, both approaches were implemented to estimate emissions. The emissions could be computed using the equation suggested by the 2006 IPCC guideline (Equation15):

$$Emision\ of GHG, Fuel = FuelConsumption, Feul \times Emisions \text{ factor } GHG, Fuel \quad (15)$$

Where, emissions of GHG, fuel is emissions of a given GHG by type of fuel (kg GHG), Fuel Consumption, fuel is the amount of fuel combusted (TJ), and Emission Factor GHG, fuel is emission factor of a given GHG by type of fuel (kg gas/TJ).

The CO_2 emission factor is dependent on the carbon content of the fuel for energy generation. Emission factors for CO_2 are in units of kg CO_2/TJ on a net calorific value basis and reflect the carbon content of the fuel. Apart from CO_2, non-CO_2 emissions are emitted during fuel combustion. When kerosene, diesel, charcoal, and other biomass fuels are burnt, the main non-CO_2 gases emitted are methane (CH_4) and nitrous oxide (N_2O).

Activity data for the energy sector was collected from energy industries, manufacturing industries and construction, transport, residential, commercial/institutional, and agriculture, forestry, and fishing activities. The consumption of electricity per major sector (residential, commercial/institutions, industries) was collected from Ethiopia Electric Utility (EEU). Much of the consumption of electricity in the region is taken by residential buildings which is almost half of the sum of commercial/institutions and industries. As it has been reported by various sources, the share of consumption of electricity in the emission of GHGs is negligible. The consumption of electricity per industry category is presented in annex Table 4. The total industrial consumption of electricity in the region as reported by the EEU is 243,921,280 KWh and the emission of GHGs from this consumption is considered in the study.

The major contributor to the emission of GHGs is the combustion of fuels. The industrial sector emits a significant proportion of GHGs in the region. A total of 5,073,242.5 L or 4.262 Gg or 4262 tons of diesel oil was consumed by the construction industry in the year 2020. A total of nearly 2 million liters or 1.99 Gg or 1990 tons of fuel is consumed by manufacturing industries of which the major is diesel fuel (annex Table 4). Manufacturing industries were mainly dependent on electricity to produce energy rather than using fuels. Therefore, the consumption of fuel in these industries is lower than in the construction industries. Data about industries were found from the construction enterprise industries and the Bureau of Industry and Investment (BoII) of the region. Consumption of fuels per machinery is acquired from these construction enterprises to compute the total annual fuel consumption. The total electricity consumption by manufacturing industries as reported by EEU and presented in Table 4 is about 243,921,280 KWh. The number of vehicles in different categories in the transport sector is obtained from the Transport and Logistics Bureau (BoTL) to calculate gasoline and diesel consumption in the region. The annual average fuel consumption per vehicle category (annex Table 2) is acquired from the major construction industries of the region and the Addis Ababa City 2016 Greenhouse Gas Emissions Inventory Report (Haji et al., 2020) because of lack of fuel consumption data from the respective Bureau of the region. The authors of this study understood that the data handling and reporting of these construction industries in the region are of a better standard and reliable to extend the fuel consumption of these industries to transport vehicles. The total gasoline consumption both in the water and on-road transport is about 46,534,488.8 litters and diesel is about 278,481,229.17 litters. On-road transport took the highest fuel consumption from the transport sector and diesel constitutes the highest amount in terms of fuel usage in the sector. To calculate the fuel

consumption (activity data) in the water transport the number of water boats was mainly obtained from Tana Water Transport Enterprise, Bahir Dar City Bureau of Tourism, the districts bordering Lake Tana, and Lake Haike in South Wollo Zone.

Data on machinery and vehicles that have been involved in agricultural development were found from the Bureau of Agriculture (BoA) and Bureau of Transport and Logistics (BoTL) to calculate the energy consumption in the sector. Water pumps for irrigation purposes in the agriculture sector also consumed a significant amount of gasoline (7,326,200 L or 5.42 Gg or 5420 tons) and diesel oil (1,831,550 L or 1.539 Gg or 1539 tons). Agricultural machinery has also utilized diesel fuel and has contributed to the GHG emission. The total figure of diesel fuel used in this sector was 5,588,941.46 L or 4.695 Gg or 4695 tons. Water pumps mainly consumed about 7,326,200 L of gasoline and 1,831,550 L of diesel in the study year. The average fuel consumption of a motor pump is calculated using information of farmers involved in irrigation using the motor pumps and multiplied by the total number of pumps in the Region. Agricultural machines and vehicles like combine harvesters and tractors used 5,588,941.5 L of diesel fuel. Data of biomass fuel in cubic meters from the Bureau of Plan and Development (BoPD) and CSA for residential and commercial/institutional activities were converted into Kilograms for the computation of GHG emissions. The main source of energy for residential buildings was electricity (545,151,652 KWh) which is reported from EEU. The total biomass consumption in all institutions is about 1,468,889,282.4 kg. Concerning residential buildings a total of 1,450,364,802.4 kg of biomass (firewood (1,117,710,242.5 kg) and charcoal (332,654,559.9 kg) were the energy sources. A total of 256,537,443 kWh of electricity and 18,524,480 Kg of biomass fuel (firewood, tree residues, and sawdust) were consumed by commercial/institutions in the region in the year of study. From all energy sectors transport took the highest fossil fuel consumption (92.1%) followed by agriculture, forestry, and fishing (4.2%). Commercial/Institutional has little or no data recorded for fossil fuel consumption in the region (Figure 3)

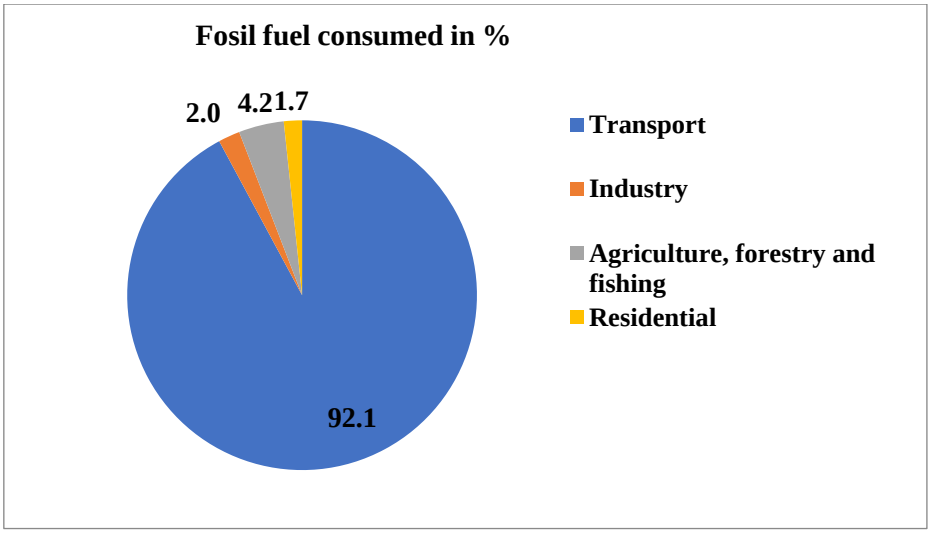


Figure 3. Fossil fuel consumption in the energy sectors of the Amhara Region

2.2.2.3. GHG Emission Projection

Projecting emissions in the future has vital importance to take management options to reduce the emission levels. Future emission in 2030 was predicted by taking 2020 as a base year. In this study, two projection scenarios were considered which are projection with business-as-usual (BAU) and projection with interventions in 2030. In the BAU scenario, the future condition was predicted based on the assumption that the data usage in the energy sector continues at the rate of the presented years. Activity data for 2021, 2022, 2023, and 2024 were analyzed and percentage changes of the previous years in the number of industries, expansion of construction, number of vehicles, biomass consumption, agricultural mechanization, and population were used to convert the baseline activity data for future years (Table 9). The other form of scenario prediction is with intervention measures of energy uses in the sector. In the scenario with intervention, expert knowledge was used to set expected interventions to reduce the emission of greenhouse gases. Among the expected interventions: increment of electric vehicles, reduction of biomass consumption due to the increased electric utilization (electrification), improved biogas utilization, improved technologies in biomass utilization, the expansion of solar energy basically in the rural areas, and enhanced gravitational irrigation practices were considered.

Table 9. Percentage increase of sectors that directly increase the GHG of the energy sector in the business-as-usual scenario

Sector	Annual percentage increase
Electricity	15.8

Construction machineries	5.5
Mechanization machineries	5.5
Residential fuelwood consumption	23.8
Irrigation water pump	10.5
Number of vehicles	17.8
Urban population growth	5.17
Rural population growth	0.73

2.2.3. Industry, Process, and Product Use (IPPU)

2.2.3.1. Data Sources

All relevant data have been collected from its respective sources: Industry and Investment Development Bureau, Trade and Development Bureau, EFPA, Industrial Parks Office, and fuel stations. In addition, interviews with key persons to the concerned authorities/ institutions for consultation on the type of input, output, and method of production and about greenhouse gas emissions.

According to the 2006 IPCC Guidelines, lime production from the mineral industry, ammonia production from the chemical industry, Lubricant and paraffin wax from non-energy production of fuel use, and food and beverage industries are among the industrial sectors involved in this study.

2.2.3.2. Calculating GHG Emissions

Step 1. Determine the needed activity data for each emission source. Activity data is a measurement of the activities that generate GHG emissions (e.g., fuel consumption; the amount of electricity purchased).

Step 2. Collect the activity data.

Step 3. Select appropriate emission factors based on the activity data. Emission factors are ratios of the GHGs emitted per unit of activity data (e.g., metric tons of CO_2 emitted per kilowatt hour of generated electricity or gallons of fuel burned).

Step 4. Calculate GHG emissions by gas (i.e.CO_2, CH_4, N_2O) by multiplying activity data by the appropriate emission factors.

Step 5. Convert emissions to metric tons CO_2 equivalent (CO_2e), to take into account the global warming potential (GWP) of the different GHGs.

Accordingly, 1. Emissions from lime production(Equation16)

$$CO_2 \text{ emissions} = \Sigma(EF_{lime,i} \times M_{lime,i}) \quad (16)$$

Description Value

CO_2 emissions - CO_2 emissions in tonnes; Mlime - Weight (mass) of lime produced of lime type i in metric tonnes; EFlime -CO_2 per mass unit of lime produced of lime type i
(e.g. CO2/tonne lime of type i); i - Type of lime*In the absence of country-specific data, it is *good practice* to assume 85 % production of high calcium lime and 15 percent production of dolomitic lime (Miller, 1999).

2.2.3.3. CO_2 Emissions From Ammonia Production

$$ECO_2 = AP * FR * CCF * COF * 44\ 12 - RCO_2 \quad (17)$$

Where ECO_2 - emissions of CO_2, kg; AP - ammonia production, tonnes; FR - fuel requirement per unit of output, GJ/tonne ammonia produced; CCF - carbon content factor of the fuel, Kg C/GJ; COF - carbon oxidation factor of the fuel, fraction; RCO_2 - CO_2 recovered for downstream use (urea production), Kg; *Where no information is available on the fuel type and/or process type, it is good practice to use the average value for partial oxidation and use the highest emission factor (IPCC, 2006).

2.2.3.4. Lubricant and paraffin wax

The emission factor is composed of a specific carbon content factor (ton C/TJ) multiplied by the ODU factor. A further multiplication by 44/12 (the mass ratio of CO_2/C) yields the emission factor (expressed as tone CO_2/TJ). Note that kg C/GJ is identical to ton C/TJ.) It is assumed that use is combustion resulting in 100 percent oxidation to CO_2, with no long-term storage of carbon in the form of ash or post-combustion residue.
Having only total consumption data for all lubricants (i.e., no separate data for oil and grease), the weighted average ODU factor for lubricants as a whole is used as the default value in the Tier 1 method. Assuming that 90 percent of the mass of lubricants is oil and 10 percent is grease, applying these weights to the ODU factors for oils and greases yields an overall (rounded) ODU factor of 0.2(See Table 5.2 in Chapter 1 of Volume 2 of IPCC,2006 guideline).

A. Lubricants

$$CO_2 Emissions = LC * CCLubricant * ODULubricant * 44/12 \quad (18)$$

Where: CO_2 Emissions - CO_2 emissions from lubricants, tonne CO_2; LC - total lubricant consumption, TJ; CCLubricant - carbon content of lubricants (default), tonne C/TJ (= kg C/GJ); ODULubricant - ODU factor (based on default composition of oil and grease), fraction; 44/12 - mass ratio of CO_2/C
Default oxidation fractions for lubricating oils, grease, and lubricants in general
Lubricant/type of use Default fraction in total lubricant a (%) ODU factor
Lubricating oil (motor oil /industrial oils) 90 0.2 and Grease 10 0.05

IPCC Default for total lubricants 0.2

Assuming 90 percent lubricating oil consumption and 10 percent grease consumption rounded to one significant digit (Rinehart, 2000).

For calculating CO_2 emissions the total amount of lubricants lost during their use is assumed to be fully combusted and these emissions are directly reported as CO_2 emissions. Since CH_4 and N_2O emissions are very small in comparison to CO_2, these can be neglected for the greenhouse gas calculation in the IPPU sector.

B. Paraffin Waxes

$$CO_2Emissions = PW \bullet CCWax \bullet ODUWax \bullet 44/12 \quad (19)$$

Where: CO_2 Emissions - CO_2 emissions from waxes, ton CO_2; PW - total wax consumption, TJ; CCWax - carbon content of paraffin wax (default), ton C/TJ (kg C/GJ); ODUWax - ODU factor for paraffin wax, fraction; 44/12 - mass ratio of CO_2/C

Accordingly, the number of Companies for fuel and Related (Lubricant& paraffin) distributers in the Amhara region is 33, and the number of stations was 259 in 2015 as indicated in Table 10.

Table 10. Number of companies distributing fuel and fuel-related products in the region

No.	Company Name	No. of stations in the region	No.	Company Name	No. of stations in the region
1	Total	21	17	Baro	3
2	Oil Lybia	28	18	Habesha	7
3	NOC	46	19	Taf	11
4	Delta	22	20	Dalol	4
5	Zagol	5	21	Zoble	2
6	Yetebaberut	28	22	Kobil	3
7	Alpha	8	23	Zemen	6
8	Ella	1	24	Nile	3
9	Tsehay	9	25	Workupetro	3
10	Abyssinia	2	26	Rubis	2
11	Kokeb	1	27	Full	2

12	Gior	7	28	Was	2
13	Mesh	5	29	Angi	2
14	Gomeju	9	30	Yeshi	1
15	Green	3	31	Sky	2
16	Felegion	9	32	Time (BelstiNegasa)	2
	Total			**259**	

Source: Trade and Investment Office, 2015

In our case total number of stations that distribute fuel and lubricant oils in the region in 2020 was 224 as per the information obtained from the Trade and Investment office. Concerning this, we have collected activity data in NOC, Delta, and Total companies but we didn't get lubricant data from all other companies and stations in the regions.

As per our communication with branch managers in Bahir Dar City, NOC Company has 46 stations, Delta Company has 22 stations, and Total Company has 21 stations and distributed yearly on average 1, 800,000L, 1,056,000L and 305,088L lubricants and related products in the region, respectively. From other companies and stations, we didn't get lubricant data in the region but based on our expert judgment we agreed that the remaining stations (135) approximately distribute 5,400,000L (three times of NOC).

Hence, the expected total lubricant in the region for the year 2020 was 8,561,088L (1,800, 000* 4=7,200,000L +1, 056,000 L+305,088L). Assuming that 90 percent of the mass of lubricants is oil and 10 percent is grease, 7704,979.2L is Lubricant oil, and 856,108.8L is paraffin wax.

To convert this value in terms of energy units, we assumed 1kg oil=8.98J; 7,704,979.2L lubricant is 69, 190713.22J and 856,108.8L paraffin wax is 7,687,857.02J when multiplied by 8.98.

2.2.3.5. Emissions from Food and Beverage factory

The emission factors for beer production in hecto-litter/ year is 0.035 kg/hl/yr, alcoholic drinks other than beer is 3.5kg/HL, bread & other food products is 8kg/ton and animal feed is 1kg/ton which is driven from IPCC 1996 and Revised 2006 IPCC guidelines.

2.2.4. Waste Sector

The waste sector constitutes emissions originating from the disposal and treatment of solid and liquid waste and includes CH_4, N_2O, and CO_2 emissions. The waste sector greenhouse gas (GHG) emission inventory was estimated based on the IPCC (2006) guideline for emission inventory. For the estimation, the Tier 1 method according to the guideline was used due to a lack of country-specific

data. The starting point for the estimation of GHG emissions from solid waste disposal was then made from the compilation of activity data on waste generation, composition, and management.

