Inventory of greenhouse gas emissions from cattle, sheep and goats in Ethiopia (1994-2018) calculated using the IPCC Tier 2 approach

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MINISTRY OF AGRICULTURE

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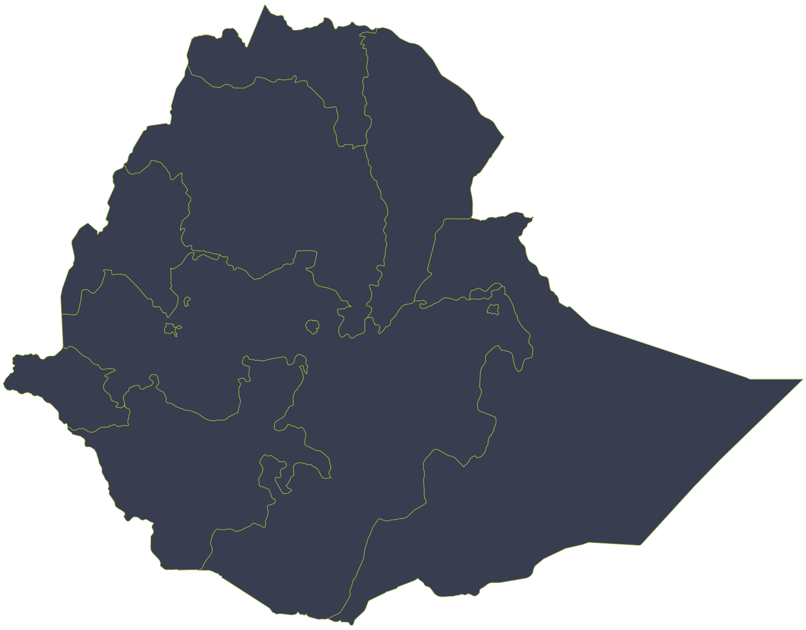

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Final Report
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Foreword

The livestock sector is an important source of incomes and livelihoods, especially for resource poor livestock keepers in Ethiopia. However, the sector is also a major source of national greenhouse gas (GHG) emissions. Ethiopia's Nationally Determined Contribution (NDC) states the intention to reduce GHG emissions from the livestock sub-sector. This can be achieved by reducing GHG emissions from different livestock production systems with various levels of intensification. The current national GHG inventory is one of the main tools through which Ethiopia can measure and report livestock sub-sector GHG emissions. This GHG inventory was compiled using recommended international guidelines and represents a unique opportunity to assess the effectiveness of policies and measures in addressing climate change. This GHG inventory strengthens national capacities to identify livestock GHG mitigation options and to track the effects of policies and measures, such as the livestock mitigation measures set out in Ethiopia's Climate Resilient Green Economy (CRGE) Strategy (2011).

The periodic GHG inventory report contains all sources of GHG emissions for the period from 1994 through 2018 with a detailed description of the methods applied and the findings of scientific research on national circumstances.

The Government of Ethiopia would like to thank UNIQUE forestry and land use GmbH and the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) for their support in compiling the inventory. The Environment and Climate Change Directorate (Ministry of Agriculture) deserves special commendation for its tremendous effort in coordinating the preparation of this report.

State Ministry for Livestock

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Ministry of Agriculture

Acknowledgements

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Acronyms

BUR	Biennial Update Report
CH_4	Methane
CO_2	Carbon dioxide
COP	Conference of the Parties
CP	Crude protein
CSA	Central Statistical Agency
CRGE	Climate Resilient Green Economy
DE	Digestible energy
DM	Dry matter
EFCCC	Environment, Forest and Climate Change Commission
EIAR	Ethiopian Institute of Agricultural Research
EF	Emission factor
FAO	Food and Agriculture Organization of the United Nations
GE	Gross energy
Gg	Giga gram (1 million gram; 1000 kg, or 1 ton)
GHG	Greenhouse gas
GLEAM	Global Livestock Environmental Assessment Model
GRA	Global Research Alliance
ILRI	International Livestock Research Institute
IPCC	Intergovernmental Panel on Climate Change
LW	Live weight
MC	Monte Carlo
MCF	Methane conversion factor
ME	Metabolizable energy
MJ	Megajoule
MMS	Manure management system
MRV	Measurement, verification and reporting
MOE	Margin of error
N	Nitrogen
NCs	National Communications
N_2O	Nitrous oxide
NDC	Nationally Determined Contribution
NE	Net energy
QAQC	Quality assurance and quality control
SNC	Second National Communication
TACCC	Transparency, Accuracy, Consistency, Comparability, Completeness
UNFCCC	United Nations Framework Convention on Climate Change
VS	Volatile solids
WG	Weight gain

Technical summary

Livestock production is an important source of incomes and livelihoods for the rural population in Ethiopia, and is also an important contributor to greenhouse gas (GHG) emissions. Ethiopia's GHG profile is dominated by emissions from the agriculture sector, representing 79% of total national emissions. Of these emissions, livestock accounts for the largest share (60%) due to enteric fermentation, manure management and emissions from managed soils due to livestock deposit of dung and urine.

Under the United Nations Framework Convention on Climate Change (UNFCCC), Ethiopia is obliged to report its GHG emissions to the Conference of the Parties (COP). Decision 1/CP.16 decided that developing country parties should submit their national communications (NCs), which include a national GHG inventory, every four years, and a Biennial Update Report (BUR), including an update to the national inventory, every two years. In addition, as part of the Paris Agreement (2015), countries have established Nationally Determined Contributions (NDCs). The modalities, procedures and guidelines for the transparency framework agreed in 2018 require that signatories to the Paris Agreement submit a national GHG inventory every two years starting from 2024 at the latest, with flexibility for least developed countries.

Ethiopia submitted NCs in 2001 and 2016 using Tier 1 methods for estimating livestock emissions in their GHG inventories. The Intergovernmental Panel on Climate Change (IPCC) Tier 1 methods require the least resources (input data) to compile, but are unable to reflect a country's unique circumstances or trends over time other than changes in total livestock numbers. The IPCC Tier 2 method is an advanced inventory method that is more accurate but requires more detailed data to reflect country specific circumstances. A Tier 2 method is also better able to reflect the effects of policies and measures in the livestock sector on GHG emissions, and can therefore improve the quality of estimates of GHG emissions and emission reductions in line with Ethiopia's CRGE Strategy.

Therefore, the Ministry of Agriculture (MoA) has taken the initiative to compile an inventory for the main ruminant livestock species (cattle, sheep and goats) using a Tier 2 method. This more advanced inventory method will strengthen Ethiopia's ability to measure, report and verify emissions and emission reductions from the livestock sector. This livestock inventory report will also inform the compilation of the national GHG inventory update in Ethiopia's first BUR to the UNFCCC, being prepared in 2020.

To ensure comparability and consistency with other sector reports for the BUR, the livestock inventory followed the 2006 IPCC Guidelines, with additional reference to the 2019 Refinement to the 2006 IPCC Guidelines to ensure that calculation methods and default values used are based on the latest available science. All time series for activity data and emission factors within each production system have been produced using consistent methods, although data sources may differ within a time series due to the lack of a single data source covering the whole of the 1994-2018 period. Where time series data was missing, the gap-filling methods recommended by the IPCC (2006) have been applied. In this report, emissions are estimated from dairy cattle, other cattle, sheep and goats for the main livestock emission sources. These sources are: 1) enteric fermentation CH4 (reporting category 3A1); 2) manure management, CH_4 and N_2O (reporting category 3A2); 3) direct N_2O emissions from managed soils, dung and urine deposit on pasture (which contributes to reporting category 3C4); 4) indirect N_2O emissions from managed soils, dung and urine deposit on pasture (which contributes to reporting category 3C5); and 5) indirect N_2O emissions from manure management (reporting category 3C6) from the base year for Ethiopia's GHG inventory (i.e. 1994) until 2018.

The GHG emissions time series were calculated for

- 12 sub-categories of dairy cattle (adult dairy cows, adult males, calves < 6 month, calves 6 month -<1 year, growing males, growing females) in two dairy production systems (smallholder intensive, and commercial intensive);
- 16 sub-categories of other cattle (i.e. dual purpose indigenous breeds) in the mixed crop-livestock production system (adult multipurpose cows ≥3 years, adult males used for draught 3-10 years, adult males used for breeding & other purpose >3-10 years, calves < 6 months, calves 6 m-<1 year, growing males 1-<3 years, growing females 1-<3 years, smallholder fattening cattle male 3-10 years, commercial feedlot-fed cattle male 3-10 years) and the pastoral/agro-pastoral production system (adult multipurpose cows ≥3 years, adult males used for draught 3-10 years, adult males used for breeding & other purpose >3-10 years, calves < 6 months, calves 6 m-<1 year male & female, growing males 1-<3 years, growing females 1-<3 years);
- 14 sub-categories of sheep (breeding ewes ≥ 2 years, mature male sheep ≥ 2 years, female 1-<2 years, male 1-< 2 year, intact male < 1 year, castrated male < 1 year, females <1 year) in two production systems (mixed crop-livestock, pastoral/agro-pastoral production system); and
- 8 sub-categories of goat (does ≥2 years, bucks ≥2 years, yearlings 1-<2 years, and kids < 1 year) in the mixed crop-livestock and pastoral/agro-pastoral systems in Ethiopia.

Calculations were implemented in an Excel spreadsheet.

Uncertainty analysis was carried out using Monte Carlo simulation and consistent methods have been used to estimate the time series for each source category. Quality assurance and quality control (QAQC) activities were implemented and included checking that the equations programmed in the spreadsheet were correctly input; checking that inputs to summed totals were obtained from the correct fields; checking that all data sources were fully documented; checking that the figures in the inventory spreadsheet were correctly transcribed from prior worksheets; checking that the figures in the inventory report were correctly transcribed; and reconstructing a number of the calculations to cross-check the intermediate calculations and results in the inventory spreadsheet. Quality assurance was also provided by a thorough review by the advisory group, experts from the Ethiopian Environment, Forest and Climate Change Commission (EFCCC) and international experts at the World Bank.

This is the first time Ethiopia has used a Tier 2 method for all main emission sources, which has been applied to dairy cattle, other cattle, sheep and goats. The largest source of emissions in the livestock sector is enteric fermentation. It is estimated that in 1994 CH_4 emissions amounted to 1,615.90 Gg CH_4 and increased to 3672.11 Gg CH_4 in 2018. This increase is due to both an increase in animal numbers and to changes in animal management and animal performance. Dairy and other cattle in 2018 contributed an estimated 3145 Gg or 85.7% of the total livestock methane emissions in Ethiopia. Other cattle in both the mixed crop-livestock and pastoral/agro-pastoral production systems were the largest contributor (82.8%), followed by goats (7.4%) and sheep (6.95%). The enteric methane emission factors for dairy cattle and other cattle across time series average 77.6 and 47.8 kg CH_4 per head per year, respectively. Emissions estimated using the Tier 2 method were consistently lower than emissions estimated using the Tier 1 method as previously reported in Ethiopia's Second National Communication (SNC). This indicates that accuracy was improved by using country specific activity data. Uncertainty analysis indicated that feed digestibility and live weight (LW) for both cows and oxen in the mixed crop livestock system, as well as the percentage of manure in different manure management systems across all production systems were the most influential variables. These are the key potential areas to reduce uncertainty and improve the accuracy of the GHG inventory in the future.

For further continuous improvement of the inventory, it is recommended to:

- Conduct representative sample surveys in all production systems to collect more accurate estimates of activity data used in the Tier 2 enteric fermentation and manure management models; and
- Research to develop cost-effective methods for accurate representation of diet composition for different cattle, sheep, goat sub-categories in different feeding systems.

It is also recommended for the MoA to delegate the Ethiopian Institute of Agricultural Research (EIAR) to conduct an annual review of newly published materials, survey reports and other relevant data sources. Every two years, inventory compilation agencies should undertake systematic review of newly available data and decide whether to revise the historical time series in light of improved activity data, or to revise input values used in estimating emission factors. Decisions should be made and justified in consideration of the Transparency, Acuracy, Consistency, Comparability and Completeness (TACCC) principles that underlie IPCC good practice guidance on inventory compilation. Whenever a historical time series is recalculated due to change in input data or assumptions, the inventory report should describe the changes made, their justification and the comparison between the new time series and the previously reported time series.

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CIAT/GeorginaSmith

Introduction

1. Introduction

Under the UNFCCC, Ethiopia is obliged to report its GHG emissions to the COP. Decision 1/CP.16 agreed that developing country parties should submit their NCs, which includes a national GHG inventory, every four years and a BUR, including an update to the national inventory, every two years. The decision provides for flexibility for least developed country parties. After 2024, these arrangements will be superceded by the modalities, procedures and guidelines for the enhanced transparency framework under the Paris Agreement, which also require submission of a GHG inventory every two years, with flexibility for developing countries that need it in light of their capacities.

Ethiopia submitted NCs in 2001 and 2016. The SNC (MEF 2015) included a GHG inventory for the 2013 calendar year. Total emissions from the agricultural sector were estimated at 115,466.7 Gg CO_2e, representing 79% of total emissions (MEF 2015). Of these emissions, the livestock sector contributed approximately 69,334.5 Gg CO_2e or 60% of agricultural emissions. The main sources of emissions were methane from enteric fermentation and methane (CH_4) and nitrous oxide (N_2O) from manure management. These emissions were estimated using the IPCC Tier 1 method. The SNC noted that "the adoption of a Tier 2 methodology for emission factors would significantly increase the quality of the estimates" (MEF 2015: 69). Adopting a Tier 2 methodology to estimate livestock emissions is in line with the IPCC Guidelines for national GHG inventory compilation, which recommend that Tier 2 methods are used for key sources. According to the SNC, enteric fermentation, manure management and indirect N_2O emissions from manure management are key categories identified by both level and trend assessment (MEF 2015).

Adopting a Tier 2 methodology is also important in consideration of national climate change policies. The IPCC Tier 2 approach is better able to reflect change in both the structure of livestock populations and animal management and performance. The Tier 2 approach can therefore improve the quality of estimates of GHG emissions and emission reductions in line with Ethiopia's CRGE Strategy and its commitments in the NDC.

Therefore, the Ministry of Agriculture has taken the initiative to compile an inventory for the main ruminant species – dairy cattle, other cattle, sheep and goats – using a Tier 2 approach. This more advanced inventory method will strengthen Ethiopia's ability to measure, report and verify emissions and emission reductions from the livestock sector. This report will inform compilation of the GHG inventory update in Ethiopia's first BUR to the UNFCCC, being prepared in 2020.

The IPCC has adopted guidelines that provide internationally agreed methodologies to estimate GHG emissions and guidance on how to ensure quality in all steps of inventory compilation. To ensure consistency with other sector reports for the BUR, this inventory uses the methods set out in the 2006 IPCC Guidelines (IPCC 2006). IPCC has recently refined the 2006 IPCC Guidelines to take account of the latest advances in research and methodologies on emission estimation, which were published as the 2019 Refinement to 2006 IPCC Guidelines for National GHG Inventories (IPCC 2019). In this inventory report, the methods used follow the 2006 IPCC Guidelines, but default coefficients and emission factors have been taken from the 2019 Refinement to the 2006 IPCC Guidelines (IPCC 2019) because they reflect the most up to date science. For goats in particular, the 2019 Refinement provides additional detail on calculation methods not given in the 2006 Guidelines.

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

- Enteric fermentation, CH_4 (reporting category 3A1)
- Manure management, CH_4 and N_2O (reporting category 3A2)
- Direct N_2O emissions from managed soils, dung and urine deposit on pasture (which contributes to reporting category 3C4)
- Indirect N_2O emissions from managed soils, dung and urine deposit on pasture (which contributes to reporting category 3C5)
- Indirect N_2O emissions from manure management (reporting category 3C6).

The structure of this report follows the template given in the UNFCCC's national inventory report outline for developed countries. While this structure is not obligatory for developing countries, it is useful to support transparent reporting and comparability with other countries' Tier 2 livestock GHG inventories. For each of the abovementioned GHG emission sources, the text describes the following:

(1) Source category description, including the estimated total emissions for the category;

(2) Methodological issues, including choice of methods, activity data, emission factors, assumptions and any other methodological issues;

(3) Uncertainties and time series consistency;

(4) Source-specific QAQC and verification;

(5) Source-specific recalculations, which are required to transparently document the differences between the original Tier 1 and new Tier 2 estimates; and

(6) Source-specific planned improvements.

For each source category, the main text describes the results of inventory compilation, the methodologies and key input data used. Details of data sources and methods used to calculate the key input data are given in the annexes.

2


ILRI/Zerihun Sewunet

Enteric fermentation (Category 3A1)

2. Enteric fermentation (Category 3A1)

2.1 Source category description

Emissions sources	Sources included	Method	Emission factors
3A1ai	Dairy cattle enteric fermentation	T2	CS
3A1aii	Other cattle enteric fermentation	T2	CS
3A1c	Sheep enteric fermentation	T2	CS
3A1d	Goat enteric fermentation	T2	CS
Gases reported	CH_4		
Completeness	All dairy cattle, other cattle, sheep and goats accounted for. No known omissions.		
Improvements since last submission	This is the first inventory for dairy and other cattle, sheep and goats that uses a Tier 2 approach.		

Methane is produced by ruminants in the digestive process of enteric fermentation. This is the first time Ethiopia has used a Tier 2 approach for enteric fermentation, which has been applied to dairy cattle, other cattle, sheep and goats. Using the Tier 2 approach, it is estimated that in 1994 CH_4 emissions amounted to 1,615.90 Gg CH_4 and increased to 3672.11 Gg CH_4 in 2018 (Table 1, Figure 1). This increase is due to both an increase in animal numbers and to changes in animal management and animal performance. In 2018, dairy cattle accounted for 2.87% of total enteric fermentation emissions, other cattle for 82.78%, sheep for 6.95% and goats for 7.40%. A comparison with the trend estimated using a Tier 1 approach is provided in Section 2.4. The atypical increase in enteric fermentation emissions in the year 2001 is due to an increase in populations of other cattle, sheep and goats in the official livestock population statistics for that year, and the subsequent decline is most likely due to drought conditions which reduced population numbers. Annex A1.5 compares the livestock population numbers used in this inventory with those of the Central Statistics Agency (CSA) of Ethiopia and those used in the SNC.

