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NATIONAL GHG INVENTORY REPORT FOR ETHIOPIA, AGRICULTURE, FORESTRY AND OTHER LAND USE SECTOR: 1990-2019

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

1.1 Sector Overview

AFOLU sector description

Ethiopia's GHG profile is dominated by emissions from the agriculture sector, followed by land-use change and forestry (LUCF). Agricultural production is dominated by smallholder households which produce more than 90% of agricultural output and cultivate more than 90% of the total cropped land. Smallholders drive their income either in cash or through own consumption from agricultural production. Agriculture has been the dominant sector of the country's economy, representing nearly 42% of GDP, 77% of employment, and 84% of exports. According to the national accounts, the agricultural sector consists of crop, livestock, fishery, and forestry sub-sectors. Crop production is the dominant sub-sector within agriculture, accounting for more than 60% of the agricultural GDP followed by livestock which contributes more than 20% of the agricultural GDP. The contributions of forestry, hunting and fishing are roughly at 10%. There are two main production systems in Ethiopia: the pastoral nomadic system, and the mixed crop production system. The pastoral livestock production system dominates the semiarid and arid lowlands (usually below 1500 meters above sea level). These regions cover a vast area of lands with a small livestock production. The crop production system can be classified into smallholders' mixed farming, producers' cooperative farms, state farms, and private commercial farms based on their organizational structure, size, and ownership. The major objectives of small holder farmers' production are to secure food for domestic consumption and to generate cash to meet household needs such as clothing, farm inputs, taxes and others. Ethiopia has a variety of fruits, leafy vegetables, roots and tubers adaptable to specific locations and altitudes. The major producers of horticultural crops are small scale farmers, production being mainly rain fed and few under irrigation[1].

The Government of Ethiopia has developed the Agricultural Transformation Agenda as a systematic, multi-stakeholder approach to identify and prioritize the main drivers of agricultural change in Ethiopia. Despite significant progress over the past 25 years, the vast majority of agricultural production is still conducted by subsistence-based smallholder farmers. According to the Agricultural Transformation Agenda Progress Report, agricultural productivity remains exceptionally low in Ethiopia, with yields of smallholder farmers below Sub-Saharan Africa averages due to limited use of irrigation and improved seed and fertilizer. Furthermore, poor land management practices have led to severe land degradation. Differentiated interventions are necessary for the poorest farmers living in marginalized areas and/or on very small plots of land[2].

Land tenure is governed by Proclamation laws 891199 and Proclamation No. 721/2011for Rural land Administration and Lease Holding of Urban Lands respectively. There are 4 types of forest ownership which are governed under the federal laws in Ethiopia ፡ as follows: (i) Private forest; (ii) Community forestry; (iii)Association forest and (iv) State forest.

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[1] Urgessa Tilahun Bekabil. (2014). Review of Challenges and Prospects of Agricultural Production and Productivity in Ethiopia, Journal of Natural Sciences Research, Vol.4, No.18, pages 70-78

[2] Agricultural Transformation Agenda progress report,2011-2015 GTP period 1, Agricultural Transformation Agency (ATA)

Ethiopian forests generate greater economic benefits than previously thought (Proclamation No. 1065/2018).

Ethiopia is a land of natural contrasts. It stretches over more than 1.1 million km2 and has a wide variety of climate zones and soil conditions. Forests cover some 162,000 km2 of the country's landmass, with woodland and shrubland accounting for another 492,000 km2, according to the 2013 land cover map of Ethiopia (Ethiopian Mapping Agency, 2013)

Until now, the common understanding, based on measured GDP statistics, had been that about 4% of national income was attributable to forests (the exact share was estimated (MOFEC, 2015) to be 3.8% in 2012-13). The more comprehensive assessment undertaken UN-REDD shows that this figure is about 12.9% (not counting the non-market benefits associated with forest preservation[3].There is enormous pressure on Ethiopia's forests. Due to conflicting data sources and varied definitions of forests, determining a reliable estimate of forest cover and forest cover change in Ethiopia is challenging. The major direct drivers of deforestation and degradation are forest clearance and land-use conversion for smallholder agricultural expansion, promotion of large-scale commercial and state development investments in forest frontiers, illegal extraction and collection of forest products (mainly fuelwood collection and charcoal making), human settlement in forest areas, forest fires, and development of infrastructure and road networks. Indirect drivers of deforestation are the dependence of the rural poor on natural resources, rapid population growth, legal and institutional gaps such as the lack of stable and equitable forest tenure and property right arrangements, lack of a clear and standard definition and classification of forests, weak forest governance and law enforcement, and ineffective coordination among government agencies.

Ethiopia's development agenda is governed by two key strategies: The Second Growth and Transformation Plan (GTP-2) and the Climate Resilient Green Economy (CRGE) strategy. Both strategies prioritize attainment of middle-income status by 2025 and, through the CRGE Strategy, to achieve this by taking low carbon, resilient, green growth actions. Both strategies emphasize agriculture and forestry; The CRGE Strategy targets 7 million hectares for forest expansion. GTP-2 Goal 15 aims to: "Protect, restore and promote sustainable use of terrestrial ecosystems by managing forests, combating desertification, and halting and reversing land degradation and halt biodiversity loss."

This chapter includes greenhouse gas (GHG) emissions and removals from the AFOLU sector. The emissions/removals from the AFOLU sector are influenced by the combination of the factors and implementation of national policies, available technologies and the management practices. The aggregate effects of the way policies, technologies and management practices are used largely determine land use practices and the associated emissions or removal of GHG from the AFOLU sector. Some of the practices include (a) livestock rearing (b) land use change via forest conversion (deforestation), (c) afforestation, (d) woodfuel extraction, (e) wildfire disturbance (f) application of nitrogen-based fertilisers. The 2006 IPCC guidelines divide the AFOLU sector activities into three clusters of emission/removal categories. The criteria for the clustering are based on the activity being a land-based or non-land based. Each category is further disaggregated into the activities that contribute to emissions/removals. The three clusters of emission/removal categories are:

[3] The contribution of forests to national income in Ethiopia and linkages with REDD+(2016). United Nations Environment Programme: Nairobi

livestock, land and aggregated source and non-CO_2 emission sources from land. The IPCC Guidelines assign unique code for sector, categories, sub-categories and activities. The code for AFOLU sector is prefixed with the figure 3, since it is the third in the sequence of IPCC inventory sectors. The three categories under the AFOLU sector and their codes are as follows: Livestock (3A), Land (3B) and Aggregated and Non-CO_2 Emissions Sources (3C). Based on the IPCC 2006 Guidelines, the following categories are included in the inventory emission/removal estimates:

- **Livestock (Category 3A)**
    - Enteric fermentation (IPCC Category 3A1)
    - Manure management (IPCC Category 3A2)
- **Land (Category 3B)**
    - Forest land (IPCC Category 3B1)
    - Cropland (IPCC Category 3B2)
    - Grassland (IPCC Category 3B3)
    - Wetlands (IPCC Category 3B4)
    - Settlements (IPCC Category 3B5)
    - Other lands (IPCC Category 3B6)
- **Aggregate sources and non- CO_2 emissions on land (Category 3C)**
    - Biomass burning (IPCC Category 3C1)
    - Liming (IPPC Category 3C2)
    - Urea application (IPCC Category 3C3)
    - Direct N_2O emission from managed soils (IPCC Category 3C4)
    - Indirect N_2O emission from managed soils (IPCC Category 3C5)
    - Indirect N_2O emission from manure management (IPCC Category 3C6)
- Other (Category 3D)
    - Harvested wood products (IPCC Category 3D1)

Categories that form part of the Ethiopia agriculture sector but were not included in this inventory report are rice cultivation (3C7), Biomass burning (IPCC Category 3C1), Liming (IPPC Category 3C2) and Harvested wood products (IPCC Category 3D1), due to lack of data or activity data available (see details in Table 5.1). With improvements, data on these categories can be incorporated into future inventories. Categories includeTier 1 approaches. Manure management includes all emissions from confined, managed animal waste systems. Methane emissions from livestock manure produced in the field during grazing are included under manure management (3A2); however, the N_2O emissions from this source are included under category 3C4, direct N_2O emissions from managed soils, in accordance with IPCC 2006 Guidelines. Methane emissions from managed soils are regarded as non-anthropogenic and are, according to the guidelines, not included.

Overall emission trends

AFOLU emissions in 2018

In 2019 the AFOLU sector was a net emitter at 1899084.12 Gg CO_2 equivalent (e). The current emissions also represented 286.1% more (excluding Land) than the levels reported in 1990, contributing 491915.90 Gg CO_2e. The emission increases relate to activities and management practices such as deforestation through forest conversions to cropland and grassland, emissions from livestock enteric fermentation, urea application and nitrogen additions to soils. On gas-by-gas basis, N_20 had the greater share of the AFOLU reported at 74.6 % of the AFOLU sector emissions, followed by CO_2 at 22% and CH_4 at 3. % (see figure 5.1 and 5.1a)

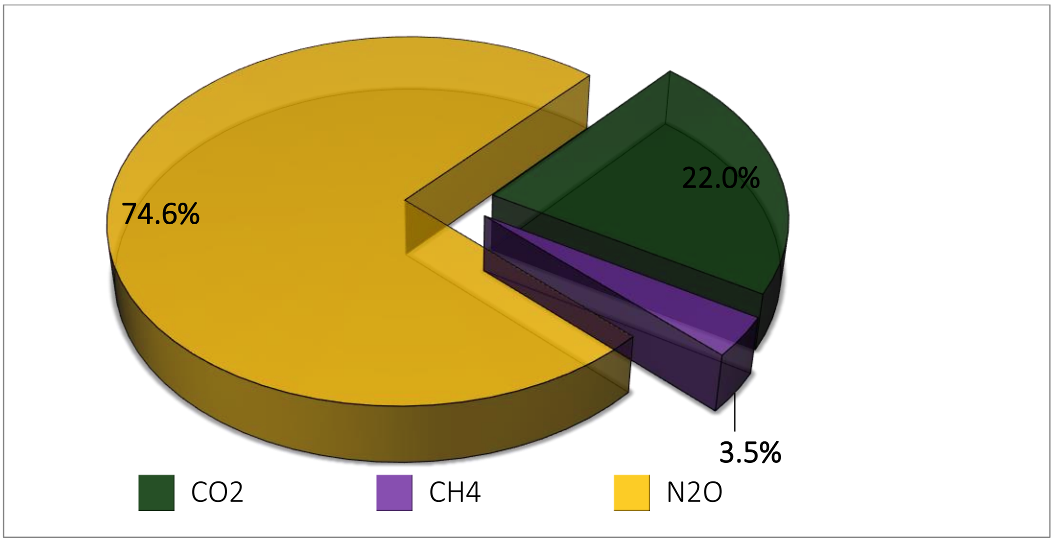

Figure 5.1: Summary of percent contribution by gas for Ethiopia's AFOLU sector in 2019

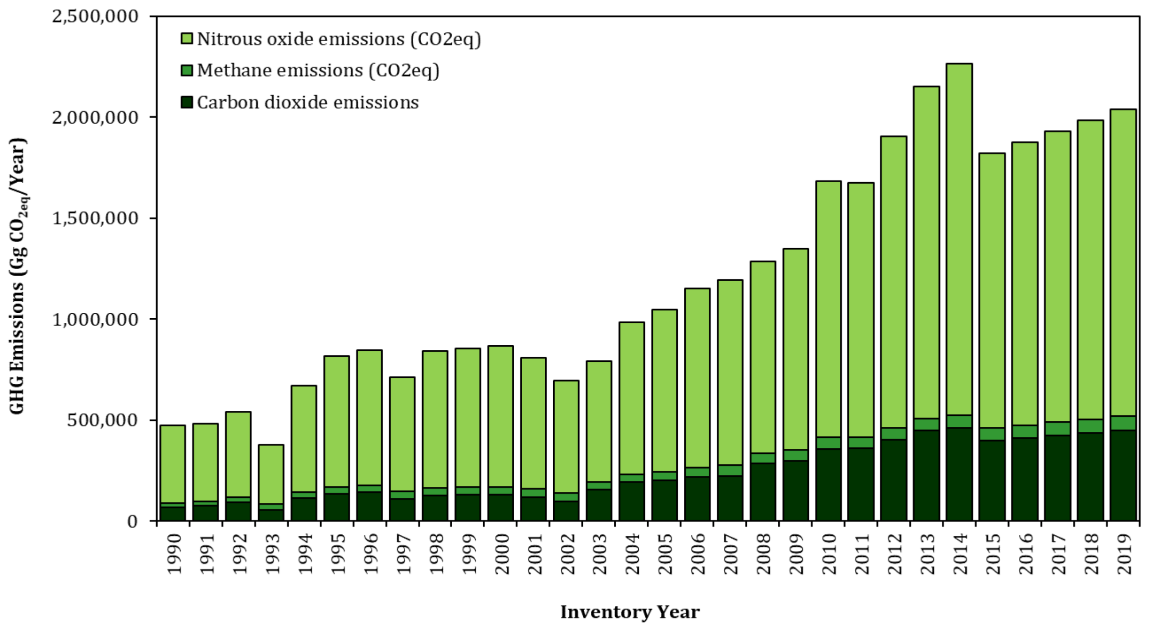

Figure 5.1a: Summary of Emissions by gas for AFOLU sector for Ethiopia 1990-2019

Within the AFOLU sector, the emissions from soils, direct N_2O from managed soils category was the main emission source consisted 51.8%, followed by indirect N_2O from managed soils at 16.8%, Urea application at 14%, grassland at 5.8%, Croplands at 4.1%, enteric fermentation at 3.1% and forest land at -3.1% of the AFOLU emissions. The rest were shared among the remaining sources manure management at 0.6%, and other land at -0.5% in 2019 (see figure 5.2).

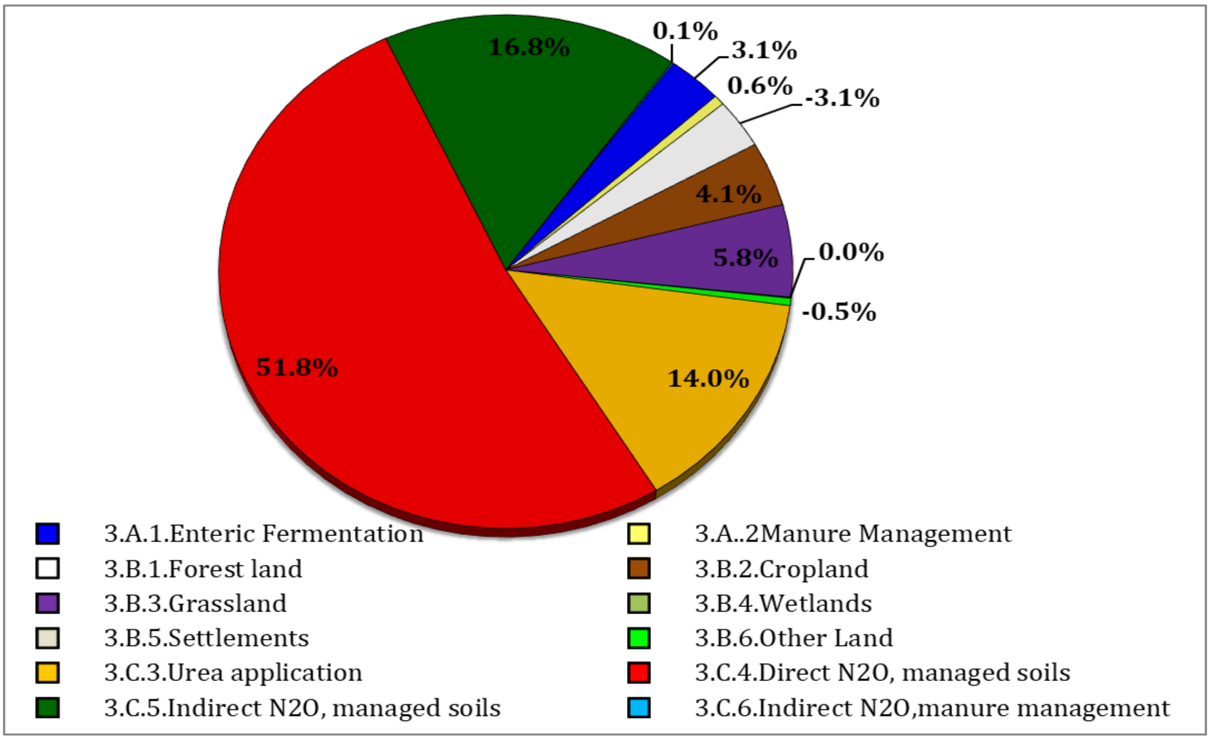

Figure 5.2: Summary of percent contribution of AFOLU sector categories for Ethiopia in 2019

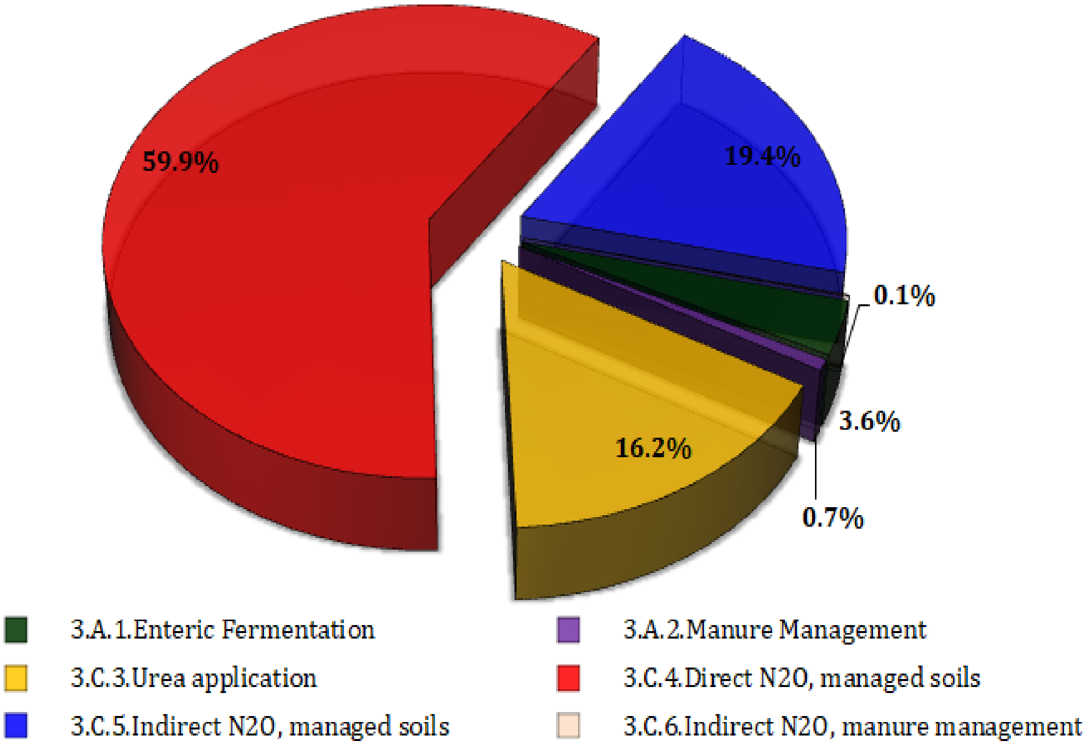

Figure 5.3: Summary of the estimated emissions from Ethiopia's agriculture components of the AFOLU sector in 2019

In 2019, the emissions from soils, direct N2O from managed soils category was the main emission source at 59.9.8% (1137190.75 Gg CO_2e), followed by indirect N2O from managed soils at 19.4% (369277.62 Gg CO_2e), Urea application at 16.2% (308144.34 Gg CO_2e), enteric fermentation 3.6% (68501.97 Gg CO_2e) to the total agriculture emissions, with manure management second contributing 0.7%, 13825.13 Gg CO_2e (Figure 5.3).

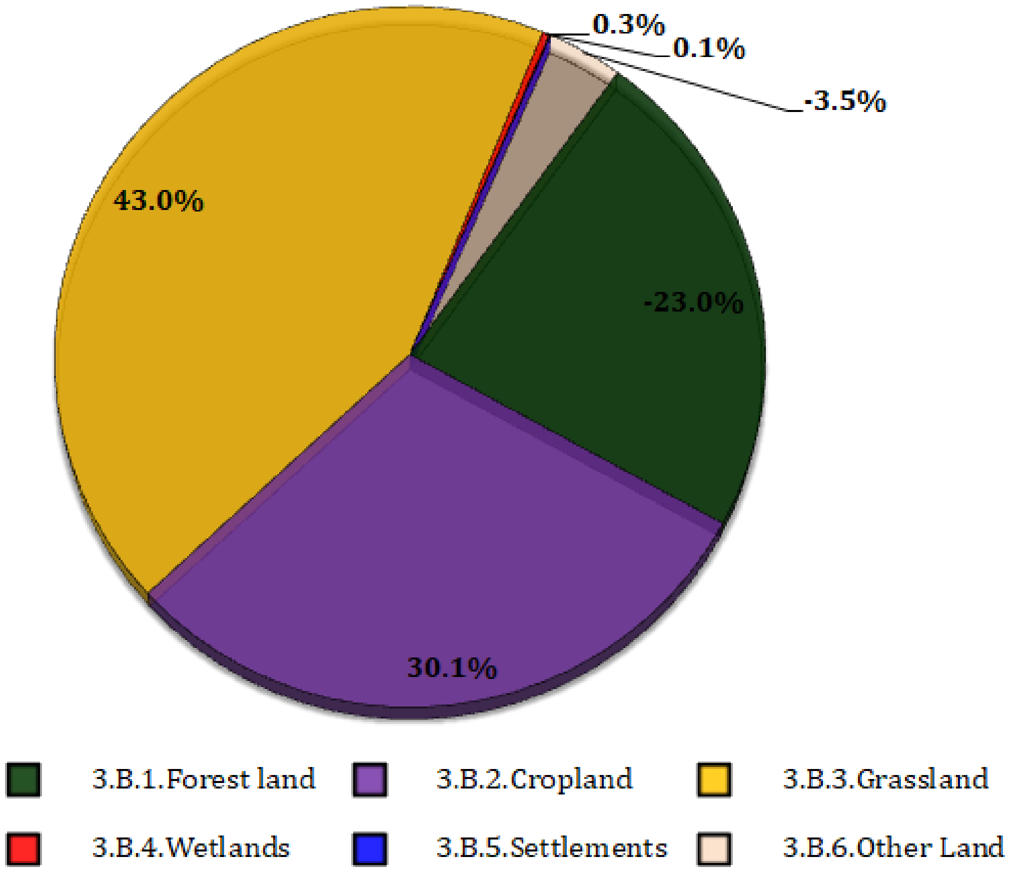

Figure 5.4: Summary of the estimated emissions from Ethiopia's forestry and land use components of the AFOLU sector in 2019

Summary of the estimated emissions and removals for the forestry and other land use sector, Grassland and Cropland 2019, accounted for 43.0% (127277.74 Gg CO_2e) and 30.1% (89182.16 Gg CO_2e) respectively of the absolute value of emissions, forestland was a net sink at -23.0% (-67975.29 Gg CO_2e). Whilst Other land was -3.5% (-10280.39 Gg CO_2e) and Wetlands and Settlements were 0.3% (983.94 Gg CO_2e) and 0.1% (148.12 Gg CO_2e). (Figure 5.4).