This assessment has taken into account the decomposition of organic waste in solid waste disposal sites (SWDS) where they decompose at a diminishing rate and may take many years to decompose completely. In the process of anaerobic decomposition of organic waste disposed at the SWDS methane (CH_4) is emitted. The methodological guidance was intended to provide emission estimation of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) of the waste volume from the following sources

i) Solid waste disposal,
ii) Open burning of waste,
iii) Biological treatment (composting and biogas production)
iv) Wastewater treatment and discharge (Sludge/sewage and industrial wastewater).

However, due to an insufficiency of appropriate data on biological treatment and incineration in the region, the assessment was limited to solid waste disposed at SWDS.

2.2.4.1. Defining Emission Boundary

The IPCC, 2006 guideline did provide the default waste generation data for East African countries. Thus, it considered all relevant GHG emissions (CH_4 and CO_2 emissions) that are of organic or biodegradable origin from MSW. It is considered mainly the MSW generated by the cities and their vicinity (Urban centers). The scope of this GHG emission inventory, therefore, is restrictively based on MSW per capita waste generation data for the base year from the IPCC, 2006 default values.

Solid waste generation is the basic starting point for activity data to estimate emissions from waste disposal and management. Generation rates and composition vary from country to country depending on the economic situation, industrial structure, waste management regulations, and lifestyle. The availability and quality of data on solid waste generation as well as subsequent treatment also vary significantly from country to country. Therefore, to estimate emissions from waste the emission boundary was defined in the region and cities and urban centers, and their respective population was used as the core of interest.

2.2.4.2. Waste measurement

Municipal Solid Waste (MSW) generation/quantification and composition data

The following are the steps for calculating emissions resulting from MSW:

Step 1: Determine the quantity (mass) of waste (equation 20).

Per capita SW generation rate: the default value for Africa (290kg/c/y) (IPCC, 2006).

Quantifying the total amount of MSW generated: population data CSA and the Regional Plan and Development Commission

Computing the per capita waste generation (Equation20)

$$WR_{Tkg}=\Sigma Nj\bar{X}uc \quad (20)$$

Where $\boldsymbol{WR_{Tkg2020}}$ is the amount of waste generated in the Region in kg/year (ton/year) for the year 2020 (baseline),

Nj is the total number of waste generators (population) in Amhara Regional States and

$\boldsymbol{\bar{X}uc}$ is as mentioned above.

The calculation of the inventory analysis-year emissions (base year) associated with the waste generated is based on how that waste is ultimately disposed of. Waste that is deposited in disposal sites/landfills is calculated based on the total future emissions associated with landfilling the waste (Table 11).

Table 11. MSW generation and management data regional default

Base Year	Urban Population	kg/c/y	Total Waste Generation kgyd	Total Waste Generation Gg/y	Total Waste generation t/y	Fraction of MSW Disposed (069)
2020	X	290	X	X	X	X

Sources: IPCC, 2006 v3

Step 2: Determine the composition (Table 12).

Waste composition is one of the main factors influencing emissions from solid waste disposal and management.

Table 12. Total composition of MSW (2020)

Component	East Africa Default value (IPCC, 2006)	SWG kg/y
Food waste	53.9	X
Paper	7.7	X
Plastic	5.5	X
Textile	1.7	X
Rubber	1.1	X
Leather	1.1	X
Yard waste	5.2	X
Wood &Charcoal	7.0	X
Others (Nappies)	11.6	X

Much of the analysis of MSW resulting from the disposal of solid waste depends on the composition of the waste stream. As is clarified in many studies, the main factor that influences the decomposing

waste is the different amounts of degradable organic carbon (DOC) and fossil carbon present in the waste stream.

Solid Waste Disposal (SWD) provides also a methodology for estimating changes in carbon stored in solid waste disposal sites (SWDS). 1) Food waste, (2) Garden (yard) and park waste, (3) Paper and cardboard, (4) Wood, (5) Textiles, (6) Nappies, (disposable diapers), (7) Rubber and leather, (8) Plastics, (9) Metal, (10) Glass (and pottery and china) and 11) Other (e.g., ash, dirt, dust, soil, electronic waste

The preferred method for determining the composition of the waste stream is to undertake a waste composition study using survey data and a systematic approach to analyze and determine the fraction of waste. However, there is no comprehensive waste composition study at the country or the regional level. Hence, the IPCC, 2006 default data on waste composition in MSW is used in this Regional analysis. For the GHG emission inventory purpose, the following different kinds of waste materials were identified using the East African default values from the guideline IPCC, 2006 (Table 13).

Table 13. The default total carbon contents and fossil carbon fractions for estimating fossil CO_2 emissions from incineration and open burning.

MSW component	Dry matter content in % of wet weight	DOC content in % of wet waste	DOC content in % of dry waste	Total Carbon content in % of dry weight	Fossil carbon fraction in % of total carbon
	Default	Default	Default	Default	Default
Food waste	40	15	38	38	-
Paper & Cardboard	90	40	44	46	1
Plastic	100	-	-	75	100
Textile	80	24	30	50	20
Rubber	84	(39) 5	5 (47)	5 67	20
Leather	84	(39) 5	5 (47)	5 67	20
Yard waste	40	20	49	49	0
Wood &Charcoal	85	43	50	50	-
Yard waste	40	24	60	70	10
Others/Nappies	50	-	-	3	100

For the regional GHG emission inventory, the MSW composition assessment was done using the East African default values and is based on the weight of wet waste. The missing values of some materials were taken from the regional MSWM quantification and compositional analysis studies. The default values for each organic waste component were used in the computations as described below, as there was no comprehensive data in this regard. DOC can be calculated from a weighted average of the carbon content of various components of the waste stream. The following equation was used to estimate DOC using default carbon content values (Equation 21):

$$DOC = (0.15 \times A) + (0.4 \times B) + (0.24 \times C) + (0.39 \times D) + (0.39 \times E) + (0.2 \times F) + (nj*Xi) \quad (21)$$

Where**;** A - Fraction of MSW that is food, B -Fraction of MSW that is paper and cardboard; C - Fraction of MSW that is textiles; D - Fraction of MSW that is rubber; E -Fraction of MSW that is leather; F - Fraction of MSW that is garden waste and other plant debris (yard waste); Xi- Fraction of DOC contained in the MSW; nj-The default value of the MSW components

2.2.4.3. Disposed/ Land filled MSW

Downstream emissions associated with MSW disposed of/land filled in the inventory year were calculated using the following equation for each landfill (Table 14)

Table 14. General information on landfilled MSW and factors used

	Description	Value
MSW	Mass of MSW sent to landfill in inventory year measured in Gg	Input from MSW data
CH4 Emissions	Total CH_4 emissions in kilogram/metric tone	Computed
L0	Methane generation potential, see below	Input from MSW data
frec	Fraction of methane recovered at the landfill (flared or energy recovery)	Input from MSW data
OX	Oxidation factor	0.1 for well-managed landfills

i) Disposed/ Landfilled MSW

For this mass and composition of the MSW sent to landfills in the inventory year were measured (Kg/year - Gg/year 2020). The IPCC, 2006 Guideline provides a Tier 1 version of the FOD method, and the methodology for estimating CH_4 emissions from SWDS is based on the First Order Decay (FOD) method.

ii) Methane (CH_4) Generation Potential, L_0

The methane generation potential (L0) is an emission factor that specifies the amount of CH4 generated per kilogram or Gg of solid waste. L0 is based on the portion of degradable organic carbon (DOC) that is present in solid waste, which is in turn based on the composition of the waste stream. L0 can also vary depending on the characteristics of the landfill. Unmanaged landfills produce less CH_4 from a given amount of waste than managed landfills because a larger fraction of waste decomposes aerobically in the top layers of the landfill. The following equation (Equation22), as the best alternative was used because almost all of the SWDS in the region have no methane recovery systems.

$$Lo = DDOCm \bullet F \bullet 16/12 \text{ (transformation from DDOCm)} \quad (22)$$
$$L_{o=} MCF \times DOC \times DOCF \times F \times 16/12$$

Where: MCF= Methane correction factor based on the type of disposal/landfill site*;* DOC- Degradable organic carbon*;* DOCF- Fraction of DOC that is ultimately degraded (some organic carbon does not)*;*

F-Fraction of methane in the disposal/landfill gas*;* 16/12- Stoichiometric ratio between methane and carbon*;* NB: Default emission factors were used from the 2006 IPCC Guidelines.

2.3. Quality Assurance and Quality Control (QA/QC) Procedures

The primary objective of the quality assurance and quality control (QA/QC) plan is to verify that the inventory is carried out in accordance with the best practices, including accuracy, comparability, consistency, transparency, and completeness. To support the GHG emissions inventory, a Quality Assurance and Quality Control (QA/QC) procedure has been carried out

A technical team was established to check the documented data and methods used throughout the inventory compilation process and worked to ensure that the data, units, and methodologies conform to the standards and parameters set out for the IPCC GHG inventory. Quality assurance measures included a review of the data, equations, and conversion factors used to calculate GHG emissions in this inventory report were also checked by the team. Data processing and spreadsheet calculations were also checked, in accordance with standard practices.

3. SECTORIAL GHG EMISSION

The total GHG emissions estimated for the Amhara National Regional State in 2020 was 79,829,885t CO2e. The largest contribution was found to be from the AFOLU sector (94.34% of the total GHGs), followed by energy sector emissions (5.5%), IPPU (0.1%), and waste sector (0.06%) as indicated in Figure 4.

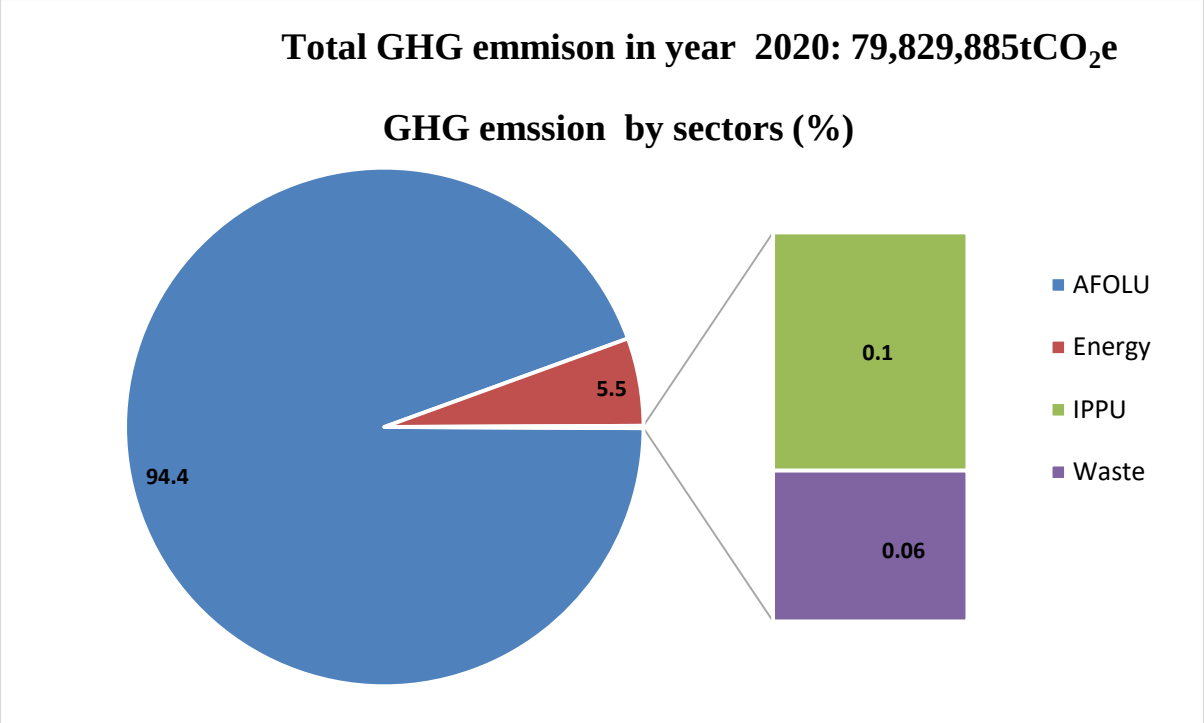


Figure 4. Percentage of estimated GHG emission by sector (base year)

3.1. Agriculture, Forestry, and Other Land Use (AFOLU)

Greenhouse Gas (GHG) inventory in the Agriculture, Forestry, and Other Land Use (AFOLU) sector requires quantification of emissions, removals, and terrestrial carbon stock across all types of land use. The AFOLU sector covers three categories: land, livestock, and aggregate and non-CO_2 emission sources from land. Regarding land, which is expected to have a major contribution to CO_2 emission, the IPCC identified six major land use categories including forest land, cropland, grassland, wetlands, settlements, and other land. These land categories are further subdivided into land remaining in the same category and land converted from one category to another.

The AFOLU sector has also some unique characteristics for developing and using inventory methods. This is partly because there are many processes leading to emissions and removals of GHGs, which can be widely dispersed in space and highly variable in time. Although the focus is on addressing emissions because of anthropogenic factors, the factors governing emissions and removals can also be both natural and anthropogenic. Differentiating the causal factors between the two could also be difficult at times.

For the AFOLU sector, anthropogenic GHGs and removals by sinks are defined as all those occurring on "managed land." Managed land is "land where human interventions and practices have been applied to perform production, ecological, or social functions" (IPCC, 2006). The key rationale for the use of managed land as a proxy for anthropogenic effects is that the preponderance of anthropogenic effects occurs on managed lands.

Accordingly, the estimation of GHG emissions and removals in the AFOLU sector includes:

- CO_2 emissions and removals from carbon stock changes in biomass, dead organic matter, and mineral soils, for all managed soils;
- CO_2 and non-CO_2 emissions from a fire on all managed lands;
- N_2O emissions from all managed soils;
- CO_2 emissions associated with liming and urea application to managed soils;
- CH4 emissions from rice cultivation;
- CO_2 and N_2O emissions from managed wetlands;
- CH4 emission from livestock (enteric fermentation);
- CH4 and N_2O emissions from manure management systems; and
- Carbon stock change associated with harvested wood products.

Consequently, emissions from the AFOLU sector consist of CO_2, N_2O, and CH4 gases emanating from the three categories mentioned above. A summary of the respective emissions from the three categories of the AFOLU sector in the Amhara region (land, livestock, and Aggregate and non-CO_2 sources on land) for the baseline year (2020) and projections for 2030 with business-as-usual and intervention scenarios are given. The AFOLU sector has a total emission of 75,341,476 tons of CO2e for the base year, 101,463,840 tons of CO_2e with BAU scenario, and 54,623,090 tons of CO_2e with interventions (Tables15 &16 and Figures 5 & 6). The majority of the contributions in the AFOLU sector come from the two subcategories, livestock and land, and the contribution of the aggregate and non-CO_2 sources on land is small. Land use and land cover change accounts for more than 70% of the total emissions witnessing the fact that there are serious problems of deforestation and land degradation in the region. This further entails the need to focus on the sector and design appropriate strategies to curve the situation. For example, had intervention measures started in time in 2020, the base year, it would have been possible to reduce the emission level to about 30 million tons of CO_2e by 2030. This should have been a huge reduction from the possible emission of 54.6 million tons of CO_2e projected to occur in the same year. The details are presented under each subsection.