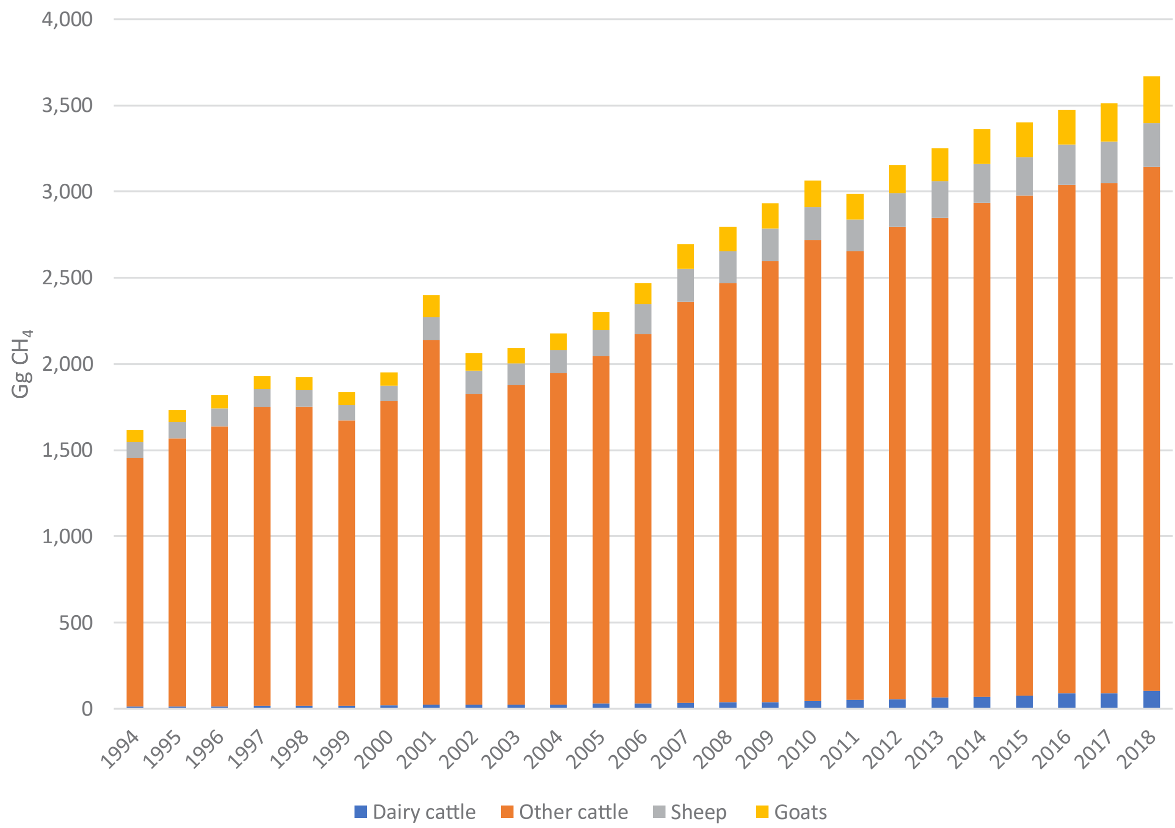

Figure 1. Trend in enteric fermentation emissions from cattle, sheep and goats, 1994-2018 (Gg CH_4)

Table 1. Enteric fermentation emissions from cattle, sheep and goats in different production systems, 1994-2018 (Gg CH_4)

Year	Commercial dairy cattle	Smallholder dairy cattle	Other cattle, Pastoral/ Agrop.	Other cattle, Mixed-crop	Sheep Mixed-crop	Sheep Pastoral/ Agrop.	Goats Mixed-crop	Goats Pastoral/ Agrop.	Total
1994	2.37	9.78	202.82	1238.99	79.98	14.59	47.32	20.06	1,615.90
1995	2.38	10.55	218.28	1335.87	80.07	15.16	47.06	20.79	1,730.17
1996	2.38	11.02	278.61	1345.01	81.07	25.09	44.32	32.35	1,820.06
1997	3.66	11.79	291.75	1440.21	80.88	24.90	44.55	32.42	1,930.36
1998	4.95	11.76	301.41	1433.88	73.76	24.81	40.70	32.35	1,923.69
1999	6.25	11.16	299.15	1356.02	66.08	25.69	36.68	33.52	1,834.82
2000	7.56	11.95	307.00	1455.72	69.07	24.25	41.13	34.16	1,950.89
2001	8.88	14.27	365.72	1750.79	103.83	28.79	76.16	50.12	2,398.56
2002	10.20	12.25	313.73	1489.31	102.10	31.84	70.84	32.38	2,062.64
2003	11.54	13.01	216.67	1636.68	104.27	20.07	62.09	27.75	2,092.07
2004	12.89	11.02	213.71	1709.67	114.94	18.36	67.35	28.92	2,176.89
2005	14.25	15.42	223.11	1790.73	134.00	19.59	77.45	26.64	2,301.19
2006	15.62	15.08	276.30	1866.63	149.58	25.46	83.05	38.93	2,470.82
2007	16.99	17.79	272.26	2054.38	162.41	30.22	99.46	39.98	2,693.50
2008	18.38	18.32	282.00	2151.13	154.39	29.97	99.76	41.46	2,795.42
2009	19.79	17.16	297.71	2261.27	159.56	31.52	99.08	45.16	2,931.32
2010	21.21	21.90	362.42	2312.55	154.18	38.94	97.48	54.86	3,063.72
2011	22.64	30.60	342.17	2259.16	143.66	40.83	93.13	55.72	2,988.50
2012	24.08	31.69	430.57	2309.33	150.89	44.04	96.95	67.84	3,155.50
2013	25.47	40.09	448.49	2335.68	154.76	55.18	105.17	86.15	3,251.00
2014	26.89	42.70	490.47	2374.92	169.32	57.84	109.27	90.44	3,361.89
2015	28.31	46.22	500.15	2403.00	165.42	56.35	111.61	90.14	3,401.21
2016	29.73	60.57	471.18	2476.99	176.76	56.41	115.29	87.13	3,474.26
2017	31.17	58.42	467.69	2491.23	177.23	63.20	124.79	97.24	3,510.90
2018	32.62	72.66	520.24	2517.44	171.78	83.16	121.75	149.85	3,672.11

2.2. Enteric fermentation by cattle

This section summarizes the main methods and data used in the Tier 2 inventory for enteric fermentation from dairy cattle and other cattle. Specific description of data sources and methods used in data compilation and analysis are given in the Annexes.

2.2.1 Emissions model and inventory structure

Enteric fermentation emissions have been estimated using the IPCC Tier 2 model (IPCC 2006, Vol 4, Ch 10, Equations 10.3-10.16). These equations were used to estimate emissions from 12 sub-categories of dairy cattle and 16 sub-categories of other cattle (Table 2). Animal sub-categories were defined based on IPCC (2006) guidelines on livestock characterization and the availability of IPCC default coefficients, and the sub-categories presented in annual agricultural sample surveys for livestock reported by the CSA of Ethiopia (CSA 1995-2018). Annex Table 1.2 shows the correspondence between the inventory categories, IPCC recommended categories and CSA categories.

For dairy cattle, two production systems have been identified: a smallholder dairy production system and a commercial dairy production system. CSA livestock surveys enumerate cattle by breed type (i.e. indigenous, hybrid, and pure exotic). Pure exotic breeds and hybrids are almost exclusively used for dairy production. The CSA annual livestock surveys only sample rural households. Therefore, this inventory identifies all hybrid and exotic cattle enumerated in the CSA annual livestock surveys as representing the smallholder dairy production system. CSA annual livestock surveys do not sample households in urban or peri-urban areas or on farms owned by companies. The commercial dairy production system is defined as consisting of dairy cattle in urban and peri-urban areas and on commercial farms. These included large, medium and small sized dairy farms located mainly in the proximity of Addis Ababa and regional towns and characterized by using improved shelters; having limited access to farming or grazing land, often based exclusively on stall feeding; and use of agro-industrial by-products and purchased roughage as feed resources (Tegegn et al. 2007). For both dairy production systems, cattle sub-categories include dairy cows as well as other classes of dairy cattle defined by age and sex (Table 2).

For other cattle, two production systems were identified based on differences in agroecology and management: the mixed crop-livestock system located in the highland areas, where rainfed agriculture dominates and cattle feed on communal grazing land and crop residues, and a pastoral/agropastoral system found in lowland grazing areas, where extensive grazing of natural pastures is the main source of feed. Mixed crop-livestock and pastoral/agro-pastoral zones were identified as shown in Table 3. Two classes of fattening cattle were identified: cattle in smallholder fattening operations and cattle in commercial feedlots. Smallholder fattening operations are run by farmers in the highland mixed crop-livestock system, and males 3-10 years of age are fattened based on green forage. Commercial feedlots are run by private commercial farmers or meat and live animal exporters in the highland areas. They purchase male cattle 3-10 years of age from lowland (pastoral/agro-pastoral) areas and use concentrate and agro-industrial by-products as the main feed.

Table 2. Cattle sub-categories

Dual purpose cattle	**Mixed crop livestock system**	Adult multipurpose cows >3 years
		Adult males used for draught (3-10 years)
		Adult males used for breeding & other purpose (>3-10 years)
		Calves < 6 months (male & female)
		Calves 6 m-<1 year (male & female)
		Growing males 1-<3 years
		Growing females 1-<3 years
		Smallholder fattening cattle (male 3-10 years)
		Commercial feedlot-fed cattle (male 3-10 years)
	Pastoral and agropastoral system	Adult multipurpose cows >3 years
		Adult males used for draught (3-10 years)
		Adult males used for breeding & other purpose (>3-10 years)
		Calves < 6 months (male & female)
		Calves 6 m-<1 year (male & female)
		Growing males 1-<3 years
		Growing females 1-<3 years

Dairy cattle	Commercial intensive system	Adult crossbred & pure exotic dairy cows (3-10 years)
		Adult crossbred & pure exotic males 3 years & above
		Pure exotic calves (<6 months) male & female
		Crossbred & pure exotic calves (6 m - < 1 yr) male & female
		Crossbred & pure exotic growing males (1 - < 3 years)
		Crossbred & pure exotic growing females (1 -< 3 years)
	Smallholder intensive system	Adult crossbred & pure exotic dairy cows (3-10 & above years)
		Adult crossbred & pure exotic males (3 & above years)
		Crossbred & pure exotic calves (<6 months) male & female
		Crossbred & pure exotic calves (6 m - < 1 yr) male & female
		Crossbred & pure exotic growing males (1 - < 3 years)
		Crossbred & pure exotic growing females (1 -< 3 years)

Table 3. Zones in the mixed crop-livestock and pastoral/agro-pastoral systems

Region	Zones in the pastoral / agro-pastoral production system	Zones in the mixed crop livestock production system
Tigray	West Tigray	North West Tigray, Central Tigray, East Tigray, South Tigray
Afar	All zones	
Ahmara		North Gonder, South Gonder, North Wello, South Wello, North Shewa, East Gojam, West Gojam, Waghmera, Awi, Oromia and Argoba Special Woreda
Oromia	Borena	West Wellega, East Wellega, Illubaabor, Jima, West Shewa, East Shewa, North Shewa, Arsi, West Hararghe, East Hararghe, Bale, South West Shewa, Guji. West Arsi, Kelem Wellega and Horroguduru Wellega
Somali	All zones	
B/Gumuz	Metekel	Asosa, Kemeshi, Pawi Special Woreda, Mao Kpmo
SNNP	South Omo	Gurage, Hadiya, Kembata Tembaro, Sedama, Gedio, Walayta, Shaka, Kaffa, Gamo Goffa, Bench Maji, Yem Special Woreda, Amaro Special Woreda, Burji Special Woreda, Konso Special Woreda, Derashe Special Woreda, Dawero, Basketo Special Woreda, Konta Special Woreda, Silite and Alaba Special Woreda
Gambella	Angnuwak, Nuwar, Mezhenger and Itang Special Woreda	
Harari		Hundene
Dire Dawa		Dire Dawa
Addis Ababa		Addis Ababa

2.2.2 Cattle populations

The primary data source for cattle populations in the smallholder dairy, mixed crop-livestock and pastoral/agro-pastoral production systems is CSA annual livestock sample survey reports. This time series of cattle population data is available by age, sex, purpose and breed at national, region and zone levels. Annex 1 describes the data sources and methods used to estimate cattle populations based on the CSA sample survey data. CSA sample surveys do not enumerate cattle in the commercial dairy production system, so research surveys and other data sources and assumptions described in Annex 1.1 were used to estimate a time series for the commercial dairy cattle population.

The total cattle population is estimated to have increased from 30.32 million head in 1994 to 65.63 million head in 2018 (Figure 2). This represents an increase of 116% since 1994. For 2018, dairy cattle are estimated to account for 2.87% of the total cattle population, with 0.62 million dairy cattle in the commercial production system and 1.27 million dairy cattle in the smallholder production system. The mixed crop-livestock production system (53.3 million head) accounts for 81.25% of the total cattle population, or 83.66% of all dual purpose (other) cattle. The pastoral/agro-pastoral production system (10.4 million head) is estimated to account for 15.87% of the total national cattle population or 16.34% of all dual purpose (other) cattle. These figures differ from some other estimates suggesting that pastoral livestock account for about 30% of the total cattle population. Since this inventory allocated all woredas to either the mixed crop-livestock or pastoral/agro-pastoral production systems, some districts or kebeles with pastoral cattle populations may have been wrongly allocated to the mixed crop-livestock system. However, since woreda level data was not available throughout the country, it is not possible with currently available data to improve these estimates. The inventory's total population figures also differ from the cattle populations estimated in annual CSA livestock sample survey reports because the cattle population in this inventory includes (a) the estimated cattle population in pastoral/agro-pastoral zones of Afar and Somali Regions that have not been enumerated in the CSA surveys, which are estimated at 3.45 million cattle in 2018, and (b) dairy cattle in the commercial production system, which are estimated at 0.62 million dairy cattle in 2018. The data and methods used to estimate these populations are described in Annex 1. The population numbers in each production system are presented in Table 4 and Table 5.

In general, there has been an increasing trend in livestock population from 1994 to 2018. This increase is partly due to increased human population, as historical data from CSA indicate a positive correlation between human population growth and the livestock population growth rate. The increase from the mid-1990s to 2001 may be related to improved conditions for livestock raising after regime transition in 1991, which encouraged more farmers to engage in livestock production. The atypical increase in cattle numbers for the year 2001 is due to the reported cattle numbers in the CSA annual livestock survey report for that year, and the subsequent decline is most likely due to drought conditions which reduced population numbers. Annex A1.5 compares the livestock population numbers used in this inventory with those of CSA and those used in the SNC. The decline after 2001-2002 and the slower growth rate in cattle population between 2002-2006 is most likely related to droughts, which affected the north, central, west, and southwest parts of the country (Liou et al. 2019). The increase in cattle population since 2015 may also be related to increased demand for animal source food products (Abegaz et al. 2018).

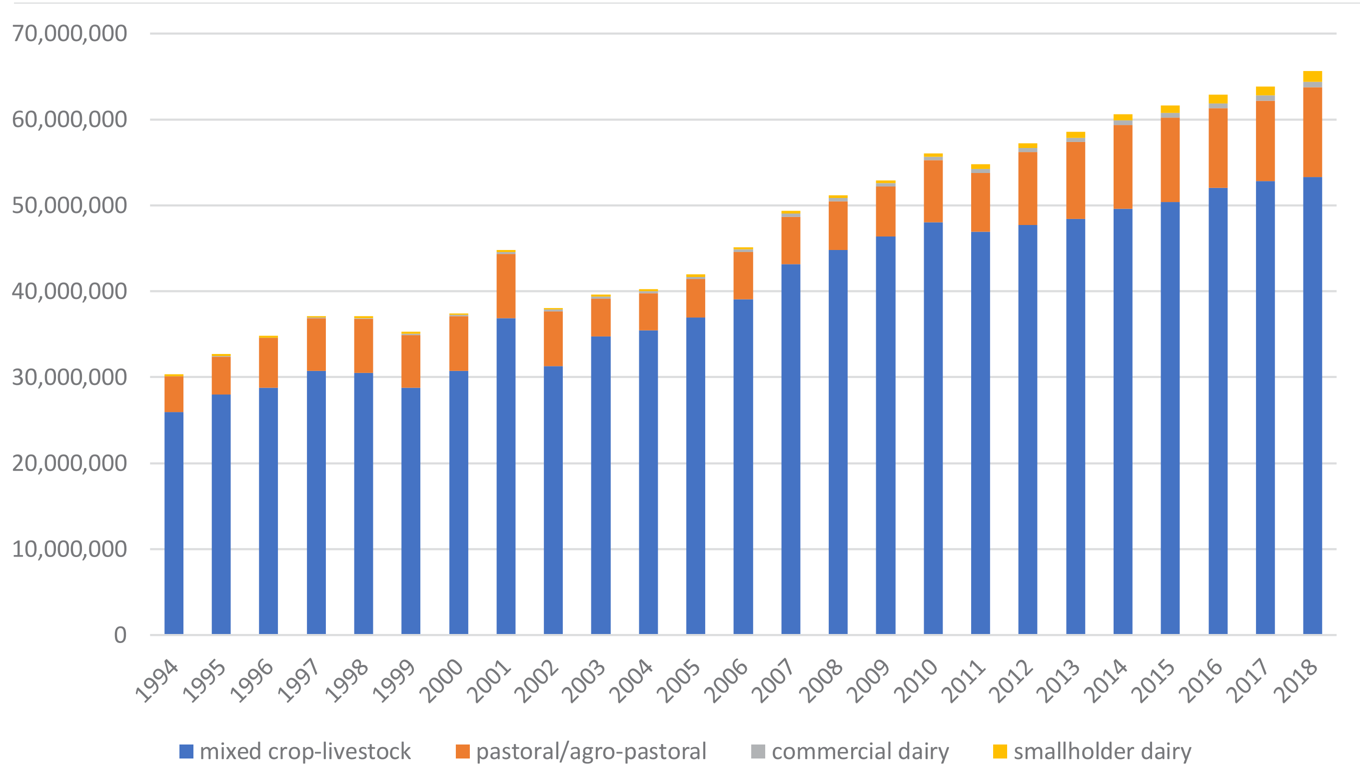

Figure 2. Population structure for dairy and other cattle in Ethiopia, 1994-2018 (head)

Table 4. Time series for dairy cattle sub-category populations, 1994-2018 (head)