AFOLU emission trends between 1990 and 2019

Overall, the AFOLU sector was an increasing net emission source from 1990 at 47217 Gg CO2e 3.75 and 2038420.41 Gg CO2e 2019 respectively. The emissions trend was driven mainly by emissions from manged soils (direct and indirect N_2O) emissions under 3C Category. This is largely driven by expansion of agricultural land and application of fertiliser inputs to soils. Between 2002-2019 there was a gradual upward trend in emissions, with a peak in 2014 at 2264150.84 Gg CO_2e. In 2002 the AFOLU sector became an increasing net source, and remained an increasing net source up to 2019, the key drivers for emissions are increased rates of deforestation on the indigenous forests, application of fertilisers in agriculture. Emissions from livestock category increased at a relatively consistent between 1990 and 2019, at between 26643.05 Gg CO_2e and 82327.10 Gg CO_2e for 1990 and 2019 respectively. However, the last five years recorded a downward trend, with the decreased emissions from the category recorded in 2014and 2019. The land (3B) was a net sink from 1990 and 2002 at

-19742.15 Gg CO_2e and -15087.60 Gg CO_2e respectively and became an increasing net source thereafter from 2003 to 2019 at 38829.51 Gg CO_2e and 139336.29 Gg CO_2e.

(Figure 5.5).

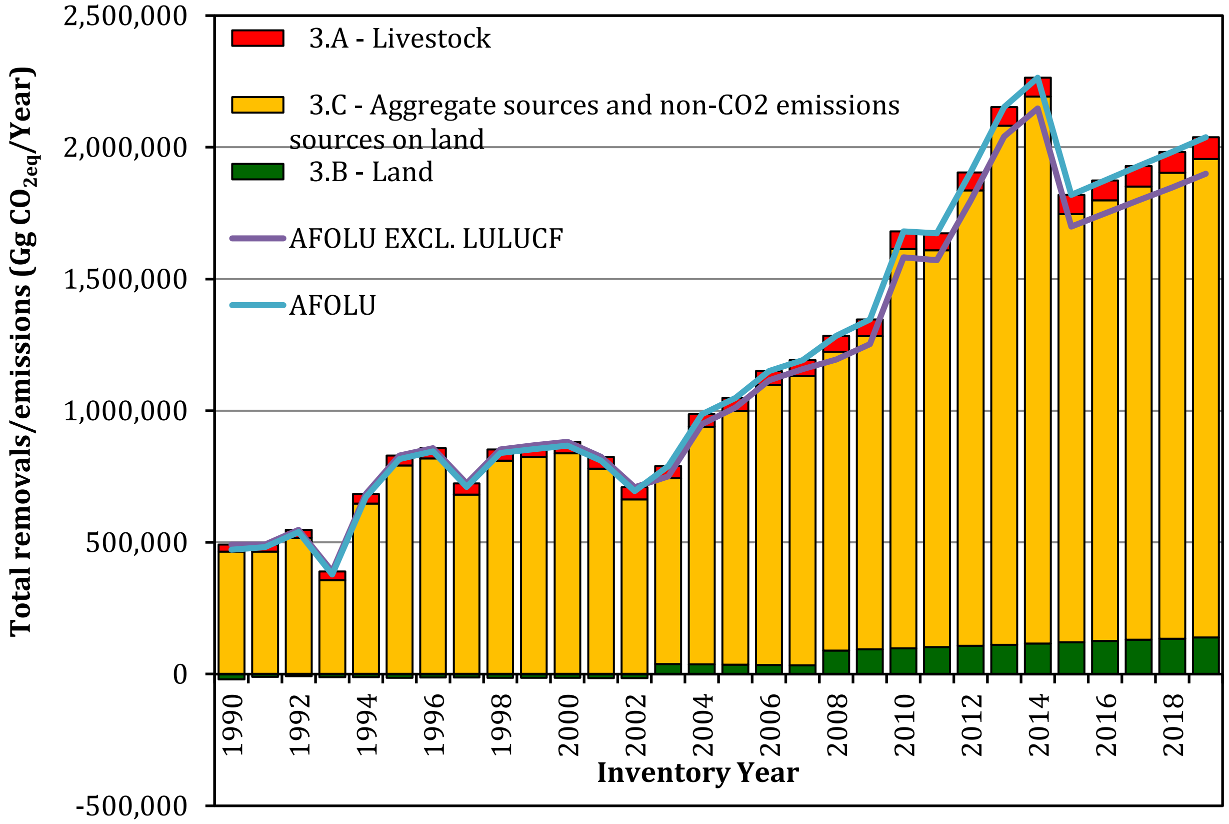

Figure 5.5: Trends in emissions and removals for the AFOLU sector in Ethiopia between 1990 and 2019.

Agriculture emission trends between 1990 and 2019

The emissions fluctuated over the whole time series. The emissions profile is dominated by both direct and indirect N_2O emissions from managed soils, with direct and indirect N_2O at 285671.26 Gg CO_2e in 1990 and at 1137190.75 Gg CO_2e in 2019 and for indirect N_2O emissions from managed soils was at 92501.54 Gg CO_2e in 1990 and at 369277.61 Gg CO_2e in 2019. Emissions from Urea application were estimated at in 1990 86435.066 Gg CO_2e and at 308144.34 Gg CO_2e in 2019. Whilst emissions from livestock for both enteric fermentation and manure management was estimated to be at 22528.06 Gg CO_2e and 4114.99 Gg CO_2e in 1990 respectively. In 2019 both enteric fermentation and manure management were estimated to be at 68501.96 Gg CO_2e and 13825.13 Gg CO_2e (Figure 5.6).

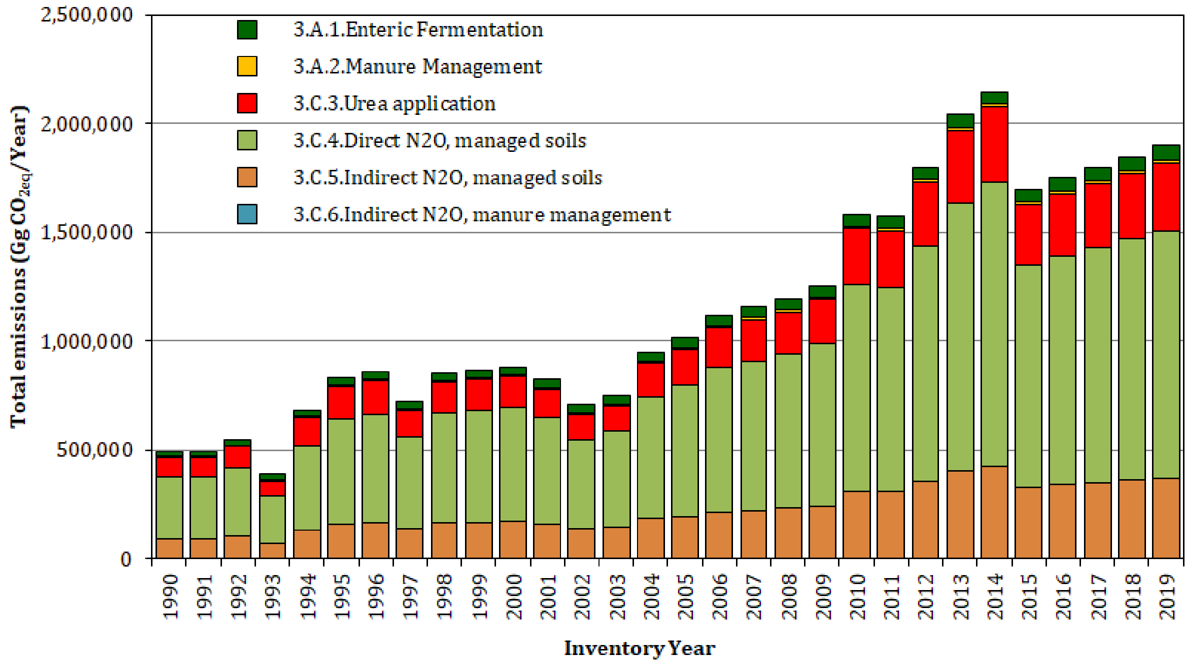

Figure 5.6: Emissions trends from Ethiopia's agriculture components of the AFOLU sector in 1990-2019

Overview of methodology and completeness for the AFOLU Sector

The table below provides a summary of the methods and types of emission factors used during the compilation of the AFOLU 2019 inventory.

Table 5. 1. AFOLU methods and completeness

AFOLU **Greenhouse Gas Source and Sink Categories**	Gases Included	Key Categories	Tier/ Notation Key	**Notes**
3A Livestock				
3A1 Enteric fermentation	**CH_4**	**KC**	**NO/T1/T2**	
a.i. Dairy cattle	CH_4		T1	IPCC defaults emission factors-2006 IPCC Guidelines
a.ii. Non Dairy cattle	CH_4		T1	
b. Buffalo	CH_4		NO	
c. Sheep	CH_4		T1	
d. Goats	CH_4		T1	
e. Camels	CH_4		T1	
f. Horses	CH_4		T1	
g. Mules and asses	CH_4		T1	
h. Swine	CH_4		NO	
3A2 Manure management	**CH_4, N_2O**	**KC**	**NO/T1/T2**	
a.i. Dairy cattle	CH_4, N_20		T1	IPCC defaults emission factors-2006 IPCC Guidelines
a.ii. Non-Dairy cattle	CH_4, N_20		T1	
b. Buffalo	CH_4		NO	
c. Sheep	CH_4		T1	
d. Goats	CH_4		T1	
e. Camels	CH_4		T1	
f. Horses	CH_4		T1	
g. Mules and asses	CH_4		T1	
h. Swine	CH_4		NO	
i. Poultry	CH_4		T1	
3B Land				
3B1 Forest land	**CO_2**	**KC**	**T1**	
a. Forest land Remaining Forest land	CO_2		T1	Land use maps 2003, 2008,2013 - 2018
b. Land Converted to Forest land	CO_2		T1	
3B2 Cropland	**CO_2**	**KC**	**T1**	
a. Cropland Remaining Cropland land	CO_2		T1	Land use maps2003, 2008,2013 - 2018
b. Land Converted to Cropland	CO_2		T1	
3B3 Grassland	**CO_2**	**KC**	**T1**	
a. Grassland Remaining Grassland	CO_2		T1	

AFOLU Greenhouse Gas Source and Sink Categories	Gases Included	Key Categories	Tier/ Notation Key	Notes
b. Land Converted to Grassland	CO_2		T1	Land use maps 2003, 2008,2013 - 2018
3B4 Wetland	**CO_2**	**KC**	**T1**	
a. Wetlands Remaining Wetlands	CO_2		T1	Land use maps 2003, 2008,2013 - 2018
b. Land Converted to Wetlands	CO_2		T1	
c. Peatlands	CO_2 N_2O and CH_4		NE	
3B5 Settlements	**CO_2**		**T1**	
a. Settlements Remaining Settlements	CO_2		T1	Land use maps 2003, 2008,2013 - 2018
b. Land Converted to Settlements	CO_2		T1	
3B6 Other land	**CO_2**		**T1**	
a. Other land Remaining Other land	CO_2		T1	Land use maps 2003, 2008,2013 - 2018
b. Land Converted to Other land	CO_2		T1	
3C Aggregated and non-CO_2 emissions on land				
3C1 Biomass burning	**CO_2, CH_4, N_2O**		**NE**	
a. Forest land	CO_2, CH_4, N_2O		T1	T1 emission factors from IPCC 2006 Guidelines
b. Cropland	CO_2, CH_4, N_2O		T1	
c. Grassland	CO_2, CH_4, N_2O		T1	
d. Wetland	CO_2, CH_4, N_2O		T1	
e. Settlements	CO_2, CH_4, N_2O		T1	
f. Other land	CO_2, CH_4, N_2O		T1	
3C2 Liming	**CO_2**		**NE**	
3C3 Urea application	**CO_2**		**T1**	**T1 emission factors from IPCC 2006 Guidelines**
3C4 Direct N_2O emissions from managed soils	**N_2O**		**T1**	**T1 emission factors from IPCC 2006 Guidelines**
3C5 Indirect N_2O emissions from managed soils	**N_2O**		**T1**	**T1 emission factors from**

AFOLU Greenhouse Gas Source and Sink Categories	Gases Included	Key Categories	Tier/ Notation Key	Notes
				IPCC 2006 Guidelines
3C7 Rice cultivation			NE	
3D Other				
3D1 Harvested wood products	CO_2		NE	

Key of Abbreviations: T1 is Tier 1, , NA is Not Applicable, NO is Not Occurring, occurring but NE is Not Estimated

Improvements for the AFOLU sector since 2015 submission of the SNC

The AFOLU sector had undergone major improvements since the submission of the TNC in 2016. In the previous inventory 1996 guidelines were used and agriculture and Land sector were treated as separate sectors. In this submission, significant improvements were made, and the 2006 IPCC Guidelines were used to compile the inventory, and this required recalculations. However, these improvements meant that it was not possible to perform recalculation for the 2016 as the changes made led to the two inventories being incomparable. Significant changes made to this sector include the following improvements:

- Livestock Categories (3A): For most categories country data on livestock population was used with some FAO data used to gap fill.
- Country specific emission factors/parameters were used in this inventory submission for some categories such as above ground biomass values for forest land, for cropland a country specific value for Harvest/maturity cycle. For Grassland values for parameter for Herbaceous biomass stocks present and Woody biomass stocks and for wetlands values for Biomass present on land.
- Manure management data was adjusted to include revised manure management systems practiced in the country, whose percentage contribution was established through expert judgement in some cases.
- Complete overlay of GIS-based land cover/land use raster maps with soil, climate and ecoregion maps.
- A systematic land representation framework was developed for the forestry and land sector.
- Update of biomass and stock change factors for some categories.

As alluded to, even though both the activity data and emission factors were revised and new updated methods were applied (e.g. the use of remote sensing and GIS analysis), recalculations were not done for the sector as these significant changes made the inventory not comparable to the 2016 inventory.

Key categories in the AFOLU sector

A key category analysis (with a level and trend assessment) was completed for the AFOLU sector only and the results are provided in Table 5.1.

Table 5.1: AFOLU key categories determined by level (L1) and trend (T1) assessments.

Greenhouse Gas Source and Sink Categories	Gas	Emissions/removal (Gg CO_2e)		Key category assessment type
		1990	2018	
Direct N_2O from managed soils	N_2O	285671.26	1137190.75	L1, T1
In direct N_2O from managed soils	N_2O	92501.54	369277.61	L1, T1
Urea application	CO_2	86435.06	308144.34	L1, T1
Cropland remaining cropland	CO_2	2330.31	59996.21	L1, T1
Forest land Remaining Forest land	CO_2	-39806.94	-22305.86	T1
Land Converted to Forest land	CO_2	-792.73	-45669.41	L1, T1
Enteric fermentation	CH_4	22528.06	68501.96	L1, T1
Land Converted to Grassland	CO_2	16448.00	127277.74	T1

Proposed improvements for the AFOLU sector

Data gaps in the AFOLU sector were considered and a list of proposed improvements for consideration in future inventories, or for data collection activities, is provided in Table 5.2.

Table 5.2: Proposed improvements for the AFOLU sector

Improvement Issue	Related to a key category	Effort required to carry out task
	Yes/No	Low/High
Improve land cover classifications for the period 1990 and 2020 using improved remote sensing techniques and field data	Yes	High
Disaggregate forest data by forest type to natural and plantation forests	Yes	High
Introduction of age class data in plantations and natural forests	Yes	High
Inclusion of specific crop data and fallow croplands to move to a higher tier calculation for croplands	Yes	High
Develop a system to collect livestock data from pastoralist area, commercial farms and urban areas	Yes	High
Improve data collection and reporting on the application of lime in both commercial agricultural areas and subsistence agricultural areas/farms of the country	Yes	High
Establish a platform for reporting on the hectarage and emission factors of rice cultivation by farmers	No	Low
Establish a platform for reporting on the hectarage and yields of cultivation of other crops by farmers	Yes	High
Develop a tool and platform for data collection on manure management in the country	Yes	High
Undertake local studies to determine country specific emission factors,	Yes	Low
Collect data and establish a methodology for estimating emissions from biomass burning across all land uses.	Yes	High
Develop country specific data collection templates for relevant sectors e.g. crop yields reported should indicate burnt residues	Yes	High
Undertake a study to establish country specific emission factors for biomass burning by land use	Yes	High
Collect data and establish a methodology for estimating emissions from Rice Cultivation	Yes	High

Develop country specific data collection templates for lime application at Regional Development Areas (RDAs) level	Yes	High
Improvement in the recording of lime application and records keeping of import records for lime.	Yes	High
Capacity to perform uncertainty assessment	Yes	High

1.2 Emissions and removals from Livestock category (3A)

Category overview

Livestock emissions in Ethiopia between 1990 and 2019 generally shows an upward trend, with notable increases recorded in the years between 2006-2010, there was a slight decline in 2011. The country recorded the highest emission from both enteric fermentation and manure management between 2012-2019 with a peak in emissions in 2019 at 68501.96 Gg CO_2e and 13825.13 Gg CO_2e for enteric fermentation and manure management, respectively. The increase in emissions is driven by the expansion in livestock production across the country since 1990 (figure 5.7).

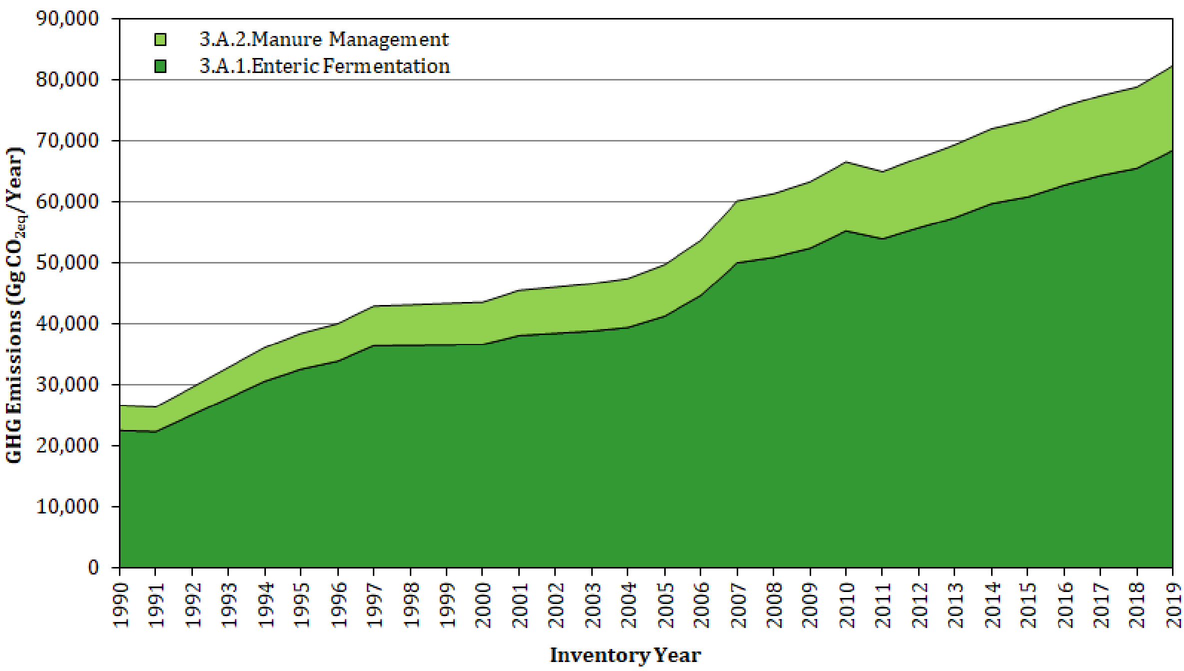

Figure 5.7: Trends in livestock emissions in Ethiopia between 1990 and 2019

Enteric Fermentation (3A1)

Category description

Emissions Sources	Enteric Fermentation Livestock population
Gases Reported	Methane (CH_4)
Methods	Tier 1 for all reported livestock categories Dairy Cattle, Non-Dairy Cattle, Sheep, Goat, Camel, Horse, Donkey, Mules, using Equation 10.19 and Equation 10.20 of the IPCC 2006 g Guidelines.
Emission Factors	Default EF values from IPCC 2006 guidelines (Chapter 10, Tables 10.14 - 10.16).
Key Category Analysis	Approach 1 in Vol. 1, Chapter 4 of IPCC 2006 Guidelines.
Completeness	Methane emissions from Dairy Cattle, Non-Dairy Cattle, Sheep, Goat, Camel, Horses, Donkey, Mules were included.
Major improvements since last submission	• The previous inventory on greenhouse gases (GHGs) in the agriculture sector was reported from 1994 to 2013. In the current inventory, GHGs estimates are provided annually form 1990-2019. • In the previous inventory, emissions for the year 1990 were not estimated (NE). This inventory calculated all emissions from 1994 to 2013. • The previous inventory collected activity data on dairy cattle, non-dairy cattle, sheep, goats. This was improved by the addition of horses, mules and asses.

Methane is produced in herbivores as a by-product of enteric fermentation, a digestive process by which plant material consumed by an animal is broken down by bacteria in the gut under anaerobic conditions. A portion of the plant material is fermented in the rumen to simple fatty acids, CO_2 and CH_4. The fatty acids are absorbed into the bloodstream, and the gases vented through eructation and exhalation by the animal. Unfermented feed and microbial cells pass to the intestines.

In Ethiopia, about 78.78 % of the population is in rural areas, dominantly small holder farmers, practising subsistence agriculture that involves livestock rearing. Livestock commonly reared include cattle, sheep, goats and chickens. Even though not as popular, some farmers also rear camel sheep, horses and asses. There are also commercial farmers that rear livestock such as cattle, goats, sheep, chickens in Ethiopia.

Emissions

Overall, there is a 67% increase in enteric fermentation emission between 1990-2019 which represents 22528.06 Gg CO_2e and 68501.96 Gg CO_2e emissions for 1990 and 2019 respectively. Enteric fermentation emissions from camels, cattle, goats and mules and asses had the highest contribution and increased from 1990 to 2019 by 98.86%, 86.17 % and 80.57% respectively, while the other sub-categories also showed an increasing trend between 1990 and 2019 (Table 5.3). Sheep contributed 1112.695 Gg CO_2e in 1990 and 4107.01 Gg CO_2e in 2019 and other cattle contributed 11893.77 Gg CO_2e in 1990 and 38542.51 Gg CO_2e in 2019. The largest decline was seen in the enteric fermentation category for dairy cattle 7923.96 Gg CO2e in 1990 and 13637.72 Gg CO2e in 2019, which declined by 41.9%, over the 18-year period. This low contribution for horses at 51.96% could be due to the decline in the demand of these animals, which were earlier used for draught purposes.