Table 15. Emissions in tons of CO_2e by the AFOLU subcategories for the base year and projections with two scenarios

Subcategory	**Base Year, 2020**	**Projections for 2030**	
		With BAU Scenario	With Intervention
Livestock	20,330,400	28,049,960	16,262,140
Land	54,700,000	73,000,000	38,080,000
Aggregate Sources	311,076	413,880	280,950
Total	**75,341,476**	**101,463,840**	**54,623,090**

Table 16. Emissions in tons of CO2e by the GHG Sources in the AFOLU sector for the base year and with BAU and Intervention Scenarios

Subcategory	**Base Year**				**BAU**				**With Intervention**			
	CO_2	CH4 CO_2e	N_2O CO_2e	Total CO_2e	CO_2	CH4 in CO_2e	N_2O, CO_2e	Total CO_2e	CO_2	CH4, CO_2e	N_2O, CO_2e	Total CO_2e
Livestock		20185220	145180	20330400		27876520	173440	28049960		16161600	100540	16262140
Land	54700000			54700000	73000000			73000000	38080000			38080000
Aggregate Sources	196976	114100		311076	262180	151700		413880	197100	83850		280950
Total	**54896976**	**20299320**	**145180**	**75,341,476**	**73262180**	**28028220**	**173440**	**101,463,840**	**38277100**	**16245450**	**100540**	**54,623,090**

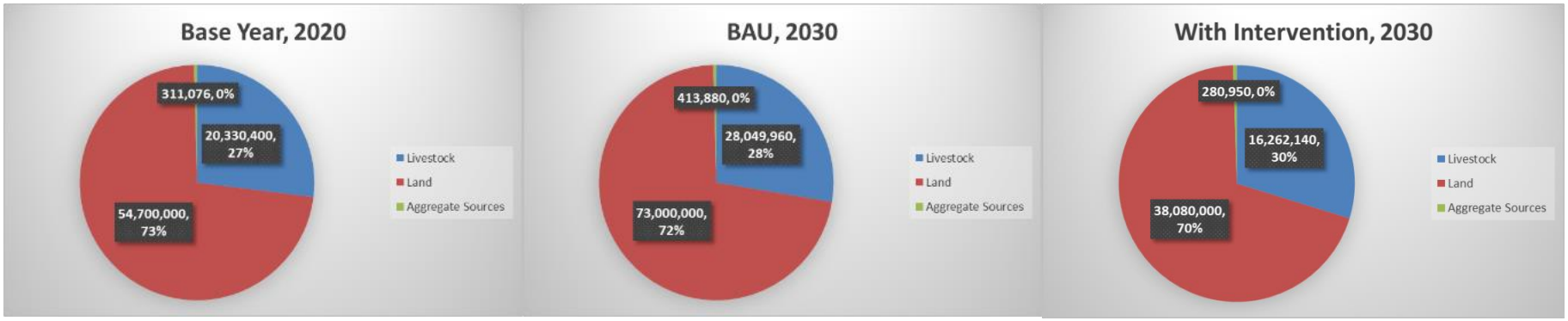


Figure 5. Emissions of the subsectors for the base year and with BAU and intervention scenarios

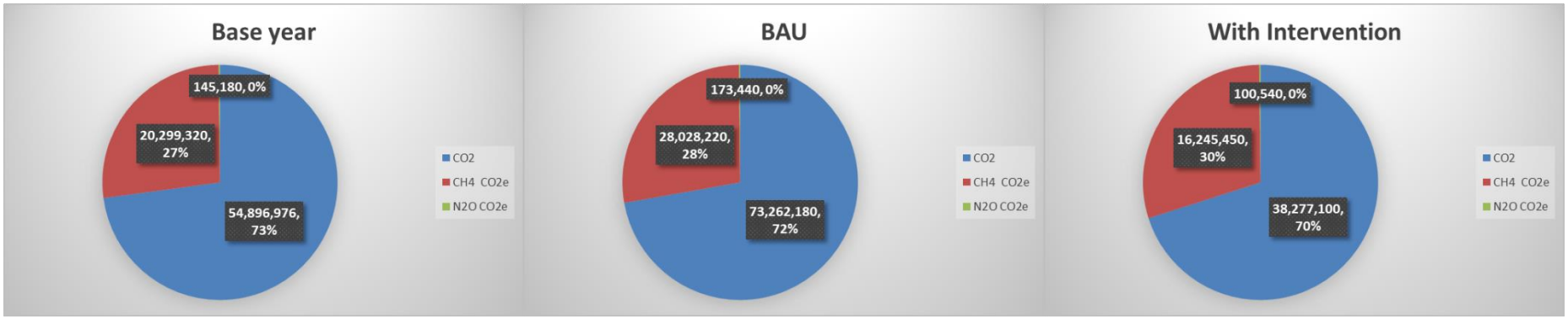


Figure 6. Emissions by GHG sources in the AFOLU sector for the base year and with BAU and Intervention Scenarios

3.1.1. Livestock

In 2020, the GHG emissions from livestock were 20,330,400 tons of CO2e. This reference emission is 22.68% of the country's total emission (89,654,970 tons of CO2e) inventoried in 2018. The contribution of GHG from livestock is increased from 20,330,400 to 28,049,960 tons of CO2e in 2030 in the business-as-usual scenario. In the intervention scenario, the GHG from livestock decreased from 20,330,400 to 16,262,140 tons of CO2 eq. in 2030. Most livestock GHG emissions were from enteric fermentation (Tables 17 and 18). Among the livestock species, cattle followed by sheep and goats contributed to the largest share of GHG emissions in the region. Other species such as camels, equines, and poultry contributed less GHG emissions.

Table 17. GHG emissions from livestock production for the baseline, 2020 (tons)

Species/Livestock category	**CH_4**	**N_2O**	**CH_4, CO_2e.**	**N_2O, CO_2e.**	**Total CO_2e.**
Dairy Cows	28,670	23	808,920	6,160	815,080
Other Cattle	544,450	475	15370,370	125,770	15,496,140
Sheep	54,250	18	1,523,870	4,870	1,528,740
Goats	36,440	15	1,024,410	4,090	1,028.500
Camels	2,410	0.3	67,550	70	67,620
Horses	9,200	3	258,320	720	259,040
Mules and Donkeys	39,950	12	1,121,700	3,100	1,124,800
Poultry	360	1	10,080	390	10,470
Total	**715,730**	**548**	**20,185,220**	**145,180**	**20,330,400**

Table 18. Projected GHG emissions from livestock production, 2030 (tons)

Species/Livestock category	Business-as-Usual Scenario					With Interventions Scenario				
	CH_4	**N_2O**	**CH_4 CO_2e**	**N_2O CO_2e**	**Total CO_2e**	**CH_4**	**N_2O**	**CH_4, CO_2e.**	**N_2O, CO_2e.**	**Total CO_2 e**
Dairy Cows	48500	31	1,358,000	8,220	1,366,220	42,430	30	1,188,040	7,950	1,195,990
Other Cattle	746,030	553	20,888,840	146,550	21,035,390	359,340	285	10,061,520	75,530	10,137,050
Sheep	66,770	23	1,869,560	6,100	1,875,660	68,900	23	1,929,200	6,100	1935,300
Goats	52,400	22	1,467,200	5,830	1,473,030	53,930	22	1,510,040	5,830	1,515,870
Camels	3,500	0.4	98000	110	98,110	2,440	0.3	68,320	80	68,400
Horses	12,240	4	342,720	1,060	343,780	9,290	3	260,120	800	260,920
Mules and Donkeys	65,680	19	1,839,040	5,040	1,844,080	40,340	13	1,129,520	3,450	1132,970
Poultry	470	2	13,160	530	13,690	530	3	14,840	800	15,640
Total	**995590**	**654**	**27,876,520**	**173,440**	**28,049,960**	**577,200**	**379**	**16,161,600**	**100,540**	**16,262,140**

3.1.2. Land use land cover

3.1.2.1. Land use land cover dynamics between 2017 and 2022

The region covers a total area of **17,029,148** ha (170,291 km^2), including the Wolqayit and Raya areas. Most of the area of the region (about 38%) was covered by wooded grassland (including shrubland) and the cropland covered around 36% of the total area of the region. Forests cover about 21% (20.8%) of the region by the reference year 2020. The settlement area (including rural villages) covered over 3% of the area of the region (Figure 7 and Table 19).

The trend of land use/land cover change (between 2017 and 2022) shows a significant decline in forest cover while there has been a significant increment in cropland and built-up areas. Despite the different efforts that have been invested to avert the trend of deforestation, the current study indicated that the net balance on forest cover change is negative. It is a matter of fact that forest development has been promoted through different responsible offices at a watershed scale, private woodlots, and forest estate scale. However, those efforts are more prevalent in the dry afro-montane biome where population density is high and hence is wood demand. In the lowland areas, particularly in the Metema and Wolqayit areas, there is a high rate of deforestation. The lack of peace and security in those areas would have exacerbated the problem, as the effort of forest development and protection in those areas might have been constrained by the ongoing conflict in the last few years. Ongoing human displacement and informal settlement in the lowland areas might also have aggravated the problem of deforestation in these areas. Therefore, considerable attention should be given to the situation of the lowland forest areas while analyzing the overall trend of vegetation cover in the region.

On the contrary, the cropland area has increased significantly during the last five years, which can also be due to the legal granting of large-scale commercial farms in the lowland areas as well as due to illegal encroachment of cropland at the forest frontier. Another pertinent reason can be that many refugees displaced from other regions and countries such as Eritrea and Sudan were deployed in the lowland areas which led to an increase in cropland area at the expense of forests and wooded land.

Besides, there had been a slight increment in wooded grassland. However, the bare land and water bodies do not show a significant change. Watershed management efforts in the highland areas had a significant effect on increasing the vegetation in the Afromontane biome. Despite the construction of medium and large-scale dams in the region such as the Rib Dam, the water bodies did not show any significant change.

Table 19. Summary of the LULC data for 2017 and 2022 and that of 2020

LULC class	2017 Area, ha	% cover	2022 Area, ha	% cover	2020 Area, ha	% cover
Water	348540.1	2.0	339976.9	2.0	343402.2	2.0
Forest	4010441	23.6	3220709	18.9	3536602	20.8
Cropland	5762710	33.8	6271906	36.8	6068228	35.6
Settlement	438336.5	2.6	624564.4	3.7	550073.2	3.2
Wooded grassland	6449871	37.9	6562701	38.5	6517569	38.3
Other land	19574.18	0.1	9072.419	0.1	13273.12	0.1
Total area(ha)	**17029472.78**	**100**	**17028929.72**	100	**17029147.52**	100

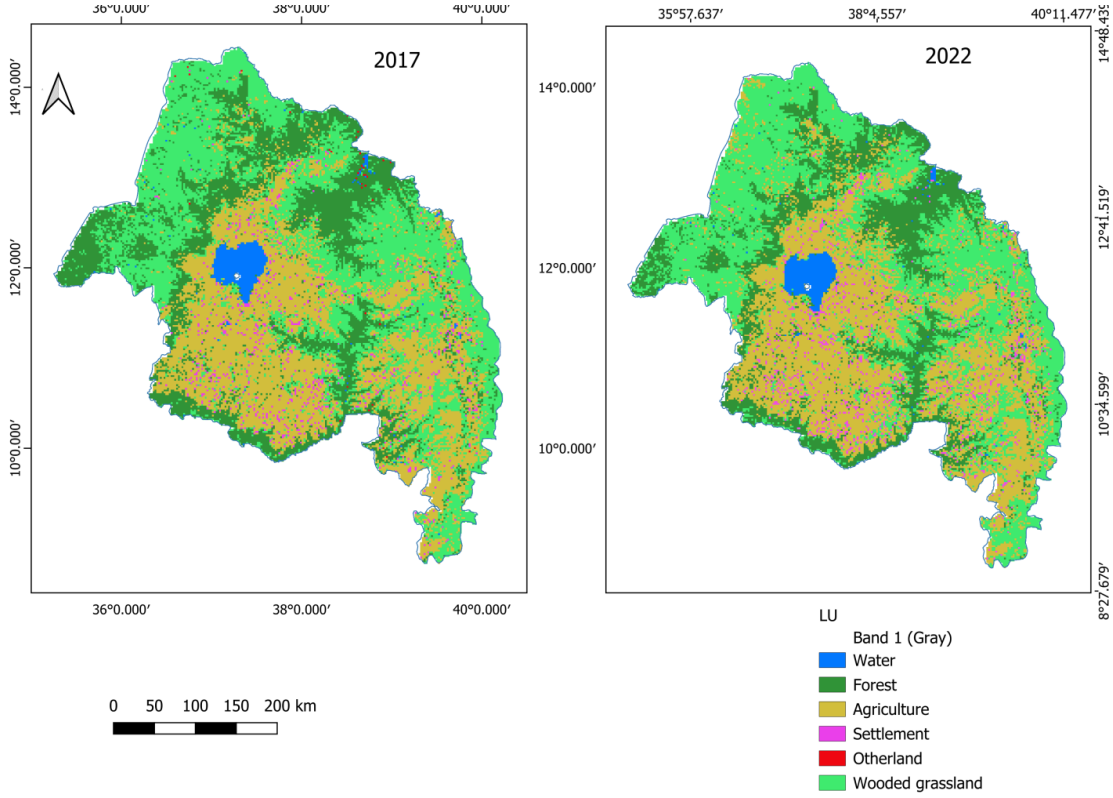


Figure 7. LULC map of the Amhara Region for the years 2017 and 2022

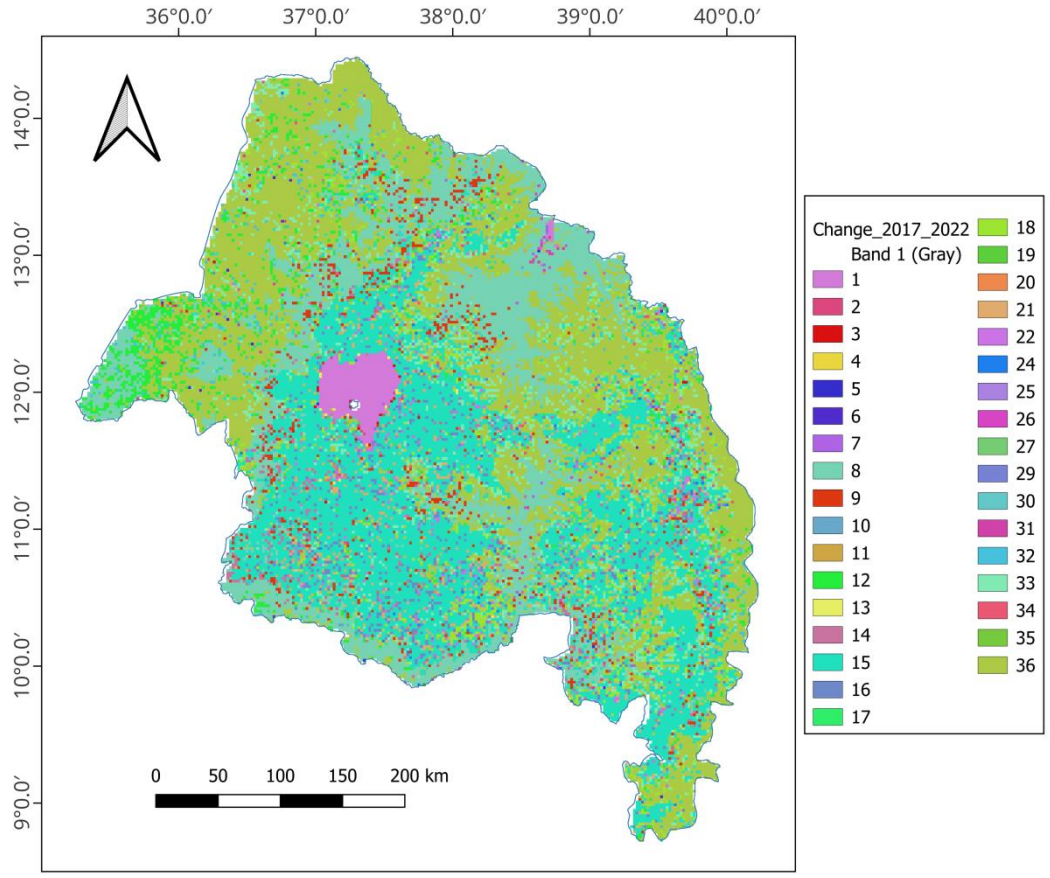


Figure 8. LULC Change matrix spatial map

Table 20. Legend guide to the LULC change detection of Figure 8.