Year	Commercial dairy production system						Smallholder dairy production system					
	Adult cows >3 years	Adult males (3-10 years)	Calves < 6 months (male & female)	Calves 6 m-1 year (male & female)	Growing males 1-3 years	Growing females 1-3 years	Adult cows >3 years	Adult males used for breeding (3-10 years)	Calves < 6 months (male & female)	Calves 6 m-1 year (male & female)	Growing males 1-3 years	Growing females 1-3 years
1994	24,721	911	2,497	7,030	1,101	12,318	109,219	7,815	14,885	14,885	1,675	37,585
1995	24,721	911	2,497	7,030	1,101	12,318	117,418	8,401	16,002	16,002	1,800	40,406
1996	24,721	911	2,497	7,030	1,101	12,318	122,179	8,742	16,651	16,651	1,873	42,045
1997	37,865	1,396	3,825	10,768	1,687	18,867	130,322	9,325	17,761	17,761	1,998	44,847
1998	51,009	1,881	5,153	14,506	2,273	25,416	129,452	9,262	17,642	17,642	1,985	44,547
1999	64,154	2,365	6,481	18,245	2,858	31,966	122,459	8,762	16,690	16,690	1,878	42,141
2000	77,298	2,850	7,809	21,983	3,444	38,515	130,674	9,350	17,809	17,809	2,004	44,968
2001	90,442	3,335	9,136	25,721	4,029	45,065	155,456	11,123	21,186	21,186	2,383	53,496
2002	103,587	3,819	10,464	29,459	4,615	51,614	132,887	9,508	18,111	18,111	2,037	45,730
2003	116,731	4,304	11,792	33,197	5,200	58,164	140,559	10,057	19,156	19,156	2,155	48,369
2004	129,875	4,789	13,120	36,935	5,786	64,713	118,608	8,486	16,165	16,165	1,819	40,816
2005	143,019	5,273	14,448	40,673	6,372	71,262	165,315	11,828	22,530	22,530	2,535	56,889
2006	156,164	5,758	15,776	44,411	6,957	77,812	161,019	11,521	21,945	21,945	2,469	55,410
2007	169,308	6,242	17,103	48,149	7,543	84,361	189,345	13,548	25,805	25,805	2,903	65,158
2008	182,452	6,727	18,431	51,887	8,128	90,911	194,162	13,892	26,462	26,462	2,977	66,816
2009	195,597	7,212	19,759	55,625	8,714	97,460	181,046	12,954	24,674	24,674	2,776	62,302
2010	208,741	7,696	21,087	59,364	9,300	104,009	230,052	16,460	31,353	31,353	3,527	79,166
2011	221,885	8,181	22,415	63,102	9,885	110,559	319,853	22,886	43,592	43,592	4,904	110,069
2012	235,030	8,666	23,743	66,840	10,471	117,108	329,920	23,606	44,964	44,964	5,058	113,533
2013	248,174	9,150	25,070	70,578	11,056	123,658	416,560	29,805	56,771	56,771	6,387	143,348
2014	261,318	9,635	26,398	74,316	11,642	130,207	442,552	31,665	60,314	60,314	6,785	152,292
2015	274,462	10,120	27,726	78,054	12,228	136,756	477,893	34,193	65,130	65,130	7,327	164,454
2016	287,607	10,604	29,054	81,792	12,813	143,306	624,702	44,698	85,138	85,138	9,578	214,974
2017	300,751	11,089	30,382	85,530	13,399	149,855	601,000	43,002	81,908	81,908	9,215	206,818
2018	313,895	11,574	31,710	89,268	13,984	156,405	745,527	53,343	101,605	101,605	11,431	256,553

Source: Annex 1 (Table A1.3, Table A1.6)

Table 5. Time series for other cattle sub-category populations, 1994-2018 (head)

	Pastoral and agro-pastoral system							Mixed crop-livestock system								
Year	Adult multipurpose cows >3 years	Adult males used for draught (3-10 years)	Adult males used for breeding & other purpose (>3-10 years)	Calves < 6 months (male & female)	Calves 6 m-<1 year (male & female)	Growing males 1-<3 years	Growing females 1-<3 years	Adult multipurpose cows >3 years	Adult males used for draught (3-10 years)	Adult males used for breeding & other purpose (>3-10 years)	Calves < 6 months (male & female)	Calves 6 m-<1 year (male & female)	Growing males 1-<3 years	Growing females 1-<3 years	Smallholder fattening male	Commercial feedlot fed male
1994	1,596,461	569,432	263,184	430,810	450,072	342,603	458,347	9,410,789	7,172,757	781,607	1,966,700	1,920,718	2,067,589	2,482,640	163,829	277
1995	1,717,453	612,793	283,368	463,573	484,330	368,824	493,313	10,148,028	7,734,400	842,834	2,120,745	2,071,162	2,229,491	2,677,158	176,658	449
1996	2,261,400	671,969	340,841	687,444	708,954	440,802	707,606	10,104,145	7,788,235	819,072	2,471,083	2,468,399	2,254,883	2,677,089	183,073	793
1997	2,359,148	699,805	357,973	720,886	743,699	462,092	743,050	10,803,558	8,327,100	875,765	2,641,854	2,639,229	2,410,902	2,862,423	195,740	1,137
1998	2,433,531	709,626	371,825	740,824	760,956	477,064	764,327	10,718,805	8,261,890	868,897	2,621,388	2,618,540	2,392,020	2,839,956	194,207	2,288
1999	2,413,050	706,779	363,562	726,947	746,295	468,361	747,859	10,101,392	7,786,352	818,852	2,470,443	2,467,760	2,254,333	2,676,336	183,029	995
2000	2,457,165	716,614	375,279	747,785	768,093	481,554	771,443	10,806,606	8,329,690	876,015	2,642,878	2,640,007	2,411,647	2,863,206	195,801	23
2001	2,911,852	848,357	446,138	888,267	912,502	571,956	916,962	12,952,743	9,983,033	1,049,977	3,167,615	3,164,174	2,890,347	3,431,916	234,665	494
2002	2,488,990	725,696	380,466	757,956	778,567	488,089	782,073	10,979,960	8,463,399	890,069	2,685,286	2,682,369	2,450,357	2,909,127	198,944	366
2003	1,867,159	481,507	204,868	608,291	499,929	287,619	493,654	12,581,688	8,855,742	1,016,146	3,299,433	2,878,468	2,682,541	3,229,619	193,274	693
2004	1,892,157	476,142	203,634	608,971	454,818	275,767	424,790	13,199,126	9,199,569	1,170,368	3,144,466	2,555,815	2,705,093	3,289,759	168,840	29,931
2005	1,935,648	485,660	240,703	619,150	464,660	293,620	438,206	13,630,722	9,834,796	1,265,187	3,356,053	2,816,924	2,575,086	3,135,648	193,147	133,837
2006	2,445,034	555,398	332,869	707,874	557,130	336,405	560,392	14,293,293	10,145,736	1,423,039	3,673,811	3,180,492	2,714,721	3,256,384	210,210	173,136
2007	2,378,464	528,907	335,252	779,529	591,685	358,355	539,202	15,774,980	10,990,446	1,515,686	4,006,531	3,658,658	3,151,044	3,770,755	277,636	29,695
2008	2,498,951	567,639	306,436	725,988	645,960	341,975	626,716	16,409,292	11,850,688	1,474,993	3,788,055	3,614,274	3,290,423	4,016,176	307,175	36,125
2009	2,609,230	565,399	339,541	706,715	640,358	353,222	631,658	16,710,463	12,256,971	1,901,663	4,496,546	3,367,686	3,250,839	4,048,244	279,146	45,707
2010	3,234,130	639,367	501,944	899,766	767,179	399,205	759,137	17,351,193	12,824,183	1,726,265	4,295,911	4,091,742	3,297,790	4,029,659	316,037	94,982
2011	3,035,535	622,598	436,716	867,627	728,078	416,816	749,745	17,201,258	12,293,382	1,439,146	4,213,249	3,881,161	3,411,446	3,959,835	361,332	172,205
2012	3,827,822	754,514	618,906	1,112,628	795,100	475,219	895,213	17,271,523	12,599,175	1,510,018	4,499,643	3,539,053	3,607,165	4,186,875	310,861	205,357
2013	4,188,434	785,683	480,342	1,176,692	930,274	502,432	866,844	17,337,370	12,914,533	1,572,693	4,437,360	3,701,625	3,721,256	4,214,737	340,815	209,744
2014	4,487,769	886,630	521,888	1,217,349	1,006,685	587,867	1,067,926	17,623,069	13,412,696	1,350,898	4,445,478	4,049,615	3,782,925	4,404,473	341,382	187,884
2015	4,718,866	801,304	731,985	1,154,372	977,554	528,436	902,135	17,781,149	13,661,066	1,356,050	4,330,519	4,493,611	3,840,318	4,470,826	354,737	142,242

2016	4,323,830	761,386	769,972	1,132,337	1,012,978	486,094	797,471	18,214,107	14,021,581	1,328,390	4,873,139	4,279,567	4,031,964	4,780,061	367,643	118,947
2017	4,282,365	792,776	751,564	1,160,170	1,033,077	506,341	825,997	18,191,910	14,739,174	1,189,667	4,607,645	4,639,607	4,184,838	4,858,034	377,322	66,858
2018	5,008,576	714,204	811,916	1,557,763	988,751	563,201	774,502	18,441,578	14,084,884	1,317,570	4,850,822	4,796,151	4,280,050	5,085,071	461,414	7,707

Source: Annex 1 (Table A1.8)

2.2.3 Net energy for maintenance (NE_m)

Net energy for maintenance (NE_m) for cattle was calculated following IPCC (2006) Equation 10.3:

$NE_{m,i} = Cf_{,i} * (Weight_j)^{0.75}$

where:

$NE_{m,i}$ is net energy for maintenance for cattle of type *i* (MJ head^{-1} day^{-1})

Cf_i is coefficient for calculating NE_m for cattle type *i*

$Weight_i$ is live weight of cattle of type *i* (kg).

IPCC 2006 Table 10.4 gives default values for Cf_i for lactating cows (0.386), non-lactating cows (0.322) and bulls (0.370). The default value of Cf_i for lactating cows refers to net energy for maintenance during lactation. Lactation duration in Ethiopia is often lower than 365 days. Country-specific values for Cf_i were calculated for dairy cows and dual purpose cows to take into account the proportion of days in the year cows are lactating and the proportion of cows lactating. Lactation length for dairy cows was estimated at 325 days (Annex A3.1) and for other cows at 248 days (Annex 3.2). The proportion of dairy cows giving birth in each year was estimated as 71.9% and this value was applied in all years in the inventory (Annex 3.1). Calving rates for other cows were estimated using annual CSA survey reports and other assumptions (Annex 3.2) and varied between 32.6% and 63.1% (Table 13). The time series for the coefficient for maintenance for cows in different production systems are shown in Table 6. For calves < 6 months and calves 6 months – 1 year, in the commercial and smallholder dairy systems, the value of Cf_i used was the simple average of the values for males (0.370) and females (0.322), which is 0.346. In the mixed crop-livestock and pastoral/agro-pastoral systems, the populations of calves in each age class by sex was taken from CSA annual agricultural sample surveys and used to estimate the population-weighted averages for males (0.370) and females (0.322), as shown in Table 6. The values used for other cattle sub-categories are shown in Table 7.

Table 6. Coefficient for maintenance values for dairy, other cows and calves, 1994-2018

Year	Commercial dairy cows	Smallholder dairy cows	Other cows, mixed crop-livestock system	Other cows, pastoral / agro-pastoral system	Calves, <6 m, mixed crop-livestock & pastoral/agro-pastoral systems	Calves 6m-1yr, mixed crop-livestock & pastoral/agro-pastoral systems
1994	0.363	0.363	0.336	0.336	0.345	0.345
1995	0.363	0.363	0.336	0.336	0.345	0.345
1996	0.363	0.363	0.337	0.337	0.344	0.344
1997	0.363	0.363	0.337	0.337	0.344	0.344
1998	0.363	0.363	0.338	0.338	0.344	0.344
1999	0.363	0.363	0.340	0.340	0.344	0.344
2000	0.363	0.363	0.341	0.341	0.344	0.344
2001	0.363	0.363	0.342	0.342	0.344	0.344
2002	0.363	0.363	0.343	0.343	0.344	0.344
2003	0.363	0.363	0.345	0.345	0.345	0.345
2004	0.363	0.363	0.345	0.345	0.345	0.345
2005	0.363	0.363	0.346	0.346	0.345	0.345
2006	0.363	0.363	0.346	0.346	0.345	0.345
2007	0.363	0.363	0.346	0.346	0.345	0.345
2008	0.363	0.363	0.345	0.345	0.345	0.345
2009	0.363	0.363	0.349	0.349	0.345	0.345
2010	0.363	0.363	0.346	0.346	0.345	0.344
2011	0.363	0.363	0.346	0.346	0.345	0.345
2012	0.363	0.363	0.348	0.348	0.345	0.345
2013	0.363	0.363	0.347	0.347	0.345	0.345
2014	0.363	0.363	0.346	0.346	0.345	0.345
2015	0.363	0.363	0.346	0.346	0.345	0.345
2016	0.363	0.363	0.347	0.347	0.345	0.344
2017	0.363	0.363	0.345	0.345	0.345	0.345
2018	0.363	0.363	0.347	0.347	0.345	0.345

Table 7. Coefficient for maintenance values for cattle sub-categories not including cows

System	Sub-category	C_{fi}
Mixed crop livestock system	Adult males used for draught (3-10 years)	0.322
	Adult males used for breeding & other purpose (>3-10 years)	0.370
	Growing males 1-3 years	0.370
	Growing females 1-3 years	0.322
	Smallholder fattening cattle (male 3-10 years)	0.322
	Commercial feedlot-fed cattle (male 3-10 years)	0.322
Pastoral and agropastoral system	Adult males used for draught (3-10 years)	0.322
	Adult males used for breeding & other purpose (>3-10 years)	0.370
	Growing males 1-3 years	0.370
	Growing females 1-3 years	0.322
Commercial intensive system	Adult crossbred & pure exotic males 3-10 years	0.370
	Pure exotic calves (<6 months) male & female	0.346
	Crossbred & pure exotic calves (6 m - < 1 yr) male & female	0.346
	Crossbred & pure exotic growing males (1 - < 3 years)	0.370
	Crossbred & pure exotic growing females (1 -< 3 years)	0.322
Smallholder intensive system	Adult crossbred & pure exotic males 3-10 * above years	0.370
	Crossbred & pure exotic calves (<6 months) male & female	0.346
	Crossbred & pure exotic calves (6 m - < 1 yr) male & female	0.346
	Crossbred & pure exotic growing males (1 - < 3 years)	0.370
	Crossbred & pure exotic growing females (1 -< 3 years)	0.322

The LW of each sub-category of cattle was estimated using sources and methods described in Annex 2. For each dairy and other cattle sub-category, the same value for LW was used in each inventory year. The values used are shown in Table 8. For dairy cows, the LW values used in this inventory are significantly higher than those estimated for dairy cattle in Africa in IPCC (2019). For other cows, the values used in the inventory are lower than the IPCC (2019) default values for mature cows grazing pasture and slightly higher than the default value for other cows grazing extensive range. The values for adult and growing males are lower than the IPCC (2019) default values. Although there is some difference with the IPCC default values, the values used in this inventory derive from a review of literature reporting measurements in each production system in Ethiopia, whereas the IPCC default assumptions refer to general values applicable at the continental level and the data sources underlying these assumptions are not known.

Table 8. Live weight (kg) values for dairy and other cattle sub-categories

System	Sub-category	Live weight (kg)
Mixed crop livestock system	Adult multipurpose cows >3 years	285.8
	Adult males used for draught (3-10 years)	342.8
	Adult males used for breeding & other purpose (>3-10 years)	342.8
	Calves < 6 months (male & female)	53.8
	Calves 6 m-1 year (male & female)	105.5
	Growing males 1-3 years	226.9
	Growing females 1-3 years	181.4
	Smallholder fattening cattle (male 3-10 years)	281.2
	Commercial feedlot-fed cattle (male 3-10 years)	281.3

Pastoral and agropastoral system	Adult multipurpose cows >3 years	295.0
	Adult males used for draught (3-10 years)	339.8
	Adult males used for breeding & other purpose (>3-10 years)	339.8
	Calves < 6 months (male & female)	58.8
	Calves 6 m-1 year (male & female)	117.0
	Growing males 1-3 years	225.1
	Growing females 1-3 years	190.2
Commercial intensive system	Adult crossbred & pure exotic dairy cows (3-10 years)	428.6
	Adult crossbred & pure exotic males 3-10 years	418.5
	Pure exotic calves (<6 months) male & female	60.0
	Crossbred & pure exotic calves (6 m - < 1 yr) male & female	117.6
	Crossbred & pure exotic growing males (1 - < 3 years)	261.0
	Crossbred & pure exotic growing females (1 -< 3 years)	261.0
Smallholder intensive system	Adult crossbred & pure exotic dairy cows (3-10 & above years)	428.6
	Adult crossbred & pure exotic males 3-10 * above years	418.5
	Crossbred & pure exotic calves (<6 months) male & female	60.0
	Crossbred & pure exotic calves (6 m - < 1 yr) male & female	117.6
	Crossbred & pure exotic growing males (1 - < 3 years)	261.0
	Crossbred & pure exotic growing females (1 -< 3 years)	261.0

Source: Annex 2 (Table A2.1a; A2.2a; A2.2b)

2.2.4 Net energy for activity (NE_a)

NE_a was calculated using IPCC (2006) Equation 10.4:

$$NE_a = C_a \bullet NE_m$$

where

NE_a is net energy for animal activity, MJ day^{-1}

C_a is a coefficient corresponding to the animal's feeding situation MJ day^{-1} kg^{-1}

NE_m is net energy for maintenance for dairy cattle (MJ head^{-1} day^{-1}) as determined above.

IPCC (2006) Table 10.5 gives default values for C_a for animals that are stall-fed (0.00), that graze pasture (0.17) and that graze large areas or hilly terrain (0.36). For all smallholder and commercial dairy cattle sub-categories, the inventory assumes that all cattle are stall-fed, which is consistent with the assumptions on diet composition and manure management used in this initial inventory. For all pastoral/agro-pastoral cattle sub-categories, the inventory uses the IPCC default value of 0.36. For all mixed crop-livestock system cattle sub-categories, the inventory uses the IPCC default value of 0.17. For cattle in smallholder fattening operations, the value of C_a is the average weighted by the time spent in feedlots (3.5 months, C_a=0) and on farm in the mixed crop-livestock system (8.5 months, C_a=0.17). For commercial feedlot, the value of C_a is the weighted average of time in the feedlot (3 months, C_a=0) and time in the pastoral/agro-pastoral system (9 months, C_a=0.36) since commercial feedlots mainly source from pastoral/agro-pastoral areas. The country-specific values of C_a are shown in Table 9.

Table 9. Country-specific coefficients for activity (C_a) used in the inventory

Cattle sub-category	C_a
Smallholder fattening	0.120
Commercial feedlot	0.270

2.2.5 Net energy for growth (NE_g)

NE_g was calculated using IPCC (2006) Equation 10.6:

$$NE_g = 22.02 \times \left(\frac{BW}{C \times MW}\right)^{0.75} \times WG^{1.097}$$

where

BW is average live weight (kg head^{-1});

C is a coefficient with a value of 0.8 for females, 1.0 for castrates and 1.2 for bulls. For sub-categories that include both male and female cattle (e.g. calves of different age classes), in the commercial and smallholder dairy systems, the simple average of the values for intact males and females was used (i.e. 1.0), and in the mixed crop-livestock and pastoral/agro-pastoral systems, the population-weighted average of females (0.8) and intact males (1.2) was used, which ranged between 0.97 and 1.0 in different years. The populations of male and female calves in each age class were taken from CSA annual agricultural sample survey reports.