Table 5.3: Trend and relative contribution of the various livestock categories to the enteric fermentation category between 1990 and 2019

Sub-Category	Emission (GgCO2 eq)		Change (1990-2019)	
	1990	2019	Difference (GgCO2 eq)	%
3.A.1 - Enteric Fermentation	22528.067	68501.96958	45973.90258	67.11
3.A.1.a - Cattle	19817.73	52180.23623	32362.50623	62.02
3.A.1.a.i - Dairy Cows	7923.96	13637.72465	5713.76465	41.90
3.A.1.a.ii - Other Cattle	11893.77	38542.51158	26648.74158	69.14
3.A.1.b - Buffalo		0		
3.A.1.c - Sheep	1112.695	4107.01125	2994.31625	72.91
3.A.1.d - Goats	636.3775	4600.747	3964.3695	86.17
3.A.1.e - Camels	48.8405	4288.7548	4239.9143	98.86
3.A.1.f - Horses	447.0165	930.52755	483.51105	51.96
3.A.1.g - Mules and Asses	465.4075	2394.69275	1929.28525	80.57
3.A.1.h - Swine				

Methodological Issues

Ethiopia used Tier 1 methods to estimate emissions. Emissions were calculated using Equation 10.19 and 10.20 of the IPPC 2006 Guidelines. Enteric emission factors (EF) for T1 were obtained from Vol. 4 of Chapter 10 of the 2006 IPCC Guidelines, Table 10.10 and Table 10.11.

Data for livestock population; Dairy Cattle, Non-Dairy Cattle, Sheep, Goat, Camel, Horses, Donkey, Mules and poultry (broilers) were available from the Ethiopian CSA for the years 1990-1992, 1994-1997, 2004-2019. The data provided detailed numbers up to the region level. The other years, data were very inconsistent or not available and were mostly reported using IPCC interpolation techniques. For all other livestock but horses, mules and asses, the totals were used to estimate data for each livestock group.

Generally, livestock data were more complete after 2003. The typical weight of livestock categories were taken from the IPCC defaults value, 2006 IPCC Guidelines.

Category Specific QA/QC & Verification

Ethiopia used the EPA templates for QA/QC procedures which requires the filling of quality assurance and control forms were for the sector were followed. Moreover, the inventory calculation files were exchanged with other sectors for QA/QC. All sources of data, emission factors used, as well as other factors and constants used were referenced using the data templates generated for this project by the AFOLU consultant. Consultations were also done with relevant stakeholders, such as personnel from the Livestock and Veterinary Department of the Ministry of Agriculture. A Technical Working Group of experts focusing on the Agriculture category was established and provided technical review and input into the sector inventory, even verified calculation procedures applied. Lastly, FAO data were used for verification in some cases.

Planned improvements

IPCC Land use category	Data gaps identified (AD and EF)	Planned Improvements /Remarks
Enteric Fermentation	i) A system to collect livestock data from pastoralist area, commercial farms, and urban areas. ii) Consistent reporting of livestock by sub-categories using data collection templates designed for this project. iii) Generalisation of annual livestock census data to regional and national level iv) Country specific enteric EF	i) Development if a system to collect livestock data from pastoralist area, commercial farms and urban areas. ii) Integrating a component in the reporting tool that ensures livestock data is reported by sub-categories. iii) Completion of the mapping and livestock census data to regional and national level iv) Undertaking of a study to establish country specific EFs

Manure Management (3A2)

Category description

Emissions Sources	Manure management Livestock population
Gases Reported	Methane (CH_4) Nitrous oxide (N_2O)
Methods	Tier 1 for all reported livestock categories Dairy Cattle, Non-Dairy Cattle, Sheep, Goat, Camel, Horse, Donkey, Mules, using Equation 10.19 and Equation 10.20 of the IPCC 2006 g Guidelines.
Emission Factors	Default EF values from IPCC 2006 Guidelines (Chapter 10, Tables 10.14 - 10.16)
Key Category Analysis	Approach 1 in Vol. 1, Chapter 4 of IPCC 2006 Guidelines.
Completeness	Manure management practices in Ethiopia were considered. Methane and nitrous oxide emissions from Dairy Cattle, Non-Dairy Cattle, Sheep, Goat, Camel, Horses, Donkey, Mules, poultry, laying hens and broilers were included
Major improvements since last submission	• See Section 5.2.2 (Enteric Fermentation) for improvements on livestock data and methodologies relating to livestock-related emissions. • This inventory estimated the emissions from this category using EFs in line with the manure management systems practiced in the country, whose percentage contribution was established by a combination of country data and through expert judgement.

Livestock manure is composed principally of organic material. When the manure decomposes in the absence of oxygen, methanogenic bacteria produce CH_4. The amount of CH_4 emissions is related to the amount of manure produced and the amount that decomposes anaerobically. These conditions occur most readily when large numbers of animals are managed in a confined area (dairy farms, beef feedlots, poultry farms etc.), and where manure is disposed of in liquid-based systems. The manure management category also includes N_2O emissions related to manure handling before it is added to agricultural soil. The amount of N_2O emissions depends on the system of waste management and the duration of storage.

Emissions

Overall, there is a 70.24% increase in manure management emissions between 1990-2019 which represents 4081.11 Gg CO_2e and 13711.83 Gg CO_2e emissions for 1990 and 2019 respectively. Manure management emissions from camels, goats, mules and asses, other cattle followed by poultry and laying had the highest contributions between 1990 and 2019 at 98.86%, 86.17%, 80.57%, 69.14% and 65.05 respectively (Table 5.4). The lowest increase was seen in the manure management category for dairy cattle 220.35Gg CO_2e in 1990 and 379.24 Gg CO_2e in 2019, which declined by 41.9%, over the 18-year period.

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Table 5.4: Trend and relative contribution of the various livestock categories to the manure management category between 1990 and 2019

Sub-Category	Emission (GgCO2 eq)		Change (1990-2019)	
	1990	2019	Difference (GgCO2 eq)	%
3.A.2 - Manure Management (1)	4081.1147	13711.83	9630.71167	70.24
3.A.2.a - Cattle	3221.93878	10106.07	6884.133768	68.12
3.A.2.a.i - Dairy cows	220.352562	379.2432	158.8905899	41.90
3.A.2.a.ii - Other cattle	3001.58622	9726.829	6725.243178	69.14
3.A.2.b - Buffalo		0		
3.A.2.c - Sheep	340.561704	892.78	552.2182986	61.85
3.A.2.d - Goats	169.617855	1226.267	1056.649318	86.17
3.A.2.e - Camels	2.71808	238.6785	235.960448	98.86
3.A.2.f - Horses	164.796549	343.0471	178.2505841	51.96
3.A.2.g - Mules and Asses	168.868907	868.8926	700.0237232	80.57
3.A.2.h - Swine		0		
3.A.2.i - Poultry	12.6128238	36.08835	23.47552955	65.05

Methodological Issues

The IPCC 2006 guidelines highlight that countries using the Tier 1 method should carefully choose emission factors (EF) closely resembling their animal operations (Table 10.14 - 10.16). These factors represent the manure management practices presented in Table 10A-4 through to Table 10A-9 of Vol. 4, Chapter 10 of the IPCC 2006 Guidelines. At the time of this inventory, in Ethiopia, 6 manure management systems (MMS) were identified as practiced through expert opinion, and these were solid storage, daily spread and pasture/range/paddock, also known as PRP, Burned as Fuel, dry lot, Poultry with and without litter. MMS differed with the different livestock as outlined in Table 5.6. Dairy cattle had a part in all three systems having 83%, 12% and 5% under, PRP, daily spread and solid storage, respectively, while in the same order non-dairy cattle had 35% of PRP, 15% - burned as fuel and 45% for dry lot. Sheep had 38% of PRP and 20 of dry lot, goats had 80% PRP and 20% dry lot, poultry has 93% and 7% without and with litter respectively. Horses and donkey's percent share by MM system was at 70% for PRP and 30% for dry lot. Whilst camel had 100% PRP.

Table 5.5: Manure management systems practised in Ethiopia.

Livestock	PRP	Daily Spread	Burned as Fuel	Dry Lot	Poultry Without Litter	Poultry With Litter	Solid Storage	Sum
Dairy	83	12	0	0	0	0	5	100
Non-Dairy	35	0	15	45	0	0	5	100
Sheep	80	0	0	20	0	0	0	100
Goat	80	0	0	20	0	0	0	100
Camel	100	0	0	0	0	0	0	100
Horse	70	0	0	30	0	0	0	100
Donkey	70	0	0	30	0	0	0	100
Mules	70	0	0	30	0	0	0	100
Poultry	0	0	0	0	93	7	0	100

Tier 1 method was used using Equation 10.22 from the IPPC 2006 Guidelines. The emission factors (EF) from Vol 4, Chapter 10 of 2006 IPCC Guidelines, Table 10.14 to Table 10.16 were used. Livestock data were used, and for details of the reader is referred to under the section on enteric fermentation (Section 5.2.3).

Category Specific QA/QC & Verification

Ethiopia used the EPA templates for QA/QC procedures which require the filling of quality assurance and control forms were followed, with the inventory calculation files also exchanged with other sectors for QA/QC. All sources of data, emission factors used, as well as other factors and constants used were referenced. Expert judgement on manure management was used, and this was done in consultation with experts such as officers from the Livestock and Veterinary Department of the Ministry of Agriculture. A Technical Working Group of experts focusing on the Agriculture category was also established and provided technical review and input into the inventory.

Planned improvements

IPCC Land use category	Data gaps identified (AD and EF)	Planned Improvements /Remarks
Manure Management	i) Lack of country specific activity data on manure management ii) Lack of country specific emission factors	i) Development of a system for collecting data on manure management nationally, both in small holder farms and commercial farms and in rural areas ii) Undertaking of a study to establish country specific EFs iii) Develop a system to collect livestock data from pastoralist area, commercial farms and urban areas

1.3 Emissions and removals from Land category (3B)

Category overview

This section provides estimates of emissions and removals from the Land category, using the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) (hereinafter referred to as IPCC 2006 Guidelines) for all the IPCC six land use categories – forestland, cropland, grassland, wetlands, settlements and Other land. IPCC Inventory Software was used to estimate emissions and removals in the Land category.

Overall, the land category remained a net sink from 1990 until 2002 and became a net source from in 2003 at 38829.51Gg CO_2e rising up to 139336.29 Gg CO_2e in 2019. The Land category had a net removal of -19742.15 Gg CO_2e in 1990 and -15087.60 Gg CO_2e in 2002. This constitutes a 605% increase in emissions since 1990. The key drivers for this decrease are increased rates of deforestation on the indigenous forests to pave way for agricultural land, promotion of large-scale commercial and state development investments in forest frontier, illegal extraction and collection of forest products (mainly fuelwood collection and charcoal making), human settlement in forest areas, forest fires, and development of infrastructure and road (figure 5.8).

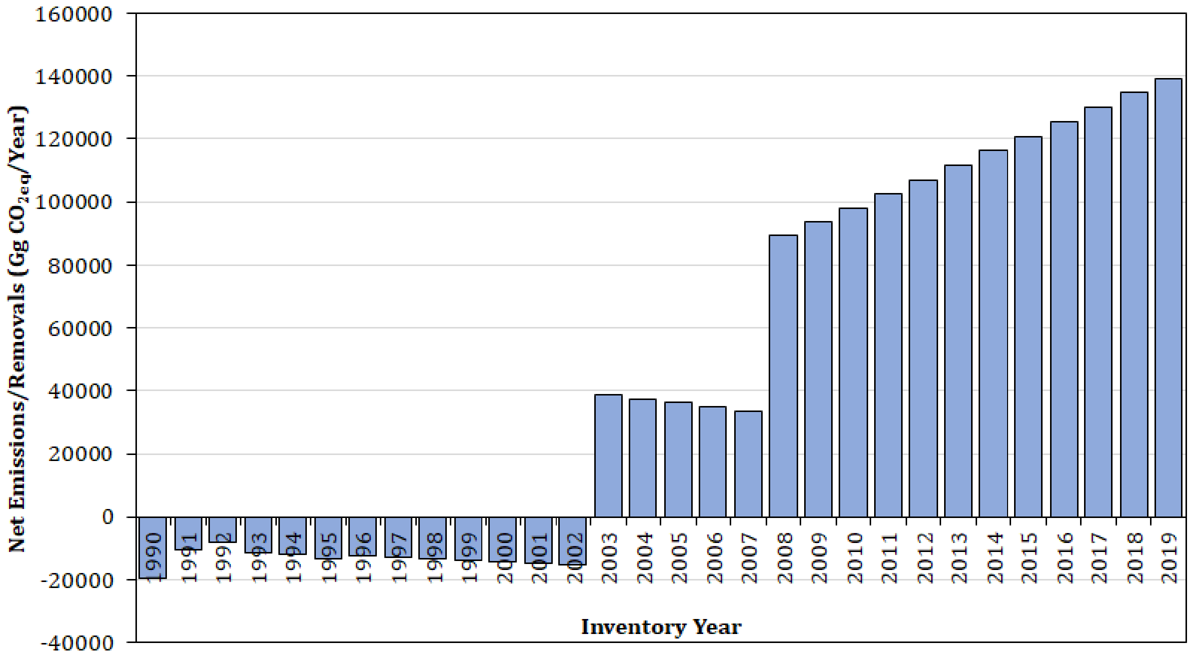


Figure 5.8: Net CO_2 emissions and removals (Gg CO_2e per year) from the Land category – time series 1990-2019

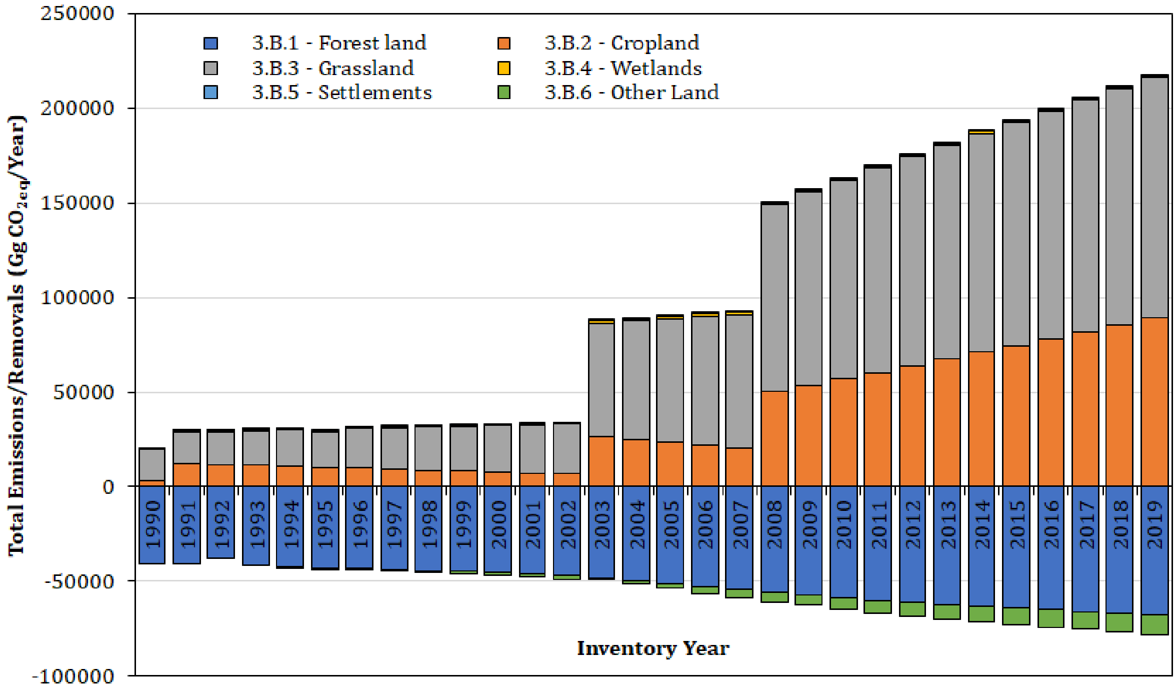


Figure 5.9: Net CO_2 emissions and removals (Gg CO_2e per year) from the Land category by land-use type from 1990 to 2019

Forest land is responsible for most of the CO_2 removals in the sector and is an increasing sink across the time series from 1990 to 2019 at -40599.68 Gg CO_2e and -67975.28 Gg CO_2e respectively. Grassland land use category was the largest emissions source in the beginning of the inventory period time series, with 16448.00 Gg CO_2e in 1990, and 127277.74 Gg CO_2e in 2019. This was followed by cropland emissions which also show an increasing trend and is the second largest source of emissions across the time series at 3104.57 Gg CO_2e in 1990 and at 89182.16 Gg CO_2e in 2019. Emissions from Wetlands were at 451.83 Gg CO_2e in 1990 and 983.94 Gg CO_2e in 2019. Emissions from Settlements though showed an increase, 26.41 Gg CO_2e in 1990 and 148.12 Gg CO_2e in 2019. Lastly, emissions from Other Land were 826.71 Gg CO_2e in 1990 and -10280.39 Gg CO_2e in 2019. (Figure 5.9).

Land areas and on land-use databases used for the inventory preparation.

Land-use maps are the main source of activity data for land category inventory. Land areas are represented using the IPCC Approach 2 (total land-use area, including changes between categories) for the six identified IPCC land use categories or sub-categories per ecological zone. IPCC Approach 2 provides an assessment of both the net losses or gains in the area of specific land-use categories and what these conversions represent (i.e., changes both from and to a category) but does not provide spatially explicit location of area data. The result of this approach is presented as a non-spatially explicit land-use conversion matrices covering the period 1990 until the currently reported year. The main dataset for the land categories were derived from processing of satellite imageries for the years 2003, 2008, 2013, and 2018. Four sets of raster data derived from supervised classification of Landsat imagery covering the years 2003, 2008, 2013, and 2018 were included in the preparation of this NIR. This means that land-use maps for 2003, 2008, 2013, and 2018 were produced from wall-to-wall remote sensing and GIS ground-truthing. Activity data used for the land were generated from GIS data maps produced for 4-time steps, for the years 2003, 2008, 2013, and 2018. These wall-to-wall maps were generated from 30m resolution, Landsat 7 and Landsat 8 OLI satellite imagery.

Two of the total four raster data sets of land use and land cover change data for the years 2003 and 2008 were produced at RCMRD in Nairobi while those for 2013 and 2018 were produced in Ethiopia by GII. Both data sets consist of 17 land classes generated by unsupervised classification on Landsat 7 and Landsat 8 OLI imagery.

All the maps provided for the areas for the six IPCC land classes. The change detection analysis on the land use data were undertaken for three change pairs: 2003, 2008, 2013, and 2018. A pixel-based approach was adopted to enable tracking of land use changes showing the exact areas of change, transition among classes and areas. The generated change raster maps were used to create land cover change maps between the 4 epochs of study representing the various changes in land use.

In order to retain consistency among GHG estimates reported for different years the total land area was adjusted using a proportional approach to the area covered by all data sets. The adjusted data allowed for establishment of 4 land use matrices 1990-2003, 2003-2008, 2008-2013 and 2013-2018 (Table 5.6 to Table 5.). All matrices were linearly interpolated/ extrapolated to obtain annual land use change data for all individual years within these periods. The annual land use change data were extrapolated backwards to obtain annual land use change data for the period 1980-1990 (due to lack of measured data, it was assumed that for all reported land pre-1990 land uses were not different from the land use in 1990). The 1990-2003 was obtained from the 2003 extrapolated backwards and assumed the rates of laund use change from 2003 and 2008 were same, 2003– 2007 and 2009-2012 and 2014-2017 annual land use change data were interpolated to obtain annual land use change data to the reported year. In the future all, extrapolated and interpolated data will be replaced/ supplemented by the measured data if resources permit.

Table 5.6: Land use transition matrix for the period 1990 -2003

Initial year	1990
Final year	2003

2003 \ 1990	Forest land	Perennial	Annual	Grassland	Wetlands	Settlements	Other lands	Total
Forest land	10,436,947.17	470.39	397,495.80	925,569.55	9,937.70	151.60	23,961.29	11,794,533.50
Perennial	2,137.32	29,244.41	3,207.52	5,945.39	74.79	6.24	160.23	40,775.90
Annual	319,839.28	2,250.18	17,064,740.00	1,170,654.73	3,661.49	410.40	30,337.22	18,591,893.30
Grassland	554,506.33	2,279.25	895,993.16	60,043,183.13	26,746.93	489.39	689,103.91	62,212,302.10
Wetlands	14,200.92	169.64	6,049.89	60,278.37	954,857.71	1.07	12,577.79	1,048,135.40
Settlements	877.90	1.23	3,859.98	2,148.09	79.80	108,011.93	637.68	115,616.60
Other lands	16,665.55	125.20	33,489.80	679,900.33	12,777.15	31.43	12,492,205.35	13,235,194.80
Total	11,345,174.48	34,540.30	18,404,836.14	62,887,679.57	1,008,135.58	109,102.06	13,248,983.47	

Table 5.7: Land use transition matrix for the period 2003 -2008

Initial year	2003
Final year	2008

2003 / 2008	Forest land	Perennial	Annual	Grassland	Wetlands	Settlements	Other lands	Total
Forest land	6,554,760.60	2,713.80	2,293,245.00	5,339,824.30	57,332.90	874.60	138,238.20	14,386,989.40
Perennial	12,330.70	10,222.70	18,504.90	34,300.30	431.50	36.00	924.40	76,750.50
Annual	1,845,226.60	12,981.80	10,860,569.40	6,753,777.30	21,124.00	2,367.70	175,022.40	19,671,069.20
Grassland	3,199,075.00	13,149.50	5,169,191.30	45,801,745.70	154,309.20	2,823.40	3,975,599.50	58,315,893.60
Wetlands	81,928.40	978.70	34,903.20	347,759.80	740,763.10	6.20	72,564.20	1,278,903.60
Settlements	5,064.80	7.10	22,269.10	12,392.80	460.40	109,327.40	3,678.90	153,200.50
Other lands	96,147.40	722.30	193,210.40	3,922,501.90	73,714.30	181.30	8,869,167.20	13,155,644.80
Total	11,794,533.50	40,775.90	18,591,893.30	62,212,302.10	1,048,135.40	115,616.60	13,235,194.80	

Table 5.9: Land use transition matrix for the period 2008 -2013

Initial year	2008
Final year	2013

2013 \ 2008	Forest land	Perennial	Annual	Grassland	Wetlands	Settlements	Other lands	Total
Forest land	6,381,596.80	31,977.20	3,174,302.60	5,274,463.70	156,135.90	15,012.90	356,279.70	15,389,768.80
Perennial	786,027.10	13,988.20	1,841,817.60	1,166,386.30	8,870.10	5,336.80	18,157.50	3,840,583.60
Annual	2,228,347.20	17,201.60	8,533,888.30	6,687,292.60	31,644.30	26,251.40	246,173.00	17,770,798.40
Grassland	4,787,401.20	12,025.80	5,823,092.80	41,621,049.10	318,345.10	18,671.00	4,358,649.40	56,939,234.40
Wetlands	60,474.90	526.60	47,155.20	219,152.20	726,651.10	1,038.30	125,968.50	1,180,966.80
Settlements	13,892.80	451.70	45,539.30	21,071.00	782.50	79,013.70	1,775.30	162,526.30
Other lands	129,249.40	579.40	205,273.40	3,326,478.70	36,474.60	7,876.40	8,048,641.40	11,754,573.30
Total	14,386,989.40	76,750.50	19,671,069.20	58,315,893.60	1,278,903.60	153,200.50	13,155,644.80	

Table 5.10: Land use transition matrix for the period 2013 -2018

Initial year	2013
Final year	2018

2018 \ 2013	Forest land	Perennial	Annual	Grassland	Wetlands	Settlements	Other lands	Total
Forest land	7,031,027.70	760,493.90	2,836,289.00	5,153,111.10	91,523.80	17,257.30	162,223.60	16,051,926.40
Perennial	3,312,819.40	1,817,145.30	8,807,150.90	9,425,494.60	77,069.50	28,884.80	670,808.00	24,139,372.50
Annual	842,425.50	474,061.80	1,503,710.90	3,811,870.80	23,753.70	2,446.40	121,431.30	6,779,700.40
Grassland	3,650,412.30	731,512.90	3,856,892.30	36,135,296.10	178,673.60	22,965.50	2,108,856.20	46,684,608.90
Wetlands	130,159.90	28,155.30	176,902.60	443,660.80	676,884.10	803.80	48,521.00	1,505,087.50
Settlements	9,538.10	4,538.50	27,593.90	15,997.00	572.40	89,716.70	2,995.50	150,952.10
Other lands	413,385.90	24,675.90	562,258.80	1,953,804.00	132,489.70	451.80	8,639,737.70	11,726,803.80
Total	15,389,768.80	3,840,583.60	17,770,798.40	56,939,234.40	1,180,966.80	162,526.30	11,754,573.30	

Land-use definitions and the classification systems used and their correspondence to the Land categories

The IPCC 2006 identifies six broad land-use categories for the purpose of estimating and reporting greenhouse gas emissions and removals from land use and land-use conversions: (i) Forest Land; (ii) Cropland; (iii) Grassland; (iv) Wetlands; (v) Settlements; and (vi) Other Land. In the preparation of this inventory Ethiopia

used national definitions of the land uses consistent with the definitions of the categories referred to in IPCC 2006 guidelines as listed below.