Year		**Year 2022**					
	LULC class	Water	Forest	Cropland	Built-up Area	Wooded grassland	Other land
	Water	**1**	2	3	4	6	5
	Forest	7	**8**	9	10	12	11
2017	Cropland	13	14	**15**	16	18	17
	Built-up Area	19	20	21	**22**	24	23
	Wooded grassland	31	32	33	34	**36**	35
	Other land	25	26	27	28	30	**29**

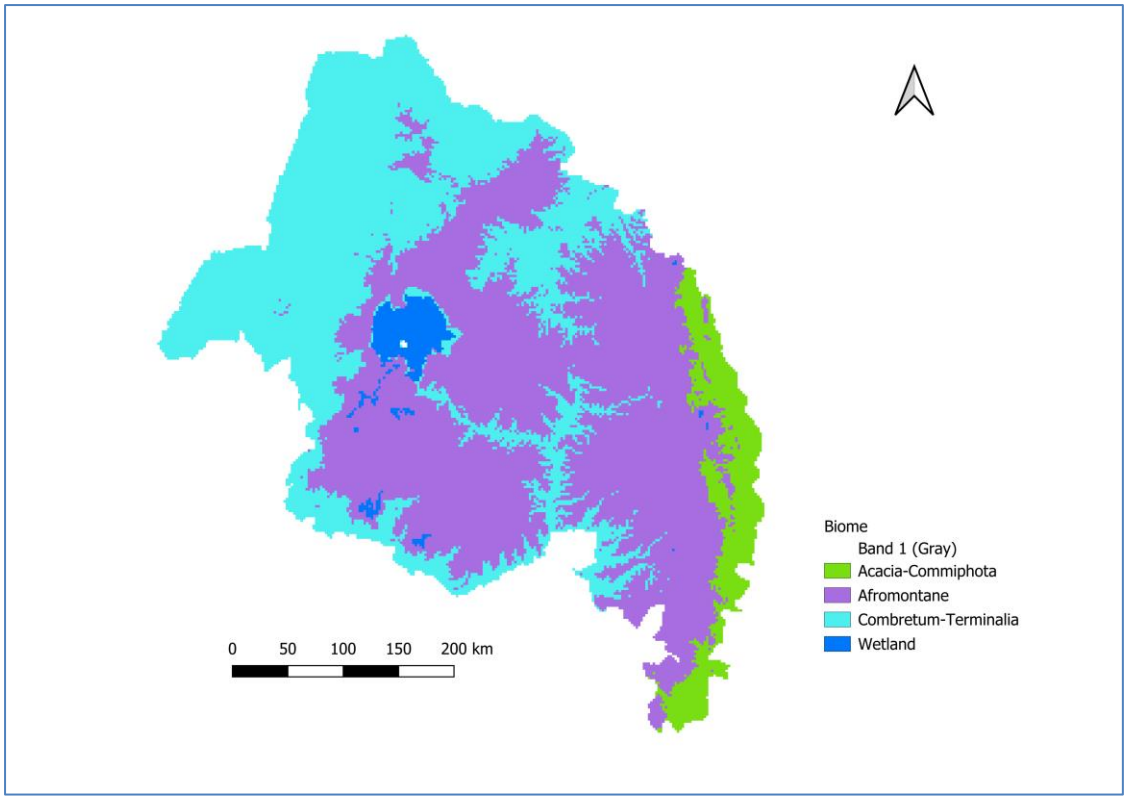


Figure 9. Map of the different biomes in the Amhara Region, Ethiopia

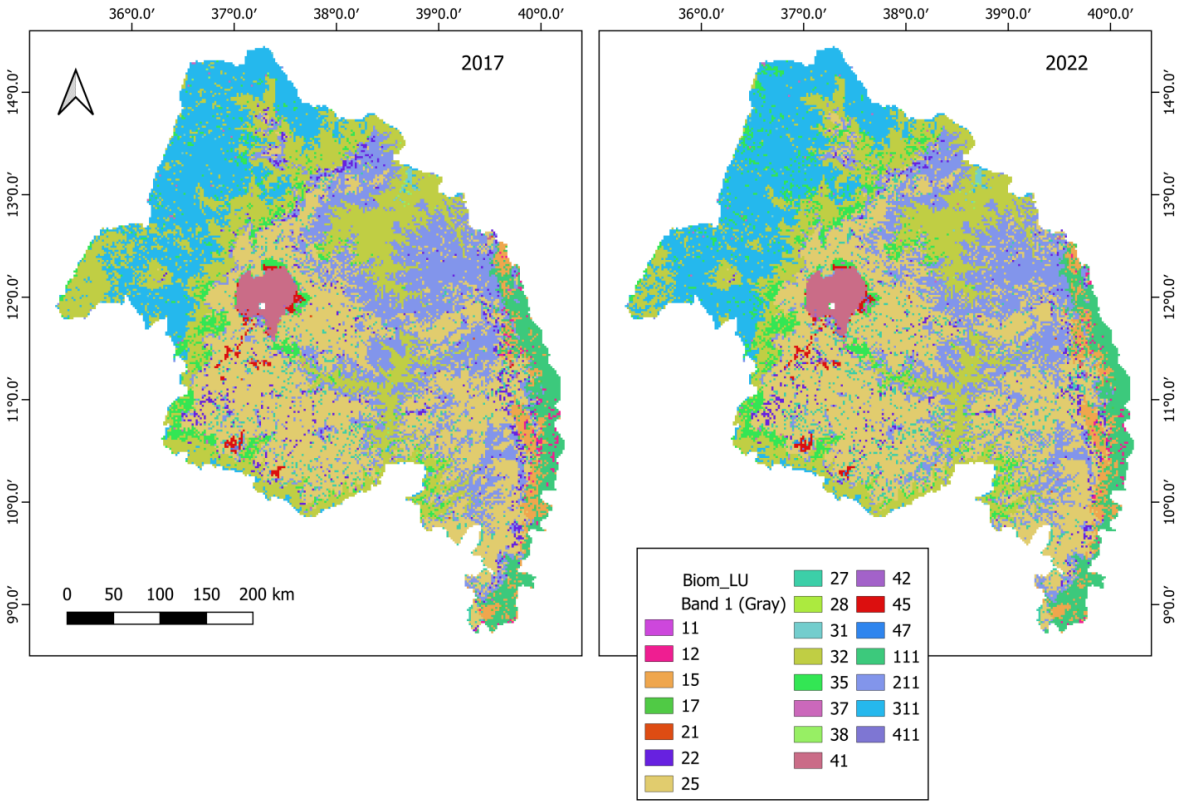


Figure 10. Biome and LULC classes combined in different periods

Table 21. Code of Biome and LULC combined (a reference to the legend of Figure 10)

LULC	Biomes			
	Acacia-Commiphora	Dry-Afromontane	Combretum-Terminalia	Wetlands
Water	11	21	31	41
Forest	12	22	32	42
Cropland	15	25	35	45
Settlement	17	27	37	47
Other land	18	28	38	48
Wooded grassland	111	211	311	411

Looking at the land cover change matrix (Table 23), about 392,427.6 ha of forest was converted to cropland during the 2017 to 2022 period, which translates to an average annual deforestation rate of 78,485 ha, which is not far from the national deforestation rate of 92, 000 ha per year reported for the period extending between 2000 and 2013 (MEFCC 2017). There is a large area of forest converted to wooded grassland too, although this variation can happen due to the detection capacity of the satellites of the two periods to differentiate between the forest and wooded grassland areas. There was also over 21,983 ha of forest converted to the built-up area, which implies the conversion of over 4,387 ha of forest per annum to the built-up area on average. On the other hand, about 12,000 ha of other land (predominantly bare land) was converted to forestland and about 9 ha of other land was converted to water, which can be due to the recent dams constructed in different parts of the region (Table 22).

Table 22. LULC change matrix between 2017 and 2022 of the Amhara Region

Year		**Year 2022**					
	LULC class	Water	Forest	Cropland	Built-up Area	Wooded grassland	Other land
2017	Water	**308870.4**	15275.3	10533.9	1918.4	9557.1	952.7
	Forest	11953.0	**3011095.2**	392427.6	21983.2	563790.8	5256.0
	Cropland	9114.8	200835.9	**4629439.0**	433597.3	487765.0	954.8
	Built-up Area	961.4	16247.6	272231.9	**108746.3**	40149.2	-
	Wooded grassland	8589.2	157984.6	964623.4	57842.3	**5252429.0**	477.4
	Other land (bare land)	8.8	11931.1	950.5	-	5256.0	**1427.9**

3.1.2.2. Carbon stock of the region

The region's carbon stock was determined by estimating three carbon pools, namely, the above-ground biomass, below-ground biomass, and deadwood. Each source was determined separately and added together to give the total carbon stock of the region.

i) Above-ground carbon stock

The above-ground carbon stock takes the biggest share of the total carbon stock. The above-ground carbon stock of the Amhara region was found to be 202.8 million tons in 2017 and declined to 185.5 million tons in 2022 (Figure 11). Accordingly, the above-ground carbon stock in 2020 was estimated to be about 192.5 million tons (Table 23).

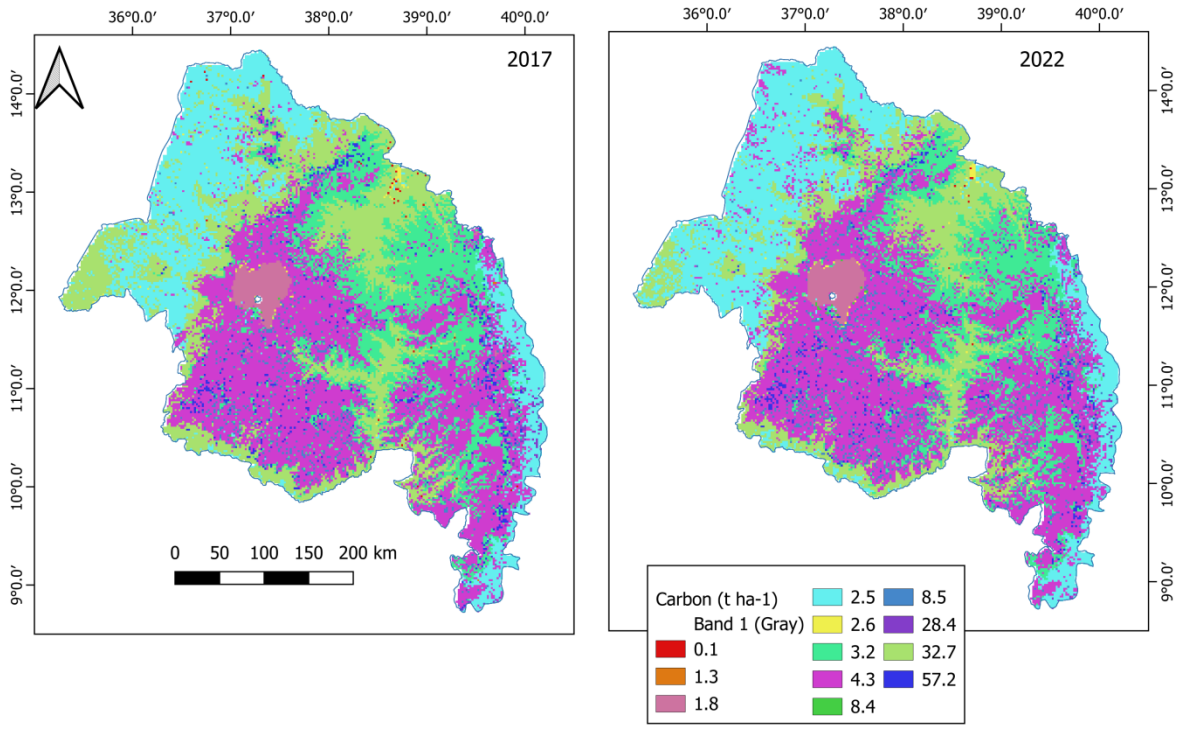


Figure 11. Spatial distribution of estimated above-ground carbon stock (ton ha-1) in the Amhara region in years 2017 and 2022.

Table 23. Above-ground carbon stock in the Amhara region in different land use land cover classes and biomes and different periods

Biome	LULC	Biome LULC CODE	carbon stock (ton/ha)	2017		2022		2020	
				Area (ha)	Carbon stock (ton)	Area (ha)	Carbon stocks (ton)	Area (ha)	Carbon stock (ton)
Acacia-Commiphora	Water	11	1.3	1432	1862	955	1241	1146	1490
Acacia-Commiphora	Forest	12	28.4	63026	1789936	50137	1423892	55293	1570311
Acacia-Commiphora	Cropland	15	4.3	325634	1400225	335202	1441369	331375	1424912
Acacia-Commiphora	Built-up	17	8.5	22441	190749	36290	308462	30750	261377
Acacia-Commiphora	Bare land	18	0.1	955	95	0	0	382	38
Acacia-Commiphora	Shrub-grass	111	2.5	741987	1854967	735343	1838359	738001	1845002
Dry-Afromontane	Water	21	1.8	5252	9454	4775	8595	4966	8938
Dry-Afromontane	Forest	22	57.2	344255	19691392	261190	14940077	294416	16840602
Dry-Afromontane	Cropland	25	4.3	4768005	20502421	5006543	21528133	4911128	21117850
Dry-Afromontane	Built-up	27	8.5	385317	3275198	541958	4606640	479301	4074062
Dry-Afromontane	Bare land	28	0.1	2865	286	1432	143	2005	201
Dry-Afromontane	Shrub-grass	211	3.2	3244879	10383612	2934689	9391004	3058765	9788048
Combretum-Terminalia	Water	31	2.6	41062	106762	34857	90629	37339	97082
Combretum-Terminalia	Forest	32	32.7	3599638	117708173	3096082	101241888	3297504	107828394
Combretum-Terminalia	Cropland	35	4.3	586332	2521227	854717	3675285	747363	3213662
Combretum-Terminalia	Built-up	37	8.5	23396	198866	33902	288169	29700	252448
Combretum-Terminalia	Bare land	38	0.1	15756	1576	7640	764	10886	1089
Combretum-Terminalia	Shrub-grass	311	8.9	2454668	21846543	2691166	23951376	2596567	23109445
Wetlands	Water	41	1.8	300805	541450	299390	538902	299956	539921
Wetlands	Forest	42	8.4	3342	28075	10505	88241	7640	64174
Wetlands	Cropland	45	4.3	82602	355189	75444	324411	78307	336722
Wetlands	Built-up	47	8.5	7162	60877	12415	105527	10314	87667
Wetlands	Bare land	48	0.1	8117				3247	325
Wetlands	Shrub-grass	411	1.8	1432	14611	4297	7735	3151	5672
Total					**202483547**		**185800840**		**192469427**

ii) Below-ground carbon stock

Below-ground carbon accounts for 20 – 40% of the above-ground carbon depending on the root-to-shoot ratio of the species. In this study, the estimated amount of below-ground carbon is about 71 million tons for 2020, which is about a third of the above-ground carbon (Figure 12, Table 24).

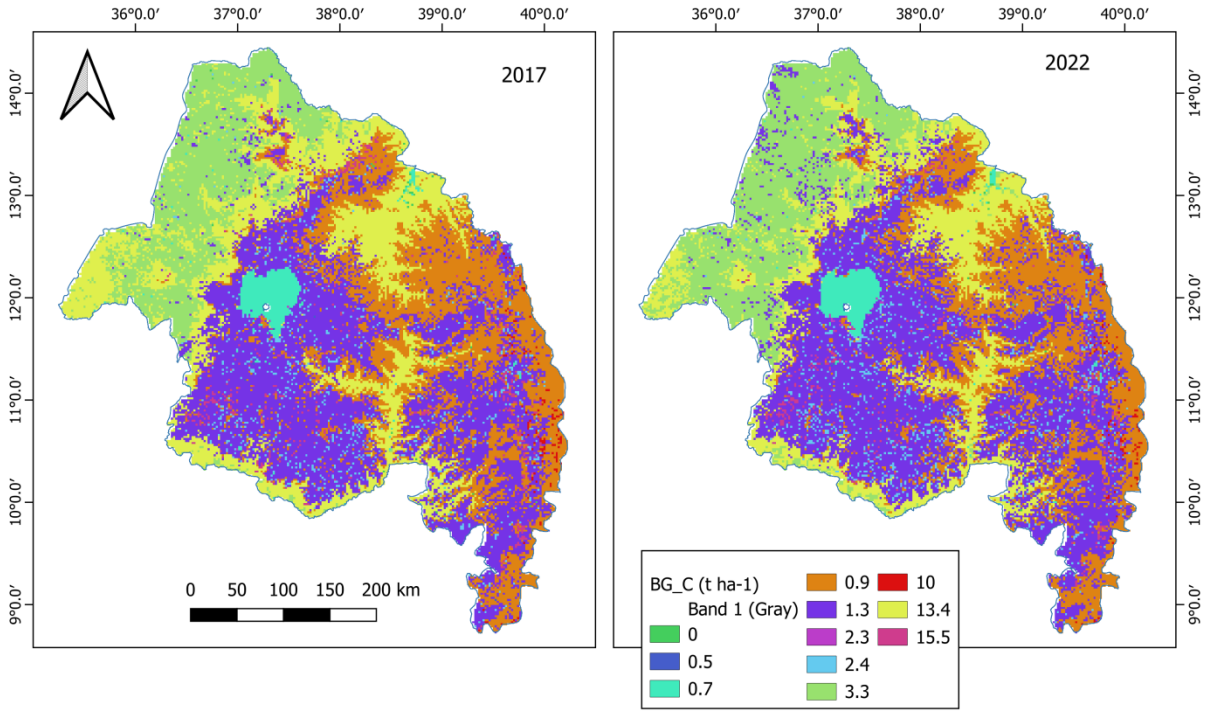


Figure 12. Below ground carbon stock (ton ha-1) for 2017 and 2022

Table 24. Below-ground carbon stock (ton) in the Amhara region in different land use land cover classes and biomes and different periods