MW is the mature live body weight of an adult animal in moderate body condition, kg

WG is the average daily weight gain of cattle in each sub-category, kg day^{-1}.

The inventory used the LW values shown in Table 8. Weight gain per day was calculated as the change in weight between the median age of each adjacent age class divided by the number of days between the median ages. The weight gain values used are shown in Table 10. The weight gain estimates for calf sub-categories are close to the IPCC (2019) default value (i.e. 0.33 kg day^{-1}), but the estimates for growing cattle types are lower than the IPCC (2019) default value (i.e. 0.24 kg day^{-1}). The weight gain values used in this inventory derive from a review of literature reporting LW measurements at different ages in each production system in Ethiopia, whereas the IPCC default assumptions refer to general values applicable at the continental level and the data sour^c^es underlying these assumptions are not known.

Table 10. Average daily weight gain (kg day^{-1}) values used for different cattle sub-categories

	Commercial dairy	Smallholder dairy	Mixed crop livestock other cattle	Pastoral/agro-pastoral other cattle
Cows	0	0	0	0
Adult males	0	0	0	0
Calves < 6 months	0.340	0.340	0.362	0.402
Calves 6 m – <1 year	0.300	0.300	0.213	0.298
Growing males	0.254	0.254	0.202	0.186
Growing females	0.263	0.263	0.149	0.144

Source: Annex 2 (Table A2.1a, Table A2.2a, Table A2.2b)

2.2.6 Net energy for lactation (NE_l)

NE_l was calculated using IPCC (2006) Equation 10.8:

$NE_l = Milk \times (1.47 + 0.40 \times Fat)$

Where

NE_l is net energy for lactation, MJ day^{-1}

Milk is amount of milk produced, kg of milk day^{-1}, and

Fat is fat content of milk, % by weight.

In the IPCC equations, milk yield is expressed in kg $head^{-1}$ day^{-1} over 365 days. For the commercial and smallholder intensive dairy production systems, milk yield was estimated using methods and data sources described in Annex A3.1.2. The milk yield estimates consider reported milk off-take, length of lactation and proportion of cows lactating, as well as estimated calf suckling. For other cattle in the mixed crop-livestock system and the pastoral/agro-pastoral system, milk yield was estimated using methods and data sources described in Annex A3.2.2.

CSA annual agricultural sample survey reports were the main source of data on milk yields used for the mixed crop-livestock and pastoral/agro-pastoral systems, but the inventory time series differs from the CSA reported milk yields because the inventory estimates consider reported milk off-take (i.e. CSA data), length of lactation estimated using different sources from that reported in CSA, as well as the proportion of cows lactating and estimated milk consumption by suckling calves.

For the smallholder and commercial dairy production systems, milk yields were estimated using literature reports, considering milk off-take, length of lactation, the proportion of cows lactating and estimated milk consumption by suckling calves. CSA annual livestock sample survey reports do not separately report the milk yield of exotic or hybrid cattle in the smallholder dairy production system, and available literature reports are for urban/peri-urban farms in the commercial production system. The breeds used in smallholder and commercial dairy production systems are very similar. Therefore, literature reports cited in Table A3.1b from urban/peri-urban farms were used to estimate milk yield for both the smallholder and commercial dairy production systems.

The resulting trends in average milk yields for lactating cows in each production system are shown in Table 11. For milk fat content, a default value of 4% was used (IPCC 2006). For most of the time series, the estimated milk yields for other cows are slightly lower than the IPCC (2019) default value for low productivity systems in Africa (i.e. 1.2 kg), and lower values in the time series reflect the low estimated proportions of cows giving birth, particularly from 1994-2002. For dairy cows, the estimated yields are higher than the IPCC (2019) default estimate for high productivity systems in Africa (i.e. 2.9 kg), which assumed cows with lower LW (i.e. 390 kg). Since a positive correlation can be expected between LW and milk yield, the higher dairy cow milk yield estimates in this inventory are consistent with the higher LW in this inventory.

Table 11. Average milk yields for cows in each production system, 1994-2018 (kg head^{-1} day^{-1})

Year	Commercial dairy cows	Smallholder dairy cows	Mixed crop livestock other cows	Pastoral/agro-pastoral other cows
1994	4.54	4.54	0.56	0.62
1995	4.61	4.61	0.57	0.62
1996	4.68	4.68	0.58	0.64
1997	4.76	4.76	0.60	0.66
1998	4.84	4.84	0.65	0.71
1999	4.92	4.92	0.70	0.77
2000	5.00	5.00	0.75	0.82
2001	5.08	5.08	0.80	0.88
2002	5.17	5.17	0.84	0.93
2003	5.25	5.25	0.90	0.97
2004	5.34	5.34	0.91	0.99
2005	5.43	5.43	0.97	1.11
2006	5.52	5.52	0.96	1.04
2007	5.61	5.61	0.95	1.08
2008	5.70	5.70	0.90	0.98
2009	5.80	5.80	1.15	1.19
2010	5.90	5.90	0.98	1.08
2011	6.00	6.00	0.98	1.02
2012	6.10	6.10	1.01	1.12
2013	6.15	6.15	1.01	1.08
2014	6.21	6.21	0.95	1.04
2015	6.27	6.27	0.93	0.99
2016	6.33	6.33	0.98	1.05
2017	6.38	6.38	0.90	0.97
2018	6.44	6.44	0.96	1.06

Source: Annex 3 (Table 3.1c; Table 3.2c)

2.2.7 Net energy for pregnancy (NE_p)

NE_p was calculated using IPCC (2006) Equation 10.13:

$NE_p = C_{pregnancy} \times NE_m$

where $C_{pregnancy}$ is a coefficient with a value of 0.1.

$C_{pregnancy}$ was applied to the proportion of cows giving birth in the year (see Annex 1.3), the values of which are shown in Table 12. The proportions of cows giving birth in the commercial and smallholder dairy systems were estimated using methods and data sources described in Annex A3.1.1, and a constant value of 0.719 was used. For cows in the mixed crop-livestock and pastoral/agro-pastoral systems, the proportion of cows giving birth in the year was estimated using methods described in Annex A3.2.1, which used the ratio of calves to cows in milk reported in CSA data together with an estimate of calf mortality to estimate the proportion of cows giving birth in the year. For the commercial and smallholder dairy production systems, the estimated calving rate is higher than the IPCC (2019) default value for high productivity systems in Africa (i.e., 65%). The higher calving rate is consistent with higher milk yield and LW assumed in this inventory, which together suggest that dairy cattle in Ethiopia have better performance than assumed in the IPCC Guidelines. For other cows, the average proportion in the time series (i.e., 48.9%) is lower than the IPCC (2019) default value for low productivity systems in Africa (i.e., 54%), which may reflect the lower quality feed assumed in this inventory compared to the IPCC (2019) assumptions.

Table 12. Proportions of cows giving birth, 1994-2018

Year	Commercial dairy	Smallholder dairy	Mixed crop livestock other cows	Pastoral/agro-pastoral other cows
1994	71.9%	71.9%	32.6%	32.6%
1995	71.9%	71.9%	33.0%	33.0%
1996	71.9%	71.9%	33.7%	33.7%
1997	71.9%	71.9%	35.1%	35.1%
1998	71.9%	71.9%	37.9%	37.9%
1999	71.9%	71.9%	40.7%	40.7%
2000	71.9%	71.9%	43.5%	43.5%
2001	71.9%	71.9%	46.3%	46.3%
2002	71.9%	71.9%	49.1%	49.1%
2003	71.9%	71.9%	51.9%	51.9%
2004	71.9%	71.9%	53.9%	53.9%
2005	71.9%	71.9%	56.2%	56.2%
2006	71.9%	71.9%	55.4%	55.4%
2007	71.9%	71.9%	55.8%	55.8%
2008	71.9%	71.9%	52.6%	52.6%
2009	71.9%	71.9%	63.1%	63.1%
2010	71.9%	71.9%	55.9%	55.9%
2011	71.9%	71.9%	54.9%	54.9%
2012	71.9%	71.9%	59.2%	59.2%
2013	71.9%	71.9%	58.5%	58.5%
2014	71.9%	71.9%	55.6%	55.6%
2015	71.9%	71.9%	54.1%	54.1%
2016	71.9%	71.9%	57.7%	57.7%
2017	71.9%	71.9%	52.7%	52.7%
2018	71.9%	71.9%	56.5%	56.5%

Source: Annex 3 (Table A3.1a, Table A3.2a)

2.2.8 Net energy for work (NE_{work})

NE_{work} was calculated using IPCC (2006) Equation 10.9:

$NE_{work} = 0.10 \text{ X } NE_m \text{ X } Hours$

where

NE_{work} is net energy for work, MJ day^{-1} and

Hours is the average number of hours of work per calendar day.

For 2018, the estimate of work hours is taken from Holeta Agricultural Research Center (2019). In the mixed crop-livestock system and pastoral/agro-pastoral system, oxen are assumed to plow for 2 months of the year (not including Sundays) and 6 hours per day, making an annual daily average of 0.85 hours, and thresh for 1 month (not including Sundays) and 6 hours per day, making an annual daily average of 0.43 hours, with a grand total of 1.28 hours per calendar day. For 1994, a report cited in Wilson (2003) was taken that indicated oxen work for 1.66 hours per calendar day, i.e. 30% higher than in 2018. Work hours for 1995-2017 were linearly interpolated between these two values. The reasons for the decrease in oxen work hours are: (a) in the 1990s, farms in the highlands used to cultivate crops in both the main rainy season (June-July) and a short rainy season (February-March), but the short rainy season is now unreliable and cultivation in these months is no longer common; (b) livestock numbers have increased more rapidly than cultivated area and yield, so work hours per animal have decreased; and (c) in some areas, mechanization has increased over time.

Other sub-categories above 1 year of age in the smallholder dairy system (except dairy cows), mixed crop-livestock system and pastoral/agro-pastoral system are used for threshing. Holeta Agricultural Research Center (2019) estimated these work hours at 0.43 hours per calendar day. For 1994, we assume that work hours were 30% higher than in 2018 (i.e. 0.56 hours) and linearly interpolate the values for 1995-2017. Cattle in the commercial dairy production system are assumed to do no work. By comparison, the IPCC

(2006) default value for Africa is 1.37 hours per day and the IPCC (2019) default value is 1.1 hours per day for draft bullocks and 0.55 hours for mature females. The values used in this inventory are within the range proposed by the IPCC.

2.2.9 Digestible energy as a proportion of gross energy in feed

Composition of feed baskets and digestible energy (DE) as a proportion of gross energy in feed were estimated using data sources and methods described in Annex 4. For commercial and smallholder dairy cattle, a single value of 61.8% was applied to each dairy sub-category throughout the time series. For cattle in the mixed crop-livestock system, data from annual CSA agricultural sample surveys was used together with other data sources described in Annex 4 to estimate a time series for diet composition and feed digestibility. The estimated feed digestibility was applied to all cattle sub-categories and varied from 53.94% in 1994 to 53.51% in 2018, except for fattened and feedlot fed cattle. For cattle in smallholder fattening operations, feed digestibility was calculated as the weighted average of digestibility during time spent in fattening (60.05%) and on-farm (varying from 53.94% in 1994 to 53.51% in 2018). For cattle in commercial feedlots, feed digestibility was calculated as the weighted average of digestibility during time spent in the feedlot (68.86%) and on-farm (54.89%). For the pastoral/agro-pastoral production system, where natural pasture was estimated to account for 97.7% of dry matter intake, a single value for feed digestibility of 54.89% was used consistently throughout the time series. The values for DE% used in the 2018 inventory are shown in Table 13. The IPCC (2019) default values for low productivity dairy cattle in Africa are 51% (where it is assumed that dairy cows graze pasture), which is significantly lower than the 61.80% estimated here. For other cattle, IPCC (2019) provides default values between 58% and 61% in low and high productivity systems, which are higher than the values estimated in this inventory for mixed crop-livestock and pastoral/agro-pastoral systems. Further explanation of differences with the IPCC (2019) default values is given in Section 2.2.13.

Table 13. Feed digestibility (%) estimates for cattle sub-categories, 2018

Species	System	Sub-category	DE%
Dual purpose cattle	Mixed crop livestock system	Adult multipurpose cows >3 years	53.94%
		Adult males used for draught (3-10 years)	53.94%
		Adult males used for breeding & other purpose (>3-10 years)	53.94%
		Calves < 6 months (male & female)	53.94%
		Calves 6 m-1 year (male & female)	53.94%
		Growing males 1-3 years	53.94%
		Growing females 1-3 years	53.94%
		Smallholder fattened cattle (male 3-10 years)	55.42%
		Commercial feedlot-fed cattle (male 3-10 years)	58.38%
	Pastoral and agropastoral system	Adult multipurpose cows >3 years	54.89%
		Adult males used for draught (3-10 years)	54.89%
		Adult males used for breeding & other purpose (>3-10 years)	54.89%
		Calves < 6 months (male & female)	54.89%
		Calves 6 m-1 year (male & female)	54.89%
		Growing males 1-3 years	54.89%
		Growing females 1-3 years	54.89%
Dairy cattle	Commercial intensive system	Adult pure exotic dairy cows (3-10 years)	61.80%
		Adult pure exotic males 3-10 years	61.80%
		Pure exotic calves (<6 months) male & female	61.80%
		Pure exotic calves (6 m - < 1 yr) male & female	61.80%
		Pure exotic growing males (1 - < 3 years)	61.80%
		Pure exotic growing females (1 -< 3 years)	61.80%
	Smallholder intensive system	Adult pure exotic dairy cows (3-10 years)	61.80%
		Adult pure exotic males 3-10 years	61.80%
		Pure exotic calves (<6 months) male & female	61.80%
		Pure exotic calves (6 m - < 1 yr) male & female	61.80%
		Pure exotic growing males (1 - < 3 years)	61.80%
		Pure exotic growing females (1 -< 3 years)	61.80%

Source: Annex 4 (Table A4.1b, Table A4.2b, Table A4.2c)

2.2.10 Calculation of gross energy

Gross energy was calculated using IPCC (2006) equations 10.14-10.16. Gross energy for each sub-category is shown in Table 14 and Table 15. The estimated gross energy was cross-checked against the implied dry matter intake (DMI) using IPCC equations 10.17 and 10.18 in the 2019 Refinement. The ratio of estimated DMI to body weight was in the range of 1.91%-3.50% of body weight for all animal types, which is consistent with the suggested "in the order of 2% to 3% of the bodyweight" in IPCC (2019). The higher values were for growing animal types.

2.2.11 Calculation of emission factors

The emission factors were calculated using IPCC (2006) Equation 10.21. The value for the methane conversion factor used was the IPCC default value of 6.5%. For calves <6 months a methane conversion factor of 3.25% was used, rep resenting emissions after weaning at the age of 90 days and no emissions during the 90 day suckling period. Emission factors for calves <6 months and calves 6 m - <1 year also account for the fact that animals are not in each of these age classes for more than 6 months of the year. The resulting emission factors for each year are shown in Table 16 and Table 17. The emission factor for dairy cows (i.e. 77.59 kg CH_4 head^{-1} year^{-1} in 2018) is similar to the IPCC (2019) default value for stall-fed high productivity dairy cows in Africa of 86 kg CH_4 head^{-1} year^{-1}, which assumed lower body weight, milk yield and feed digestibility than in this inventory. For other cattle, the implied emission factor (i.e. population-weighted emission factor) averages 47.68 kg CH_4 head^{-1} year^{-1} across the time series, which is higher than the IPCC (2006) default factor of 32 kg CH_4 head^{-1} year^{-1}, but close to the estimate of 48 kg CH_4 head^{-1} year^{-1} for low productivity systems in IPCC (2019). The implied emission factors (i.e., population-weighted average emission factors) (Figure 3) suggest an increasing trend for dairy cattle over the entire inventory time series, which is mainly due to the assumed increase in milk yield. For the mixed crop-livestock and pastoral/agro-pastoral systems, implied emission factors are estimated to have increased since the mid-1990s until 2009, after which they have been relatively stable with slight inter-annual variation. A small decreasing trend in the mixed crop-livestock system since 2013 is primarily due to a shift in herd structure reported in CSA annual livestock surveys in which the proportion of adult animals has decreased slightly while the proportion of calves and growing animals has increased slightly.