Forestland: This refers to all land with woody vegetation as per FAO definitions. This land category was divided into two forest types, plantation and indigenous forests.

Plantation forests refer to the woody vegetation that at maturity is predominantly composed of trees established through planting and/or deliberate seeding. These are typically intensively managed that at maturity is composed of one or two species, has uniform age classes, and has regular tree spacing.

Indigenous forests include all 'Land spanning more than 0.5 ha covered by trees (including bamboo) (with a minimum width of 20m or not more than two-thirds of its length) attaining a height of more than 2m and a canopy cover of more than 20% or trees with the potential,

to reach these thresholds in situ in due course (Minutes of Forest sector management, MEFCC, Feb. 2015 and Ethiopian FREL 2017).

In summary this includes systems with a vegetation structure that could potentially reach the proposed national values used to define the indigenous forest land category in Ethiopia as follows:

- Minimum mapping unit (MMU) is 0.5 ha
- Minimum tree cover is 20 %
- Potential to reach minimum height at maturity (in situ) as 2 m

Cropland: This refers to parcels of land that are currently cropped or in fallow and some agro-forestry systems where the vegetation structure falls below the thresholds used for the forestland category. This includes land where over 50% of any defined area is used for crop agriculture. This was also divided into perennial and annual cropland. The former is predominantly fruits tress whilst the latter is a mixture of cereals, pulse, root crops, oils seeds and vegetables.

Grassland: This refers to all land that is dominated by grass cover and includes rangelands and pasture lands that are not considered cropland or forestland. It also includes areas covered by both grass and herbaceous plants that fall below the threshold values used in the forestland category such as the other wooded land.

Wetland: This refers to land that is covered or saturated by water for all or part of the year but does not fall into the forest land, cropland, and grassland or settlements categories. This category is dominated by reservoirs or flooded land as a managed sub-division.

Settlement: This refers to all developed land, including transport and industrial infrastructure and human settlements.

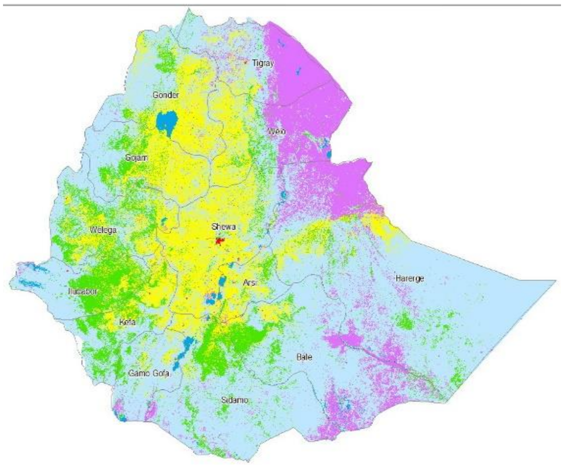
Other lands: this refers to land that is covered by bare soil, rock and all land areas that do not fall into any of the other five categories.

All land within Ethiopia was re-classified into the six IPCC land categories and where all land is treated in this inventory as managed land. This implies that all land has been accounted for in the compilation of emissions and removals. The land cover change data by RCMRD: Regional Centre for Mapping Of Resources For Development; GII: Ethiopian Geospatial Information Institute and EFCCC: Environment Forestry, and Climate Change Commission was the basis for the land use and land use change and forestry analyses.

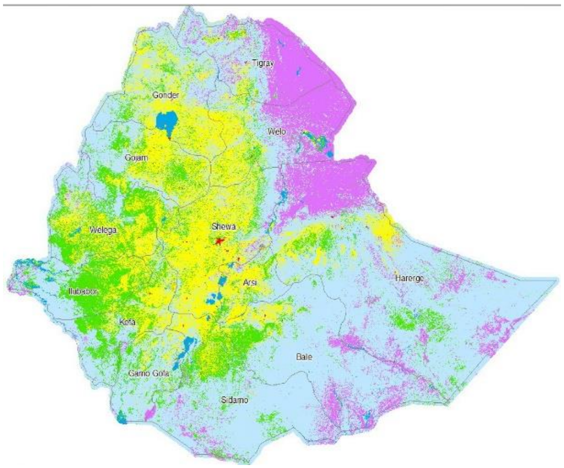
The original data had 17 classes, which were condensed to 7 as shown in Table 5.. Hence, the land change mapping within the land classes and between the classes was only done on the 7 land classes (Figure 5.10).

Table 5.11: Land use categories used in the Land category

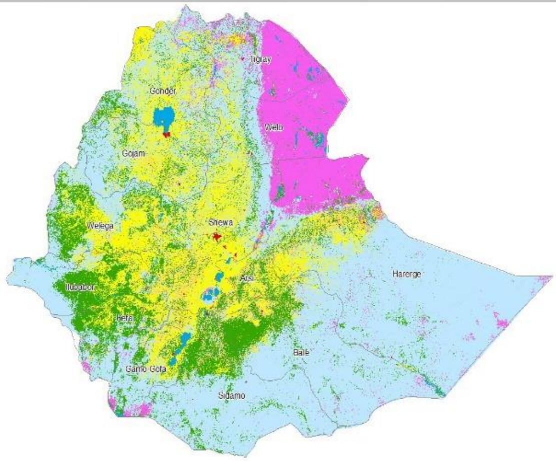
IPCC 2006		RCMRD – GII 17 Class
1	Forest	Dense Moderate Sparse Woodland
2	Grassland	Closed Grassland Open Grassland Closed Shrubland Open Shrubland
3	Perennial Cropland	Perennial Cropland
4	Annual Cropland	Annual Cropland
5	Wetland /Water	Wetland Water
6	Settlement	Settlement
7	Other	Bare Soil Lava Flow Rock Outcrop Salt Pan



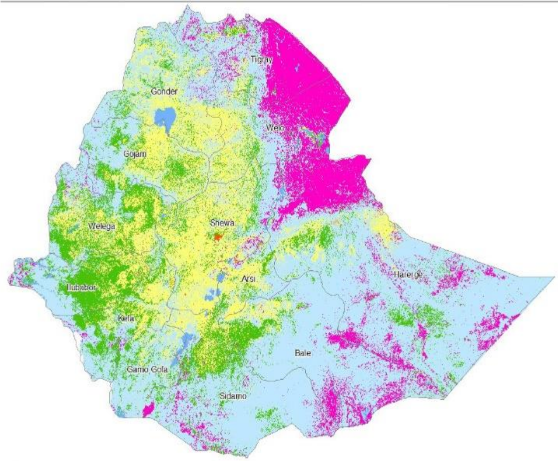
2003



2008



2013



2018

Figure 5.2: Land use maps for Ethiopia for the periods 2003, 2008, 2013, and 2018

Legend

1	Forest
2	Grassland
3	Perennial Cropland
4	Annual Cropland
5	Wetland /Water
6	Settlement
7	Other

With respect to the 2018 map, accuracy assessment was undertaken by collecting ground referencing points, some which were used in refining the classification and the remaining for accuracy assessment. Of the 248 points collected, 143 points were used in improving the classification by correcting the wrongly classified regions while 105 points were used in checking the accuracy of the classification. The error matrix is the most common way to present the accuracy of the remotely sensed classification results. Overall accuracy, user's and producer's accuracies, and the Kappa statistic were derived from the error matrices. The Kappa statistic incorporates the off-diagonal elements of the error matrices and represents agreement obtained after removing the proportion of agreement that could be expected to occur by chance. The overall accuracy of classification imagery dated 2018 was 85.05% and the Kappa coefficient was 82.49%. The results of the accuracy assessment are provided below in Table 5.12.

Table 5.12: Confusion matrix for the 2018 image classification of the 17 classes

		Ground Truth																
	Class Name	Lava flow	Salt pan	Sparse forest	Moderate fo	rockout crop	Dense Forest	Annual crop	Water body	Perennial crops	Wetland	Closed shrub	open shrub	Settlements	Wood land	Bare Soil	Closed Grassland	Open grassland
Mapped	Lava flow	12	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
	Salt pan	0	8	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0
	Sparse forest	0	0	18	0	0	0	1	0	0	0	0	1	0	0	0	0	0
	Moderate forest	0	0	8	111	0	0	8	0	0	0	1	3	0	0	1	0	1
	rockout crops	7	0	1	1	99	1	2	0	0	0	1	14	0	1	2	4	0
	Dense Forest	0	0	0	0	0	29	3	0	0	0	0	1	0	0	0	0	0
	Annual crop land	0	0	2	7	1	0	274	0	0	0	6	33	0	0	0	1	2
	Water body	0	0	0	0	0	0	0	18	0	0	0	0	0	0	0	0	0
	Perennial crops	0	0	1	1	0	0	4	0	60	0	2	22	0	0	0	4	0
	Wetland	0	0	1	0	0	0	1	0	0	20	0	1	0	0	2	0	0
	Closed shrub la	0	0	0	0	1	0	14	0	1	0	171	13	0	0	7	0	2
	open shrub land	0	0	1	0	0	0	12	0	0	0	9	323	0	0	2	0	0
	Settlements	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0
	Wood land	0	0	0	0	0	0	1	0	0	1	0	0	1	26	0	0	1
	Bare Soil	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	0	0
	Closed Grasslan	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	25	0
	Open grass land	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	44

Then confusion matrix above was then used to derive uncertainty information using the approach from (Olofsson et al., 2014). The analysis indicates a relatively high uncertainty for the ‘Perennial Crop’ category and for Dense forests (Table 5.13). The rest of the land uses had comparatively low uncertainty.

Table 5.13: Accuracy assessment and uncertainty of change areas of the 17 classes

	Area in ha	Pi	Area(Ai)(Ha)	Standard Error(Propotion)	Standard Error(Ha)	Confidence intervals(H	Uncertainty ±
Lava flow	405546.48	0.009302326	1068228.352	3.71492E-12	0.000426601	0.000836139	0.399667522
Salt pan	251222.58	0.00730897	839322.2763	3.40081E-13	3.9053E-05	7.65439E-05	1
Sparse forest	1707723.9	0.013289037	1526040.502	7.36799E-12	0.000846099	0.001658355	0.601774996
Moderate forest	11469397.86	0.088372093	10148169.34	1.32577E-11	0.001522442	0.002983986	0.915224488
rockout crops	9920656.89	0.088372093	10148169.34	1.41047E-11	0.001619712	0.003174636	0.97600143
Dense Forest	2111440.68	0.02192691	2517966.829	3.90192E-12	0.000448075	0.000878227	0.982157296
Annual crop land	25689646.26	0.216611296	24874460.19	4.7954E-11	0.005506776	0.010793281	0.850048157
Water body	820928.7	0.011960133	1373436.452	0	0	0	1
Perennial crops	7263285.3	0.062458472	7172390.361	1.19866E-11	0.001376478	0.002697898	0.983004727
Wet land	792613.08	0.016611296	1907550.628	1.44631E-12	0.000166086	0.000325529	0.876706816
Closed shrub lan	16774469.37	0.138870432	15947123.25	2.71147E-11	0.003113699	0.00610285	0.900528086
open shrub land	28712814.12	0.230564784	26476802.72	5.36369E-11	0.006159364	0.012072352	0.795710913
Settelement	160602.93	0.006644518	763020.2512	3.97204E-13	4.56127E-05	8.94009E-05	0.727339209
Wood land	1806177.42	0.019933555	2289060.753	1.92971E-12	0.000221597	0.00043433	0.954515915
Bare Soil	2137306.59	0.021262458	2441664.804	6.68676E-12	0.000767872	0.001505028	0.679667452
Closed Grassland	1530689.58	0.017275748	1983852.653	5.09903E-12	0.000585545	0.001147667	0.673057973
Open grass land	3280026.06	0.02923588	3357289.105	3.0094E-12	0.000345584	0.000677344	0.880310356

Data and data sources for Land emission factors

Above ground biomass data for natural forests was taken from the Ethiopian FREL Document (2017) submitted to the UNFCCC, the values for above ground biomass (AGB) are derived from weighted averages based on data from forest biomes. The National Land cover maps provided a detailed wall-to-wall analysis of carbon stocks and flux for woody biomass, herbaceous biomass for forest land. It should be noted, though, that the assessment included all the ecosystems found within Ethiopia. In this and the Ethiopian analysis, comparisons were made to IPCC default factors and literature assessed to determine the most appropriate biomass value for each category (Table 5.14 and 5.15).

Table 5.14: Overview of the Land categories, data and data sources in the inventory

Category	Sub-categories	Data Type	Data Source	Data Providers	Remarks
3B Land	3.B.1: Forest Land	Land use maps (2003,2008 and 2013 and 2018), Land use change maps (2003,2008 and 2013 and 2018), Land use matrix and land use change matrix Accuracy estimates	Ethiopia Land Cover, Land Cover Change Analysis (2003,2008 and 2013 and 2018)	The land cover change data by RCMRD: Regional Centre for Mapping of Resources for Development; GII: Ethiopian Geospatial Information Institute and EFCCC: Environment Forestry, and Climate Change Commission	The land use change maps were derived from maps for the years (2003,2008 and 2013 and 2018). Land representation map matrix and change matrix are in excel format and obtained from land individual maps. Accuracy assessment were derived from the individual and change matrix.
		Biomass estimates for Above-ground biomass, Below-ground biomass,	National data from NFI	Ethiopian NFI	Biomass estimates for natural forest (Indigenous forest) are based on Ethiopian forest biomes data with similar climate types. NFI data analysis was based on the analysis of 539 accessible and surveyed sample units from the NFI out of the 631

		Deadwood, Litter and Soil for forestland	IPCC 2006 GHG inventory Guidelines	Default IPCC values	sample units from the original sampling design. Values for deadwood and litter are based on, Soils are IPCC default values.
		Annual Biomass Growth for Natural Forest and Planation forests	National data from NFI	Ethiopian NFI	Values for increment for biomass estimates for natural forest (Indigenous forest) are based on Ethiopian forest biomes data with similar climate types
		Ecological zone map	National data	Ethiopian Geospatial Information Institute and EFCCC: Environment Forestry, and Climate Change Commission	The GIS layer of the ecological zone map was used to delineate and calculate the areas ecological zones.
3B Land	3.B.2: Cropland	Data on cropland area by cropland was divided by type annual and perennial crops and area changes across time) according to different management practices. Biomass estimates for Above-ground biomass, Below-ground	Agricultural Survey, Ethiopia Land Cover, Land Cover Change Analysis (2003,2008 and 2013 and 2018 IPCC 2006 GHG inventory Guidelines	Ministry of Agriculture-Ethiopia IPCC 2006 GHG inventory Guidelines	Cropland areas were divided into annual and perennial crops according to different management practices Land use maps and national reports Biomass estimates for above-ground biomass, Below-ground biomass, Deadwood, Litter and Soils annual

		biomass, Deadwood, Litter and Soils for the Cropland			and perennial crops and area changes across time) according to different management practices.
	3.B.3: Grassland	Data on grassland area and area changes across time Land use matrix	Ethiopia Land Cover, Land Cover Change Analysis (2003,2008 and 2013 and 2018	Ethiopian Geospatial Information Institute	Grassland were mapped using remote sensing based on Landsat imagery.
		Biomass estimates for Above-ground biomass, Below-ground biomass, Deadwood, Litter and Soils for the Cropland	Country Specific values for Herbaceous biomass stocks present and Woody biomass stocks – Kisambo et al (2016).	Kisambo et al (2016) - national data based on Ethiopian literature	Biomass estimates for grassland were based on Ethiopian National data from paper by Kisambo et al (2016) Deadwood and Litter, soils were based on IPCC default values
	3.B.4: Wetlands	Land use and land use, change maps, area and change matrix and Accuracy assessment estimates	Ethiopia Land Cover, Land Cover Change Analysis (2003,2008 and 2013 and 2018	Ethiopian Geospatial Information Institute	Data on land use and land use change maps and national reports available
			Biomass present on land	Kisambo et al (2016) - national data based on Ethiopian literature	Biomass present on land was based on the national data
	3.B.5: Settlements	Land use and land use, change maps, area and change matrix and Accuracy assessment estimates.	Ethiopia Land Cover, Land Cover Change Analysis (2003,2008 and 2013 and 2018	Ethiopian Geospatial Information Institute	Dataset (maps and tables, reports) are readily available.

		Biomass estimates for Above-ground biomass, Below-ground biomass, Deadwood, Litter and Soils for the Settlements	Country specific		Biomass estimates for grassland present on land were based on a Conservative approach on IPCC GPG assumption that 10% of value of 12- ABG on perennial crops as highest conversions of cropland are converted to Settlements. Deadwood, Litter , soils were based on IPCC default values
	3.B.6: Other Land	Land use maps, Land use change map, Land use change matrix	Ethiopia Land Cover, Land Cover Change Analysis (2003,2008 and 2013 and 2018	Ethiopian Geospatial Information Institute	Biomass, Deadwood, soils, Litter were based on IPCC default values

Table 5.15: Emission factors and parameters applied in the estimation of sources and sinks for the Land category

Forest Land

Land Category	Parameter (Symbol)	Units	Value	Source reference for data	Remarks
Forest Land					
Forest Land	Climate Region		Tropical montane moist	IPCC 2006 Guidelines	
Forest land	*Soil type*		High activity clay mineral	IPCC 2006 Guidelines	
Forest land	*Forest type*		Natural	IPCC 2006 Guidelines	
Forest land	*Age class*	*years*	> 20 years	IPCC 2006 Guidelines	
Forest land	*Growing stock level*	*m^3/ha*	81 - 120	IPCC 2006 Guidelines	
Forest land	*C fraction of above-ground biomass*	*tonne C/tonne dm*	0.47	IPCC 2006 Guidelines	
Forest land	*Ratio of below-ground biomass to above ground biomass (R)*	*t root dm/t shoot dm*	0.27	IPCC 2006 Guidelines	
Forest land	*Biomass conversion and expansion factor for wood and fuelwood removal ($BCEF_R$)*	*t/m^3 wood volume*	1.67	IPCC 2006 Guidelines	
Forest land	*Above-ground biomass*	*t dm/ha*	200.00	Country Specific	NFI
Forest land	*Above-ground biomass growth*	*t dm/ha/yr*	1.30	Country Specific	NFI

Land Category	Parameter (Symbol)	Units	Value	Source reference for data	Remarks
Forest land	*Reference soil organic carbon stock (SOCRef)*	*t C/ha*	88.00	IPCC 2006 Guidelines	
Forest land	*Litter carbon stocks of mature forests*	*t C/ha*	2.10	IPCC 2006 Guidelines	
Forest land	*Soil stock change factor for land use (F_{LU})*	*factor*	1.00	IPCC 2006 Guidelines	
Forest land	*Soil stock change facto for management (F_{MG})*	*factor*	1.00	IPCC 2006 Guidelines	
Forest land	*Soil stock change factor for input (F_I)*	*factor*	1.00	IPCC 2006 Guidelines	
Forest land	*Above-ground biomass growth*	*t dm/ha/yr*	1.30	Country Specific	Could national experts cross check, and cite data source reference here
Forest land	*Reference soil organic carbon stock (SOCRef)*	*t C/ha*	88.00	IPCC 2006 Guidelines	

Cropland

Land Category	Parameter (Symbol)	Units	Value	Source reference for data	Remarks
Cropland					
Cropland	*Climate region*		Tropical montane moist	IPCC 2006 Guidelines	
Cropland	*Soil type*		High activity clay mineral	IPCC 2006 Guidelines	
Cropland	*Cropland type*		Perennial	IPCC 2006 Guidelines	
Cropland	*Above-ground biomass*	*t dm/ha*	12.00	IPCC 2006 Guidelines	
Cropland	*Reference soil organic carbon stock (SOCRef)*	*t C/ha*	88.00	IPCC 2006 Guidelines	
Cropland	*Harvest/maturity cycle*	*years*	8.00	IPCC 2006 Guidleines	
Cropland	*Biomass carbon loss (L) due to harvesting fuelwood collection, disturbance, etc*	*t C/ha/yr*	21.00	IPCC 2006 Guidelines	
Cropland	*Biomass accumulation rate (G)*	*t C/ha/yr*	2.60	IPCC 2006 Guidelines	
Cropland	*Carbon fraction of dry matter*	*t C/t dm*	0.50	IPCC 2006 Guidelines	
Cropland	*Soil stock change factor for land use (F_{LU})*	*factor*	1.00	IPCC 2006 Guidelines	
Cropland	*Soil stock change factor for input (F_I)*	*factor*	1.00	IPCC 2006 Guidelines	