Biome	LULC	LULC class_2017	carbon stocks (Mg/ha)	2017		2022		2020	
				Area (ha)	Carbon stocks (tone)	Area (ha)	Carbon stocks (tone)	Area (ha)	Carbon stocks (tone)
Acacia-Commiphora	Water	11	0.5	1432	716	955	477	1146	573
Acacia-Commiphora	Forest	12	10	63026	630260	50137	501371	55293	552926
Acacia-Commiphora	Cropland	15	1.3	325634	423324	335202	435763	331375	430787
Acacia-Commiphora	Built-up	17	2.4	22441	53858	36290	87095	30750	73800
Acacia-Commiphora	Bare land	18	0	955	0	0	0	382	0
Acacia-Commiphora	Shrub-grass	111	0.9	741987	667788	735343	661809	738001	664201
Dry-Afromontane	Water	21	0.5	5252	2626	4775	2387	4966	2483
Dry-Afromontane	Forest	22	15.5	344255	5335953	261190	4048448	294416	4563450
Dry-Afromontane	Cropland	25	1.3	4768005	6198407	5006543	6508506	4911128	6384466
Dry-Afromontane	Built-up	27	2.4	385317	924761	541958	1300698	479301	1150323
Dry-Afromontane	Bare land	28	0	2865	0	1432	0	2005	0
Dry-Afromontane	Shrub-grass	211	0.9	3244879	2920391	2934689	2641220	3058765	2752889
Combretum-Terminalia	Water	31	0.7	41062	28743	34857	24400	37339	26137
Combretum-Terminalia	Forest	32	13.4	3599638	48235149	3096082	41487499	3297504	44186559
Combretum-Terminalia	Cropland	35	1.3	586332	762232	854717	1111132	747363	971572
Combretum-Terminalia	Built-up	37	2.4	23396	56150	33902	81365	29700	71279
Combretum-Terminalia	Bare land	38	0	15756	0	7640	0	10886	0
Combretum-Terminalia	Shrub-grass	311	3.3	2454668	8100404	2691166	8880848	2596567	8568670
Wetlands	Water	41	0.7	300805	210564	299390	209573	299956	209969
Wetlands	Forest	42	2.3	3342	7687	10505	24161	7640	17571
Wetlands	Cropland	45	1.3	82602	107383	75444	98078	78307	101800
Wetlands	Built-up	47	2.4	7162	17189	12415	29796	10314	24753
Wetlands	Bare land	48	0	8117	0		0	3247	0
Wetlands	Shrub-grass	411	0.7	1432	1002	4297	3008	3151	2206
Total					**74684587**		**68137635**		**70756416**

iii) Carbon stock in deadwood

Carbon stock stored in deadwood was estimated and presented as follows (Table 25).

Table 25. Deadwood carbon stock (tone) in the Amhara region in different land use land cover classes and biomes

Biome	LULC	LULC class_2017	carbon stocks (Mg/ha)	2017		2022		2020	
				Area (ha)	Carbon stocks (ton)	Area (ha)	Carbon stocks (ton)	Area (ha)	Carbon stocks (ton)
Acacia-Commiphora	Water	11	0.9	1432	1289	955	859	1146	1031
Acacia-Commiphora	Forest	12	2.6	63026	163868	50137	130356	55293	143761
Acacia-Commiphora	Cropland	15	2.6	325634	846648	335202	871525	331375	861574
Acacia-Commiphora	Built-up	17	0.5	22441	11221	36290	18145	30750	15375
Acacia-Commiphora	Bare land	18	0	955	0	0	0	382	0
Acacia-Commiphora	Shrub-grass	111	1.9	741987	1409775	735343	1397152	738001	1402202
Dry-Afromontane	Water	21	0.9	5252	4727	4775	4297	4966	4469
Dry-Afromontane	Forest	22	15.8	344255	5439229	261190	4126805	294416	4651775
Dry-Afromontane	Cropland	25	2.6	4768005	12396813	5006543	13017012	4911128	12768932
Dry-Afromontane	Built-up	27	0.5	385317	192659	541958	270979	479301	239651
Dry-Afromontane	Bare land	28	0	2865	0	1432	0	2005	0
Dry-Afromontane	Shrub-grass	211	1.9	3244879	6165270	2934689	5575909	3058765	5811654
Combretum-Terminalia	Water	31	0.9	41062	36956	34857	31371	37339	33605
Combretum-Terminalia	Forest	32	2.6	3599638	9359059	3096082	8049813	3297504	8573511
Combretum-Terminalia	Cropland	35	2.6	586332	1524463	854717	2222265	747363	1943144
Combretum-Terminalia	Built-up	37	0.5	23396	11698	33902	16951	29700	14850
Combretum-Terminalia	Bare land	38	0	15756	0	7640	0	10886	0
Combretum-Terminalia	Shrub-grass	311	1.9	2454668	4663869	2691166	5113215	2596567	4933477
Wetlands	Water	41	0.9	300805	270725	299390	269451	299956	269960
Wetlands	Forest	42	2.6	3342	8689	10505	27313	7640	19863
Wetlands	Cropland	45	2.6	82602	214765	75444	196155	78307	203599
Wetlands	Built-up	47	0.5	7162	3581	12415	6207	10314	5157
Wetlands	Bare land	48	0	8117	0		0	3247	0

Wetlands	Shrub-grass	411	1.9	1432	2721	4297	8165	3151	5987
Total					**74684587**		**68137635**		**70756416**

iv) Total Carbon stock in the LULC of the Amhara Region

The total carbon stock in the Amhara Region is estimated to be about 305 million tons in 2020 and it has shown a significant reduction from about 320 million tons to 244 million tons between 2017 and 2022. This is mostly related to deforestation and expansion of cropland areas which mostly has taken place in the western part of the region (Table 26).

Table 26. Total Carbon stock (AGB + BGB + Deadwood) in different land use land cover classes and biomes (tone) in the Amhara region

Biome	**LULC**	**LULC class_2017**	**2017**		**2022**		**2020**	
			Area (ha)	**Carbon stocks (tone)**	**Area (ha)**	**Carbon stocks (tone)**	**Area (ha)**	**Carbon stocks (tone)**
Acacia-Commiphora	Water	11	1432	3867	955	3055	1146	3094
Acacia-Commiphora	Forest	12	63026	2584064	50137	1604385	55293	2266998
Acacia-Commiphora	Cropland	15	325634	2670198	335202	2648096	331375	2717273
Acacia-Commiphora	Built-up	17	22441	255828	36290	362897	30750	350552
Acacia-Commiphora	Bare land	18	955	95	0	0	382	38
Acacia-Commiphora	Shrub-grass	111	741987	3932531	735343	3970855	738001	3911404
Dry-Afromontane	Water	21	5252	16807	4775	17667	4966	15890
Dry-Afromontane	Forest	22	344255	30466574	261190	19328072	294416	26055827
Dry-Afromontane	Cropland	25	4768005	39097641	5006543	39551688	4911128	40271248
Dry-Afromontane	Built-up	27	385317	4392617	541958	5419576	479301	5464036
Dry-Afromontane	Bare land	28	2865	286	1432	1575	2005	201
Dry-Afromontane	Shrub-grass	211	3244879	19469273	2934689	17901602	3058765	18352590
Combretum-Terminalia	Water	31	41062	172461	34857	156858	37339	156824
Combretum-Terminalia	Forest	32	3599638	175302381	3096082	112387783	3297504	160588464
Combretum-Terminalia	Cropland	35	586332	4807922	854717	6752267	747363	6128378

Combretum-Terminalia	Built-up	37	23396	266714	33902	339022	29700	338577
Combretum-Terminalia	Bare land	38	15756	1576	7640	8404	10886	1089
Combretum-Terminalia	Shrub-grass	311	2454668	34610817	2691166	31755757	2596567	36611592
Wetlands	Water	41	300805	1022738	299390	1107743	299956	1019850
Wetlands	Forest	42	3342	44451	10505	126059	7640	101609
Wetlands	Cropland	45	82602	677337	75444	596011	78307	642121
Wetlands	Built-up	47	7162	81647	12415	124149	10314	117577
Wetlands	Bare land	48	8117	0	0	0	3247	325
Wetlands	Shrub-grass	411	1432	18334	4297	20198	3151	13866
Total			**17029502**	**319896156**	**17029502**	**244183721**	**17029502**	**305129421**

v) The above and below-ground biomass carbon stock change

The total carbon stock in the region was estimated to be about **320** million tons in the year 2017 which is reduced to **244** million tons in 2022. This implies that there is a difference of about 76 million tons between the two periods. Therefore, based on the stock difference approach, the average annual carbon stock change is equivalent to **15.2** million tons which is about **54.7** million tons of carbon dioxide equivalent (CO_2e) that emanate from land use and land cover change. Most of this comes from the forest where the emission from deforestation contributes about **35.5** million tons of carbon dioxide equivalent, which is higher than the national emission reference that comes from deforestation as estimated for the 2000 to 2013 baseline scenario. This is because the national assessment report has undermined the dry forest areas that are dominant in the Amhara Region.

vi) The forest sector

As forests contain the highest above-ground biomass and carbon, and are the biggest sequesters of carbon dioxide, it was necessary to give particular emphasis to the forest sector. Emissions due to deforestation and sinks due to afforestation are critical processes in analyzing climate change. Since 2010 the UNFCC has approved the REDD+ (Reducing Emission from Deforestation and Forest Degradation) project to support countries that have significant forests but are facing the problem of deforestation and forest degradation. Hence monitoring the forest loss and gain (deforestation and afforestation) during a historic period is pertinent to determining the carbon emission reference level. Therefore, during the 2017 – 2022 period, the forest land has reduced from 4,010,441 ha in 2017 to 3,536,602 ha in 2020, and 3,220,709 ha in 2022 (Table 20). Considering the land use and land cover change dynamics in the region, 402,275 ha of land was converted to forest (this can be due to large-scale plantation, area closure, and other watershed management activities that enhanced other wooded lands to forest land) while, contrarily, 995,411 ha of forest was converted to other land, indicating a net loss in forest area (Table 27).

Table 27. The forest land conversion trend and hence carbon stock (tons) between 2017 and 2022

Forest land trend	**Area in ha**	**Carbon stock (tons)**
Forest Remains as Forest (FL)	3,011,095	156,576,940
Forest converted to other land (FOL)	995,410.6	8,560,531.16
Other land converted to forest (OLF)	402,274.5	20,918,274
FOL - OLF	593,136.1	25,682,793.13

The average annual emission from the LULC between 2017 and 2022 was equivalent to 25,682,793 tons of carbon, which is equivalent to a net emission of 18,851,170 tons of CO_2e per annum, which is net emission due to deforestation, which can be considered as the annual average emission that can be

considered as reference emission of Amhara Region for the year 2020 from deforestation. The total annual emission from deforestation is estimated at around 31 million tons of CO_2e (Table 27). This value is even higher than the reference emission level estimated for Ethiopia (MEFCC, 2017). This can be because dense woodlands are considered as forests in this study and that has raised the forest area as well as the estimated carbon. Since the new forest definition of Ethiopia accommodates trees with a height of 2 m and above as forest, the woodland in the Combretum-Terminalia Biome and above 1200 m a. b. s. l. was considered a forest as this was validated with Google Earth. Therefore, this can be one of the reasons for the inflated result, as compared to the national report, demanding further investigation.

vii) The LULC and carbon stock of the reference year (2020) and target year (2030)

For the reference year, about 21% of the area was covered by forest, 35% by cropland, 3.3% by built-up area, 2% by water, and about 54% by other wooded land. But when it comes to the carbon stock, 37% was from the forest, 18% from cropland, and 43% from other wooded lands, these three LULC types covered about 98% of the total above- and below-ground biomass carbon stock. For the target year, 2030, the forest will cover 14.5%, and wooded grassland 36.6%, respectively, showing a significant reduction from the reference year. On the contrary, cropland and built-up areas will increase to 42.6% and 5.4%, respectively. The corresponding share of the carbon stock will be 44.7% by forest (with significant reduction), 26% by cropland (with significant increment), and 24.4% by wooded grassland (Table 28).

Table 28. LULC and corresponding carbon stock of the different periods with BAU

LULC	2017		2020		2022		2030 (BAU)	
	Area (ha)	Carbon stock (ton)	Area (ha)	Carbon stock (ton)	Area (ha)	Carbon stock (ton)	Area (ha)	Carbon stock (ton)
Water	348551	1215873	343407	1195658	339977	1285323	327321.3	1237477
Forest	4010261	208397470	3654853	189012898	3417914	133446299	2464352	96216185
Cropland	5762573	47253098	6068173	49759020	6271906	49548062	7083806	55962069
Built-up	438316	4996806	550065	6270742	624565	6245644	921289.3	9212884
Bare land	27693	1957	16520	1653	9072	9979	0	0
Wooded GL	6442966	58030955	6396484	58889452	6365495	53648412	6226149	52474004
Total	**17029502**	**319896159**	**17029502**	**305129423**	**17029502**	**244183719**	**17029502**	**215102618**

3.1.2.3. The predicted emission with BAU in 2030

Table 28 presents the proportional LULC based on the 2017 -2022 trajectory. However, three major factors will affect the amount of emission of carbon dioxide from deforestation in the year 2030. The first is the expansion of cropland areas with a proportional increase in population; the second is urbanization (expansion of settlement areas, also related to the increase in population) which in

particular is aggravated by the flux of refugees; and the third is the development of large-scale investment in the forest areas. Since the population will rise from 30 million in 2020 to 40 million in 2030, considering the business-as-usual scenario, the emission from the land use land cover change is expected to rise from the current **54.7** million tons of CO_2e to about **73** million tons of CO_2e per annum in 2030.

With detailed planning and allocation of sufficient resources to realize the above three activities, the forestry sector would have the abatement potential of **58.2** million tons of CO_2e, which is higher than the current emission of **54.7** million tons of CO_2e and could have offset them. However, since four out of ten years of the implementation period have already passed it may only be practically possible to abate **34.92** million tons of CO_2e in the remaining period until 2030. This means that the potential to sequester 23.3 million tons of CO_2e is an opportunity forgone particularly considering the role that forest resources could have played in society and the environment as well as the income that they could have generated through the global carbon market. This in turn implies that the net emission in 2030 will remain at **38.08** million tons of CO_2e (73 million tons under BAU less 34.92 million tons of CO_2e that can still be sequestered with intervention). This will be much lower than the emission level estimated at 54.7 million tons of CO_2e for the base year, 2020, and the projected emission level for 2030 with the BAU scenario (73 million tons of CO_2e). Thus, realizing the potential of the sector and creating carbon-positive situations in the region will require concerted efforts and tangible commitments from all stakeholders and an injection of adequate resources into the same.

3.1.3. Aggregate Sources and Non-CO2 Emissions Sources on Land

Under this subcategory, emissions from liming, urea application, and rice cultivation were estimated. A total of 311,076 tons of CO_2e for the base year (2020) was found from the three subcategories (1,388 tons of CO_2e from lime, 195,588 tons of CO_2e from urea application, and 114,100 tons of CO_2e from rice cultivation). Predictions with business as usual (BAU) and intervention scenarios were also made. The details are presented under each subsection.

i) Emissions from liming

Lime is applied to treat acidic soils and improve crop productivity. Low crop productivity as a result of high acidic levels of soils has been reported to be a major problem of the region, particularly in east Gojam, west Gojam, Awi, and south Gondar zones. Consequently, lime application was started in 2016 in Ethiopia as well as the Amhara region to reduce the acidity of the soils and enhance plant growth. It is applied in the form of calcic limestone ($CaCO_3$), or dolomite ($CaMg(CO_3)_2$). However, lime application, be it in the form of limestone or dolomite, leads to CO_2 emissions as the carbonate limes dissolve and release bicarbonates ($2HCO_3$-), which in turn evolves into CO_2 and water (H_2O). The amount of lime applied to soils in the Amhara region in the base year (2020) and the emissions it created were analyzed and presented in Table 29.

Table 29. Emissions from liming

Sub-Category	Annual amount Tons/yr	EF	Annual carbon emissions Tons C/yr	Annual CO_2 emissions Tons CO_2/yr
Lime	3,155.5	0.12	378.66	1,388.42

ii) Emissions from urea application

Urea is applied to soils to increase the amount of nitrogen needed for optimum plant growth. However, as described in the methods section, urea emits CO_2 into the atmosphere in the process of fertilization. The total amount of urea fertilizer used in the region in the base year (2020) and the estimated amount of CO_2 emitted in the process of fertilization are presented in Table 30.