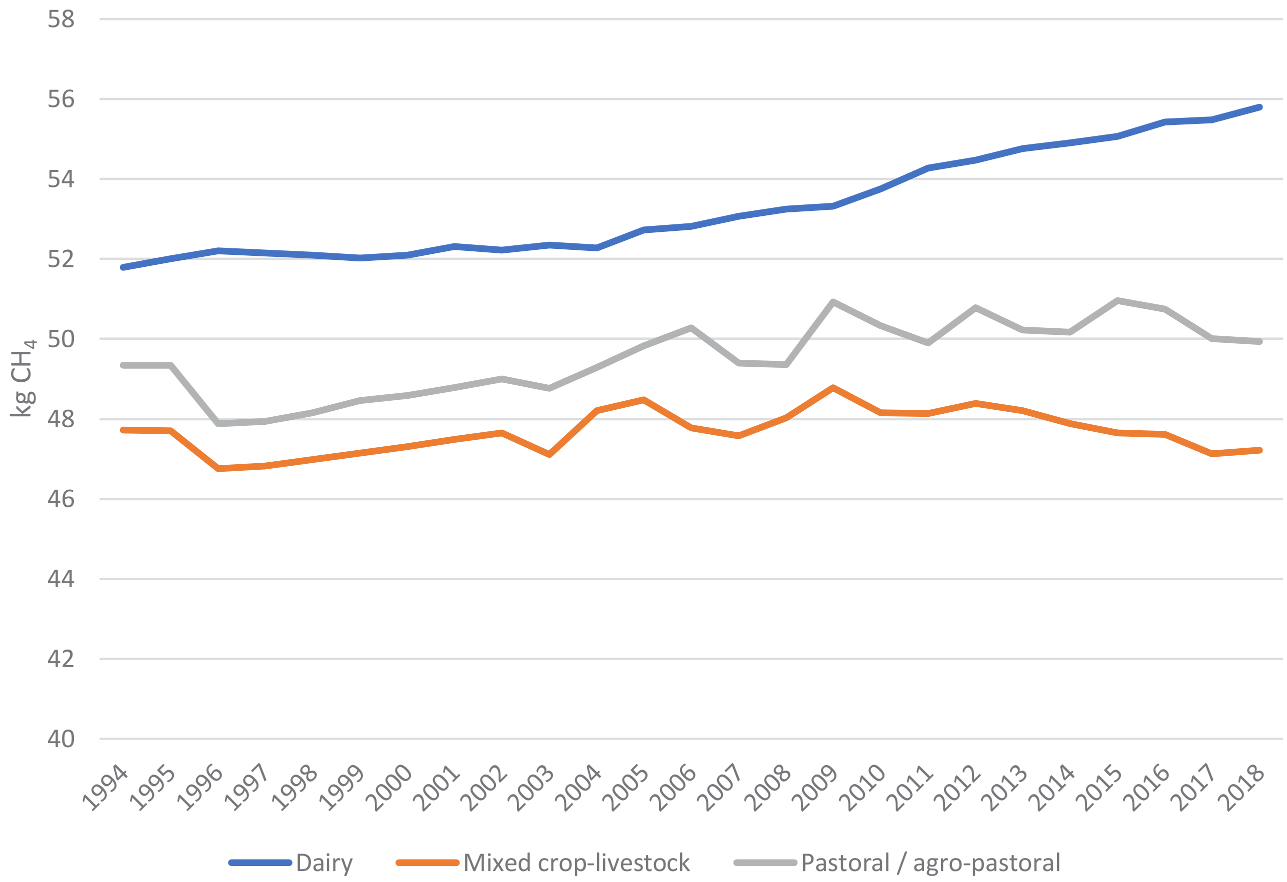

Figure 3. Implied emission factors for each production system, 1994-2018 (kg CH_4 head^{-1} year^{-1})

Table 14. Gross energy for dairy cattle sub-categories, 1994-2018 (MJ head^{-1} day^{-1})

	Commercial dairy production system						Smallholder dairy production system					
Year	Adult cows >3 years	Adult males (3-10 years)	Calves < 6 months (male & female)	Calves 6 m-1 year (male & female)	Growing males 1-3 years	Growing females 1-3 years	Adult cows >3 years	Adult males used for breeding (3-10 years)	Calves < 6 months (male & female)	Calves 6 m-1 year (male & female)	Growing males 1-3 years	Growing females 1-3 years
1994	163.08	110.38	32.75	52.40	95.34	90.57	163.08	116.55	32.75	52.40	99.67	94.34
1995	163.81	110.38	32.75	52.40	95.34	90.57	163.81	116.49	32.75	52.40	99.63	94.31
1996	164.55	110.38	32.75	52.40	95.34	90.57	164.55	116.43	32.75	52.40	99.58	94.27
1997	165.31	110.38	32.75	52.40	95.34	90.57	165.31	116.37	32.75	52.40	99.54	94.23
1998	166.08	110.38	32.75	52.40	95.34	90.57	166.08	116.31	32.75	52.40	99.50	94.20
1999	166.86	110.38	32.75	52.40	95.34	90.57	166.86	116.25	32.75	52.40	99.46	94.16
2000	167.66	110.38	32.75	52.40	95.34	90.57	167.66	116.19	32.75	52.40	99.42	94.12
2001	168.47	110.38	32.75	52.40	95.34	90.57	168.47	116.14	32.75	52.40	99.38	94.09
2002	169.30	110.38	32.75	52.40	95.34	90.57	169.30	116.08	32.75	52.40	99.33	94.05
2003	170.17	110.39	32.75	52.40	95.35	90.59	170.17	116.03	32.75	52.40	99.30	94.03
2004	171.00	110.37	32.74	52.39	95.33	90.57	171.00	115.95	32.74	52.39	99.24	93.97
2005	171.95	110.42	32.76	52.42	95.37	90.61	171.95	115.94	32.76	52.42	99.25	93.98
2006	172.81	110.40	32.75	52.41	95.35	90.59	172.81	115.86	32.75	52.41	99.18	93.92
2007	173.63	110.34	32.73	52.37	95.30	90.53	173.63	115.73	32.73	52.37	99.08	93.83
2008	174.58	110.35	32.74	52.38	95.31	90.55	174.58	115.69	32.74	52.38	99.06	93.81
2009	175.55	110.37	32.74	52.39	95.32	90.56	175.55	115.65	32.74	52.39	99.03	93.78
2010	176.56	110.39	32.75	52.40	95.35	90.59	176.56	115.62	32.75	52.40	99.01	93.78
2011	177.62	110.44	32.77	52.43	95.40	90.63	177.62	115.61	32.77	52.43	99.02	93.79
2012	178.56	110.41	32.76	52.41	95.36	90.60	178.56	115.51	32.76	52.41	98.94	93.71
2013	179.06	110.36	32.74	52.39	95.32	90.56	179.06	115.41	32.74	52.39	98.86	93.64
2014	179.64	110.37	32.74	52.39	95.33	90.57	179.64	115.36	32.74	52.39	98.83	93.61
2015	180.20	110.37	32.74	52.39	95.33	90.57	180.20	115.30	32.74	52.39	98.78	93.57
2016	180.79	110.38	32.75	52.39	95.33	90.57	180.79	115.24	32.75	52.39	98.75	93.54
2017	181.38	110.38	32.75	52.40	95.34	90.58	181.38	115.19	32.75	52.40	98.71	93.51
2018	182.01	110.41	32.76	52.41	95.36	90.60	182.01	115.15	32.76	52.41	98.69	93.50

Table 15. Gross energy for other cattle sub-categories, 1994-2018 (MJ head^{-1} day^{-1})

	Pastoral and agro-pastoral system							Mixed crop-livestock system								
Year	Adult multi-purpose cows >3 years	Adult males used for draught (3-10 years)	Adult males used for breeding & other purpose (>3-10 years)	Calves < 6 months (male & female)	Calves 6 m-1 year (male & female)	Grow-ing males 1-3 years	Growing females 1-3 years	Adult multi-purpose cows >3 years	Adult males used for draught (3-10 years)	Adult males used for breeding & other purpose (>3-10 years)	Calves < 6 months (male & female)	Calves 6 m-1 year (male & female)	Grow-ing males 1-3 years	Grow-ing fe-males 1-3 years	Small-holder fattening male	Commer-cial feed-lot fed male
1994	141.84	150.90	160.86	56.22	85.95	135.12	107.64	125.82	138.54	146.05	48.32	68.44	127.23	97.73	116.20	130.53
1995	141.96	150.75	160.80	56.22	85.95	135.07	107.61	125.93	138.38	145.99	48.32	68.44	127.19	97.69	116.16	130.49
1996	142.26	150.59	160.74	56.34	86.07	135.03	107.58	126.21	138.21	145.92	48.33	68.39	127.14	97.66	116.11	130.44
1997	142.89	150.43	160.68	56.34	86.07	134.98	107.54	126.81	138.05	145.86	48.33	68.39	127.09	97.62	116.07	130.40
1998	144.19	150.28	160.62	56.34	86.07	134.94	107.51	128.04	137.88	145.79	48.33	68.39	127.05	97.59	116.02	130.36
1999	145.59	150.12	160.56	56.34	86.07	134.89	107.47	129.30	137.72	145.73	48.33	68.39	127.00	97.55	115.98	130.32
2000	146.92	149.96	160.50	56.34	86.07	134.85	107.44	130.56	137.56	145.67	48.33	68.39	126.95	97.52	115.93	130.28
2001	148.29	149.81	160.44	56.34	86.07	134.80	107.40	131.80	137.39	145.60	48.33	68.39	126.90	97.48	115.89	130.23
2002	149.60	149.65	160.38	56.34	86.07	134.76	107.37	133.04	137.23	145.54	48.33	68.39	126.86	97.45	115.84	130.19
2003	150.83	149.51	160.33	56.27	85.95	134.73	107.35	133.42	136.06	144.40	47.87	67.85	125.75	96.58	115.17	130.15
2004	151.52	149.35	160.27	56.22	85.98	134.68	107.31	134.53	136.49	144.97	48.13	68.19	126.33	97.04	115.49	130.11
2005	153.49	149.19	160.21	56.23	85.95	134.64	107.28	136.48	136.91	145.53	48.40	68.55	126.90	97.49	115.81	130.07
2006	152.44	149.04	160.15	56.25	85.99	134.59	107.24	135.35	136.07	144.75	48.09	68.13	126.14	96.89	115.35	130.03
2007	152.95	148.88	160.09	56.29	85.93	134.55	107.21	135.31	135.91	144.69	48.10	68.16	126.10	96.86	115.31	129.98
2008	150.80	148.72	160.02	56.24	86.01	134.50	107.17	134.22	136.15	145.06	48.28	68.36	126.48	97.17	115.51	129.94
2009	156.12	148.57	159.96	56.23	86.03	134.46	107.14	140.22	136.28	145.30	48.41	68.53	126.74	97.38	115.65	129.90
2010	152.84	148.41	159.90	56.29	86.04	134.41	107.11	136.55	136.44	145.59	48.57	68.72	127.04	97.62	115.81	129.86
2011	151.78	148.26	159.84	56.23	85.96	134.37	107.07	136.28	136.36	145.61	48.60	68.81	127.08	97.65	115.81	129.82
2012	154.10	148.10	159.78	56.24	85.97	134.32	107.04	137.67	136.08	145.42	48.55	68.74	126.91	97.52	115.70	129.77
2013	153.35	147.94	159.72	56.26	85.96	134.28	107.00	136.94	135.49	144.91	48.35	68.49	126.41	97.13	115.39	129.73
2014	152.09	147.79	159.66	56.27	85.99	134.23	106.97	135.72	135.59	145.12	48.48	68.63	126.64	97.31	115.51	129.69
2015	150.97	147.63	159.60	56.25	85.95	134.19	106.93	135.08	135.45	145.09	48.49	68.66	126.63	97.30	115.48	129.65

2016	152.67	147.47	159.54	56.31	86.05	134.14	106.90	136.40	135.17	144.90	48.44	68.55	126.46	97.17	115.36	129.61
2017	150.26	147.32	159.47	56.26	85.99	134.10	106.86	133.49	134.44	144.23	48.17	68.23	125.81	96.66	114.96	129.57
2018	152.36	147.16	159.41	56.28	85.99	134.06	106.83	135.73	134.84	144.77	48.43	68.57	126.36	97.10	115.27	129.52

Table 16. Emission factors for dairy cattle sub-categories, 1994-2018 (kg CH_4 head^{-1} year^{-1})

	Commercial dairy production system							Smallholder dairy production system						
Year	Adult cows >3 years	Adult males (3-10 years)	Calves < 6 months (male & female)	Calves 6 m-1 year (male & female)	Growing males 1-3 years	Growing females 1-3 years	National implied emission factor	Adult cows >3 years	Adult males used for breeding (3-10 years)	Calves < 6 months (male & female)	Calves 6 m-1 year (male & female)	Growing males 1-3 years	Growing females 1-3 years	National implied emission factor
1994	69.53	47.06	3.49	11.17	40.64	38.61	48.77	69.53	49.69	3.49	11.17	42.49	40.22	52.58
1995	69.84	47.06	3.49	11.17	40.64	38.61	48.93	69.84	49.66	3.49	11.17	42.47	40.20	52.76
1996	70.15	47.06	3.49	11.17	40.64	38.61	49.09	70.15	49.64	3.49	11.17	42.45	40.19	52.94
1997	70.47	47.06	3.49	11.17	40.64	38.61	49.25	70.47	49.61	3.49	11.17	42.44	40.17	53.12
1998	70.80	47.06	3.49	11.17	40.64	38.61	49.42	70.80	49.59	3.49	11.17	42.42	40.16	53.31
1999	71.14	47.06	3.49	11.17	40.64	38.61	49.59	71.14	49.56	3.49	11.17	42.40	40.14	53.50
2000	71.48	47.06	3.49	11.17	40.64	38.61	49.76	71.48	49.54	3.49	11.17	42.38	40.13	53.70
2001	71.82	47.06	3.49	11.17	40.64	38.61	49.94	71.82	49.51	3.49	11.17	42.37	40.11	53.90
2002	72.18	47.06	3.49	11.17	40.64	38.61	50.12	72.18	49.49	3.49	11.17	42.35	40.10	54.10
2003	72.55	47.06	3.49	11.17	40.65	38.62	50.31	72.55	49.47	3.49	11.17	42.34	40.09	54.31
2004	72.90	47.06	3.49	11.17	40.64	38.61	50.49	72.90	49.43	3.49	11.17	42.31	40.06	54.52
2005	73.31	47.07	3.49	11.17	40.66	38.63	50.70	73.31	49.43	3.49	11.17	42.31	40.07	54.76
2006	73.67	47.07	3.49	11.17	40.65	38.62	50.88	73.67	49.39	3.49	11.17	42.28	40.04	54.96
2007	74.02	47.04	3.49	11.16	40.63	38.60	51.05	74.02	49.34	3.49	11.16	42.24	40.00	55.16
2008	74.43	47.05	3.49	11.17	40.63	38.60	51.26	74.43	49.32	3.49	11.17	42.23	39.99	55.39
2009	74.84	47.05	3.49	11.17	40.64	38.61	51.47	74.84	49.30	3.49	11.17	42.22	39.98	55.63
2010	75.27	47.06	3.49	11.17	40.65	38.62	51.70	75.27	49.29	3.49	11.17	42.21	39.98	55.88
2011	75.72	47.08	3.49	11.18	40.67	38.64	51.93	75.72	49.29	3.49	11.18	42.21	39.98	56.15
2012	76.13	47.07	3.49	11.17	40.65	38.62	52.13	76.13	49.24	3.49	11.17	42.18	39.95	56.38

2013	76.34	47.05	3.49	11.17	40.64	38.61	52.24	76.34	49.20	3.49	11.17	42.15	39.92	56.49
2014	76.58	47.05	3.49	11.17	40.64	38.61	52.36	76.58	49.18	3.49	11.17	42.13	39.91	56.63
2015	76.83	47.05	3.49	11.17	40.64	38.61	52.48	76.83	49.15	3.49	11.17	42.11	39.89	56.77
2016	77.07	47.06	3.49	11.17	40.64	38.61	52.61	77.07	49.13	3.49	11.17	42.10	39.88	56.91
2017	77.33	47.06	3.49	11.17	40.65	38.62	52.74	77.33	49.11	3.49	11.17	42.08	39.87	57.06
2018	77.59	47.07	3.49	11.17	40.66	38.62	52.88	77.59	49.09	3.49	11.17	42.08	39.86	57.21

Table 17. Emission factors for other cattle sub-categories, 1994-2018 (kg CH_4 head^{-1} year^{-1})

	Pastoral and agro-pastoral system								Mixed crop-livestock system									
Year	Adult multipurpose cows >3 years	Adult males used for draught (3-10 years)	Adult males used for breeding & other purpose (>3-10 years)	Calves < 6 months (male & female)	Calves 6 m-1 year (male & female)	Growing males 1-3 years	Growing females 1-3 years	National implied emission factor	Adult multipurpose cows >3 years	Adult males used for draught (3-10 years)	Adult males used for breeding & other purpose (>3-10 years)	Calves < 6 months (male & female)	Calves 6 m-1 year (male & female)	Growing males 1-3 years	Growing females 1-3 years	Smallholder fattening male	Commercial feedlot fed male	National implied emission factor
1994	60.47	64.33	68.58	5.99	18.32	57.60	45.89	49.34	53.64	59.06	62.26	5.15	14.59	54.24	41.66	49.54	55.65	47.71
1995	60.52	64.27	68.55	5.99	18.32	57.58	45.88	49.34	53.69	58.99	62.24	5.15	14.59	54.22	41.65	49.52	55.63	47.71
1996	60.65	64.20	68.53	6.01	18.35	57.57	45.86	47.88	53.80	58.92	62.21	5.15	14.58	54.20	41.63	49.50	55.61	46.76
1997	60.92	64.13	68.50	6.01	18.35	57.55	45.85	47.93	54.06	58.85	62.18	5.15	14.58	54.18	41.62	49.48	55.59	46.82
1998	61.47	64.07	68.48	6.01	18.35	57.53	45.83	48.16	54.59	58.78	62.16	5.15	14.58	54.16	41.60	49.46	55.58	46.98
1999	62.07	64.00	68.45	6.01	18.35	57.51	45.82	48.46	55.12	58.71	62.13	5.15	14.58	54.14	41.59	49.44	55.56	47.15
2000	62.63	63.93	68.42	6.01	18.35	57.49	45.80	48.59	55.66	58.64	62.10	5.15	14.58	54.12	41.57	49.42	55.54	47.32
2001	63.22	63.87	68.40	6.01	18.35	57.47	45.79	48.79	56.19	58.57	62.07	5.15	14.58	54.10	41.56	49.41	55.52	47.48
2002	63.78	63.80	68.37	6.01	18.35	57.45	45.77	49.01	56.72	58.50	62.05	5.15	14.58	54.08	41.55	49.39	55.50	47.64
2003	64.30	63.74	68.35	6.00	18.32	57.44	45.76	48.77	56.88	58.00	61.56	5.10	14.46	53.61	41.17	49.10	55.49	47.12
2004	64.60	63.67	68.33	5.99	18.33	57.42	45.75	49.28	57.35	58.19	61.81	5.13	14.54	53.86	41.37	49.24	55.47	48.21
2005	65.44	63.61	68.30	5.99	18.32	57.40	45.73	49.83	58.19	58.37	62.04	5.16	14.61	54.10	41.56	49.37	55.45	48.47
2006	64.99	63.54	68.27	6.00	18.33	57.38	45.72	50.28	57.70	58.01	61.71	5.13	14.52	53.78	41.31	49.18	55.43	47.78
2007	65.21	63.47	68.25	6.00	18.32	57.36	45.71	49.40	57.68	57.94	61.69	5.13	14.53	53.76	41.30	49.16	55.42	47.58
2008	64.29	63.41	68.22	5.99	18.34	57.34	45.69	49.35	57.22	58.04	61.84	5.15	14.57	53.92	41.42	49.25	55.40	48.03
2009	66.56	63.34	68.20	5.99	18.34	57.32	45.68	50.92	59.78	58.10	61.95	5.16	14.61	54.03	41.51	49.30	55.38	48.78
2010	65.16	63.27	68.17	6.00	18.34	57.30	45.66	50.33	58.21	58.17	62.07	5.18	14.65	54.16	41.62	49.37	55.36	48.15
2011	64.71	63.20	68.14	5.99	18.32	57.28	45.65	49.90	58.10	58.13	62.08	5.18	14.67	54.18	41.63	49.37	55.34	48.14
2012	65.70	63.14	68.12	5.99	18.32	57.27	45.63	50.78	58.69	58.01	62.00	5.17	14.65	54.11	41.57	49.32	55.33	48.38
2013	65.38	63.07	68.09	6.00	18.32	57.25	45.62	50.22	58.38	57.76	61.78	5.15	14.60	53.89	41.41	49.19	55.31	48.21
2014	64.84	63.00	68.07	6.00	18.33	57.23	45.60	50.17	57.86	57.80	61.87	5.17	14.63	53.99	41.49	49.24	55.29	47.88
2015	64.36	62.94	68.04	6.00	18.32	57.21	45.59	50.96	57.59	57.75	61.85	5.17	14.64	53.98	41.48	49.23	55.27	47.65
2016	65.09	62.87	68.01	6.00	18.34	57.19	45.57	50.75	58.15	57.63	61.78	5.16	14.61	53.91	41.43	49.18	55.26	47.62
2017	64.06	62.80	67.99	6.00	18.33	57.17	45.56	50.01	56.91	57.32	61.49	5.13	14.55	53.63	41.21	49.01	55.24	47.13
2018	64.95	62.74	67.96	6.00	18.33	57.15	45.54	49.93	57.87	57.49	61.72	5.16	14.62	53.87	41.39	49.14	55.22	47.21

2.2.12 Uncertainties and time-series consistency

Annex 6 gives the main results of uncertainty analysis conducted using Monte Carlo simulation. Uncertainty of 2018 enteric fermentation emissions from dairy and other cattle was (+18.2%,-15.7%). Uncertainty associated with the cattle population data used was estimated at ±3.23% in 2018, and average uncertainty of the emission factors was about ±17.9% in 2018.