Grassland

Land Category	Parameter (Symbol)	Units	Value	Source reference for data	Remarks
Grassland					
Grassland	*Climate region*		Tropical montane moist	IPCC 2006 Guidelines	
Grassland	*Soil type*		High activity clay mineral	IPCC 2006 Guidelines	
Grassland	*Reference soil organic carbon stock (SOCRef)*	*t C/ha*	88.00	IPCC 2006 Guidelines	
Grassland	*Carbon fraction of dry matter*	*t C/t dm*	0.47	IPCC 2006 Guidelines	
Grassland	*Soil stock change factor for land use (F_{LU})*	*factor*	1.00	IPCC 2006 Guidelines	
Grassland	*Soil stock change facto for management (F_{MG})*	*factor*	0.67	IPCC 2006 Guidelines for moderately degraded tropical grasslands	
Grassland	*Soil stock change factor for input (F_I)*	*factor*	1.00	IPCC 2006 Guidelines	
Grassland	*Herbaceous biomass stocks present*	*t dm/ha*	0.61	**Country Specific –** Kisambo etal (2016),	
Grassland	*Woody biomass stocks*	*t dm/ha*	5.60	**Country Specific** - Bosco KIdake Kisambo, Jan PfIster, Angela Schaffert, Folkard Asch (2016) - Leaf Area Dynamics and AboveGround	

Land Category	Parameter (Symbol)	Units	Value	Source reference for data	Remarks
				Biomass of Specific Vegetation Types of a Semi-Arid Grassland in Southern Ethiopia	
Grassland	*Herbaceous biomass stocks after conversion from other land use (B_{after})*	*t dm/ha*	0.00	IPCC 2006 Guidelines	Tier 1 assumption is that biomass after conversion is zero
Grassland	*Woody biomass stocks after conversion from other land use (B_{after})*	*t dm/ha*	5.60	**Country Specific** - Bosco Kldake Kisambo, Jan Pflster, Angela Schaffert, Folkard Asch (2016) - Leaf Area Dynamics and AboveGround Biomass of Specific Vegetation Types of a Semi-Arid Grassland in Southern Ethiopia	We assume biomass present on land and land is not cleared
Grassland	*Carbon fraction of dry matter for herbaceous biomass*	*t C/t dm*	0.47	IPCC 2006 Guidelines	
Grassland	*Carbon fraction of dry matter for woody biomass*	*t C/t dm*	0.50	IPCC 2006 Guidelines	

Wetlands

Land Category	Parameter (Symbol)	Units	Value	Source reference for data	Remarks
Wetlands					
Wetlands	*Climate region*		Tropical montane moist	IPCC 2006 Guidelines	
Wetlands	*Soil type*		High activity clay mineral	IPCC 2006 Guidelines	
Wetlands	*Carbon fraction of dry matter*	*t C/t dm*	0.50	IPCC 2006 Guidelines	
Wetlands	*Biomass stocks after conversion from other land use (B_{after})*	*t dm/ha*	0.00	IPCC 2006 Guidelines	Tier 1 assumption is that biomass after conversions is zero
Wetlands	*Biomass present on land*	*t dm/ha*	0.61	**Country Specific** – Kisambo etal 2016,	
Wetlands	*Carbon fraction of dry matter*	*t C/t dm*	0.50	IPCC 2006 Guidelines	
Wetlands	*CO2 emission factor for peat soils*	*t C/ha/yr*		NE	NE notation key Ethiopia has not estimated peat soils in this inventory
Wetlands	*N2O emission factor for drained nutrient-rich organic soils*	*kg N2O-N/ha/yr*		NE	
Wetlands	*Carbon fraction of air-dry peat by weight*	*t C/t peat*		NE	
Wetlands	*Carbon fraction of air-dry peat by volume*	*t C/m3 peat*		NE	

Settlements

Land Category	Parameter (Symbol)	Units	Value	Source reference for data	Remarks
Settlements					
Settlements	*Climate region*		Tropical montane moist	IPCC 2006 Guidelines	
Settlements	*Soil type*		High activity clay mineral	IPCC 2006 Guidelines	
Settlements	*Biomass present on land*	*t dm/ha*	1.20	Country Specific	Conservative approach on IPCC GPG assumption that 10% of value of 12- ABG on perennial crops as highest conversions of cropland are converted to Settlements
Settlements	*Reference soil organic carbon stock (SOCRef)*	*t C/ha*	88.00	IPCC 2006 Guidelines	
Settlements	*Carbon fraction of dry matter*	*t C/t dm*	0.50	IPCC 2006 Guidelines	
Settlements	*Soil stock change factor for land use (F_{LU})*	*factor*	1.00	IPCC 2006 Guidelines	
Settlements	*Soil stock change facto for management (F_{MG})*	*factor*	1.00	IPCC 2006 Guidelines	
Settlements	*Soil stock change factor for input (F_I)*	*factor*	1.00	IPCC 2006 Guidelines	

Other Lands

Land Category	Parameter (Symbol)	Units	Value	Source reference for data	Remarks
Other lands					
Other lands	*Climate region*		Tropical montane moist	IPCC 2006 Guidelines	
Other lands	*Soil type*		High activity clay mineral	IPCC 2006 Guidelines	
Other lands	*Biomass present on land*	*t dm/ha*	0.00	IPCC 2006 Guidelines	
Other lands	*Reference soil organic carbon stock (SOCRef)*	*t C/ha*	88.00	IPCC 2006 Guidelines	
Other lands	*Carbon fraction of dry matter*	*t C/t dm*	0.50	IPCC 2006 Guidelines	
Other lands	*Soil stock change factor for land use (F_{LU})*	*factor*	1.00	IPCC 2006 Guidelines	
Other lands	*Soil stock change facto for management (F_{MG})*	*factor*	1.00	IPCC 2006 Guidelines	
Other lands	*Soil stock change factor for input (F_I)*	*factor*	1.00	IPCC 2006 Guidelines	

Forest land (3B1)

Category description

Emissions Sources	Forestland: Carbon stock Change
Gases Reported	CO_2
Methods	Tier 1 Loss and Gain Method Equation 2.7 for estimating carbon stock changes using IPCC Inventory Software
Emission Factors	Country specific values for AGB and annual increment (growth rates) values for Indigenous were based on national data from NFI reported in the FREL 2017. Forests for biomass, biomass increment.
Key Category Analysis	Forest land - CO_2 (L1, L2)
Completeness	All carbon pools estimated
Major improvements since last submission	- Use of Approach 2 for land representation of land areas and land area changes instead of Approach 1 - Spatially explicit analysis based on GIS-based land cover/land use raster maps. - Calculation of the annual change using the new map overlays. - Improved biomass calculations due to the improved map overlays and new region-specific and emission factors.

In this inventory Forest land was includes both indigenous and planation forests. In the future Ethiopia intends to disaggregate forest land into indigenous forest (natural) and Plantation Forests as new data becomes available.

Ethiopia is a land of natural contrasts. It stretches over more than 1.1 million km^2 and has a wide variety of climate zones and soil conditions. Forests cover some 162,000 km^2 of the country's landmass, with woodland and shrubland accounting for another 492,000 km^2, according to the 2013 land cover map of Ethiopia (Ethiopian Mapping Agency, 2013).

The land tenure remains one of the most politically debated issues in Ethiopia. In general, above 80% is smallholder and land are public property. The owner of land can get land certification/registration and has use and transfer rights (forest proclamation of Ethiopia (1065/2018). Ethiopia also follows regional administration (10 regional states and 2 city administrations), customized regional land governance systems are also applicable.

With respect to forest governance, Ethiopia recognizes 4 types of management/ownership: 1) State Forest; 2) Private forest; 3) Association Forest and 4) Community Forest. Part of the state forest is considered as protected forests which is mainly administered through PFM (Participatory Forest Management) approach.

- **State forest,** these are mostly natural forests – All-natural forests are owned by the government and are the main source of wood used for firewood and charcoal. Natural forests account for about 91% of forest area. Participatory management forests – Forests that are jointly managed by local communities, regional governments and international non-governmental organizations. About 2% of forests are managed this way.
- **Private forest:** These are privately owned plantations and woodlots – Commercial plantations and small-scale woodlots that are legally recognized by the government. Owners have the right to harvest wood from the plantations and/or sell the plantations themselves. Plantations are mostly planted with non-native species, particularly eucalyptus. They are used mainly as a source of wood for construction and raw material inputs to processed wood products. About 5% of forests fall into this category.
- **Association Forest**: Publicly owned forest plantations – A small area of forest (about 1%) is made up of larger publicly owned plantations. Plantations are mostly planted with non-native species, particularly eucalyptus. They are used mainly as a source of wood for construction and raw material inputs to processed wood products.
- **Community Forest**: Community woodlots – Small areas of natural forests or plantations managed by local communities. They are used mainly as a source of wood for fuel or materials for local construction. About 1% of forests are under community management.

The CRGE Strategy recognizes that deforestation and forest degradation must be reversed if the country is to meet its development goals. Wood fuel accounts for more than 80% of household energy supply in Ethiopia and is particularly important in rural areas. Beyond wood fuel, forests provide other timber products and a host of valuable non-timber products, including livestock fodder, coffee and honey. Forests are also the source of essential ecosystem services, including carbon sequestration, crop pollination, conservation of agricultural soils and control of water discharge to streams and rivers. Ethiopia's forests are an important source of timber products. Harvested wood is used primarily as an energy source (wood fuel) for households and by small businesses, either directly as firewood or after conversion first into charcoal. In addition, wood is harvested for use for:

- Construction materials
- Raw materials for sawn lumber and other processed wood products (chipboard, fibreboard and plywood)
- Furniture manufacturing, and
- Production of utility poles to carry utility power and telecommunications cables

Ministry of Finance and Economic Cooperation (MOFEC) estimates the value added of wood fuel production in 2012-13 to have been 25.5 billion ETB, or 65% of the value estimated by UNREDD study (2016). MOFEC's estimate is derived from data on household wood fuel expenditures and, as a result, does not include the value of subsistence use of wood fuel (Metaferia, 2015). Given that collection of wood fuel from forests for subsistence use is common in Ethiopia, it is to be expected that MOFEC's estimate would be considerably lower.

Emissions and removals

Forest Land includes carbon stock gains and losses and GHG emissions from forest management and overall is the only net sink in the Land Inventory in the Ethiopia at -40599.68 in 1990 Gg CO_2e and at -67975.28 Gg CO_2e in 2019 (Figure 5.11). It is evident that the forest sink is increasing across the time series. The reason for the increase is related to conversion of grassland, followed by cropland for forestland. In some cases, conversions from cropland were to plantation forest for charcoal production. Forest remaining forest and land converted to forests land is responsible for most of the CO_2 removals in the sector across the time series and is an increasing sink across the time series. Ethiopia reported carbon stock changes in all forests using IPCC Inventory Software. Carbon stock changes resulting from afforestation on Cropland, Grassland, Wetlands, Settlements and Other land areas are calculated. The reported forest area and carbon stock changes take account of losses of forest land converted to other land use categories (deforestation) and the associated carbon stock changes and emissions and removals are then estimated and reported under the category concerned. Ethiopia did not estimate the carbon stocks in the Harvested Wood Products pool due to lack of data.

Forest land comprises emissions and removals from forest land remaining forest land and land converted to forest land. Forest land remaining forest land includes plantation forests and indigenous forests (bushlands and woodlands). Emissions from fuelwood consumption in forests (controlled burning and wildfire) are also included as are the losses. Land converted to forest land includes grassland, croplands, settlements and wetlands on which forest, including for new plantations, is identified to emerge.

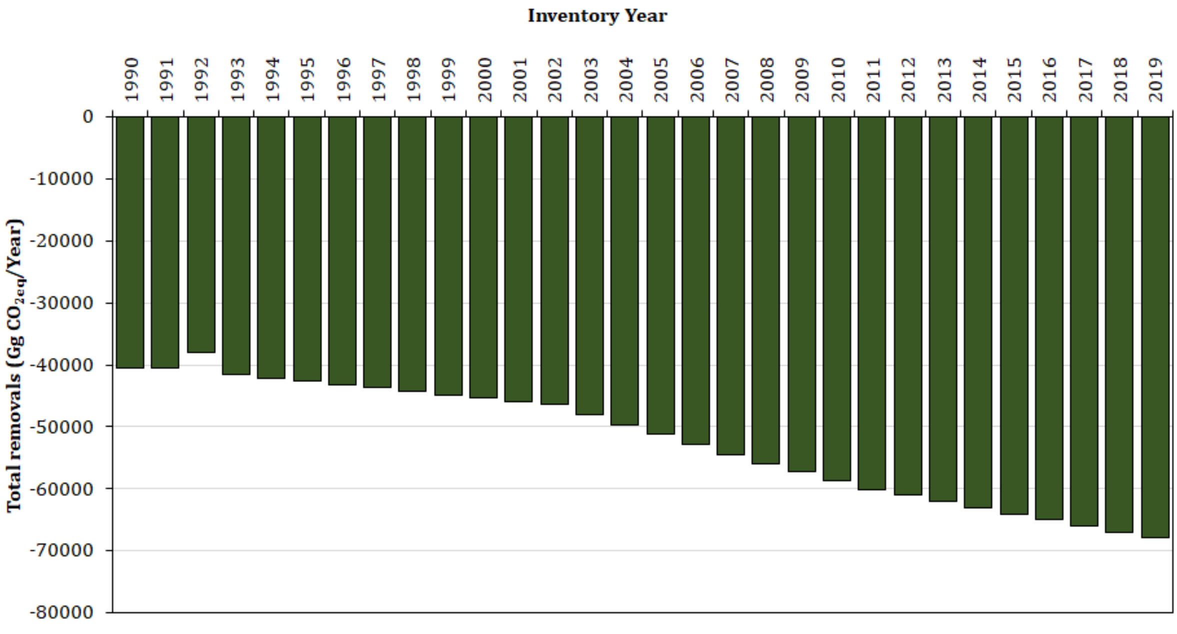


Figure 5.3: Forest land removals for Ethiopia between 1990 and 2019

Methodological issues

In this inventory the IPCC Gain and Loss Equation 2.4, page 2.9, Vol 4, IPCC 2006 Guidelines was used to produce estimates forestland (indigenous and plantation forests) and calculations were performed using the IPCC Inventory software (Version 2.69). Gain-Loss Method (Tier 1) Equation 2.7 was used to estimate annual change in carbon stocks in living above- and below-ground biomass, considering the region-specific data on mean annual increment, Ethiopia used country specific values for AGB and growth rates, commercial cutting, fuelwood removal (1990-1998, 2000-2011 and 2012-2019, and the rest was interpolated for the missing years) for forest land. However, for the biomass expansion factors (BCEFI, BCEFR) and basic wood densities (D), and default root-to-shoot ratios (R) and carbon fractions (CF), IPCC values were used.

The annual biomass loss is a sum of losses from commercial round wood felling's, fuelwood gathering and other losses in forest land was calculated by using the following Equation 2.11 of Volume 4 of the 2006 IPCC guidelines. For example, commercial round wood felling's have been calculated in different worksheets as well as fuelwood gathering and other losses according to the Equation 2.12, Equation 2.13 and Equation 2.14 respectively. The calculations of biomass losses are consistent with the IPCC 2006 Guidance for AFOLU (Vol 4). Biomass gains and biomass losses are estimated separately. Deadwood and litter values were based IPCC default values. IPCC default values were used for estimation of soils carbon pool.

Category specific QA/QC and verification

Activity data (GIS) was cross-checked with officially reported data from the Ethiopian Geospatial Information Institute. Furthermore, consultations with various stakeholders in the forestry and land use sector was undertaken to ensure consistency and agreement on the data and EF. The data was stored and shared between experts to ensure that all changes are easily traceable. The IPCC Inventory Software Version 2.69 was used to compile all the Land inventory numbers and associated data. This database was used to produce consistent outputs for reporting and archiving purposes. A Technical Working Group of experts focusing on the Land category was established and provided technical review and input into the sector inventory. UK Aether's QAQC procedure was adopted.

Planned improvements

IPCC Land use category	Data gaps identified (AD and EF)	Planned Improvements /Remarks
Forest Land		
Indigenous forests/Savanna Woodlands	i) Data for deadwood ii) Data on fuelwood collection iii) Disaggregated data for land areas to other land uses iv) Information on BCEF by forest and species type v) Disaggregated area and area change data by forest type and species type across the inventory time series vi) Growing stocks and annual volume increments by forest type for and indigenous species	Collection of country specific data on deadwood by forest type for Savanna woodlands Collection of country specific data on fuelwood Collection of information on BCEF by forest and species type Collection of disaggregated area and area change data by forest type and species type across the inventory time series. Collection of data on growing stocks and annual volume increments by forest type for indigenous species
Plantation Forests	i) Data on land areas disaggregated by species type (Pine, Wattle and Eucalyptus) ii) Data for deadwood by species type iii) Data on wood removals disaggregated by species type (Pine, Wattle and Eucalyptus) iv) Data on fuelwood disaggregated by species type (Pine, Wattle and Eucalyptus) v) Disaggregated data for land areas to other land uses by forest type and species vi) Information on BCEF by forest and species type vii) Growing stocks and annual volume increments by forest type for plantation	Collection of country specific data on deadwood by forest type and species type (Pine, Wattle and Eucalyptus) Collection of country specific data on wood removals and fuelwood by forest type and species type (Pine, Wattle and Eucalyptus) Collection of data areas and land area change at a disaggregated level by forest type and species Collection of disaggregated data for land areas to other land uses by forest type and species for plantations Collection of Information on BCEF by forest and species type Collection of data on Growing stocks and annual volume increments by forest type for plantation

Cropland (3B2)

Category description

Emissions Sources	Cropland: Carbon stock Change
Gases Reported	CO_2
Methods	Tier 1 Loss and Gain Method Equation 2.7 for estimating carbon stock changes using IPCC Inventory Software
Emission Factors	IPCC default values were used for both annual and perennial crops for biomass, stock change factors
Key Category Analysis	Land converted to cropland (L1 and L2)
Completeness	All carbon pools estimated
Major improvements since last submission	- Use of Approach 2 for land representation of land areas and land area changes instead of Approach 1 - Spatially explicit analysis based on GIS-based land cover/land use raster maps; - Re-calculation of the annual change using the new map overlays; - Improved biomass calculations due to the improved map overlays

Emissions and removals

Croplands refer mainly to crop fields on which annual and perennial crops are cultivated as well as temporary fallow land. Ethiopian cropland production systems consist of Cereals, Pulses, Oilseeds, Vegetables, Root Crops and Fruit Crops. Cropland comprised emissions and removals from cropland remaining cropland, forest land converted to cropland, grassland converted to cropland, settlements converted to cropland, wetlands converted to cropland and other land converted to cropland. GHG Emissions associated farmland management practices such as fertiliser application, handling of crop residues, burning etc. are reported under 3C, though emission from biomass burning were not reported due to lack of data. Grassland -cropland conversion was the biggest contributor of all the conversion categories, for example area of grassland converted to annual crops increased by 198% between 1990 (90050.36 ha) and 2019 (267,491.70 ha), this was followed by deforestation through cropland expansion has been identified as one of the key categories in the entire emission inventory. It occurred across the country with varied degrees of intensity. The drivers of the forest-cropland conversion are localised but factors such as type of crop, agronomic and management practices and the land tenure also influenced the emission levels.

In 1990 emissions from cropland were at 3104.57Gg CO_2e and at 89182.16 Gg CO_2e in 2019 (Figure 5.14). This represents an increase of 277.2% across the time series, since 1990 Cropland was the second largest source of net CO_2 emission in the land category.

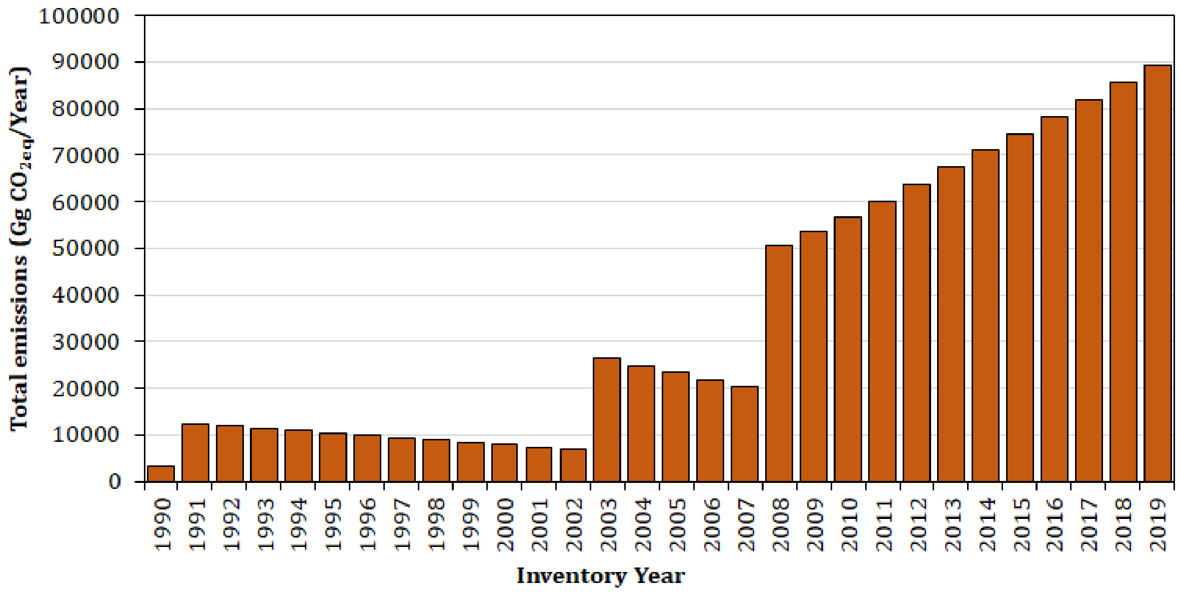


Figure 5.12: Trends in Cropland emissions in Ethiopia between 1990 and 2019

Methodological issues

In this inventory the IPCC Gain and Loss Equation 2.4, page 2.9, Vol 4, IPCC 2006 Guidelines was used to produce estimates for croplands (irrigated and subsistence) and calculations were performed using the IPCC Inventory software (Version 2.69). Gain-Loss Method (Tier 1) was used to estimate cropland remaining annual cropland and land converted to cropland.

Above- and below-ground biomass

For annual crops increase in biomass stocks in a single year is assumed equal to biomass losses from harvest and mortality in that same year (IPCC 2006).

Dead organic matter

According to Tier 1 method there is no need to estimate the carbon stock changes for DOM.

Mineral and organic soils

Currently, there is no specific data on management systems in the country to apply reference carbon stocks and stock change factors. Emissions from organic soil are not estimated.

Reference to 2006 IPCC equations: Vol. 4., Ch. 2: 2.24 / 2.25 /

Land converted to Cropland.