Table 30. Emissions from urea application

Sub-Category	**Annual amount Tons/yr**	**EF**	**Annual carbon emissions Tons C/yr**	**Annual CO_2 emissions Tons CO_2/yr**
Urea	266710.3	0.2	53,342.06	195,587.55

iii) CH4 emission from rice cultivation

Rice production is a recent phenomenon in Ethiopia and covers relatively small areas. It was started in the Amhara region in the South Gonder zone around Fogera plains. There is a tendency and strategy, however, to expand it and cover more areas in the region as well as in the country. In the Amhara region, it is now practiced in eight zones although the major producer remains south Gondar Zone. Yet, rice cultivation emits methane into the atmosphere and contributes to global warming. The emission levels vary with the area covered by rice, the cultivation period, and most importantly the water regime followed during the production process. Accordingly, the methane potentially emitted from rice cultivation in the region in 2020 and its CO_2e are presented in Table 31.

Table 31. CH4 emission from rice cultivation and CO2 equivalents

Sub-Category	**Annual harvested area, ha**	**Cultivation period, days**	**CH4/yr Tons**	**CO_2 Equivalent Tons**
Rice	53,707	113	4,564	**114,100**

iv) Summary of Emissions Aggregate and Non-CO_2 Sources on Land

A summary of emissions from aggregate sources and non-CO2 emission sources on land in the Amhara region in 2020 (i.e., emissions from liming, urea application, and rice cultivation) is given in Table 32. The total CO2e from this subcategory is found to be 311,076 tons of CO_2e.

Table 32.Summary of Emissions from Aggregate and Non-CO_2 Emission Sources on land

Sub-Category	Tons		
	Net CO_2	**CH4**	**Total CO_2e**
Liming	1,388.42		1,388.42
Urea Application	195,587.55		195,587.55
Rice Cultivation		4,564	114,100
Total	**196,975.97**	**4,564**	**311,076**

v) Emission Predictions for Aggregate and Non-CO_2 Sources with BAU in 2030

Emissions for the 2020 baseline year for aggregate sources and non-CO_2 emission sources on land are presented in Table 32 above. With the business-as-usual scenario, these emissions are predicted to rise roughly with the rate of growth of the population of the region. The national average rate of growth of the population was assumed and emission predictions for this subsector were made and presented as follows (Table 33).

Table 33. Predicted emissions for aggregate and non-CO_2 sources for 2030 with BAU scenario

Sub-Category	Tons of CO_2e					
	2020			**2030**		
	CO_2	CH4	Total CO_2e	CO_2	CH4	**Total CO_2e**
Liming	1,388.42		1,388.42	1,850		**1,850**
Urea Application	195,587.55		195,587.55	260,330		**260,330**
Rice Cultivation		4,564	114,100		6,070	**151,700**
Total	**196,975.97**	**4,564**	**311,076**	**262,180**	**6,070**	**413,880**

vi) Emission predictions with interventions

Appropriate interventions and mitigation measures could reduce the level of emissions of these GHG gases. Thus, measures that could help reduce GHG emissions in each sub-sector are suggested and their consequent reduction in emissions is predicted.

Liming: Liming in Ethiopia and the Amhara region has a short history. Nationally, it was started in 2016. However, it is expected to expand in the future as it is one of the strategies to treat and improve the productivity of acidic soils. The current as well as the predicted emissions from liming in the Amhara region is low though – less than 2Gg of CO_2e in ten years. So, there is no major reason to worry about it, particularly considering its role in improving the productivity of the soil as well as the livelihood of the vast majority of the people. However, it is suggested that its application should be efficient and be made based on a proper assessment of the acidity level of the soils, as the current

practice is to use an average of 30 kg per hectare. That may help reduce the use of lime and hence its contribution to GHG emissions.

Urea fertilizer application: Urea is applied to increase crop yield and will continue for the foreseeable future. However, its application and consequent contribution to GHG gas emissions can be reduced by substituting them with organic fertilizers, compost, farm yard manure, green manure, nitrogen management, and climate-smart agricultural practices. Thus, a twenty-five percent reduction in urea fertilizer application is assumed in the 2030 emission prediction.

Rice cultivation: Rice cultivation is one of the strategic directions to achieve food security in the region and is not expected to be halted. It is rather expected to expand and cover more areas in the region. Its emission to date is also low though its warming effect is twenty-five times more than CO_2, as it emits CH4. Thus, it draws attention, and measures have to be taken to reduce its emissions. The most important factor in reducing emissions from rice cultivation is managing the field and the water regime, which in turn is a combination of ecosystem type and flooding pattern. Accordingly, the following suggestions are given:

i) Conduct research and develop country-specific emission factors as we are currently using the IPCC's suggestion of 1.19, which is the world average emission factor. This factor is the default CH4 baseline emission factor assuming no flooding for less than 180 days before rice cultivation and continuous flooding during rice cultivation without organic amendments. According to the IPCC's report, the range varies between 0.65 and 1.32, and we predicted the emission factor for Ethiopia to be 0.85 for 2030, equivalent to the one used by South Asia.

ii) Conduct a study on rice cultivars that can mature in short periods as emission is partly a function of the cultivation period of rice. Currently, we are using the world average suggested for Africa, which is 113 days. It is 102 days for South East Asia, for example.

iii) Manage water regimes for irrigated schemes by arranging multiple drainage periods. This will give us a scaling factor to account for the differences in water regime during the cultivation period of 0.55 from the previously assumed 0.71 for the irrigation scheme with a single drainage period. Thus, a 0.55 scaling factor is assumed for 2030 predictions.

iv) It is also suggested to extend the range of water regimes before cultivation for more than 180 days. The scaling factor for less than 180 days was 1 and this can be reduced to 0.89 by extending the pre-season flooding for greater than 180 days. Accordingly, a scaling factor of 0.89 was assumed in the 2030 prediction.

v) Use organic amendments for rice cultivation as they significantly reduce CH4 emissions. The default emission factor for incorporating straws shortly (<30) days before cultivation is 1 and is used for our calculation. However, the use of compost, farm yard manure, green manure, and even straw incorporated for long (>30 days) before cultivation can reduce emissions with

respective emission factors of 0.17, 0.21, 0.45, and 0.19, respectively. Emission projections for 2030 are presented in Table 34.

Table 34. Predicted emissions for aggregate and non-CO2 sources for 2030 with interventions

Sub-Category	Tons of CO_2e					
	2030 BAU			2030 With Intervention		
	CO_2	CH4	Total CO_2e	CO_2	CH4	Total CO_2e
Liming	1,850		1,850	1,850		1,850
Urea Application	260,330		260,330	195,250		195,250
Rice Cultivation		6,070	151,700		3,350	83,850
Total			413,880	197,100	3,350	280,950

3.2. Energy sector

In the inventory year (2020), the regional total emission was estimated to be 79,829,885tCO_2e. The total reference greenhouse gas emissions from the energy sector accounted for 4,369,800 tCO_2e (Table 35). This indicated that the energy sector has a 5.5% contribution to the total emission of the region. Similarly, this reference emission is 16.2% of the country's total emission (25,851Gg CO2-e or 25,851,000 tons) inventoried in 2018. The national total emission of the year 2018 was about 368,835 Gg CO2-e or 368,835,000 tons. Here it could be understood that the share of the energy sector from the total regional emissions (5.5%) is comparable to the share of the national energy from the total national emissions of the year 2018 (7%). the proportion of the regional energy emission is 16.9% of the national emission of the 2018 inventory.

3.2.1. Stationary combustion emissions

The total combined CO_2 equivalent emissions from liquid and solid fuel burning in the stationary sector was 3,397.40 Gg CO_2.e or 3,397,400 tons which is 78% (4,369.8 Gg CO_2e or 4,369,800 tons) of the total energy sector emission (Table 35; Figure 15). This is comparable to about 70% of the inventory in most scientific reports in the same sector. The estimated stationary GHG emission in the Amhara region shared 16.7% of the national stationary emission of 2018. The 3,397.40 Gg CO_2e or 3,397,400 tons comprised the emission from the energy industries (2.3 Gg CO_2e or 2,300 tons), manufacturing industries and construction (13.67 Gg CO_2e or 13,670 tons), commercial/institutional (40 Gg CO_2e or 40,000 tons), residential (3,303.2 Gg CO_2e or 3,303,200 tons), and agriculture (38.2 Gg CO_2e or 38,200 tones) (Table 35; Figure 15). The lion's share of the stationary combustion emission (3,303.2 Gg CO_2e or 3,303,200 tons) was from the consumption of fuel wood and charcoal in residential areas of the urban and rural areas. The practice of pump irrigation and off-road machinery in the agricultural sector shared 38.2 Gg CO_2e or 38,200 tons of GHG emissions.

3.2.2. Mobile combustion emissions

Mobile combustion emission is the emission sourced from the transport sector. The transport sector accounted for 972.4 Gg CO_2e or 972,400 tons of the total energy sector emission which is 22% of the regional energy emission (Figure 13). Road transport accounted for 89.2% (867.7 Gg CO_2e 867,700 tons) of the total transport sector emission (972.4 Gg CO_2e) of the region. The remaining 10.8% (104.7 Gg CO_2e or 104,700 tons) was from the water transport of the region (Table 35). Compared to the national transport sector of the 2018 GHG emissions (6411.8 Gg CO_2e or 6,411,800 tons), the regional transport emissions shared 15.2%

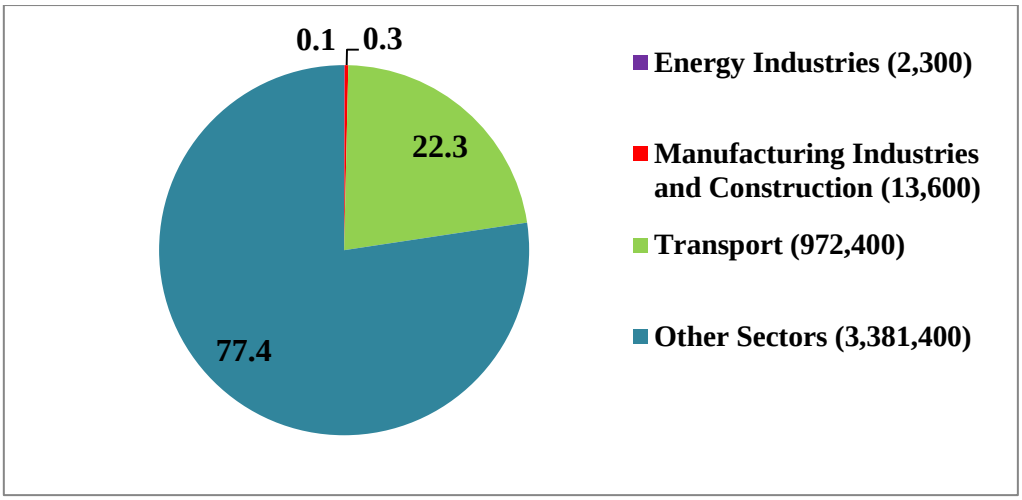


Figure 13. GHG emissions in energy sub-sectors (Gg CO_2e)

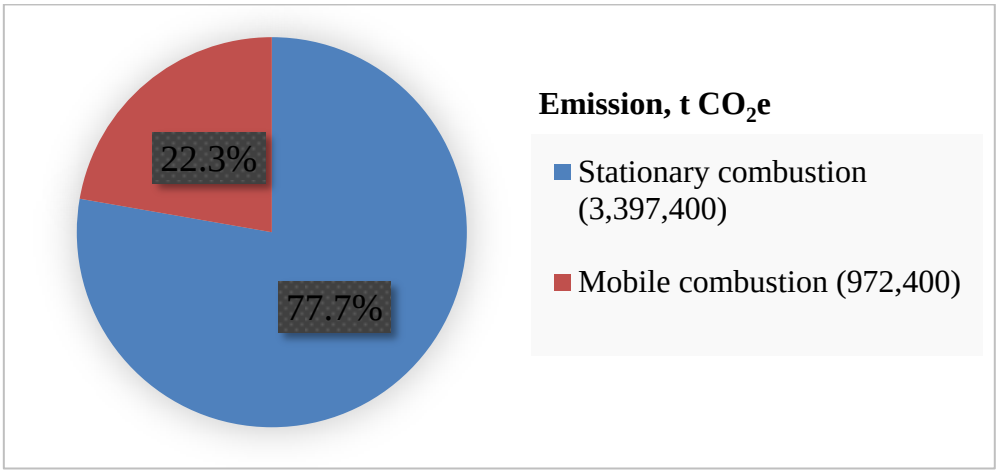


Figure 14. GHG emissions of stationary and mobile combustions

Table 35. GHG emissions from the energy sector

Total National emissions	CO2	CH4	N2O	CO_2, t CO_2-e	CH_4, t CO_2-e	N_2O, t CO_2-e	Total emission tons
Total energy emissions	4,108.143	7.403	0.205	4,108.143	207.283	54.340	**4,369,800**
Energy Industries	2.315	0.000	0.000	2.315	0.003	0.005	**2,300**
Manufacturing and Construction Industries	13.603	0.001	0.000	13.603	0.035	0.029	**13,700**
Transport	952.515	0.113	0.063	952.515	3.167	16.679	**972,400**
Road	851.884	0.077	0.051	851.884	2.153	13.610	867,700
Water	100.632	0.036	0.012	100.632	1.014	3.069	104,700
Other Sectors	3,139.710	7.289	0.142	3139.710	204.078	37.626	**3,381,400**
Commercial/Institutional	32.613	0.087	0.019	32.613	2.445	4.984	40,000
Residential	3070.593	7.197	0.117	3070.593	201.524	31.065	3,303,200
Agriculture/Forestry/Fishing	36.5045	0.0039	0.00595	36.505	0.109	1.577	**38,200**

3.2.3. Energy sector emissions by gas

From the energy sector regional total GHG emissions of (4,369.8 Gg CO_2e or 4,369,800 tons), 94% is carbon dioxide (CO_2), 5% is methane (CH_4) and 1% is nitrous oxide (N_2O) (Figure 17). This is an indication that energy combustion is the major source of CO_2 emissions as compared to other primary greenhouse gases. The burning of liquid and solid fuels has the lion's share of all three primary greenhouse gases.

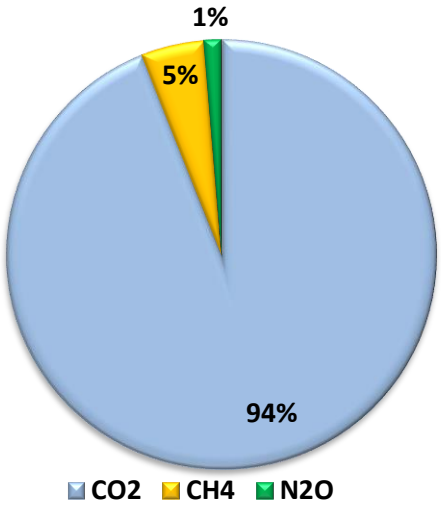


Figure 15. Greenhouse gas (GHG) emissions of the energy sector by gas type

3.2.4. Projected GHG Emissions

In GHG emission projections, both the BAU scenario and the scenario with intervention showed increased emissions. Compared to the baseline period (4,369.8 Gg CO_2e or 4,369,800 tons) a 116% (9,433.6 Gg CO_2e or 9,433,600 tons) increase of GHG emission was estimated in 2030 in the BAU scenario. In the intervention scenario of the energy sector, a 98% (8,673.7 Gg CO_2e or 8,673,700 tons) increment of GHG emissions was expected in 2030 (Table 36). The emission of GHG in the intervention scenario is lower than in the BAU scenario. In all the projected scenarios, the share of CO_2 is between 95.2% and 95.3% of the total emissions. The share of CH_4 is between 3.6% and 3.8% while the variability of NO_2 was consistently 1% (Figures 16 and 17).