Within each production system, consistent methods have been used to estimate the time series for enteric fermentation emissions.

2.2.13 Source-specific QAQC and verification

Tier 1 and Tier 2 QAQC activities have been implemented. This inventory was compiled in an Excel spreadsheet. Quality control activities included:

- Checking that the equations programmed in the spreadsheet were correctly input
- Checking that inputs to summed totals were obtained from the correct fields
- Checking that all data sources were fully documented
- Checking that the figures in the inventory spreadsheet were correctly transcribed from prior worksheets
- Checking that the figures in the inventory report were correctly transcribed
- Reconstructing a number of the calculations to cross-check the intermediate calculations and results in the inventory spreadsheet.

QAQC activities identified and addressed the following issues:

- Implied emission factors disaggregated by production system were not presented in the inventory report for all animal categories, which has now been rectified;
- The calculation of implied emission factors had errors, which have now been rectified;
- Data sources were not given where relevant for tables in the inventory report and this has now been rectified.

The inventory was also reviewed by members of the Tier 2 livestock inventory advisory group and all comments and queries have been responded to and addressed in the revised inventory report. Most comments related to increasing the transparency of emission estimates, explaining the reason for trends in input parameters and emission factors, revising the uncertainty estimate for cattle LW and uncertainty analysis results, and elaborating options for inventory improvement.

For verification, the estimated emission factors were compared with (a) IPCC default values, (b) estimates for Ethiopia used in the Global Livestock Environmental Assessment Model (GLEAM) model,[1] (c) and with emission factors used in other countries' national GHG inventories internationally and in Sub-Saharan Africa.

(a) Comparison with IPCC default values: The IPCC (2006) default emission factor for dairy cows in Africa and the Middle East is 46 kg CH_4 head^{-1} year^{-1}, assuming a LW of 275 kg, 60% feed digestibility and a milk yield of 1.3 kg head^{-1} day^{-1}. The IPCC (2019) default emission factors for dairy cows in Africa are 86 kg CH_4 head^{-1} year^{-1} in high productivity systems (LW 250 kg, milk yield 5.8 kg, DE 50%) and 66 kg CH_4 head^{-1} year^{-1} in low productivity systems (LW 270 kg, milk yield 1.2 kg, DE 51%). The estimated emission factor for dairy cows in this inventory varies between 69.5 and 77.6 kg CH_4 head^{-1} year^{-1} in different years, assuming a LW of 428 kg, milk yield of 4.5 – 6.5 kg, and DE of 61.78%. With a higher LW and a higher digestibility value in this inventory, the emission factor is in between the IPCC (2019) low and high productivity system default emission factors, and close to the IPCC (2019) generic Tier 1 default factor of 76 kg CH_4 head^{-1} year^{-1}, but higher than the IPCC (2006) default value. For other cattle, IPCC (2006) gives a default value of 31 kg CH_4 head^{-1} year^{-1}. IPCC (2019) provides a generic Tier 2 default factor for other cattle in Africa of 52 kg CH_4 head^{-1} year^{-1}. This Tier 1 emission factor is similar to the average implied emission factor (i.e. population-weighted emission factor) of 47.95 kg CH_4 head^{-1} year^{-1} in this inventory.

Comparison with GLEAM estimates: GLEAM was the model used by the Food and Agriculture Organization of the United Nations (FAO) to estimate the IPCC (2019) Tier 1 default emission factors for enteric fermentation (FAO 2018). For Ethiopia, four production systems were modelled: mixed crop-livestock, pastoral/agro-pastoral, smallholder dairy and medium commercial dairy. GLEAM milk yield estimates for the smallholder dairy (i.e. 5.9 kg) system are similar to those used for both commercial and smallholder dairy systems in this inventory. Tables 18-20 compare key input parameters for key variables used in the GLEAM model and in this inventory and the resulting emission factors. For the

1 Félix Teillard (FAO), email communication, 24 April 2020.

Table 18. Comparison of key input variables and emission factors between the GLEAM model and this inventory, smallholder dairy system

Sub-category	GLEAM					Inventory				
	LW	WG	MY	DE	EF	LW	WG	MY	DE	EF
Milking cow	400	-	5.9	49	104	429	-	6.4	61.80	78
Breeding males	450	-	-	49	87	419	-	-	61.80	47
Replacement females	212	0.50	-	49	86	261	0.26	-	61.80	39
Replacement males	237	0.50	-	49	83	261	0.25	-	61.80	41

Table 19. Comparison of key input variables and emission factors between the GLEAM model and this inventory, mixed crop-livestock system

Sub-category	GLEAM					Inventory				
	LW	WG	MY	DE	EF	LW	WG	MY	DE	EF
Milking cow	247	-	2.4	45.35	88	286	-	1.25	53.94	58
Breeding males	382	-	-	45.35	104	343	-	-	53.94	57
Replacement females	135	0.28	-	45.35	76	181	0.15	-	53.94	41
Replacement males	202	0.28	-		87	227	0.20	-	53.94	54
Steers fattened	225	0.28	-	43.35	64	281	0.15-0.26	-	55.42-58.38	49-55

Table 20. Comparison of key input variables and emission factors between the GLEAM model and this inventory, pastoral/agro-pastoral system

Sub-category	GLEAM					Inventory				
	LW	WG	MY	DE	EF	LW	WG	MY	DE	EF
Milking cow	280	-	1.5	42.77	116	295	-	1.22	54.89	65
Breeding males	338	-	-	42.77	120	340	-	-	54.89	63
Replacement females	152	0.28	-	42.77	108	190	0.14	-	54.89	46
Replacement males	180	0.28	-		110	225	0.19	-	54.89	57

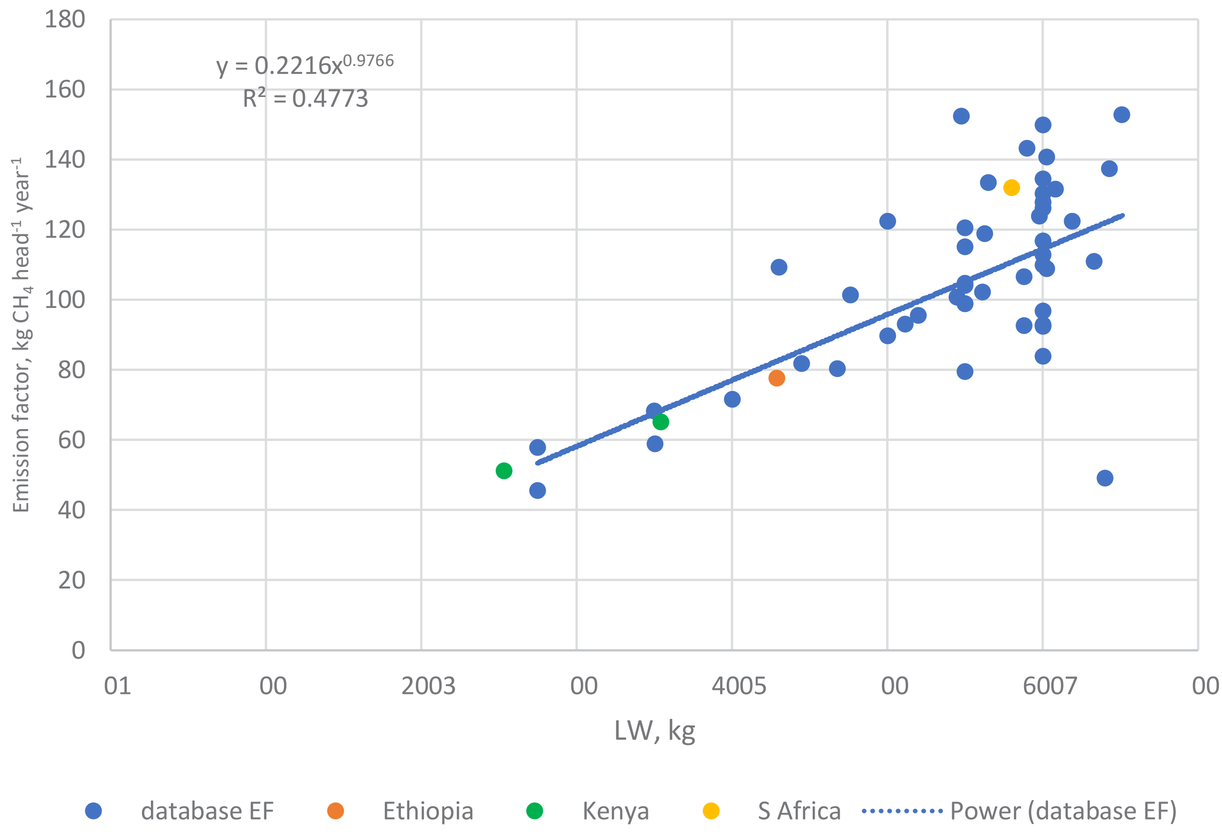

Figure 4. Comparison of dairy cow emission factor with emission factors from Africa and internationally

Comparison with other emission factors for Sub-Saharan Africa and internationally: Tier 2 emission factors have been estimated in national GHG inventories for dairy cattle in Kenya (SDL 2019) and dairy and other cattle in South Africa (du Toit et al. 2013). Net energy for maintenance (which depends on metabolic LW) accounts for more than two thirds of total estimated net energy requirements for dairy cows in the Ethiopia inventory. Figure 4 shows the relationship between LW and emission factors for dairy cows in this inventory (orange), the Kenyan inventory (green), the South African inventory (yellow) and an international database of emission factors from the IPCC and other submissions to the UNFCCC (Thorley et al. 2019). Both the LW and EF for Ethiopian dairy cows are higher than in Kenya but much lower than in South Africa. The estimated EF for Ethiopia is close to but slightly lower than would be predicted by values in the international database, most likely reflecting the lower milk yields of dairy cattle in Ethiopia compared to those in the international database, which average 13 kg day^{-1}.

For other cattle, a similar comparison suggests that at lower values of LW, the estimated emission factors in the Ethiopian inventory are lower than would be predicted using an international database, but at higher values of LW, emission factors tend to be higher than would be predicted (Figure 5). The lower LW values in this inventory are calves < 6 months and 6-12 months, for which the emission factor has been multiplied by 0.5, hence the emission factors are lower than those in the international database where only one emission factor was treated similarly. At higher values of LW, the higher estimated emission factors in this database are probably due to the lower estimated feed digestibility (i.e., ca. 53-55% in the mixed crop-livestock and pastoral/agro-pastoral systems) compared to those in the international database (i.e. average of 64%).

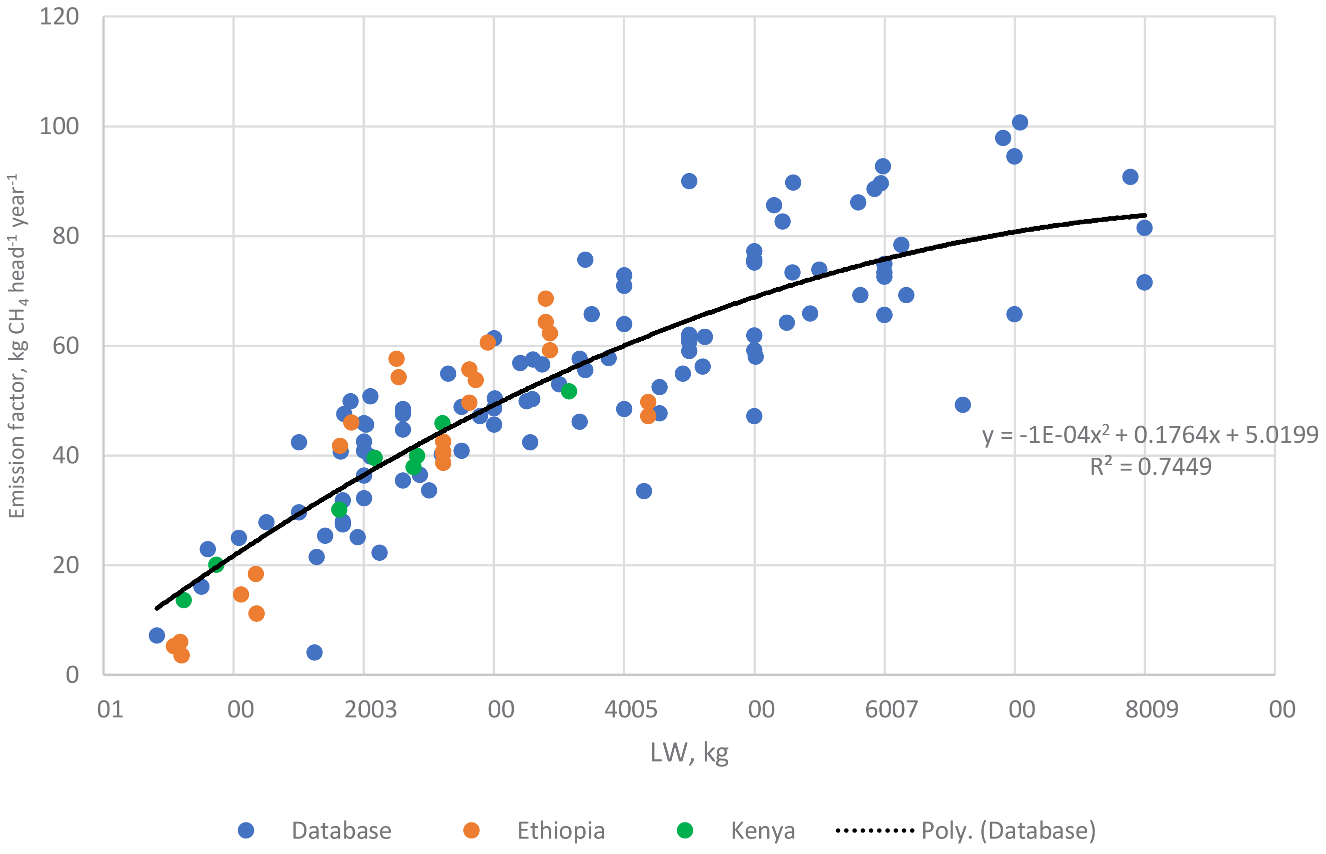

Figure 5. Comparison of other cattle emission factors with emission factors from Africa and internationally

2.3 Enteric fermentation by sheep and goats (Categories 3A1b and 3A1c)

2.3.1 Emissions model and inventory structure

Enteric fermentation emissions have been estimated using the IPCC Tier 2 model (IPCC 2006, Vol 4, Ch 10, Equations 10.3-10.16). These equations were used to estimate emissions from 14 sub-categories of sheep and 8 sub-categories of goat (Table 21). Animal sub-categories were defined based on IPCC 2019 guidelines on population characterization and the availability of IPCC default coefficients, and the sub-categories presented in annual agricultural sample surveys for livestock reported by the CSA. Annex Tables A1.11 and A1.13 show the correspondence between categories used in this inventory, IPCC recommended categories and CSA categories.

Based on agro-ecological and management system differences, two production systems for sheep and goat populations were defined: 1) a mixed crop-livestock system located in highland rain fed agricultural areas where sheep and goats graze on communal grazing land and crop residues from crop production, and 2) a pastoral and agro-pastoral system found in lowland grazing areas, where sheep and goats are kept in extensive grazing, moving from place to place in search of feed and water. The allocation of sub-category populations to pastoral/agro-pastoral and mixed crop-livestock populations is the same as for cattle (see Table 3). Within each production system, further sub-categories were defined based on age, sex and physiological state (Table 21).