Above- and below-ground biomass

Changes in biomass carbon stocks have been estimated according to Tier 1 with activity data disaggregated between irrigated and subsistence crops. Conversions from all other land uses (e.g. from forest land, grassland etc.) to cropland occur in the country. The principle of estimating the CSC in biomass in land converted to cropland assumes that biomass loss is accounted only for the year of conversion, thus ΔC conversion must be multiplied by annual area (i.e. area in the year of conversion).

Reference to 2006 IPCC equations: Vol. 4., Ch. 2: 2.15 / 2.16

Dead organic matter

A Tier 1 method takes into account the estimation of CSC in dead organic matter only for major conversion categories (e.g. forest land to cropland). It is assumed that all dead organic matter is

removed in the year of conversion, so there is no accumulation in land converted to cropland afterwards.

Reference to 2006 IPCC equation: Vol. 4., Ch. 2: 2.23,

Category specific QA/QC and verification

This was compared to data from the Ministry of Agriculture, and it became evident that the GIS data was higher. This deviation from could be attributed to the differences in the approaches to estimation of area. The agriculture surveys utilize a combination of interviews and visual estimates of area planted. Hence the official data tends to exclude fallow land, trees and other shrubs, which are part of cropland as per the IPCC definition of cropland. This assessment will need to be improved in the next submission.

Planned improvements

IPCC Land use category	Data gaps identified (AD and EF)	Planned Improvements /Remarks
Cropland		
Cropland Annual crops: Perennial Crops:	i) Data on land area conversions to other land uses by crop type ii) Data AGB by crop type iii) Country specific stock changes factors by crop type (management/LU, inputs and tillage) iv) Areas for Perennial crops and stock change factors v) AGB for perennial crops vi) Data on biomass accumulation rates and biomass loses for perennial crops vii) ABG growth/Increment for perennial crops viii) Data on litter and deadwood for perennial crops	i) Collection of country specific information on area conversions to other land uses by crop type ii) Collection of country specific data AGB by crop type iii) Collection of country specific stock changes factors by crop type iv) Collection of information on area/area change and country specific stock changes factors by crop type for perennial crops v) Collection of ABG/ growth/Increment for perennial crops vi) Collection of data on litter and deadwood for perennial crops vii) Collection of data on biomass accumulation rates and biomass loses for perennial crops

Grassland (3B3)

Category description

Emissions Sources	Grassland: Carbon stock Change
Gases Reported	CO_2
Methods	Tier 1 Loss and Gain Method Equation 2.7 for estimating carbon stock changes using IPCC Inventory Software
Emission Factors	Country specific EF values were used based on the Kisambo e tal study (2016). This includes values for herbaceous biomass stocks, woody biomass stocks, herbaceous biomass stocks after conversion from other land use, woody biomass stocks after conversion from other land use. IPCC default values were used for carbon fraction of dm for herbaceous biomass and the carbon fraction of dry matter for woody biomass.
Key Category Analysis	Land converted to grassland (L1 and L2)
Completeness	All carbon pools estimated
Major improvements since last submission	Spatially explicit analysis based on GIS-based land cover/land use raster maps. Re-calculation of the annual change using the new map overlays. Improved biomass calculations due to the improved map overlays and new country specific emission factors.

Emissions and removals

Grassland comprises all land that is dominated by grass cover and includes rangelands and pastureland that are not considered cropland or forestland. The grassland category predominantly comprises montane grassland which have vegetation dominated by perennial grasses and grazing or pasture are predominant. Grassland comprised emissions and removals from grassland remaining cropland, forestland converted to grassland, cropland converted to grassland, settlements converted to grassland, wetlands converted to grassland and other land converted to grassland. GHG emissions associated with management practices such as burning are reported in this inventory, but they occur. The Ethiopian grasslands are extensively managed rangelands such as private grazing land used by smallholder farmers and ranch and savannahs where animal (both wild and domestic) stocking rates and fire regimes are the main management variables (Mosisa et al 2021).

Area and annual area of annual croplands converted to grassland constitute the largest share of land conversion to grassland, 1990 area of annual cropland converted to grassland was 68922.55ha and in 2019 was at 4104613.01 ha and in annual area of cropland converted to grassland was at 68922.56ha in 1990 and at 232923.71ha in 2019. In some cases, grassland is increasingly being replaced by other land uses such as human settlements, cropland and plantation forestry, although the influence of the latter is cyclic due to the cycle of harvesting and replanting. The conversion of forestland to grassland through the cycle of harvesting and replanting of exotic plantation forests such as *Acacia decurrens* is one of the key categories in the entire emission inventory. The drivers of the grass-forestland conversion are related to expansion of land for commercial plantation forestry to provide charcoal. In 1990 emissions from grassland were at 16448.00Gg CO_2e and at 127277.74Gg CO_2e in 2019, largely attributed to conversion of cropland grassland and forestland to grassland conversion or harvesting of exotic forest plantations (Figure 5.15). This represents an increase of 673%.

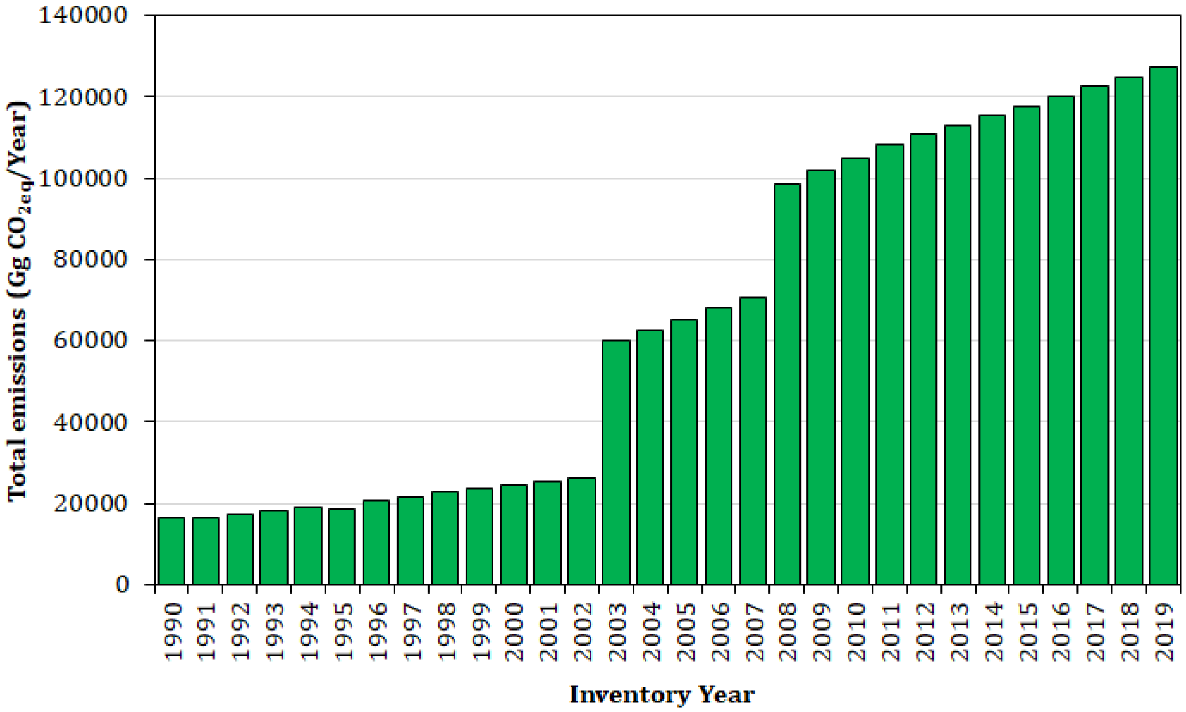


Figure 5.13: Trends in Grassland emissions for Ethiopia between 1990 and 2019

Methodological issues

In this inventory the IPCC Gain and Loss Equation 2.4, page 2.9, Vol 4, IPCC 2006 Guidelines was used to produce estimates for grassland and calculations were performed using the IPCC Inventory software (Version 2.69). Gain-Loss Method (Tier 1) was used to estimate grassland remaining annual grassland and land converted to grassland.

For land converted to Grassland, Equation 2.16 was computed for both herbaceous biomass and woody biomass since each of these components has a different carbon fraction.

The EF used for grassland were default IPCC default for a Subtropical Steppe.

Gain-Loss Method (Tier 1) was used to estimate grassland remaining grassland and land converted to grassland.

Above- and below-ground biomass

- For annual grassland increase in biomass stocks in a single year is assumed equal to biomass losses from harvest and mortality in that same year (IPCC 2006).

Dead organic matter

- According to Tier 1 method by estimating the area of each type of land conversion using only the major conversion categories such as Forest Land to Grassland.

Mineral and organic soils

- Currently, there is no specific data on management systems in the country to apply reference carbon stocks and stock change factors. Emissions from organic soil are not estimated.
- Reference to 2006 IPCC equations: Vol. 4., Ch. 2: 2.24 / 2.25 /

Land converted to Grassland.

Above- and below-ground biomass

- Changes in biomass carbon stocks have been estimated according to Tier 1. Conversions from all other land uses (e.g. from forest land) to grassland occur in the country. The principle of estimating the CSC in biomass in land converted to grassland assumes that biomass loss is accounted only for the year of conversion, thus ΔC conversion must be multiplied by annual area (i.e. area in the year of conversion).
- Reference to 2006 IPCC equations: Vol. 4., Ch. 2: 2.15 / 2.16

Dead organic matter

- A Tier 1 method takes into account the estimation of CSC in dead organic matter only for major conversion categories (e.g. forest land to grassland). It is assumed that all dead organic matter is removed in the year of conversion, so there is no accumulation in land converted to grassland afterwards. Reference to 2006 IPCC equation: Vol. 4., Ch. 2: 2.23. (See Method Statement for Grassland land (GL) – MS 4 for detailed information on estimation methods on grassland.

Category specific QA/QC and verification

Activity (GIS) data was cross-checked with grassland ecosystem data from the Ethiopian Geospatial Institute. Furthermore, consultations with various stakeholders in the land use sector were undertaken to ensure consistency and agreement with regards to the activity data and EF. The data was stored and shared between experts to ensure that all changes are easily traceable. The IPCC Inventory Software Version 2.69 was used to compile all the Land inventory numbers and associated data. This database was used to produce consistent outputs for reporting and archiving purposes. A Technical Working Group of experts focusing on the Land category was established and provided technical review and input into the sector inventory.

Aether’s QAQC procedure.

Planned improvements

IPCC Land use category	Data gaps identified (AD and EF)	Planned Improvements /Remarks
Grassland	i) Limited information on grassland management.	i) Improving the raster maps using more field validation and improved algorithms ii) Improving the time series by using shorter intervals (=< 5 years) iii) Obtaining country specific EF for grassland management types iv) Collection of country specific stock changes factors (management/LU and tillage) v) Collection of data on grassland herbaceous biomass carbon stocks vi) Collection of data on wood biomass carbon stocks for grassland management types

Wetland (3B4)

Category description

Emissions Sources	Wetland: Carbon Stock Change
Gases Reported	CO_2
Methods	Tier 1 Stock Change Method for carbon stock changes using IPCC Inventory Software Equation 7.10
Emission Factors	Country specific values for biomass stocks present on land.
Key Category Analysis	Land converted to wetland
Completeness	Only emissions resulting from conversion of land to flooded land were estimated.
Major improvements since last submission	Spatially explicit analysis based on GIS-based land cover/land use raster maps; Re-calculation of the annual change using the new map overlays.

Emissions and removals

This category comprised emissions and removals from wetlands remaining wetlands and all land converted to wetlands. In accordance with IPCC guidance Wetlands remaining wetlands estimates include N_2O emissions from wetlands and net CO_2 emissions from removal of wetland vegetation in addition to other vegetation-related sources of emissions and removals. However, for this inventory only flooded lands are reported. Flooded lands included reservoirs or impoundments which are predominantly used for irrigation and, to a lesser extent, energy production and recreation. Data on peatlands is very scarce to non-existent in the country and as such, available data was not used.

The conversion of indigenous forestland to flooded land through the construction of reservoirs is the biggest contributor in the wetland's emissions category. This is driven by the agricultural development drive in the country, particularly the expansion of land for commercial cropland irrigation. In 1990 emissions from wetland were at 451.83 Gg CO_2e, steadily rising to a peak of 1355.49 Gg CO_2e in 2003-2007 and were at 983.94 Gg CO_2e in 2019 (Figure 5.14).

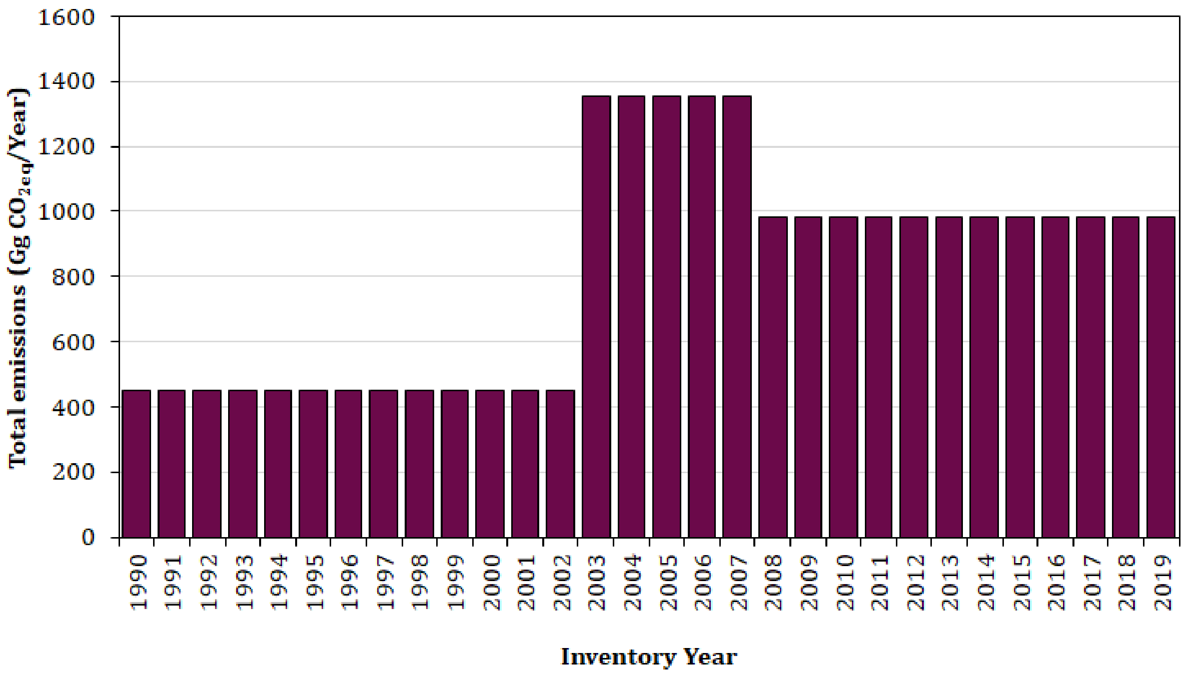


Figure 5.14: Trends in Wetland emissions for Ethiopia between 1990 and 2019

Methodological issues

In this inventory the IPCC Stock Change Equation 7.10, page 7.20, Vol 4, IPCC 2006 Guidelines was used to estimate emissions from CO_2 in lands converted to flooded land and calculations were performed using the IPCC Inventory software (Version 2.69). Stock Change Method (Tier 1) was used to estimate land converted to wetlands. At present, the notation key NE has been used for peat extraction. When more detailed data on peat extraction are available, an IPCC default methodology can be applied.

Reference to 2006 IPCC equation: Vol. 4., Ch. 7: 7.10

Category specific QA/QC and verification

Activity data (GIS) was cross-checked with reservoirs data from the Ministry of Natural Resources and Energy's Department of Water Affairs. Furthermore, consultations with various stakeholders' wetlands management were undertaken to ensure consistency and agreement with regards to the activity data and EF. The data was stored and shared between experts to ensure that all changes are easily traceable. The IPCC Inventory Software Version 2.69 was used to compile all the Land inventory numbers and associated data. This database was used to produce consistent outputs for reporting and archiving purposes. A Technical Working Group of experts focusing on the Land category was established and provided technical review and input into the sector inventory.

Aether's QA/QC procedure.

Planned improvements

IPCC Land use category	Data gaps identified (AD and EF)	Planned Improvements /Remarks
Wetlands	iv) Data on land area conversions to other land uses by wetland type v) Data AGB by wetland type i.e. peatlands vi) Country specific stock changes factors by wetland type vii) Areas for natural wetlands and stock change factors viii) AGB for peatlands ix) Data on biomass accumulation rates and biomass loses for wetlands	x) Collection of country specific information on area conversions to other land uses by wetland type xi) Collection of country specific data AGB by wetland type i.e. peatlands xii) Collection of country specific stock changes factors by wetland type xiii) Collection of information on area/area change and country specific stock changes factors by wetland type xiv) Collection of ABG/ growth/increment for wetlands

Settlements (3B5)

Category description

Emissions Sources	Settlements: Carbon stock Change
Gases Reported	CO_2
Methods	Tier 1 Loss and Gain Method for carbon stock changes using IPCC Inventory Software
Emission Factors	Country specific values for biomass stocks present on land.
Key Category Analysis	Not identified as a key category
Completeness	All carbon pools estimated.
Major improvements since last submission	Spatially explicit analysis based on GIS-based land cover/land use raster maps; Re-calculation of the annual change using the new map overlays; Improved biomass and soil carbon calculations due to the improved map overlays and new region-specific (South African) emission factors.

Emissions and removals

Settlements comprises emissions and removals from settlements remaining settlements, forest land converted to settlements and wetlands converted to settlements. Settlements included rural settlements, infrastructure and urban areas that were detectable from satellite imagery. However, it should be noted that the settlements may have been underestimated due to the fact that rural homesteads are typically surrounded by and interspersed within cropland and other vegetation, thereby increasing the probability of their spectral signature being missed by satellite imagery.

The conversion of forestland (especially indigenous forest) to settlements and, to a lesser extent, the grassland to settlements were significant contributors in the settlement's category. This is driven by the expanding human population and urbanisation. In 1990 emissions from settlements were at 26.41 Gg CO_2e steadily rising to a peak of 190.44 Gg CO_2e in 2008 thereafter declining but still higher than previous decades to 148.12 Gg CO_2e in 2019 (Figure 5.15).

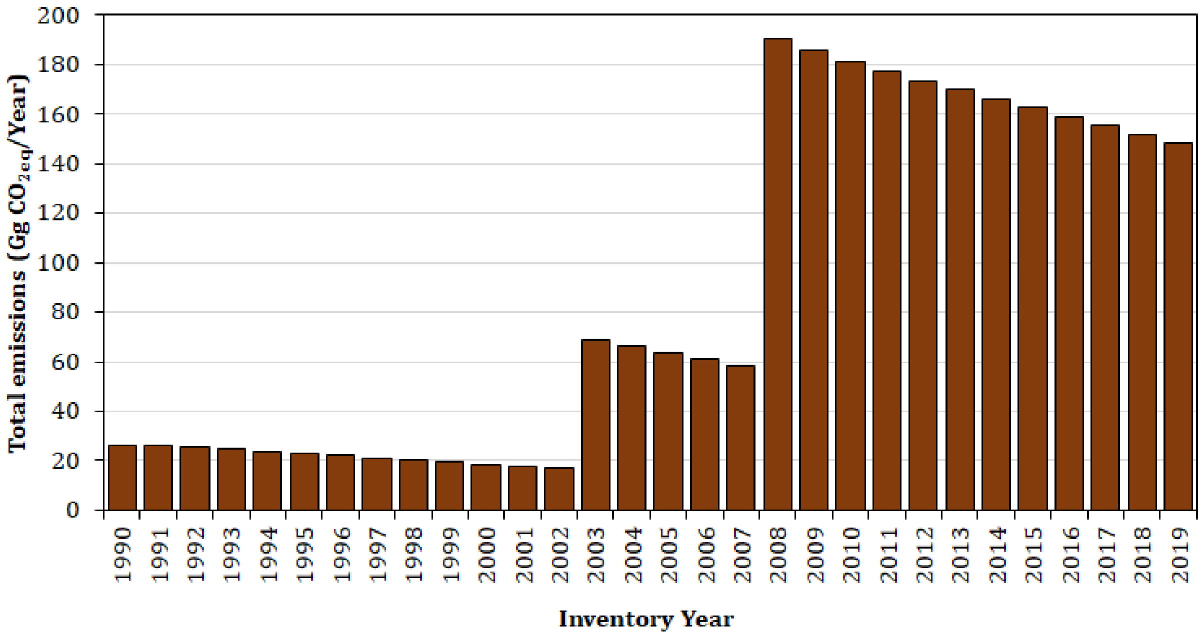


Figure 5.15: Trends in Settlement emissions in Ethiopia between 1990 and 2019

Methodological issues

In this inventory the IPCC Gain and Loss Equation 2.7, IPCC 2006 Guidelines was used to produce estimates for changes in carbon stocks for settlements and calculations were performed using the IPCC Inventory software (Version 2.69).

Activity data were derived through wall-to-wall supervised classification of Landsat imagery covering the years 1990, 2000, 2010 and 2015. This means that GIS-based settlement maps for 1990, 2000, 2010, and 2015 were produced from wall-to-wall remote sensing and ground-truthing. Estimation methods based on IPCC 2006, Vol4, Ch8

All carbon pools in Settlements remaining Settlements (SL-SL) is assumed to be not changing thus reported as NO. Tier 1 assumes no change in carbon stocks in live biomass in Settlements Remaining Settlements, in other words, that the growth and loss terms balance. Thus, the carbon stock change in settlements remaining settlements has not been estimated.

Land converted to settlements was estimated and shows increasing trend. The major driver of the emissions has been conversions from other land uses that resulted in loss of carbon.

Land converted to Settlements.

Above- and below-ground biomass

Country specific values for biomass stocks present on land.

- Changes in biomass carbon stocks have been estimated according to Tier 1. Conversions from all other land uses to settlements occur in the country. The principle of estimating the CSC in biomass in land converted to settlements assumes that biomass loss is accounted only for the year of conversion, thus ΔC conversion must be multiplied by annual area (i.e. area in the year of conversion).
- Reference to 2006 IPCC equations: Vol. 4., Ch. 2: 2.15 / 2.16

Dead organic matter

- A Tier 1 method takes into account the estimation of CSC in dead organic matter only for major conversion categories (e.g. forest land to settlements). It is assumed that all dead organic matter is removed in the year of conversion, so there is no accumulation in land converted to settlements afterwards.
- Reference to 2006 IPCC equation: Vol. 4., Ch. 2: 2.23

Change in soil organic C stocks can be estimated for mineral soils with land-use conversion to Settlements using Equation 2.25 in Chapter 2 using a tier 1 method.

Category specific QA/QC and verification

Activity data (GIS) was cross-checked with land tenure data from the Central Statistics Office. Furthermore, consultations with various land use stakeholders were undertaken to ensure consistency and agreement with regards to the activity data and EF. The data was stored and shared between experts to ensure that all changes are easily traceable. The IPCC Inventory Software Version 2.69 was used to compile all the Land inventory numbers and associated data. This database was used to produce consistent outputs for reporting and archiving purposes. A Technical Working Group of experts focusing on the Land category was established and provided technical review and input into the sector inventory.