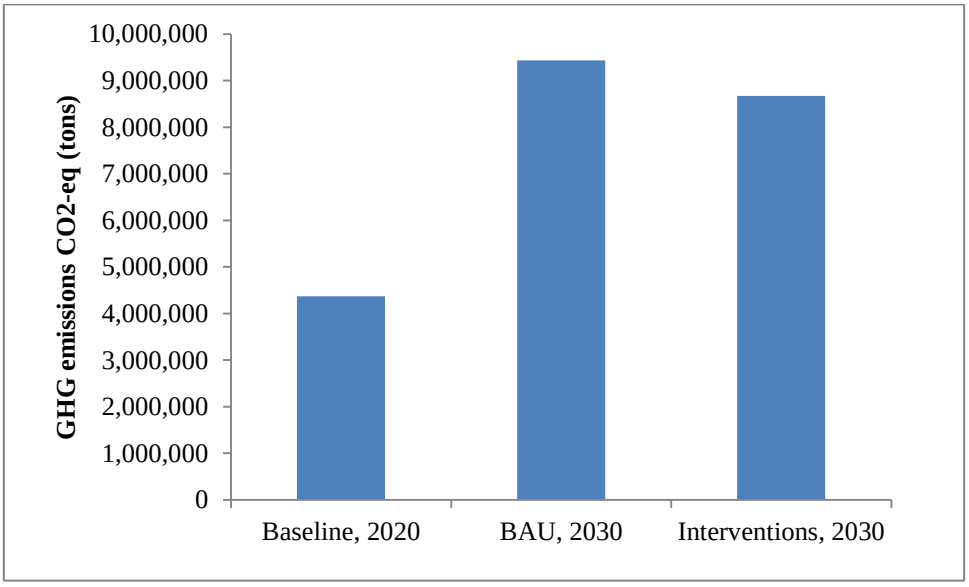


Figure 16. GHG gas emissions in the baseline and future scenarios (tons CO_2-e)

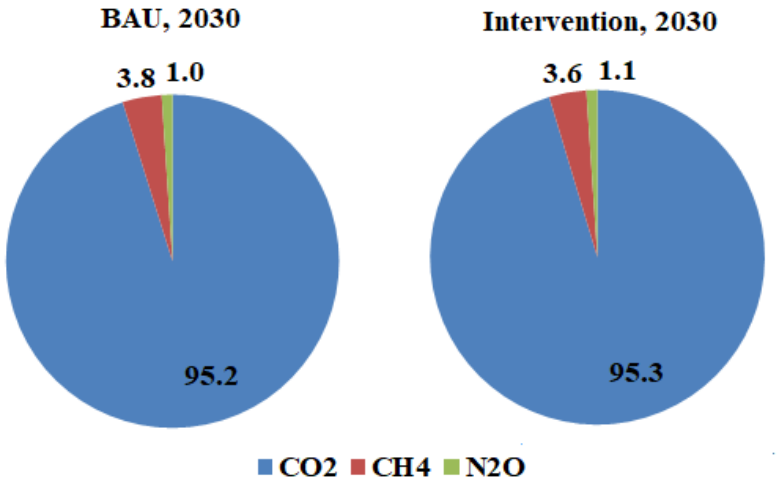


Figure 17. Percentage of CO_2, CH_4, & NO_2 in projected emissions (CO_2e)

Table 36. Share of CO_2, CH_4, and NO_2 from the projected GHG emissions in tons CO_2e.

Emission years	**CO_2**	**CH_4**	**N_2O**	**Total**
Baseline period, 2020	4,108,100	207,300	54,300	4,369,800
BAU, 2030	8,977,300	357,700	98,600	9,433,600
Interventions, 2030	8,270,200	311,700	91,800	8,673,700

Carbon equivalent increase in transport and other sectors (biomass use) is to be the highest in the coming years (projections) (Table 37). The intervention in the transport and other sectors highly contributed to the reduction of GHG emissions in the coming years (Table 37). For more detailed information on projections in each sub-sector in both scenarios and years, refer to Annex Table 37

Table 37. GHG emissions in the baseline and future scenarios of the sub-sectors of the energy

Sub-sectors	**GHG emission, Tons CO_2e**			**% change in emissions**	
	Baseline, 2020	BAU, 2030	Intervention, 2030	BAU (2020-2030)	Interventions (2020-2030
Energy Industries	23200	18700	18700	706	706
Manufacturing Industries and Construction	13700	23200	23200	70.0	70.0
Transport	972400	3716900	3661000	282.3	276.5
Other sectors	3381400	5674800	4970800	67.8	47.0

3.3. GHG Emissions from the IPPU sector

3.3.1. IPPU base year emissions

In Amhara National regional state, the major IPPU sectors that contribute to the region's economy are lime and ammonia production, Lubricant and Paraffin wax use, and Food and beverages. Greenhouse gas emission in terms of CO_2e is calculated for different sectors based on the methodology described in the above Section and the result is presented in Table 38.

Table 38. Number of Industries and their GHG Emissions by Sources, 2020

Item	Industrial Source	**No**	Amount of production	EF,tonCO_2/ton	CO_2 emissions,tCO_2	CO_2 emission $GgCO_2$
1	Lime Production	4	78646t	0.77	60557.00 ton	60.557
2	Ammonia not used in Urea	4	3550t	1COF	11,617.00 ton	11.617
3	Lubricant use	224 stations	6.9190713E-05TJ	0.2ODU	0.00089 ton	0
4	Paraffin wax use	224 stations	7.687857E-06TJ	0.2ODU	0.0001ton	0
5 Food and beverages						
5.1	Breweries	4	10800000 HL	3.5E-08	378	0.378
5.2	Alcoholic other than beer	1	5617.4 HL	3.5E-06	19.66	0.01966
5.3	Animal Feed	4	1624.25t	11E-06	1.62	0.00162
5.4	Bread & Other Food Products	12	4380t	8E-06	35.04	0.03504
5.5	Soft Drinks*	2	51,840,000,000L	?	0	0
5.6	Bottled and Mineral water*	8	1.5M	?	0	0
5.7	Flour Mills*	29	4,606560Q	?	0	0
Total CO_2 e from Industry					**72,609.00**	**72.609**

*No EF, in both 1996 and 2006 IPCC guidelines, though AD was collected in these three industries we didn't include GHG emissions believing that their contribution is also very small.

As can be seen, the total GHG emissions estimated from the IPPU sector of the Amhara National Regional State in 2020 was 72.61Gg CO_2e (72,609tCO2e). In Ethiopia, this sector contributed 4,000,000tCO_2e (3%) of its total greenhouse gas emission in the CRGE report (FDREMoEF, 2015). Accordingly, this sector contributed 0.2% of GHG emissions in the Amhara National regional state. Among the subsectors that have contributed to greenhouse gas emissions based on the collected activity data, lime production (83.4%) and ammonia production (16.1%) are the dominant subsectors. Other subsectors like lubricant use, paraffin wax use, and food and beverage production have a small contribution to industrial processes and product use emissions.

Although the contribution of GHG emissions from Food and Beverages Industries is very trivial, brewery factories were contributing emissions of 400tCO_2ein the region. There are no other gases from the IPPU emissions estimated in our study.

3.3.2. Emissions Projections from IPPU

The Ethiopian Government's decision to restrict the increase in GHG emissions while retaining a certain level of output growth could be one of the reasons for the slowdown in the increase in GHG emissions in IPPU sectors. According to 10YDP, Ethiopian's Vision to achieve a "low carbon future" through its CRGE strategy by 2030 is through its initiatives on economic transformation and increased use of renewable energy in general and interventions including activities geared towards improving the efficiency of product use and utilization of advanced technologies that presents an opportunity to significantly reduce GHG emissions from the IPPU sector (FDREMoEF, 2015; UNDCFDRE, 2021). Despite its triviality, nationally the IPPU sector has an average growth rate of 20% and an emission growth rate of 16% per year, which is very high compared with other sectors (Besfat, 2020; FDRE, CRGE, 2015). We assumed this national emission growth rate holds true for Amhara National Regional State too because there are many industries currently under construction. Based on this assumption, the GHG emissions are projected to grow by 16%, from 72.61Gg CO_2e (72,609tCO_2e) base year to 317.62Gg CO_2e (317,620t) by 2030 from the IPPU sector in the BAU scenario for the Amhara region.

In its INDC, Ethiopia promises to limit its 2030 GHG emissions at 145,000 Gg CO_2e, which equates to a 64% (255,000 Gg CO_2e) reduction from projected business-as-usual emission levels (400,000 Gg CO_2e) in 2030. The reduction includes 20,000 Gg of CO_2e from the industry sector alone in the country. From this national reduction, the experts judged that the

Amhara region will take at least one-fourth of its share as there are many mitigation strategies designed and practiced in the region as per our communication with many stakeholders. Based on the collected AD in the region, the projected GHG emission in 2030 in the BAU scenario is 317.62Gg CO_2e (317,620t). Hence, with the above assumption, the projected GHG emission will be 80Gg of CO_2e (80,000t) with some mitigation interventions in 2030 in the Amhara region. This equals a relative reduction of emissions of 25% compared to BAU emissions.

The share of industrial economic activity in the region is comparatively small in 2019/20 (15%) (Region's plan commission office) and industry accounts for only 0.5% of GHG emissions in 2020 as compared to all other sectors. Although greenhouse gas (GHG) emissions from the industry sector in the region are minimal and not significant, planning and implementing climate change mitigation strategies without affecting economic growth is necessary.

3.4. Waste sector Emissions

Municipal solid waste (MSW) landfills/disposal sites are among the largest sources of human-related methane, carbon dioxide, and nitrous oxide emissions in the world including Ethiopia. These gases often referred to as landfill gases (LFG) are natural by-products of the decomposition of organic material in landfills/disposal sites. LFG is composed of roughly 50 percent methane (the primary component of natural gas), 50 percent carbon dioxide (CO_2), and a small amount of non-methane organic compounds (N2O). Methane is a potent greenhouse gas at least 28 times more effective than CO_2 at trapping heat in the atmosphere over 100 years, per the latest IPCC assessment report (AR5). This regional GHG emission inventory is containing Methane (CH_4), which is the dominant GHG in the waste sector

3.4.1. Base year emission and waste emission trends (2020 and 2030)

3.4.1.1. .

The waste sector accounted for a significant emissions source arising from the decomposition of organic components of the MSW on disposal sites. It was largely dominated by Methane (CH_4). The Business-as-usual (BAU) emission level for the base year 2020 was about 46 GgCO_2 e (46,000t Co2e). The emission level increased substantially in 2030 which was about 157,000tCO_2e (77.3%). This shows an increase of about 54.6% from the 2020 levels. The trend for CH_4 has shown a linear increase as is depicted in the figure below (Figure 18).

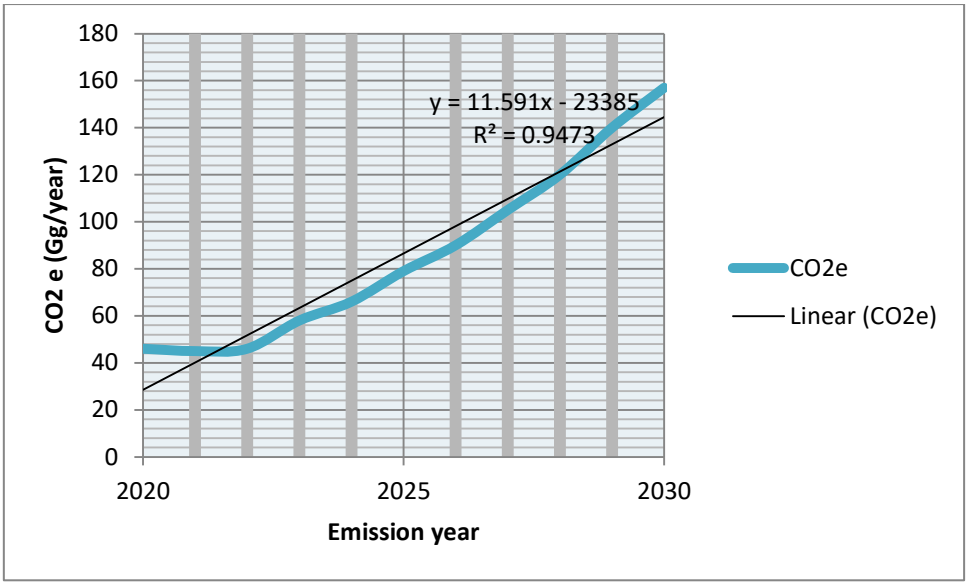


Figure 18. The BAU Methane (CH_4) emission trend (2020 & 2030)

The observed emissions trends can be attributed to the growing population, changing lifestyles due to improving socio-economic conditions in the region at large or capital city, increased fraction of solid waste deposited on SWDS, and poor landfill management program in the region.

3.4.2. Projections with intervention

In the region urbanization and an increase in population associated with rural-urban migration are becoming a challenge in terms of the huge amount of waste generated from different streams and disposed of indiscriminately. The current 4.4% average national population growth rate and affluence due to economic growth will substantially increase the waste generation and landfilling rate which in turn will increase the level of GHG emission as discussed above in the BAU emission. Thus, solid waste will be considered as one of the major causes that will increase GHG emissions level. As the sector has a substantial contribution to the regional total and about 3.3% of the total national BAU emission, mitigation action in the waste sector will have a significant potential for emission reductions. This requires interventions as a mitigation measure towards minimizing the release of these gases in urban and the surrounding areas.

The emission trend with intervention through the use of various and appropriate technologies for the year 2030 has shown a substantial decline in the level of emission from the BAU, 157,000t CO2e(77.3%) to 92,000t CO2e. which is about 66.7% (Figure 19).

Compared to the BAU scenario, there will be a decline in emission level from 157,000t CO_2e. to 92,000tCO_2e**.** (Table 39).

Table 39. Level of emission in BAU vs. Intervention (tCO_2e)

Gas type	Base year (2020)	Projection year for 2030	
		BAU	with Intervention
CH_4	46,000	157,000	92,000

This shows a 26.2% difference between the years 2020 and 2030, which indicates the more solid waste is diverted through appropriate technologies, the less the emission will be (Figure 21).

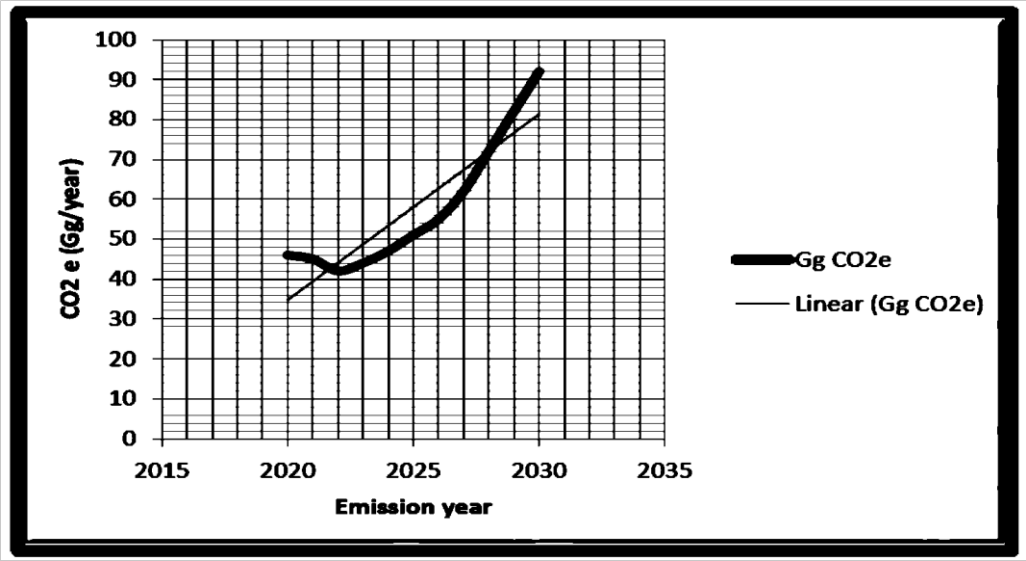


Figure 19. Methane (CH4) Emission with intervention (2020 & 2030)

4. MITIGATION STRATEGIES

Recently, Ethiopia has submitted its revised Nationally Determined Contribution (NDC), in which the country has committed a GHG emissions reduction target of 68.8% by 2030 from the BAU levels projected from 2010. To support the commitment of the country to achieve the above ambitious goal, some of the proposed technology options identified for carbon dioxide emissions reduction include industrial processes energy efficiency improvements, renewable energy sources, and carbon dioxide sink enhancement. In line with this, the proposed mitigation strategies for all the sectors in the region are mentioned below in this inventory study.