Table 21. Sheep and goat sub-categories represented in the inventory

Species	Production system	Animal sub-category
Sheep	Mixed crop livestock system	Breeding ewes (>2 yrs)
		Mature male (>2 years)
		female (1-2 yrs)
		Male (1-2 years)
		Intact male lambs (< 1 yr)
		Castrated male lambs (< 1 yr)
		Female lambs (< 1 yr)
	Pastoral and agropastoral system	Breeding ewes (>2 yrs)
		Mature male (>2 years)
		female (1-2 yrs)
		Male (1-2 years)
		Intact male lambs (< 1 yr)
		Castrated male lambs (< 1 yr)
		Female lambs (< 1 yr)
Goats	Mixed crop livestock system	Adult does (2+ years)
		Bucks (2+ years)
		Yearlings (1-2 yrs)
		Kids (male & female, <1 yr)
	Pastoral and agropastoral system	Adult does (2+ years)
		Bucks (2+ years)
		Yearlings (1-2 yrs)
		Kids (male & female, <1 yr)

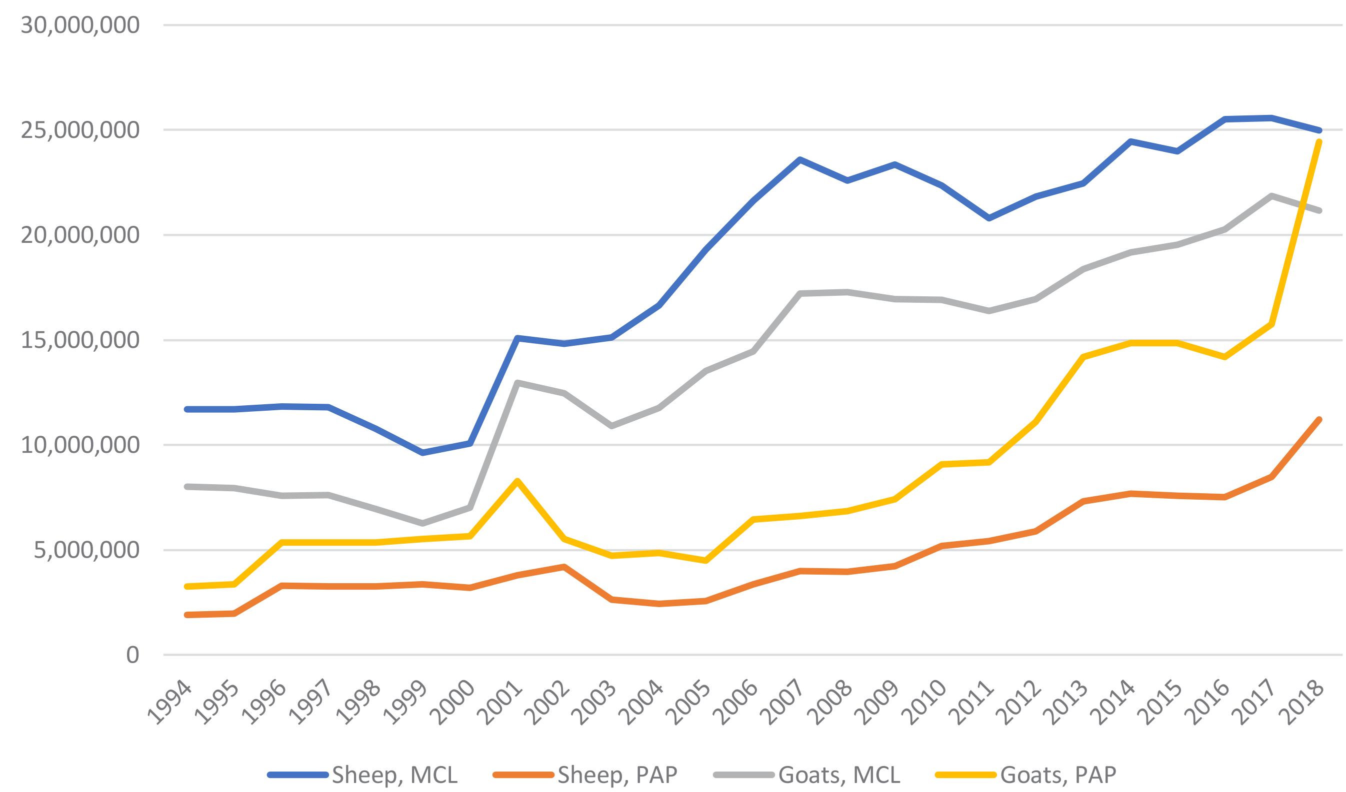

Figure 6. Trend in sheep and goat populations, 1994-2018 (head)

2.3.2 Sheep and goat populations

Sheep and goat population data were estimated using data from CSA annual agricultural sample surveys with additional data sources and assumptions as described in Annex 1.3. Figure 6 shows the trend in total populations of sheep and goats in each production system and the specific population figures are given in Tables A1.9 and A1.10. The total population figures for the mixed crop-livestock production system are the same as those reported in the CSA annual agricultural sample surveys, with data for missing years interpolated as described in Annexes A1.3 and A1.4. For sheep and goat populations in the pastoral/agro-pastoral system, the populations in this inventory are greater than in the CSA reports because sheep and goat populations in zones of Afar and Somali Regions that are not enumerated in CSA annual agricultural sample surveys have been estimated using other data sources and assumptions described in Annexes A1.3 and A1.4. The sharp increase in pastoral/agro-pastoral goats in 2017-2018 is due to a 32% increase in goat populations reported in CSA data between 2016 and 2018, as well as a sharp increase in the goat populations of zones in Afar and Somali region that are not enumerated by CSA (33% increase between 2016 and 2018). This may be related to the greater adaptability of goats to drought. In general, the growth rate of goat populations has been faster than sheep populations, as a result of increased preference for goat meat and/or greater adaptability of goats to drought compared to sheep.

2.3.3 Net energy for maintenance (NE_m)

Net energy for maintenance (NE_m) for sheep and goats were calculated following IPCC (2006) Equation 10.3:

$$NE_{m,i} = Cf_{,i} * (Weight_i)^{0.75}$$

where:

$NE_{m,i}$ is net energy for maintenance for sheep and goat type *i* (MJ head^{-1} day^{-1})

Cf_i is coefficient for calculating NE_m for sheep and goat type *i*

$Weight_i$ is live weight of sheep and goat of type *i* (kg).

IPCC 2019 Refinement Table 10.4 gives default values for Cf_i for different sub-categories of sheep and goat. Table 22 shows the values of *Cf* used for different sub-categories.

Table 22: Coefficient for maintenance values for different sheep and goat sub-categories

Species, sub-category	Cf	Source, assumptions
Sheep		
Breeding ewes (>2 yrs)	0.217	IPCC (2019) Table 10.4
Mature male (>2 years)	0.220	Assuming 90% are castrated (0.217) and 10% are intact (0.24955) as per IPCC (2019) Table 10.4
Female (1-2 yrs)	0.217	IPCC (2019) Table 10.4
Male (1-2 years)	0.220	Assuming 90% are castrated (0.217) and 10% are intact (0.24955) as per IPCC (2019) Table 10.4
Intact male lambs (< 1 yr)	0.2714	0.236 increased by 15% as per IPCC (2019) Table 10.4
Castrated male lambs (< 1 yr)	0.236	IPCC (2019) Table 10.4
Female lambs (< 1 yr)	0.236	IPCC (2019) Table 10.4
Goats		
Adult does (2+ years)	0.315	IPCC (2019) Table 10.4
Bucks (2+ years)	0.315	IPCC (2019) Table 10.4
Yearlings (1-2 yrs)	0.315	IPCC (2019) Table 10.4
Kids (male & female, <1 yr)	0.315	IPCC (2019) Table 10.4

The live weight of each sub-category of sheep and goat was estimated using various sources described in Annexes A2.3 and A2.4 and are shown in Tables 23-26. The population-weighted average LW are slightly lower than the values (i.e., 31 kg for sheep, 28 kg for goats) assumed in the IPCC Tier 1 emission factors (IPCC 2019 Table 10A.5). This most likely reflects the characteristics of the common sheep and goat breeds in Ethiopia.

Table 23. Live weight and weight gain (kg) of sheep in the mixed crop-livestock production system

Sub-category	Live weight (kg)	WG_{wean} (kg)	Initial body weight (kg)	Final body weight (kg)	WG_{lamb} (kg)
Breeding ewes 2 years and above	27.95	-	27.95	27.95	0
Adult male > 2years	28.81	-	28.81	28.81	0
Female 1-2 years	24.89	-	22.12	27.95	6.69
Male 1-2 years	25.47	-	21.82	28.81	6.99
Intact male lamb (< 1years)	17.89	8.81	11.35	22.12	10.77
Castrated lamb (< 1 year)	17.89	8.81	11.35	22.12	10.77
Female lamb (< 1 year)	17.46	8.49	10.99	20.96	9.97

Body weight initial: weaning weight; Body weight final: weight at 1 year old. Source: Annex 2 (Table A2.3a)

Sub-category	Live weight (kg)	WG_{wean} (kg)	Initial body weight (kg)	Final body weight (kg)	WG_{lamb} (kg)
Breeding ewes 2 years and above	30.63	-	30.63	30.63	0
Mature male > 2years	34.20	-	34.20	34.20	0
Female 1-2years	27.48	-	24.32	30.63	6.31
Male 1-2years	29.75	-	25.30	34.20	8.90
Intact sheep (male < 1years)	20.63	10.80	13.40	25.30	11.90
Castrated (< 1 year)	20.63	10.80	13.40	25.30	11.90
Female grassfed (< 1 year)	18.46	9.36	12.02	24.32	12.30

Table 24. Live weight and weight gain (kg) of sheep in the pastoral / agro-pastoral production system

Body weight initial: weaning weight; Body weight final: weight at 1 year old. Source: Annex 2 (Table A2.3b)

Table 25. Live weight (kg) of goats in the mixed crop-livestock production system

Sub-category	Live weight (kg)	WG_{wean} (kg)	Initial body weight (kg)	Final body weight (kg)	WG_{lamb} (kg)
Adult does 2 years and above	26.72	-	26.72	26.72	0
Bucks 2 years and above	27.90	-	27.90	27.90	0
Yearling (male & female 1-< 2 years)	20.95	-	14.04	27.85	13.81
Kids (male & female < 1 year)	10.5	6.38	8.68	14.04	5.38

Body weight initial: weaning weight; Body weight final: weight at 1 year old. Source: Annex 2 (Table A2.4a)

Table 26. Live weight (kg) of goats in the pastoral and agro-pastoral production system

Sub-category	Live weight (kg)	WG_{wean} (kg)	Initial body weight (kg)	Final body weight (kg)	WG_{lamb} (kg)
Adult does 2 years and above	29.45	-	29.45	29.45	0
Bucks 2 years and above	29.45	-	29.45	29.45	0
Yearling (male & female 1-< 2 years)	21.34	-	13.22	29.45	16.23
Kids (male & female < 1 year)	9.62	5.77	8.10	13.22	5.12

Body weight initial: weaning weight; Body weight final: weight at 1 year old. Source: Annex 2 (Table A2.4b)

2.3.4 Net energy for activity (NE_a)

NE_a was calculated using IPCC (2006) Equation 10.5:

$NE_a = C_a \bullet weight$

where

weight is liveweight of animal, kg

C_a is a coefficient corresponding to the animal's feeding situation MJ day^{-1} kg^{-1}

NE_m is net energy for maintenance for sheep or goat (MJ head^{-1} day^{-1}) as determined above.

A large-scale survey in Oromia Region estimated distances from waterpoints in different agroecological zones, and suggested that sheep and goats in the mixed crop-livestock system travel on average about 3.4 km to and from waterpoints and in the pastoral/agro-pastoral system about 6.4 km (Ayalew et al. 2004). IPCC (2019) Table 10.5 gives default values for C_a for animals under different feeding situations. Based on IPCC (2019) Table 10.5, we used a value of 0.024 for all sheep sub-categories and 0.024 for all goat sub-categories in both production systems.

2.3.5 Net energy for growth (NE_g)

NE_g was calculated using IPCC (2006) Equation 10.6:

$$NE_g = \frac{WG_{lamb/kid} \times (a + 0.5b(BW_i + BW_f))}{365}$$

where

$WG_{lamb/kid}$ is weight gain (BW_f-BW_i) (kg yr^{-1});

a and *b* are coefficients with values given in Table 10.6 of the 2019 Refinement for sheep sub-categories and goats (MJ/kg);

BW_i is live body weight at weaning, kg

BW_f is live body weight at 1-year old, kg

The inventory used the initial and final weight values shown in Tables 23-26 above to calculate $WG_{lamb/kid}$.

2.3.6 Net energy for lactation (NE_l)

NE_l was calculated using IPCC (2006) Equation 10.10 for both sheep and goats:

$NE_l = ((5 \text{ X } WG_{wean})/365) \text{ X } EV_{milk}$

Where

WG_{wean} is weight gain of lamb or kid between birth and weaning, kg.

The values used for WG_{wean} are shown in Table 27 and are based on data extracted from Appendix Tables 8 and 9. For lambs, the value of WG_{wean} was calculated as the average for males and females weighted by their proportion in the population as reported in CSA data, and shows little variation throughout the time series. For goats, the value of WG_{wean} was calculated from weaning and 12 month body weight of data for male and female goats together, with no variation throughout the time series. The resulting estimates of NE_l were then multiplied by the proportion of breeding ewes giving birth, which varied between years (see Table 28).

Table 27. Estimated live weight gain (kg) between birth and weaning for different sub-categories of lamb and kid

	Mixed crop-livestock	Pastoral / agro-pastoral
Sheep	8.64-8.65	9.9-10.0
Goats	6.38	5.77

Note: Values in this table are the weighted average of male and female lambs and kids estimated using the WG_{wean} values from Tables 23-26 and activity data on male and female lamb/kid populations from CSA data.

2.3.7 Net energy for pregnancy (NEp)

NE_p was calculated using IPCC (2006) Equation 10.13:

$NE_p = C_{pregnancy} \text{ X } NE_m$

where $C_{pregnancy}$ is a coefficient with a value of 0.077 for single births taken from the IPCC 2019 Refinement Table 10.7. To represent the average ewe and doe of breeding age, this coefficient was multiplied by the proportions of ewes and does giving birth in each year as estimated using data sources and assumptions described in Annexes 3.3 and 3.4 (Table 28). The time series shows some variation in lambing and kidding rates. From 1994 to 2002, variability is low because linear interpolation was used to fill years with missing data. From 2003, variability is most likely due to the effects of drought on feed resources and reproduction (e.g. in 2008 and 2014-15).

Table 28: Proportions of ewes and does giving birth, 1994-2018

	Ewes		Does	
	Mixed crop livestock	Pastoral/ agro-pastoral	Mixed crop livestock	Pastoral/ agro-pastoral
1994	63.2%	65.8%	65.6%	74.8%
1995	64.4%	66.8%	66.3%	76.2%
1996	66.9%	68.8%	67.7%	78.9%
1997	67.4%	68.7%	69.2%	81.6%
1998	68.4%	68.5%	71.3%	80.6%
1999	69.4%	68.3%	73.5%	79.5%
2000	70.3%	68.1%	75.6%	78.5%
2001	71.3%	67.9%	77.8%	77.4%
2002	72.3%	67.7%	80.0%	76.4%
2003	73.3%	67.5%	82.1%	75.3%
2004	73.5%	64.3%	72.6%	72.6%
2005	79.5%	69.5%	81.7%	77.3%
2006	75.7%	66.5%	75.9%	65.9%
2007	70.8%	63.4%	72.2%	69.8%
2008	65.4%	62.9%	73.9%	64.8%
2009	65.2%	54.0%	66.1%	62.3%
2010	74.4%	58.1%	71.1%	66.9%
2011	74.6%	57.8%	85.1%	64.5%
2012	74.9%	55.6%	77.3%	54.4%
2013	71.4%	58.8%	73.9%	57.9%
2014	77.5%	57.1%	80.1%	57.9%
2015	72.1%	50.6%	78.2%	55.9%
2016	75.9%	59.8%	77.9%	59.9%
2017	77.2%	55.8%	79.6%	57.9%
2018	68.0%	54.7%	76.1%	55.5%

Source: Annex 3 (Table A3.3a, Table A3.3b, Table A3.4a, Table A3.4b)

2.3.8 Net energy for wool production (NE_{wool})

NE_{wool} was calculated using IPCC (2006) Equation 10.12 in the 2019 Refinement:

$$NE_{wool} = \left(\frac{EV_{wool} \times Pr_{wool}}{365}\right)$$

where

NE_{work} is net energy required to produce wool, MJ day^{-1}

EV_{wool} is energy value of 1 kg of wool (i.e. 0.25 MJ day^{-1}); and

Pr_{wool} is annual wool production per sheep, kg yr^{-1}.

There are few detailed studies of wool production in Ethiopia. Based on available studies, wool production was estimated at 0.8 kg per year for sheep categories 1 year old and above (Abegaz and Duguma 2003; Mukasa-Mugerwa and Lahlou-Kassi 1995; Lemma et al. 1989; DAGRIS 2004). No wool production was estimated for goats.

2.3.9 Digestible energy as a proportion of gross energy in feed

Composition of feed baskets and digestible energy (DE) as a proportion of gross energy in feed were obtained from sources described in Annexes 4.3 and 4.4. Constant estimates of DE% were used throughout the time series, i.e. 54.39% and 54.89% for sheep and goats in the mixed crop-livestock and pastoral /agro-pastoral production systems, respectively (Table 29).

Table 29. Feed digestibility (%) estimates for sheep and goat sub-categories, 2018

Species	System	Sub-category	DE%
Sheep	Mixed crop livestock system	Breeding ewes (>2 yrs)	54.39%
		Mature male (>2 years)	54.39%
		female (1-2 yrs)	54.39%
		Male (1-2 years)	54.39%
		Intact male lambs (< 1 yr)	54.39%
		Castrated male lambs (< 1 yr)	54.39%
		Female lambs (< 1 yr)	54.39%
	Pastoral and agropastoral system	Breeding ewes (>2 yrs)	54.89%
		Mature male (>2 years)	54.89%
		female (1-2 yrs)	54.89%
		Male (1-2 years)	54.89%
		Intact male lambs (< 1 yr)	54.89%
		Castrated male lambs (< 1 yr)	54.89%
		Female lambs (< 1 yr)	54.89%
Goats	Mixed crop livestock system	Adult does (2+ years)	54.39%
		Bucks (2+ years)	54.39%
		Yearlings (1-2 yrs)	54.39%
		Kids (male & female, <1 yr)	54.39%
	Pastoral and agropastoral system	Adult does (2+ years)	54.89%
		Bucks (2+ years)	54.89%
		Yearlings (1-2 yrs)	54.89%
		Kids (male & female, <1 yr)	54.89%

2.3.10 Calculation of gross energy

Gross energy was calculated using IPCC (2006) equations 10.14-10.16. Gross energy for each sub-category of sheep and goats are shown in Table 30 and Table 31.

2.3.11 Calculation of emission factors

The emission factors were calculated using IPCC (2006) Equation 10.21. The value for the methane conversion factors used for sheep and goats were the IPCC default values from IPCC (2019), Table 10.13, i.e. 6.7% for sheep and 5.5% for goats. The resulting emission factors and implied emission factors (i.e. population-weighted emission factors) for each year are shown in Table 32 and Table 33. There is little variation in the emission factors for each sub-category of sheep or goat throughout the time series, with coefficients of variation of <1.2% for all sub-categories. Implied emission factors are slightly more variable (CV between 1.2% and 1.3%) because of variation in the structure of the national flock. For example, after the 2002-2003 drought, the proportion of breeding females among sheep in pastoral/agro-pastoral areas increased, while the proportion of adult males and younger females decreased, as a result of which the implied emission factor has been declining over time.

The calculated emission factors for sheep and goats are higher than the IPCC Tier 1 default emission factors for sheep in the IPCC (2006) Guidelines (i.e., 5 kg CH_4 head^{-1} year^{-1} in developing countries assuming a higher body weight of 45 kg) and in the IPCC (2019) Refinement (i.e., 5 kg CH_4 head^{-1} year^{-1} in low productivity systems assuming live weights of 31 kg for sheep and 28 kg for goats). The other assumptions underlying the IPCC default emission factors for sheep are not fully described, but it is likely that feed digestibility estimates in this inventory are lower than the default assumptions used to calculate the IPCC default values, resulting in higher methane emissions. For goats, IPCC (2019) Annex 10B.3 describes some assumptions underlying the default emission factors. The weighted average gross energy estimates in this inventory are higher than the mean estimate used to derive the IPCC default factor (i.e., 16.4 MJ day^{-1} compared to 15.2 MJ day^{-1}), probably because of lower feed digestibility in this inventory.