UK Aether's QA/QC procedure.

Planned improvements

IPCC Land use category	Data gaps identified (AD and EF)	Planned Improvements /Remarks
Settlements	i) High resolution data on land area conversions to settlements. ii) Data AGB by wetland type i.e. urban vs rural settlements iii) Country specific stock changes factors for settlements iv) Areas for settlement and stock change factors v) AGB for settlements vi) Data on biomass accumulation rates and biomass loses for settlements	i) Collection of country specific information on area conversions to other land uses for settlements ii) Collection of country specific data AGB by settlement type i.e. rural vs urban iii) Collection of country specific stock changes factors for settlements iv) Collection of information on area/area change and country specific stock changes factors for settlements v) Collection of ABG/ growth/increment for settlements

Other land (3B6)

Category description

Emissions Sources	Grassland: Carbon stock Change
Gases Reported	CO_2
Methods	Tier 1 Loss and Gain Method for carbon stock changes using IPCC Inventory Software
Emission Factors	IPCC default values
Key Category Analysis	Not identified as a key category
Completeness	All carbon pools estimated.
Major improvements since last submission	Spatially explicit analysis based on GIS-based land cover/land use raster maps. Re-calculation of the annual change using the new map overlays. Improved biomass calculations due to the improved map overlays.

Emissions and removals

This category included bare soil/erosion, rocks and all land areas that were not part of any of the other five land-use categories. The other land category was the smallest land in terms of size comprising an average of 0.1% of the total land area. Other land emissions and removals comprise those from other land remaining other land, forest land converted to other land, cropland converted to other land, and wetlands converted to other land.

The conversion of forest land (especially indigenous forest) to other land and grassland to other land were significant contributors in this category. This is driven by the expanding human population and urbanisation. This category is a net source in 1990 at 826.71 Gg CO_2e and in 1994 becomes a net sink at -8.62 Gg CO_2e, thereafter an increasing net sink, -10280.39 Gg CO_2e in 2019 due to conversions to from forest land and grassland (Figure 5.16). This trend can also be explained by observed land degradation throughout the country which results in loss of soil cover.

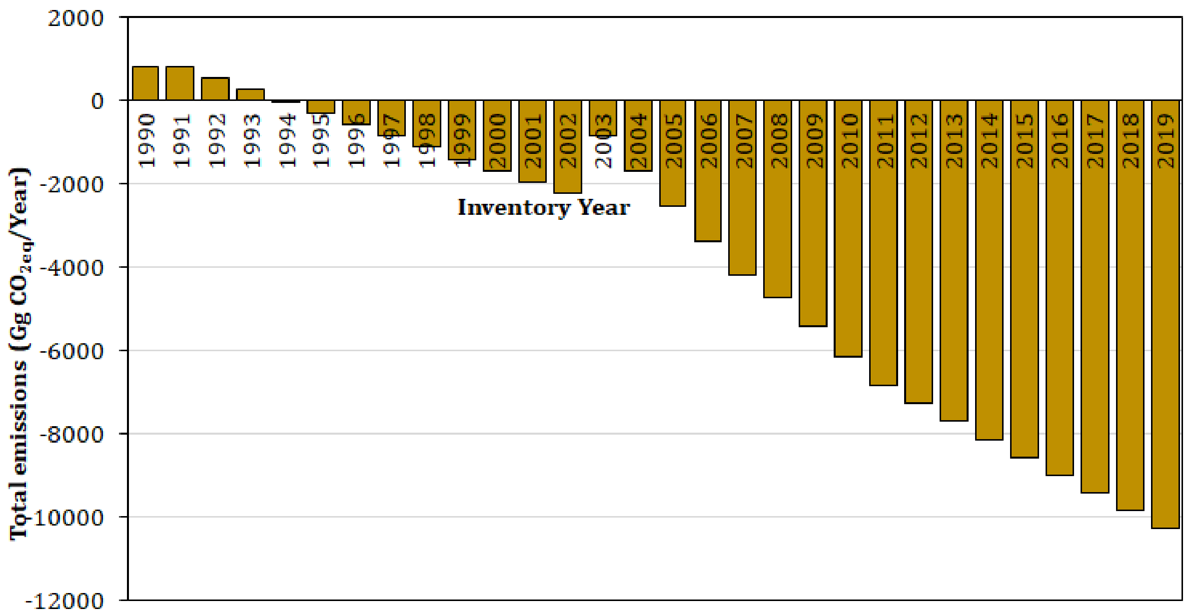


Figure 5.46: Trends in Other land emissions in Ethiopia between 1990 and 2019

Methodological issues

In this inventory the IPCC Gain and Loss Equation 2.4, page 2.9, Vol 4, IPCC 2006 Guidelines was used to produce estimates for settlements and calculations were performed using the IPCC Inventory software (Version 2.69). Other land category is a net emission due to lands converted to Other land.

Land converted to Other land.

Above- and below-ground biomass

- Changes in biomass carbon stocks have been estimated according to Tier 1. Conversions from all other land uses (e.g. from forest land) to other land occur in the country. The principle of estimating the change in biomass in land converted to other land assumes that biomass loss is accounted only for the year of conversion, thus ΔC conversion must be multiplied by annual area (i.e. area in the year of conversion).
- Reference to 2006 IPCC equations: Vol. 4., Ch. 2: 2.15 / 2.16

Dead organic matter

- A Tier 1 method takes into account the estimation of CSC in dead organic matter only for major conversion categories (e.g. forest land to Other land). It is assumed that all dead organic matter is removed in the year of conversion, so there is no accumulation in land converted to Other land.
- Reference to 2006 IPCC equation: Vol. 4., Ch. 2: 2.23

Change in soil organic C stocks can be estimated for mineral soils with land-use conversion to Settlements using Equation 2.25 in Chapter 2 using a tier 1 method.

Category specific QA/QC and verification

Activity data (GIS) was cross-checked using high resolution Google Earth imagery. Furthermore, consultations with various land use stakeholders were undertaken to ensure consistency and agreement with regards to the activity data and EF. The data was stored and shared between experts to ensure that all changes are easily traceable. The IPCC Inventory Software Version 2.69 was used to compile all the Land inventory numbers and associated data. This database was used to produce consistent outputs for reporting and archiving purposes. A Technical Working Group of experts focusing on the Land category was established and provided technical review and input into the sector inventory.

Aether's QA/QC procedure.

Planned improvements

IPCC Land use category	Data gaps identified (AD and EF)	Planned Improvements /Remarks
Other Land	i) High resolution data on other land, particularly soil erosion/bare land areas. ii) Data on AGB for other land iii) Country specific stock changes factors for other land iv) Data on biomass accumulation rates and biomass loses for other land	i) Collection of country specific information on area conversions to other land ii) Collection of country specific stock changes factors for other land iii) Collection of information on area/area change and country specific stock changes factors for other land iv) Collection of ABG/ growth/increment for other land

1.4 Emissions and removals from Aggregated and non-CO_2 emissions on land (3C)

Category overview

Overall, total emissions from aggregated and non-CO_2 emissions on land in the country show an increasing trend at 465272.84 Gg CO_2e in 1990 to 1816757.01 Gg CO_2e in 2019. This represents a 290.47% increase across the time series. The emissions in this subsector are dominated by emissions from direct N_20 in soils which were at 285671.26 Gg CO_2e in 1990 and at 1137190.75 Gg CO_2e in 2019. The key driver for this increase is related to use of nitrogen fertilisers in soils in the agriculture sector. The use of urea application in soils is the is the second largest emission source, followed by the Indirect N2O, managed soils and Indirect N2O, manure management. Ethiopia did not estimate emissions from biomass burning and liming due to lack of data and there plans to estimate in the future once data becomes available (see Table 5.3: Proposed improvements for the AFOLU sector).

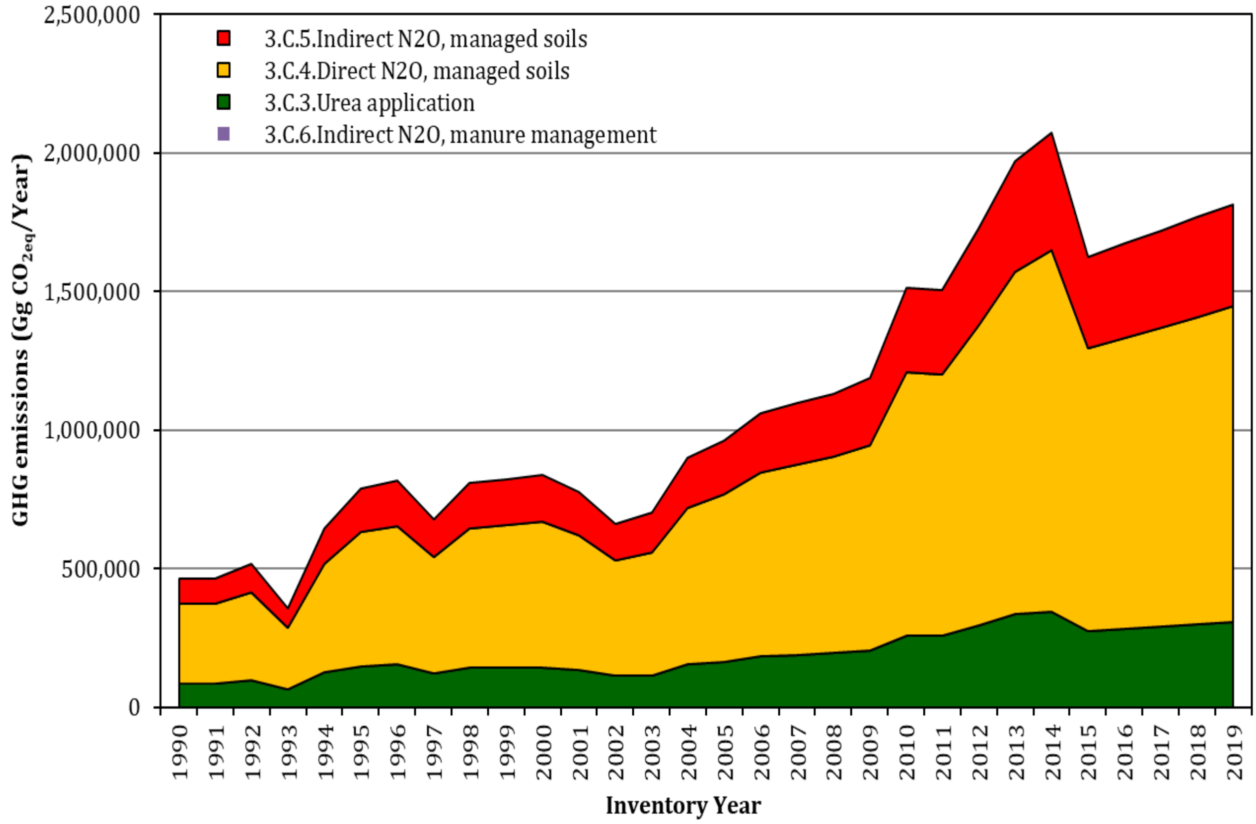


Figure 5.18: Trends in aggregated and non-CO_2 emissions on land in Ethiopia between 1990 and 2019

Urea application (3C3)

Category description

Emissions Sources	Urea application
Gases Reported	Carbon dioxide (CO_2)
Methods	Tier 1 method was used using Equation 11.13 of the IPCC 2006 Guidelines.
Emission Factors	Default EF from IPCC 2006 Guidelines (Chapter 11),value of 0.2.
Key Category Analysis	Key category (L1 and L2) Approach 1 in Vol. 1, Chapter 4 of IPCC 2006 guidelines.
Completeness	Emissions were estimated from urea imports which were assumed to have been applied.
Major improvements since last submission	This category of Urea application (3C3) was not reported in previous inventory, this inventory reported emissions from urea for first time.

During fertiliser manufacturing process CO_2 gets fixed in the fertiliser granules, therefore, the addition of urea to soils during fertilization leads to a release/loss of this CO_2 into the atmosphere. Emissions from Urea are a key category in Ethiopia and are much higher annual emission contributions than key categories such as enteric fermentation. About 70% of the population is still rural, heavily relying on subsistence agriculture from small holder farmers. These subsistence farmers are encouraged to apply fertilizers in their fields through a government subsidy programme which include the TIRR tef productivity enhancement package (D50); the RFS Input Voucher System (D28); integrated interventions in wheat and maize value chains (D54 & D60); integrated cropping system interventions for cereals and pulses (D63) (Ethiopia Agriculture Transformation Agenda-2011-2015). Moreover, the Transformation Agenda concept as an approach, it was agreed that a focus on the most important cereals should be the primary emphasis during GTP I., use substantial amounts of inputs /fertilizers/urea. Despite almost doubling yields of major cereals in the past decade, cereal yields in Ethiopia still fare lower in comparison with those of other fast developing countries. The increased cereal requirements needed to meet increased feed demand and poultry population over the next two decades require an additional 65 million hectares to be placed under cultivation.

Emissions

Between the years 1990 and 2019, there was a notable increase in emissions from urea application of about 142%, as it increased from 86435.06 Gg CO_2e in 1990 to 308144.34 Gg CO_2e in 2019 (Table 5.16). This represents an increase of 256.50% since 1990.

Table 5.16: Trend and relative contribution of urea application category between 1990 and 2019

Sub-category	Emissions (Gg CO_2e)		Change (1990 – 2019)	
	1990	2019	Difference (Gg CO_2e)	%
Urea application	86435.06	308144.34	221709.28	256.50

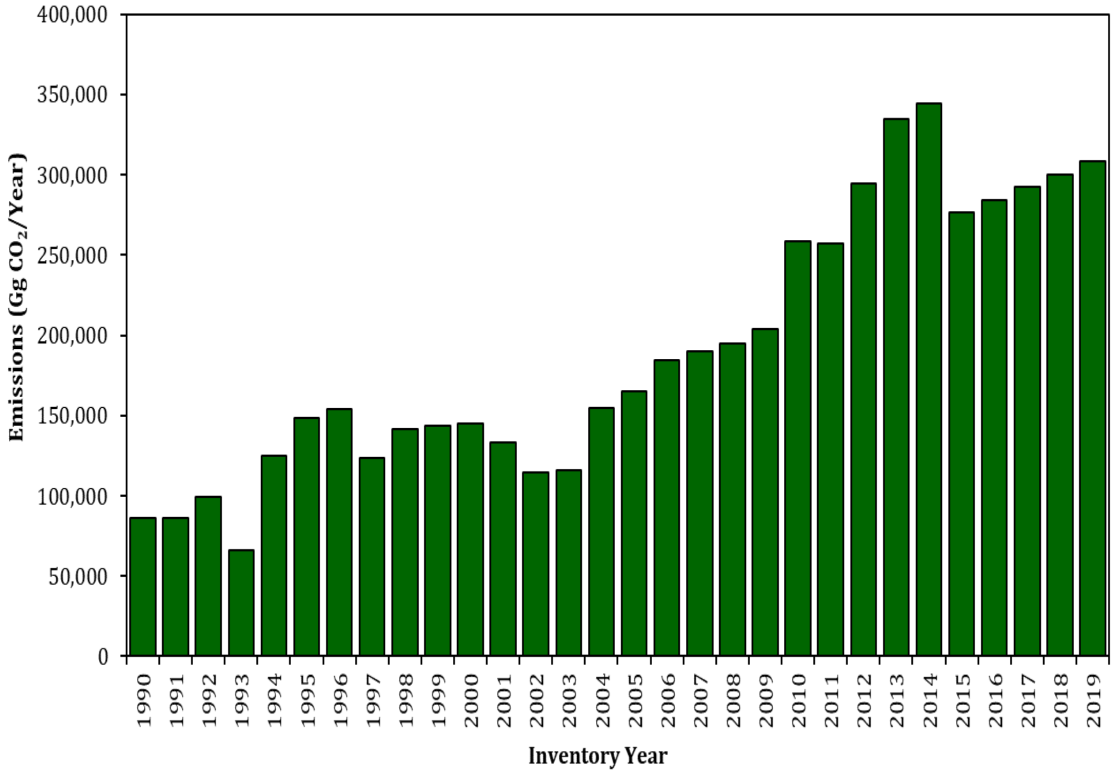


Figure 5.19: Trends in CO_2 emissions from Urea application (3.C.3.) for Ethiopia between 1990 and 2019

Methodological Issues

Tier 1 method was used applying Equation 11.13 from the IPCC 2006 Guidelines, using an emission factor of 0.2. The emission factors (EF) were obtained from Vol 4, Chapter 2 of 2006 IPCC Guidelines. Activity data for the amount of urea applied was taken from Ethiopia Central Statistics Agency. Default emission factor (EF) of 0.02 for carbon emissions from urea applications was used from the 2006 IPCC Guideline. In cases where data was not available from IPCC gap filling techniques for interpolation and extrapolation were used; hence.

Category Specific QA/QC & Verification

Following Aether's QA/QC procedures, quality assurance and control forms were filled for the sector. Moreover, the inventory calculation files were exchanged with other sectors for QA/QC. A Technical Working Group of experts focusing on the Agriculture category was established and provided technical review and input into the sector inventory, even verified calculation procedures applied.

Planned improvements

IPCC Land use category	Data gaps identified (AD and EF)	Planned Improvements /Remarks
Urea application	i) Lack of country specific activity data ii) Urea import data with gaps iii) Urea import data with inconsistencies	i) Develop country specific data collection templates for urea application at Regional Development Areas (RDAs) level ii) Improvement in the recording and records keeping of import records for urea

Direct N_2O emissions from managed soils (3C4)

Category description

Emissions Sources	Direct N_2O emissions from managed soils Fertilizer inputs
Gases Reported	Nitrous oxide (N_2O)
Methods	Tier 1 method was used using Equation 11.1 of the IPCC 2006 Guidelines.
Emission Factors	Default from IPCC 2006 Guidelines (Table 11.1)
Key Category Analysis	Key category L1, L2 Approach 1 in Vol. 1, Chapter 4 of IPCC 2006 guidelines.
Completeness	Emissions were estimated from synthetic nitrogen fertilizers, organic fertilizers (e.g. animal manure, crop residue, and animal manure deposited on pastures, rangelands and paddocks.
Major improvements since last submission	The previous inventory did not have this category, thus no recalculation was done.

A number of agricultural activities add nitrogen to soils (such as use of synthetic and organic fertilizers, deposited manure by grazing animals, crop residues, cultivation of organic soils and mineralization of N in soil organic matter due to management of organic soils), thereby increasing the amount of nitrogen available for nitrification and denitrification, and ultimately the amount of N2O emitted due to microbial process.

Agricultural soils contribute to GHGs emissions through CO_2 emissions due to the loss of soil organic matter, CH_4 from anaerobic soils such as rice paddies, and N_2O from fertilizer use and intensive cultivation. CO_2 emissions are as a result of land-use change, and thus dealt with in the Land category. Even though there is rice cultivation in Ethiopia, it is in very limited scale, and there is very poor data. Therefore, CH_4 emissions from agricultural soils were not included in the inventory. As alluded above, fertiliser application, as well as intensive cultivation are the key practices and ultimately, key sources of N_2O emissions from managed soils in the country.

According to the IPCC (2006) Guidelines, there are a number of pathways of nitrogen inputs to agricultural soils that can result in direct N_2O emissions, among them being synthetic nitrogen fertilizers, organic fertilizers (e.g., animal manure, compost and sewage sludge); crop residue, and animal manure deposited on pastures, rangelands and paddocks. The other pathway is indirect, such as soil organic matter lost from mineral soils through land-use change and organic soil that is drained or managed for agricultural purposes.

Direct N2O emissions from managed soils as a result of total amount of nitrogen applied to soils through human induced N additions and/or change or practices are considered below. Specific N sources considered for estimating N2O emission from managed soils for Ethiopia are:

- Inorganic N Fertilizer;
- Organic N Fertilizer;
- Urine and Dung deposited by Grazing Animals; and
- N from Crop Residues.

Emissions

Direct N_2O emissions from managed soils as a result of nitrogen inputs showed a decrease of 2.1% between 1990 and 2018. This was from 119.37 Gg CO_2e in 1990 to 117.27 Gg CO_2e in 2018 (Table 5.8). This represents a 298.07% increase since 1990.

Table 5.8: Trend and relative contribution of direct N_2O emissions from managed soils category between 1990 and 2019

Sub-category	Emissions (Gg CO_2e)		Change (1990 – 2018)	
	1990	2019	Difference (Gg CO_2e)	%
Direct N_2O from managed soils	285671.26	1137190.75	851519.49	298.07

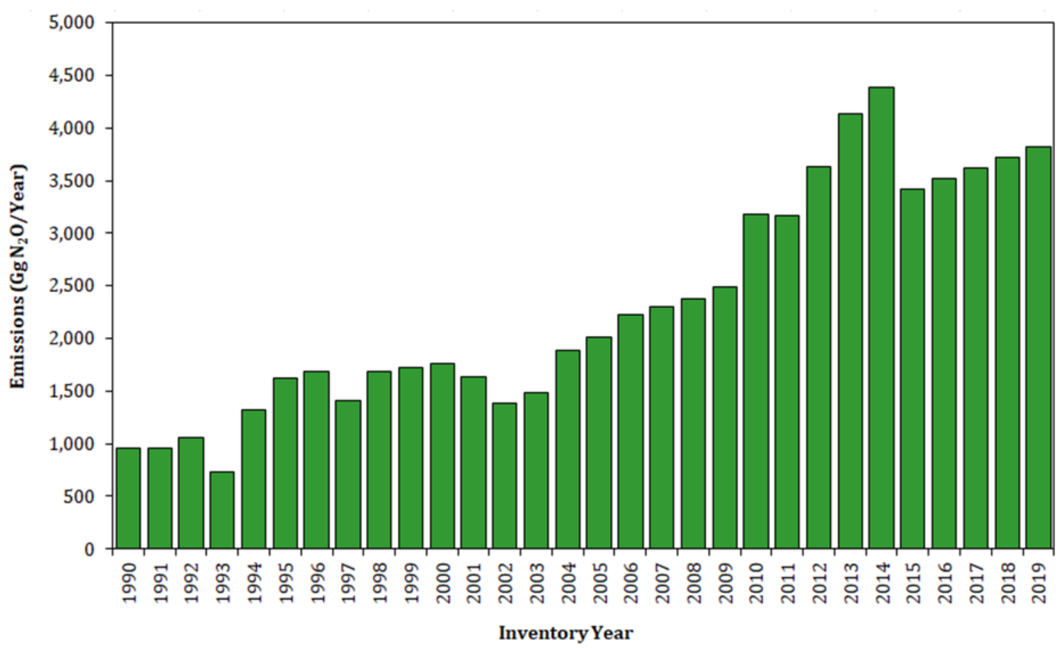


Figure 5.20 Direct N_2O Emissions from managed soils (3.C.4) 1990-2019

Methodological Issues

Tier 1 method was used applying Equation 11.1 of the IPCC 2006 Guidelines, and EF from Table 11.1. Organic fertilisers applied to soils were determined from Equation 11.3, 11.4, 11.5 and 11.7A of the IPCC 2006 Guidelines. Crop statistics was obtained FAO 2018 Annual Report, and crop residue factors were taken from Table 11.2 in the IPCC 2006 Guidelines. The amount of N mineralised in mineral soil as a result of loss of soil carbon through change in land use was not included in this inventory due to a lack of data, however since the land changes have now been incorporated this factor can be included in the next inventory. Organic soils were also not included as these were thought to be insignificant.