4.1. AFOLU

4.1.1. Livestock

The contribution of GHG from livestock is increased in 2030 in the business-as-usual scenario and this is due to increasing populations of livestock triggered by the demand of the farming communities for draught power and increasing demand for animal protein. In the intervention scenario, the GHG from livestock is decreased in 2030 and this is due to the implementation of integrated mitigation strategies. Therefore, the following mitigation strategies need to be considered to reduce GHG emissions from livestock production:

- Increase the use of agricultural machinery for land preparation, crop sowing, harvesting, and threshing. Increased use of agricultural machinery can reduce the number of cattle needed (mainly oxen) for draught power.
- As the GHG emission from small ruminants and poultry (chicken) is much lower than cattle, the mitigation strategies are to reduce the cattle population and increase the small ruminant and poultry population.
- Adopting more productive dairy breeds: More productive dairy breeds need to consume more energy to grow faster or produce more milk, but the increase in production is greater than the increase in enteric fermentation emission, so GHG emissions per unit output may decrease. Therefore, it is recommended to reduce the total number of local dairy cattle and raise the proportion of improved breeds.
- Improving off-take rate: Selling cattle, sheep, and goats at a younger age to fatten in feedlots can reduce GHG emissions because the animals are alive for fewer days in the year.
- Improving animal health: Diseases and parasites make the animals less productive and increase deaths resulting in unproductive GHG emissions. Improving animal health may increase total GHG emissions but also increase the amount of livestock products obtained and marketed.
- The livestock production system in Ethiopia mainly depends on poor-quality feeds which leads to methane emission from enteric fermentation and manure management. Therefore, the feed development, harvesting, storage, and feeding methods should be improved.
- Methane is also produced by the decomposition of manure under anaerobic conditions. When stored in liquid or slurry form, anaerobic decomposition is greater and more methane is released, and when stored as solid less methane is released. Thus, the manure management system should be improved. Compositing and using biogas made from manure reduce

methane emissions. Compost and biogas slurry are also very good fertilizers to boost crop production.

4.1.2. Land use land cover

If Amhara Region can achieve the national CRGE target, and fulfill the national plan of accomplishing a green development path by the year 2030, it is necessary to take swift measures that would demand a special plan and unreserved commitment. The net gain (sequestration) from the forest sector should be greater than the losses due to deforestation. Three possible interventions can be implemented in parallel.

i) Reducing emissions from deforestation

Ensuring that rural areas which are inhabited by about 80% of the population get access to hydropower and other green energy sources since one of the major causes of deforestation is fuel wood collection and charcoal production. The commencement of big hydropower dams such as the GERD should contribute to alleviating such a critical problem. Over 90% of the energy in the region comes from biomass, and there is a huge vacuum of alternative energy sources. Therefore, there should be a paradigm shift in provisioning access to alternative energy sources. Since forests cover a very small proportion of the region but contain a large share of the carbon stock, the conservation of remnant forests and hence emission reduction from deforestation must be a primary target. The promotion of alternative cooking stoves is one of the major interventions identified in the CRGE. If 5 million households can use improved cooking stoves, there is a potential to reduce about **8.7** million tons of carbon dioxide equivalent emissions.

ii) Enhancing sequestration through reforestation

Amhara region has suitable agroecology for forest development. Forestation/reforestation of 2 million ha of forest would offer an abatement potential of **36** million tons of carbon dioxide equivalent.

iii) Forest management and carbon stock enhancement

There is a huge potential to enhance the rate of carbon dioxide sequestration and hence the amount of forest carbon stock from degraded forests and wooded land. If wooded land is managed properly, there will be a potential that it will become dense woodland and then forest. Considering 1.5 million ha of such kind of forest management and carbon stock enhancement will offer an abatement potential of about **13.5** million carbon dioxide equivalent.

iv) Aggregate Sources and Non-CO2 Emissions Sources on Land

Mitigation measures to reduce emissions in this subsector include the following:

- Apply lime based on acidity levels and associated recommendation rates;
- Improve and select rice varieties that can mature in a short period while providing better yields;

- Improve the nitrogen management of the soil in such a way that ensures optimum application and use of inorganic fertilizer and/or manure by crops;
- Properly manage fields and water regimes for rice cultivation;
- Increase the use of organic and bio-fertilizers and minimize the use of inorganic fertilizers; and
- Use organic amendments for rice cultivation as they significantly reduce emissions.

4.2. Energy

A study of GHG emissions using the methods of BAU and with interventions showed an increasing trend in the energy sector between 2020 and 2030. Mitigation strategies by the different institutions in the energy sector have to be introduced to minimize emissions. Therefore, the following core intervention measures are recommended.

- Shifting/substitution from fossil fuels to low GHG emission energy sources, for example, electricity. Gradual reduction of the use of fossil fuels is an essential method to mitigate emissions. In this case, the region has to focus on hydropower and solar energy because these are abundant and viable resources of the region.
- Increase the number of electric vehicles and facilities mainly in the transport sector. In addition to the number of electric vehicles, the charging stations and other facilities have to be considered with appropriate spatial distribution.
- Focusing on energy-efficient vehicles, machines, and technologies. Here it includes the industries and machines that shorten the process of production and at the same time decrease the use of energy.
- Policies and laws regarding the service life or working life of vehicles. It is obvious that more missions are from old vehicles which are traveling longer total distances.
- Decrease the loss of vegetation for firewood and charcoal by expanding other energy sources like solar energy and biogas mainly in rural areas. In addition, energy-efficient appliances like stoves are recommended in both rural and urban areas.

4.3. IPPU

Although the lime sub-sector has been highlighted in this report because it represents the most GHG emitting industry, the GHG abatement initiatives of the government will take action to put the other industrial sub-sectors like the fertilizer, textile, leather, cement, and food and beverage industries also on a sustainable economic development path.

In this study, the following mitigation options are recommended to address emissions from industrial processes and product use.

- Industrial process energy efficiency improvements

- Raw materials conservation
- Efficient use of products, material recycling and
- Technology improvement.
- Switching to low-carbon and other energy sources
- Reducing synthetic fertilizer

4.4. Waste Sector

4.4.1. Designing appropriate disposal and material recovery system

One of the best options in the MSWM system is reducing the amount of waste disposed of using various disposal technologies/ methods. In the past few decades, various types of disposal technologies have been defined and used in the world, ranging from incineration, waste to energy, to biogas production through Anaerobic Digestion (biogas production) to Refuse Derived Fuels (RFD) and simple composting (Malinauskaite et al., 2017).

Option 1: Recovery of biodegradable organic wastes (040)

The largest proportion of the MSW disposed is organic waste (DOC), alternative disposal management and technology for organic material recovery (composting and biogas production) can be used. For this sorting waste at the source is mandatory not an option to practice. There are several options for SW segregation (sorting): sorting at the sources of generation is the best option. The others are using central facilities either as a transfer station at a designated site within the city premises or the disposal site as a material recovery facility (Stanchev et al., 2017).

This signifies that there is a need for proper planning and execution of the ISWM system for the region, and the primary option is to reduce the 69% disposal into 40% by sorting the solid waste generated using the possible and workable options mentioned above and diverting the waste through various material recover systems (composting, biogas production, paper, and plastic recycling or reuse options).

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The GHG inventory in the AFOLU, energy, IPPU, and waste sectors was conducted using activity data collected from different institutions in the region. The data obtained from those institutions were processed, an emission inventory was analyzed by IPCC inventory software, and emissions of the major GHGs CO_2, CH_4, and N_2O were analyzed. The results revealed that in 2020, Amhara Region's total GHG emission was estimated to be 79,829,885tCO_2e. The AFOLU sector was the largest source of GHG emissions in the region; accounted for

94.34% of the overall regional emissions of 75,341,476tCO_2e where livestock production contributed a significant source of GHG emissions. With a total of 4,369,800tCO_2e, the energy sector was the next leading source contributing 5.5% of the regional emissions. This was followed by the IPPU sector with 72.609 tCO_2e (0.1%) and then by the waste sector with 46,000t (0.06%). Emissions of CO_2 (72.84%) were the highest followed by CH_4 (26.96%). The total emission from the three GHGs was about 79,829,885tCO_2e in the base year, 111,372,060tCO_2e in BAU, and 63,468,790tCO_2e with some intervention by 2030. Therefore, the implementation of integrated mitigation strategies is recommended to reduce the GHG emissions from all economic sectors in the region.

5.2. Recommendations

- The authors understand that data handling and quality in almost all sectors except the construction enterprises is low. Therefore, the respective bureaus and offices have to follow mechanisms to record, handle, and archive the necessary data.
- The emissions of GHG both in the baseline and in the prediction are very high. Therefore, the region and the country's future strategic plans need to consider technologies and interventions to reduce GHG emissions.
- The scenario projection of GHGs has to be based on the planned mitigation strategies of the sectorial institutions. Due to the absence of these plans, the projection is done based on expert judgments. Hence, future GHG emission projections have to consider institutions' mitigation strategies.
- Therefore, mitigation measures should be devised such as appropriate technologies to reduce the GHG emissions
- Awareness creation throughout the region’s major urban centers on the need for ISWM planning, with emphasis on waste reduction.
- Implementation of SW segregation at the source diverts the waste into a resource.

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ANNEX

Annex Table 1. Annual fuel consumption per machine/vehicle in the construction industry in 2020.

Machine/vehicle	Total number of vehicles	Mean annual diesel fuel consumption, Liter	Total diesel fuel, Liter
Excavators	97	15,829.09	1,535,422.13
Graders	71	4,874.59	346,095.75
Dozer	83	17,584.87	1,459,544.55
Roller compactor	71	2,880.95	204,547.45
Asphalt pave machine	12	677.30	8,127.60
Concrete vibrator	22	379.00	8,338.00
Loader	92	10,928.78	1,005,447.77
Crane	23	8,762.00	201,526.00
Forklift	4	4,242.50	16,970.00
Wagendril	26	5,387.20	140,067.20
Walkway Compactor	9	3,790.00	34,110.00
Crushers	11	6,075.00	66,825.00
Concrete Mixer	43	1,074.91	46,221.05
Total	564	82,486.19	5,073,242.49

Annex Table 2. Number of vehicles and fuel consumption in the transport sector in 2020 in the Amhara region

Type of on-road vehicle	Total vehicle	Fuel consumed km/L	Average annual fuel consumption/vehicle		Total fuel consumption /vehicle category, Liter	
			Gasoline	Diesel	Gasoline	Diesel
Two wheeler	9,967	33	308.3		3,072,856	
Three wheeler	66,663	20	900.0		41,096,700	
Automobile	848	12	1666.7		1,413,361.6	

Van	129	12	9113.4		235,126.2	940,504.6
Station wagon	1,280	6		1,456.7		1,864,616.8
Pickup	3,305	9		2,104.1		6,954,065.45
Bus	15,099	6		13,904.3		209,941,529.57
Dam track goods	2,937	5		16,956.4		49,800,947.4
Lobed track	22	5		16,956.4		373,040.80
Tracker (Trailer)	208	5		16,956.4		3,526,931.24
Crane track	41	5		16,956.4		695,212.4
Fire engine	10	5		13,904.3		139,043.33
Power track	244	5		16,956.4		4,137,361.65
Total	100,753		11,988.4	116,151.5	45,818,043.8	278,373,253.2

Water transport boats	Number	Fuel consumed Km/L	Distance travel/day	No. of working days/year	Total fuel consumption per vehicle category, Liter	
					Gasoline	Diesel
Low bots (5-20 persons)	134	1.5	15	183	551,745	---
Medium boats (20-40 P)	30	1.5	20	183	164,700	---
Boats in Tana Transport Enterprise	11					107,976
Total					716,445	107,976

Annex Table 3. Consumption of biomass in the residential and commercial/institutional sectors, and oil fuels in the agricultural sector

Biomass	**Unit**	**Quantity per institution**		**Total**
		Residential	Commercial/Institutional	
Firewood	kg	1,117,710,242.5	13,711,580	1,131,421,822.5
Tree Residues	Kg	---	987,590	987,590
Sawdust	Kg	---	3,825,310	3,825,310
Charcoal	kg	332,654,559.9		332,654,559.9
Total		1,450,364,802.4	18,524,480	1,468,889,282.40

Fuel in the agriculture sector	**Unit**	**Number of pumps**	**Days of use per dry season**	**Pump hours per day**	**Litter /hr**	**Total fuel consumption**
Water pumps						
Gasoline	L	20,932	35	10	1	7,326,200

Diesel	L	5,233	35	10	1	1,831,550
Total						9,157,750
Agricultural machines	**L**	**No**	**Mean Annual Consumption**		**Total fuel consumption**	
Combine harvesters	L	13	5377.5		69,907.50	
Tractors	L	505	10928.78012		5,519,033.96	
Total					5,588,941	

Annex Table 4. Detail results of projected GHG emissions in both scenarios (BAU and with interventions) in tons in 2030.

Projection with BAU, 2030							
Sub-sector	CO_2	CH_4	N_2O	CO_2, t CO_2e	CH_4, t CO_2e	N_2O, t CO_2e	Total, t CO_2e
Total fuel combustion in the energy sector	8,977,248	12,775	372	8,977,248	357,710	98,613	9,433,571
Energy Industries	18631	1	0	18,631	22	42	18,695
Manufacturing Industries and Construction	23,164	1	9	23,164	26	50	23240
Transport	3,649,300	330	220	3,649,300	9,238	58,313	3,716,851
Road Transportation	3,645,582	330	220	3,645,582	9,228	58,284	3,713,094
Water Transport	3,718	0	0	3,718	10	29	3,757
Other Sectors	5,286,153	12,444	152	5,286,153	348,424	40,208	5,674,785
Commercial/Institutional	221,107	592	8	221,107	16,583	2,094	239,783
Residential	4,980,985	11,842	133	4,980,985	331,568	35,370	5,347,923
Agriculture/Forestry/Fishing/Fish Farms	84,060	9.75	10.36	84,060	273	2,745	87,079
Projection with intervention, 2030							
Sub-sector	CO_2	CH_4	N_2O	CO_2, t CO_2e	CH_4, t CO_2e	N_2O, t CO_2e	Total, t CO_2e
Total fuel combustion in the energy sector	8,270,171	11,132	346	8,270,171	311,690	91,805	8,673,667
Energy Industries	18,631	1	0	18,631	22	42	18,695
Manufacturing Industries and Construction	23,164	1	0	23,164	26	50	23,240
Transport	3,595,341	314	214	3,595,341	8,786	56,835	3,660,962
Road Transportation	3,591,623	313	214	3,591,623	8,776	56,805	3,657,205
Water Transport	3,718	0	0	3,718	10	29	3,757
Other Sectors	4,633,035	10,816	132	4,633,035	302,855	34,879	4,970,769

Commercial/Institutional	152,065	407	5	152,065	11,405	1,439	164,909
Residential	4,405,714	10,400	116	4,405,714	291,212	30,716	4,727,642
Agriculture/Forestry/Fishing/Fish Farms	75,256	8.5	10.28	75,256	238	2,724	78,218

Annex Table 5: MSW generation and treatment data - regional defaults (IPCC, 2006)

Year	Population (Million)	Total Waste generation kg/y	Total Waste Generation Gg/y
2020	4,590,254	1,331,173,660.0	1,331.17
2021	4,792,225	1,737,181,562.5	1,737.18
2022	5,003,083	2,267,021,984.4	2,267.02
2023	5,223,219	2,958,463,886.7	2,958.46
2024	5,453,040	3,860,794,908.2	3,860.79
2025	5,692,974	5,038,337,610.4	5,038.34
2026	5,943,465	6,575,030,666.5	6,575.03
2027	6,204,977	8,580,414,694.0	8,580.41
2028	6,477,996	11,197,440,872.5	11,197.44
2029	6,763,028	14,612,660,887.9	14,612.66
2030	6,912427	2,626,722,260	2,626.7

Annex Table 6: Default dry matter content, DOC content, Total Carbon Content, and Fossil Carbon Fraction of different MSW components

MSW component	Dry matter content in % of wet weight		DOC content in % of wet waste		DOC content in % of dry waste		Total carbon content in % of dry weight		Fossil carbon fraction in % of total carbon	
	Default	Total (Gg/y)	Default	Total (Gg/y)	Default	Total (Gg/y)	Default	Total (Gg/y)	Default	Total (Gg/y)
Food waste	40	287.008	15	107.6	8	57.4	38	272.7	NA	#VALUE!
Paper & Cardboard	90	92.25	40	41	44	45.1	46	47.2	1	1
Plastic	100	73.22	NA	#VALUE!	NA	#VALUE!	75	54.9	100	73.2
Textile	80	18.104	24	5.4	30	6.8	50	11.3	20	4.5
Rubber	84	12.2976	39	5.7	47	6.9	67	9.8	20	2.9
Leather	84	12.2976	39	5.7	47	6.9	67	9.8	20	2.9
Yard waste	40	33.548	20	16.8	49	41.1	49	41.1	NA	#VALUE!
Wood &Charcoal	85	79.203	43	40.1	50	46.6	50	46.6	NA	#VALUE!
Others (Nappies)	90	138.978	NA	#VALUE!	NA	#VALUE!	3	4.6	100	154.4

IPCC, 2006