Activity Data and Emission factors

National data on synthetic fertilizer application, area of crop cultivation and crop production for the years 1990-2019 -2013 was collected from Ethiopia Central Statistics Agency and default emission factor was used for all sub-sector to calculate Direct N2O emission from managed soils. Default emission factor was used from the 2006 IPCC Guidelines.

Fraction of N in Synthetic fertilizer:

Nitrous oxide emission from synthetic fertilizer was estimated based on the amount of N in synthetic fertilizer that is annually used in the country. Data on the annual consumption of synthetic fertilizers was obtained from the annual Farm Management practice Report published by the Ethiopian Central Statistics Agency from the years 1990-2019. Data on amounts of synthetic fertilizer applied to soils and N content for the period from 1990-2019- is presented in Table 5.19 (Nitrogen amount from applied synthetic fertilizer for the year 1990-2019-0 .

Table 5.19 Nitrogen amount from applied synthetic fertilizer for the year 1990-2019

	Parameter	Units	1990	1991	1992	1993	1994	1995	1996	1997	1998
UREA	*Consumption*	*t/yr*	117,866,000.00	117,392,000.00	135,467,000.00	90,109,000.00	170,000,000.00	202,312,000.00	209,883,000.00	168,623,000.00	193,395,000.00
	Fraction N in fertiliser	*fraction*	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46
	Total N	*Kg N/yr*	54,218,360,000.00	54,000,320,000.00	62,314,820,000.00	41,450,140,000.00	78,200,000,000.00	93,063,520,000.00	96,546,180,000.00	77,566,580,000.00	88,961,700,000.00
DAP	*Consumption*	*t/yr*	27,843,000.00	29,573,000.00	17,191,000.00	17,348,000.00	20,000,000.00	44,411,000.00	43,269,000.00	51,808,000.00	87,976,000.00
	Fraction N in fertiliser	*fraction*	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
	Total N	*Kg N/yr*	5,011,740,000.00	5,323,140,000.00	3,094,380,000.00	3,122,640,000.00	3,600,000,000.00	7,993,980,000.00	7,788,420,000.00	9,325,440,000.00	15,835,680,000.00
	Total Kg N/yr consumed		59,230,100,000.00	59,323,460,000.00	65,409,200,000.00	44,572,780,000.00	81,800,000,000.00	101,057,500,000.00	104,334,600,000.00	86,892,020,000.00	104,797,380,000.00

	Parameter	Units	1999	2000	2001	2002	2003	2004	2005	2006	2007
UREA	*Consumption*	*t/yr*	195,345,000.00	197,345,000.00	181,545,000.00	155,941,000.00	157,955,000.00	210,837,000.00	224,819,000.00	251,156,000.00	259,020,000.00
	Fraction N in fertiliser	*fraction*	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46
	Total N	*Kg N/yr*	89,858,700,000.00	90,778,700,000.00	83,510,700,000.00	71,732,860,000.00	72,659,300,000.00	96,985,020,000.00	103,416,740,000.00	115,531,760,000.00	119,149,200,000.00
DAP	*Consumption*	*t/yr*	94,919,000.00	100,562,000.00	98,057,000.00	76,329,000.00	106,394,000.00	112,105,000.00	121,735,000.00	124,561,000.00	129,121,000.00
	Fraction N in fertiliser	*fraction*	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
	Total N	*Kg N/yr*	17,085,420,000.00	18,101,160,000.00	17,650,260,000.00	13,739,220,000.00	19,150,920,000.00	20,178,900,000.00	21,912,300,000.00	22,420,980,000.00	23,241,780,000.00
	Total Kg N/yr consumed		106,944,120,000.00	108,879,860,000.00	101,160,960,000.00	85,472,080,000.00	91,810,220,000.00	117,163,920,000.00	125,329,040,000.00	137,952,740,000.00	142,390,980,000.00

	Parameter	**Units**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
UREA	*Consumption*	*t/yr*	265,768,000.00	278,239,000.00	352,309,000.00	350,234,000.00	401,817,000.00	456,618,000.00	469,793,000.00	377,088,226.89
	Fraction N in fertiliser	*fraction*	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46
	Total N	*Kg N/yr*	122,253,280,000.00	127,989,940,000.00	162,062,140,000.00	161,107,640,000.00	184,835,820,000.00	210,044,280,000.00	216,104,780,000.00	173,460,584,369.75
DAP	*Consumption*	*t/yr*	138,988,000.00	148,437,000.00	201,576,000.00	200,345,000.00	233,526,000.00	272,625,000.00	322,930,000.00	217,426,947.23
	Fraction N in fertiliser	*fraction*	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
	Total N	*Kg N/yr*	25,017,840,000.00	26,718,660,000.00	36,283,680,000.00	36,062,100,000.00	42,034,680,000.00	49,072,500,000.00	58,127,400,000.00	39,136,850,500.84
	Total Kg N/yr consumed		147,271,120,000.00	154,708,600,000.00	198,345,820,000.00	197,169,740,000.00	226,870,500,000.00	259,116,780,000.00	274,232,180,000.00	212,597,434,870.59

	Parameter	Units	2016	2017	2018	2019
UREA	*Consumption*	*t/yr*	387,865,377.59	398,642,528.29	409,419,678.99	420,196,829.69
	Fraction N in fertiliser	*fraction*	0.46	0.46	0.46	0.46
	Total N	*Kg N/yr*	178,418,073,691.88	183,375,563,014.01	188,333,052,336.14	193,290,541,658.26
DAP	*Consumption*	*t/yr*	224,883,075.41	232,339,203.59	239,795,331.76	247,251,459.94
	Fraction N in fertiliser	*fraction*	0.18	0.18	0.18	0.18
	Total N	*Kg N/yr*	40,478,953,573.11	41,821,056,645.38	43,163,159,717.65	44,505,262,789.92
	Total Kg N/yr consumed		218,897,027,264.99	225,196,619,659.38	231,496,212,053.78	237,795,804,448.18

Organic Nitrogen

Direct N2O emission from organic nitrogen applied to managed soils was calculated using Equation 11.3 from the 2006 IPCC Guidelines. However, N_2O emission was only calculated

from the amount of manure applied to soils other than grazing animals because application of compost and sewage is not that much practiced in the country. The amount of N in solid and liquid manure/slurry which is annually used for crop fertilization was calculated using the Equation 11.4 and amount of managed manure N available for soil application was estimated using Equation 10.34 from the 2006 IPCC Guidelines.

N from Pasture, Range and Paddock (PRP)

Annual amount of N input deposited on pasture, range and paddock soils by grazing animals was calculated using Equation 11.5 from 2006 IPCC Guidelines. Data on N deposited was obtained from the Direct N_2O emission from Manure Management using default nitrogen excretion rates for each livestock species.

Crop Residue

Tier 1 methodology using Equation 11.7A from 2006 IPCC Guidelines was used to calculate direct nitrous oxide emission from crop residues. The estimate was made based on the amount of crop residues returned to soils annually. Data on crop production and area of production (Annex XX. Area and Crop Production for the year 1990-2019.) was obtained from Ethiopia Central Statistics Agency, Report on Area and Production, which is published annually. In Ethiopia, in general, crop residues are used for different purpose such as feed and construction, therefore only nitrogen content in below ground biomass is considered to estimate N_2O emission from crop residues. In addition, Default crop specific factor was used from Table 11.2 of the 2006 IPCC Guideline o estimate N_2O emission.

Due to the absence of country specific emission factor to estimate Direct N_2O emission from Managed soils, default emission factor from the 2006 IPCC Guidelines were sued and are presented below in Table 5.20 below:

Table 5.20 Emission factors used to estimate Direct N_2O emission from Managed soils.

Emission factor for N_2O emissions from N inputs	kg N_2O-N (kg N input)-	2006 IPCC Guidelines
EF1 for N additions from mineral fertilisers, organic amendments and crop residues, and N mineralised frommineral soil as a result of loss of soil carbon [kg N_2O-N (kg N)-1]	0.01	Table 11.1
EF3PRP, CPP for cattle (dairy, non-dairy and buffalo), poultry and pigs [kg N2O-N (kg N)-1]	0.02	Table 11.1
EF3PRP, SO for sheep and 'other animals' [kg N_2O-N (kg N)-1]	0.01	Table 11.1

Category Specific QA/QC & Verification

Following Aether's QA/QC procedures, quality assurance and control forms were filled for the sector. Moreover, the inventory calculation files were exchanged with other sectors for QA/QC. A Technical Working Group of experts focusing on the Agriculture category was established and provided technical review and input into the sector inventory, even verified calculation procedures applied.

Planned improvements

IPCC Land use category	Data gaps identified (AD and EF)	Planned Improvements /Remarks
Direct N_2O emissions from managed soils	i) Poor management systems, and documenting of activity data on soil management, especially in rural areas	i) Development of management systems that should be fully documented by the rural administration areas (RDAs) level. ii) Accurate documentation of activity data on soil management, especially in rural areas iii) Development of country specific emission factors for N_2O emissions from N inputs

Indirect N_2O emissions from managed soils (3C5)

Category description

Emissions Sources	Indirect N_2O emissions from managed soils Urea import data
Gases Reported	Nitrous oxide (N_2O)
Methods	Tier 1 method was used using Equation 11.9 and 11.10 of the IPCC 2006 Guidelines.
Emission Factors	Default IPCC 2006 Guidelines (Table 11.3).
Key Category Analysis	Key category L1, L2 Approach 1 in Vol. 1, Chapter 4 of IPCC 2006 Guidelines.
Completeness	Emissions were estimated from volatilization, runoff and leaching from land where N was applied.
Major improvements since last submission	The previous inventory did not have this category, thus no recalculation was done.

According to the IPCC Guidelines (2006), there are two ways indirect emissions of N_2O-N can take place. The first one is through volatilization of N as NH_3 and oxides of N, and through the deposition of these gases into water surfaces. Secondly, it is through runoff and leaching from land where N was applied).

Volatilization of N as NH_3 and oxides of N (NOx) and the deposition of these gases and their products NH_4+ and NO_3- onto soils. Leaching and runoff from land of N from synthetic and organic fertilizer additions, crop residues, mineralization of N associated with loss of soil C in mineral and drained/managed organic soils through land-use change or management practices, and urine and dung deposition from grazing animals. Some of the inorganic N in or on the soil, mainly in the NO_3 - form, may bypass biological retention mechanisms in the soil/vegetation system by transport in overland water flow (runoff) and/or flow through soil macrospores or pipe drains.

Emissions

Indirect N_2O emissions from managed soils as a result of N_2O volatilisation showed an increase by 2.99 % between 1990 and 2019 and from 92501.54 Gg CO_2e in 1990 to 369277.61 Gg CO_2e in 2019 (Table 5.21). N sources included: synthetic N fertilizer, organic N additions, urine and crop residues.

Table 5.91: Trend and relative contribution of the various indirect N_2O emissions from managed soils category between 1990 and 2018

Sub-category	Emissions (Gg CO_2e)		Change (1990 – 2019)	
	1990	2019	Difference (Gg CO_2e)	%
Indirect N_2O from managed soils	92501.54	369277.61	276776.07	2.99

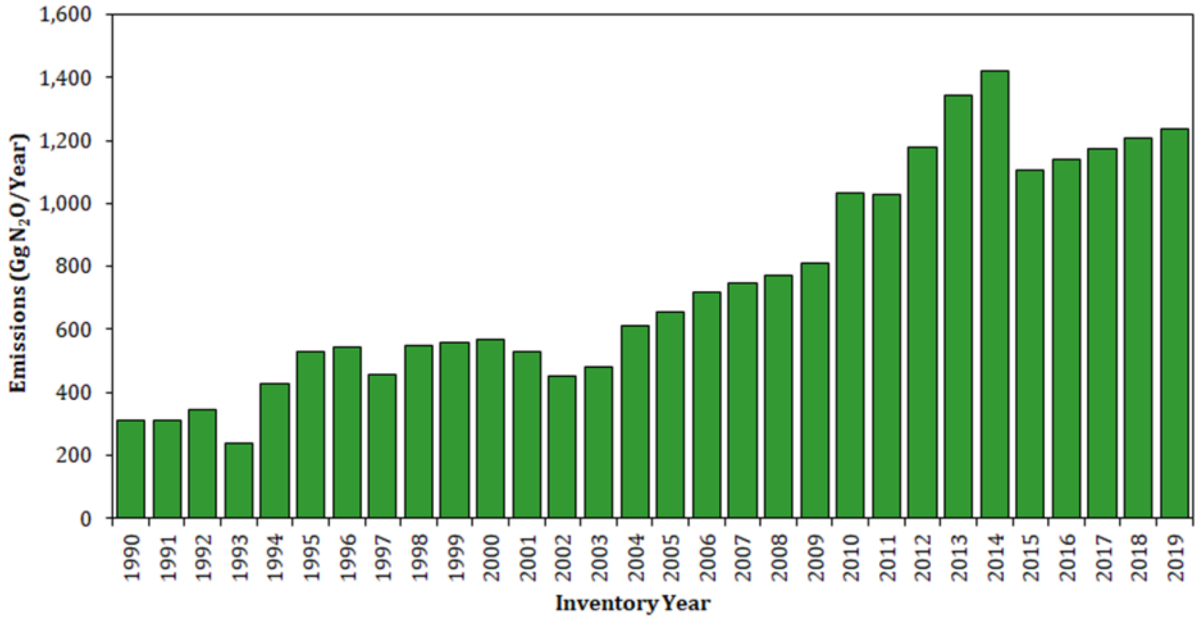


Figure 5.21 In-Direct N_2O Emissions from managed soils (3.C.5) 1990-2019

Methodological Issues

Tier 1 method was used, using Equation 11.9 and Equation 11.10 of the IPCC 2006 Guidelines, and using an EF from Table 11.3. Activity data and Emission Factor

The same activity data used to estimate direct N_2O emission from managed soil was used to estimate indirect N_2O emission from both atmospheric deposition of N volatalized and N leaching/runoff from managed soils. Whereas for the fractions and emission factors default values from the 2006 IPCC Guideline was used table 11.3,

Atmospheric deposition due to volatilization

Indirect N2O emissions from atmospheric deposition of N volatilised from managed soil were estimated using Tier 1 methodology, using Equation 11.9 from the 2006 IPCC Guidelines, using default emission factors and fractions.

Nitrogen leaching and run-off

Indirect N2O emissions resulting from nitrogen from fertilizers and other agricultural inputs that is lost through leaching and run-off were estimated using Tier 1 methodology, using Equation 11.10 from the 2006 IPCC Guidelines and default emission factors and fractions.

For details on livestock numbers, the reader is referred to Section 5.2.2 (Enteric Fermentation). Additionally, management systems were solely obtained from experts in the field, Ministry of agriculture and livestock and rural development areas consultations.

Category Specific QA/QC & Verification

Following Aether's QA/QC procedures, quality assurance and control forms were filled for the sector. Moreover, the inventory calculation files were exchanged with other sectors for QA/QC. A Technical Working Group of experts focusing on the Agriculture category was established and provided technical review and input into the sector inventory, even verified calculation procedures applied.

Planned improvements

IPCC Land use category	Data gaps identified (AD and EF)	Planned Improvements /Remarks
Indirect N_2O from managed soils	i) Poor management systems, and documenting of activity data on soil management, especially in rural areas	i) Development of management systems that should be fully documented by the rural administration areas (RDAs) level. ii) Accurate documentation of activity data on soil management, especially in rural areas iii) Development of country specific emission factors for N_2O emissions from N inputs, volatilisation and leaching

Indirect N_2O from manure management (3C6)

Category description

Emissions Sources	Indirect N_2O from manure management Livestock population
Gases Reported	Nitrous oxide (N_2O)
Methods	Tier 1 method was used, using Equation 11.9 and Equation 11.10 of the IPCC 2006 Guidelines.
Emission Factors	Default EF from IPCC 2006 Guidelines (Table 11.3).
Key Category Analysis	Approach 1 in Vol. 1, Chapter 4 of IPCC 2006 Guidelines.
Completeness	Emissions were estimated from volatilization, runoff and leaching from land where N was applied.
Major improvements since last submission	The previous inventory did not have this category, thus no recalculation was done.

IPCC Guidelines (2006) state that indirect emissions of N_2O-N can take place through volatilization of N as NH_3 and oxides of N, as well as through runoff and leaching from land where N was applied. This inventory estimated emissions from both ways, using livestock data sourced from Ministry of Agriculture. Expert judgement, through consultation with experts from the Ministry (e.g. extension officers) and the Agriculture Technical Working Group, was used to establish manure management practices in the country.

Emissions

Emissions from indirect N_2O from manure management category, showed an increase across the time series (Table 5.21). In 1990 emissions from indirect N2O from manure management were at 664.96 Gg CO_2e compared to 2019 at 2144.30 Gg CO_2e.

Table 5.10: Trend and relative contribution of indirect N_2O from manure management between 1990 and 2018

Emissions (Gg CO_2e)		Change (1990 – 2019)	
1990	2019	Difference (Gg CO_2e)	%
664.96	2144.30	1479.96	214.33

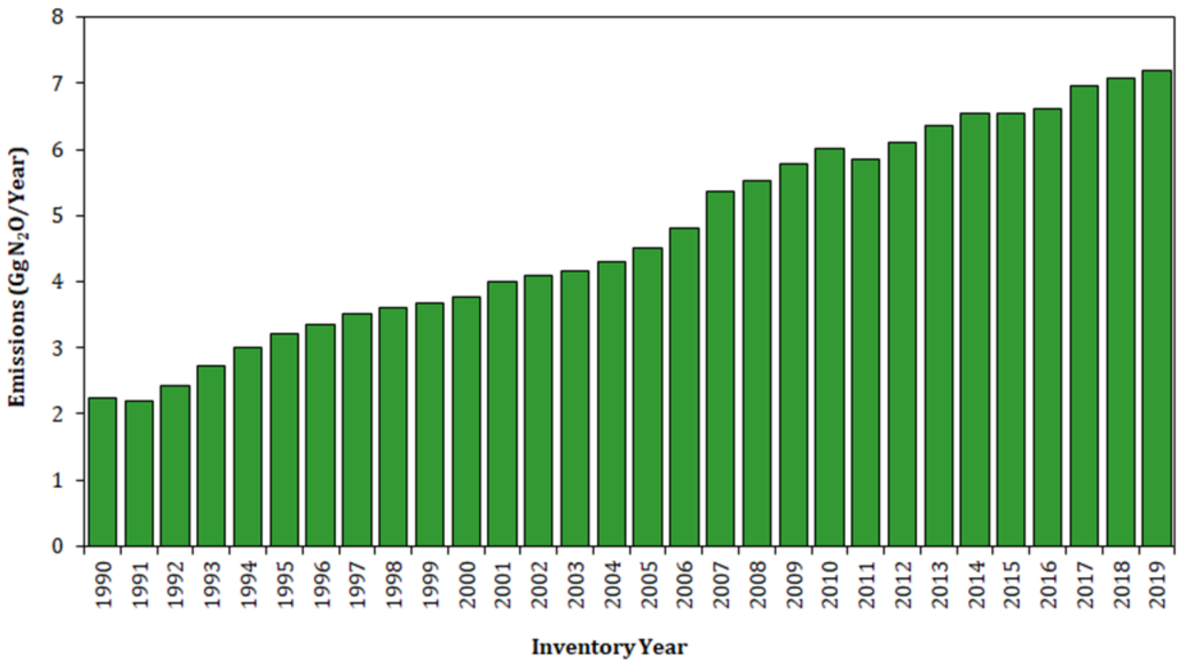


Figure 5.22 In-Direct N_2O Emissions from manure management (3.C.6) 1990-2019

Methodological Issues

Tier 1 method was used to calculate indirect Nitrous oxide (N_2O) emission from manure management, using Equation 11.9 and Equation 11.10 of the IPCC 2006 Guidelines, using EF from Table 11.3. Volatized N in forms of NH_3 and NOx was calculated for each manure management systems from all livestock categories using Equation 10.26 according to 2006 IPCC guideline. Final N_2O emissions were then estimated using Equation 10.27 (2006 IPCC guidelines), using default emission factors (Table 11.3, 2006 IPCC guidelines).

Activity data and Emission Factor

The same activity data used in estimating direct N_2O emission was used to calculate indirect N2O emission from manure management whereas default emission factor (EF4) of 0.01 kg N_2O-N (kg NH3-N + NOx-N volatilised)-1, (Table 11.3) was used from the 2006 IPCC Guidelines.

For details on livestock numbers, the reader is referred to Section 5.2.2 (Enteric Fermentation). Additionally, management systems were solely obtained through expert judgement, in consultation with experts in the field and rural development areas consultations.

Category Specific QA/QC & Verification

Following Aether's QA/QC procedures, quality assurance and control forms were filled for the sector. Moreover, the inventory calculation files were exchanged with other sectors for QA/QC. A Technical Working Group of experts focusing on the Agriculture category was established and provided technical review and input into the sector inventory, even verified calculation procedures applied.

Planned improvements

IPCC Land use category	Data gaps identified (AD and EF)	Planned Improvements /Remarks
Indirect N_2O from manure management	Poor management systems, and documenting of activity data on manure management, especially in rural areas	i) Development of management systems that should be fully documented by the rural administration areas (RDAs) level

1.5 Time series consistency issues

According to the 2006 IPCC Guidelines, developing a time series of emissions estimates is a central component of the greenhouse gas inventory because it provides information on historical emissions trends and tracks the effects of strategies to reduce emissions at the national level. In the AFOLU sector, to ensure time series consistency where data gaps existed IPCC splicing techniques were used in accordance with the 2006 IPPC Guidelines.

In agriculture sectors gap filling was conducted using some FAO data where necessary for animal population data. In the Land sector (3B) Wall-to-wall raster data on area and area changes was only available for the years 2003, 2008, 2013 and 2018. For missing years, an interpolation of average of the areas has been converted to/from other land uses. Interpolation techniques were used to allow the calculation of the annual land use matrices and extrapolation and surrogate were used to calculate the land area changes for the missing years including 1990 area change data. Similarly, in agriculture there were some gaps in livestock, biomass burning by annual area burnt and development of country specific data for rice cultivation and lime data and IPCC interpolation techniques were applied to fill the gaps.

1.6 Recalculations

No recalculations were performed as this was the first time to use the IPCC 2006 Inventory guidelines during inventory compilation process.

1.7 References

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