Table 30. Gross energy for sheep sub-categories, 1994-2018 (MJ $head^{-1}$ day^{-1})

	Mixed crop-livestock							Pastoral/agro-pastoral						
Year	Breeding ewes (>2 yrs)	Mature male (>2 years)	female (1-2 yrs)	Male (1-2 years)	Intact male (< 1 yr)	Castrated male (< 1 yr)	Female lamb (< 1 yr)	Breeding ewes (>2 yrs)	Mature male (>2 years)	female (1-2 yrs)	Male (1-2 years)	Intact male (< 1 yr)	Castrated male (< 1 yr)	Female lamb (< 1 yr)
1994	15.10	13.71	16.47	17.85	17.15	16.34	15.06	16.18	15.46	17.91	21.51	19.61	18.70	17.36
1995	15.14	13.71	16.47	17.85	17.15	16.34	15.06	16.21	15.46	17.91	21.51	19.61	18.70	17.36
1996	15.21	13.71	16.47	17.85	17.15	16.34	15.06	16.27	15.46	17.91	21.51	19.61	18.70	17.36
1997	15.23	13.71	16.47	17.85	17.15	16.34	15.06	16.27	15.46	17.91	21.51	19.61	18.70	17.36
1998	15.25	13.71	16.47	17.85	17.15	16.34	15.06	16.26	15.46	17.91	21.51	19.61	18.70	17.36
1999	15.28	13.71	16.47	17.85	17.15	16.34	15.06	16.26	15.46	17.91	21.51	19.61	18.70	17.36
2000	15.31	13.71	16.47	17.85	17.15	16.34	15.06	16.25	15.46	17.91	21.51	19.61	18.70	17.36
2001	15.34	13.71	16.47	17.85	17.15	16.34	15.06	16.24	15.46	17.91	21.51	19.61	18.70	17.36
2002	15.37	13.71	16.47	17.85	17.15	16.34	15.06	16.24	15.46	17.91	21.51	19.61	18.70	17.36
2003	15.40	13.71	16.47	17.85	17.15	16.34	15.06	16.23	15.46	17.91	21.51	19.61	18.71	17.36
2004	15.41	13.71	16.47	17.85	17.15	16.34	15.06	16.13	15.46	17.91	21.51	19.61	18.71	17.36
2005	15.58	13.71	16.47	17.85	17.15	16.34	15.06	16.31	15.46	17.91	21.51	19.61	18.71	17.36
2006	15.47	13.71	16.47	17.85	17.15	16.34	15.06	16.20	15.46	17.91	21.51	19.61	18.71	17.36
2007	15.33	13.71	16.47	17.85	17.15	16.34	15.06	16.10	15.46	17.91	21.51	19.61	18.71	17.36
2008	15.17	13.71	16.47	17.85	17.15	16.34	15.06	16.09	15.46	17.91	21.51	19.61	18.71	17.36
2009	15.16	13.71	16.47	17.85	17.15	16.34	15.06	15.79	15.46	17.91	21.51	19.61	18.71	17.36
2010	15.43	13.71	16.47	17.85	17.15	16.34	15.06	15.93	15.46	17.91	21.51	19.61	18.71	17.36
2011	15.44	13.71	16.47	17.85	17.15	16.34	15.06	15.91	15.46	17.91	21.51	19.61	18.71	17.36
2012	15.45	13.71	16.47	17.85	17.15	16.34	15.06	15.84	15.46	17.91	21.51	19.61	18.71	17.36
2013	15.34	13.71	16.47	17.85	17.15	16.34	15.06	15.95	15.46	17.91	21.51	19.61	18.71	17.36
2014	15.52	13.71	16.47	17.85	17.15	16.34	15.06	15.89	15.46	17.91	21.51	19.61	18.71	17.36
2015	15.37	13.71	16.47	17.85	17.15	16.34	15.06	15.68	15.46	17.91	21.51	19.61	18.71	17.36
2016	15.48	13.71	16.47	17.85	17.15	16.34	15.06	15.98	15.46	17.91	21.51	19.61	18.71	17.36
2017	15.51	13.71	16.47	17.85	17.15	16.34	15.06	15.85	15.46	17.91	21.51	19.61	18.71	17.36
2018	15.24	13.71	16.47	17.85	17.15	16.34	15.06	15.81	15.46	17.91	21.51	19.61	18.71	17.36

Table 31. Gross energy for goat sub-categories, 1994-2018 (MJ head^{-1} day^{-1})

Year	Mixed crop livestock				Pastoral / agro-pastoral			
	Adult does (2+ years)	Bucks (2+ years)	Yearlings (1-2 yrs)	Kids (male & female, <1 yr)	Adult does (2+ years)	Bucks (2+ years)	Yearlings (1-2 yrs)	Kids (male & female, <1 yr)
1994	18.52	17.70	24.57	10.59	19.77	18.19	26.55	9.44
1995	18.54	17.70	24.57	10.59	19.80	18.19	26.55	9.44
1996	18.57	17.70	24.57	10.59	19.86	18.19	26.55	9.44
1997	18.60	17.70	24.57	10.59	19.91	18.19	26.55	9.44
1998	18.65	17.70	24.57	10.59	19.89	18.19	26.55	9.44
1999	18.69	17.70	24.57	10.59	19.87	18.19	26.55	9.44
2000	18.74	17.70	24.57	10.59	19.85	18.19	26.55	9.44
2001	18.79	17.70	24.57	10.59	19.83	18.19	26.55	9.44
2002	18.83	17.70	24.57	10.59	19.80	18.19	26.55	9.44
2003	18.88	17.70	24.57	10.59	19.78	18.19	26.55	9.44
2004	18.67	17.70	24.57	10.59	19.73	18.19	26.55	9.44
2005	18.87	17.70	24.57	10.59	19.82	18.19	26.55	9.44
2006	18.75	17.70	24.57	10.59	19.59	18.19	26.55	9.44
2007	18.66	17.70	24.57	10.59	19.67	18.19	26.55	9.44
2008	18.70	17.70	24.57	10.59	19.56	18.19	26.55	9.44
2009	18.53	17.70	24.57	10.59	19.51	18.19	26.55	9.44
2010	18.64	17.70	24.57	10.59	19.61	18.19	26.55	9.44
2011	18.94	17.70	24.57	10.59	19.56	18.19	26.55	9.44
2012	18.77	17.70	24.57	10.59	19.34	18.19	26.55	9.44
2013	18.70	17.70	24.57	10.59	19.42	18.19	26.55	9.44
2014	18.83	17.70	24.57	10.59	19.41	18.19	26.55	9.44
2015	18.79	17.70	24.57	10.59	19.37	18.19	26.55	9.44
2016	18.79	17.70	24.57	10.59	19.46	18.19	26.55	9.44
2017	18.83	17.70	24.57	10.59	19.42	18.19	26.55	9.44
2018	18.75	17.70	24.57	10.59	19.37	18.19	26.55	9.44

Table 32. Emission factor for sheep sub-categories, 1994-2018 (kg CH_4 head^{-1} year^{-1})

Year	Mixed crop livestock								Pastoral / agro-pastoral							
	Breeding ewes (>2 yrs)	Mature male (>2 yrs)	female (1-2 yrs)	Male (1-2 yrs)	Intact male (< 1 yr)	Castrat-ed male (< 1 yr)	Female lamb (< 1yr)	National implied emission factor	Breeding ewes (>2 yrs)	Mature male (>2 yrs)	female (1-2 yrs)	Male (1-2 yrs)	Intact male (< 1 yr)	Castrat-ed male (< 1 yr)	Female lamb (< 1 yr)	National implied emission factor
1994	6.64	6.02	7.24	7.84	7.54	7.18	6.62	6.84	7.11	6.79	7.87	9.45	8.62	8.22	7.63	7.68
1995	6.65	6.02	7.24	7.84	7.54	7.18	6.62	6.85	7.12	6.79	7.87	9.45	8.62	8.22	7.63	7.69
1996	6.68	6.02	7.24	7.84	7.54	7.18	6.62	6.85	7.15	6.79	7.87	9.45	8.62	8.22	7.63	7.62
1997	6.69	6.02	7.24	7.84	7.54	7.18	6.62	6.85	7.15	6.79	7.87	9.45	8.62	8.22	7.63	7.62
1998	6.70	6.02	7.24	7.84	7.54	7.18	6.62	6.86	7.15	6.79	7.87	9.45	8.62	8.22	7.63	7.62
1999	6.72	6.02	7.24	7.84	7.54	7.18	6.62	6.87	7.14	6.79	7.87	9.45	8.62	8.22	7.63	7.62
2000	6.73	6.02	7.24	7.84	7.54	7.18	6.62	6.87	7.14	6.79	7.87	9.45	8.62	8.22	7.63	7.62
2001	6.74	6.02	7.24	7.84	7.54	7.18	6.62	6.88	7.14	6.79	7.87	9.45	8.62	8.22	7.63	7.62
2002	6.75	6.02	7.24	7.84	7.54	7.18	6.62	6.88	7.13	6.79	7.87	9.45	8.62	8.22	7.63	7.63
2003	6.77	6.02	7.24	7.84	7.54	7.18	6.62	6.90	7.13	6.79	7.87	9.45	8.62	8.22	7.63	7.62
2004	6.77	6.02	7.24	7.84	7.54	7.18	6.62	6.90	7.09	6.79	7.87	9.45	8.62	8.22	7.63	7.58
2005	6.85	6.02	7.24	7.84	7.54	7.18	6.62	6.94	7.17	6.79	7.87	9.45	8.62	8.22	7.63	7.62
2006	6.80	6.02	7.24	7.84	7.54	7.18	6.62	6.92	7.12	6.79	7.87	9.45	8.62	8.22	7.63	7.61
2007	6.73	6.02	7.24	7.84	7.54	7.18	6.62	6.88	7.07	6.79	7.87	9.45	8.62	8.22	7.63	7.57
2008	6.67	6.02	7.24	7.84	7.54	7.18	6.62	6.83	7.07	6.79	7.87	9.45	8.62	8.22	7.63	7.57
2009	6.66	6.02	7.24	7.84	7.54	7.18	6.62	6.84	6.94	6.79	7.87	9.45	8.62	8.22	7.63	7.47
2010	6.78	6.02	7.24	7.84	7.54	7.18	6.62	6.90	7.00	6.79	7.87	9.45	8.62	8.22	7.63	7.53
2011	6.78	6.02	7.24	7.84	7.54	7.18	6.62	6.91	6.99	6.79	7.87	9.45	8.62	8.22	7.63	7.53
2012	6.79	6.02	7.24	7.84	7.54	7.18	6.62	6.91	6.96	6.79	7.87	9.45	8.62	8.22	7.63	7.48
2013	6.74	6.02	7.24	7.84	7.54	7.18	6.62	6.89	7.01	6.79	7.87	9.45	8.62	8.22	7.63	7.54
2014	6.82	6.02	7.24	7.84	7.54	7.18	6.62	6.93	6.98	6.79	7.87	9.45	8.62	8.22	7.63	7.52
2015	6.75	6.02	7.24	7.84	7.54	7.18	6.62	6.89	6.89	6.79	7.87	9.45	8.62	8.22	7.63	7.42
2016	6.80	6.02	7.24	7.84	7.54	7.18	6.62	6.92	7.02	6.79	7.87	9.45	8.62	8.22	7.63	7.51
2017	6.82	6.02	7.24	7.84	7.54	7.18	6.62	6.93	6.97	6.79	7.87	9.45	8.62	8.22	7.63	7.47
2018	6.70	6.02	7.24	7.84	7.54	7.18	6.62	6.88	6.95	6.79	7.87	9.45	8.62	8.22	7.63	7.42

Table 33. Emission factor for goat sub-categories, 1994-2018 (kg CH_4 head^{-1} year^{-1})

Year	Mixed crop livestock					Pastoral / agro-pastoral				
	Adult does (2+ yrs)	Bucks (2+ yrs)	Yearlings (1-2 yrs)	Kids (male & female, <1 yr)	National implied emission factor	Adult does (2+ years)	Bucks (2+ years)	Yearlings (1-2 yrs)	Kids (male & female, <1 yr)	National implied emission factor
1994	6.68	6.39	8.86	3.82	5.91	7.13	6.56	9.58	3.41	6.17
1995	6.69	6.39	8.86	3.82	5.92	7.14	6.56	9.58	3.41	6.18
1996	6.70	6.39	8.86	3.82	5.84	7.16	6.56	9.58	3.41	6.04
1997	6.71	6.39	8.86	3.82	5.85	7.18	6.56	9.58	3.41	6.05
1998	6.73	6.39	8.86	3.82	5.85	7.18	6.56	9.58	3.41	6.06
1999	6.74	6.39	8.86	3.82	5.86	7.17	6.56	9.58	3.41	6.06
2000	6.76	6.39	8.86	3.82	5.87	7.16	6.56	9.58	3.41	6.06
2001	6.78	6.39	8.86	3.82	5.87	7.15	6.56	9.58	3.41	6.06
2002	6.79	6.39	8.86	3.82	5.68	7.14	6.56	9.58	3.41	5.87
2003	6.81	6.39	8.86	3.82	5.69	7.14	6.56	9.58	3.41	5.89
2004	6.74	6.39	8.86	3.82	5.73	7.12	6.56	9.58	3.41	5.96
2005	6.81	6.39	8.86	3.82	5.73	7.15	6.56	9.58	3.41	5.94
2006	6.76	6.39	8.86	3.82	5.75	7.07	6.56	9.58	3.41	6.03
2007	6.73	6.39	8.86	3.82	5.78	7.09	6.56	9.58	3.41	6.04
2008	6.75	6.39	8.86	3.82	5.77	7.06	6.56	9.58	3.41	6.05
2009	6.69	6.39	8.86	3.82	5.85	7.04	6.56	9.58	3.41	6.11
2010	6.72	6.39	8.86	3.82	5.76	7.07	6.56	9.58	3.41	6.04
2011	6.83	6.39	8.86	3.82	5.69	7.05	6.56	9.58	3.41	6.08
2012	6.77	6.39	8.86	3.82	5.73	6.98	6.56	9.58	3.41	6.11
2013	6.75	6.39	8.86	3.82	5.72	7.00	6.56	9.58	3.41	6.07
2014	6.79	6.39	8.86	3.82	5.70	7.00	6.56	9.58	3.41	6.08
2015	6.78	6.39	8.86	3.82	5.71	6.99	6.56	9.58	3.41	6.07
2016	6.78	6.39	8.86	3.82	5.69	7.02	6.56	9.58	3.41	6.14
2017	6.79	6.39	8.86	3.82	5.71	7.00	6.56	9.58	3.41	6.18
2018	6.76	6.39	8.86	3.82	5.75	6.99	6.56	9.58	3.41	6.13

2.3.12 Uncertainties and time-series consistency

For sheep and goats, specific uncertainty analysis was conducted for the population data. This analysis is described in Annex 6. The results suggest that uncertainty of population activity data in 2018 was ±7.81% for sheep and ±10.16% for goats. Uncertainty of the emission factors was not analyzed specifically for this inventory. IPCC (2006) suggests that Tier 2 emission factors are likely to have an uncertainty in the order of ±20%. Given that the cattle emission factor uncertainty was slightly lower than this value, it may be reasonable to assume uncertainty of ±20% for sheep and goat emission factors.

Within each production system, consistent methods have been used to estimate the time series for enteric fermentation emissions.

2.3.13 Source-specific QAQC and verification

Tier 1 and Tier 2 QAQC activities have been implemented. This inventory was compiled in an Excel spreadsheet. Quality control activities included:

- Checking that the equations programmed in the spreadsheet were correctly input
- Checking that inputs to summed totals were obtained from the correct fields
- Checking that all data sources were fully documented
- Checking that the figures in the inventory spreadsheet were correctly transcribed from prior worksheets
- Checking that the figures in the inventory report were correctly transcribed
- Reconstructing a number of the calculations to cross-check the intermediate calculations and results in the inventory spreadsheet.

QAQC activities identified and addressed the following issues:

- Implied emission factors disaggregated by production system were not presented in the inventory report for all animal categories, which has now been rectified;
- The calculation of implied emission factors had errors, which have now been rectified;
- Inconsistent values were reported for WG_{wean} between the table in the text and the table in the relevant annex, which has now been rectified;
- Data sources were not given for relevant tables in the inventory report and this has now been rectified.

The inventory was also reviewed by members of the Tier 2 livestock inventory advisory group and all comments and queries have been responded to and addressed in the revised inventory report. Most comments related to increasing the transparency of emission estimates and explaining the reason for trends in input parameters and emission factors.

For verification, the estimated emission factors for sheep and goat were compared with IPCC default values. In this inventory, implied emission factors averaged across the time series were 7.1 kg CH_4 head^{-1} year^{-1} and 5.9 kg CH_4 head^{-1} year^{-1} for sheep and goats, respectively. Compared with the generic Tier 1 emission factor of 5 kg CH_4 head^{-1} year^{-1} proposed by the IPCC for small ruminants in the Sub-Saharan Africa region, the estimated inventory values are 42% and 18% higher for sheep and goat, respectively. The IPCC (2006) estimate for sheep and goats of 5 kg CH_4 head^{-1} year^{-1} was based on a review paper that cited no data on sheep from developing countries but assumed average live weight of 45 kg, while gross energy intake for goats in developing countries was taken from one cited paper. The IPCC (2019) estimate derived from the GLEAM model, but the input data are not available for comparison.

Emission factors for small ruminants in Sub-Saharan Africa have been estimated by du Toit et al. (2013) and Ndao et al. (2018). Du Toit et al. (2013) estimated averages of 8.5 and 6.1 kg CH_4 head^{-1} year^{-1} for sheep in commercial and communal production systems in South Africa, assuming average LWs of 59 kg for commercial and 44.5 kg in communal production systems. They also estimated emission factors of 10.1 and 6.3 kg CH_4 head^{-1} year^{-1} for goats in the commercial and communal production systems, respectively. Ndao et al. (2018) estimated mean emission factors in Senegal of 2.3 kg CH_4 head^{-1} year^{-1} for sheep and 2.0 kg CH_4 head^{-1} year^{-1} for goats. However, the LWs in Senegal are lower than those estimated in this inventory, in addition to which the proportion of breeding females in the herd was lower than in this inventory, so the population-weighted average is more heavily influenced by younger animals. Methodologies and assumptions vary among these studies. The study in Senegal used the IPCC methodology, but that in South Africa used a method based on Australian gross energy equations. Methane conversion factors also varied: this inventory used 6.7% for sheep, Ndao et al. (2018) used 6.5% and du Toit et al. (2013) used an equation from Australian studies. Figure 7 compares the relationship between LW and emission factors in this inventory with the relationships shown in other studies in Africa and with the IPCC default value.

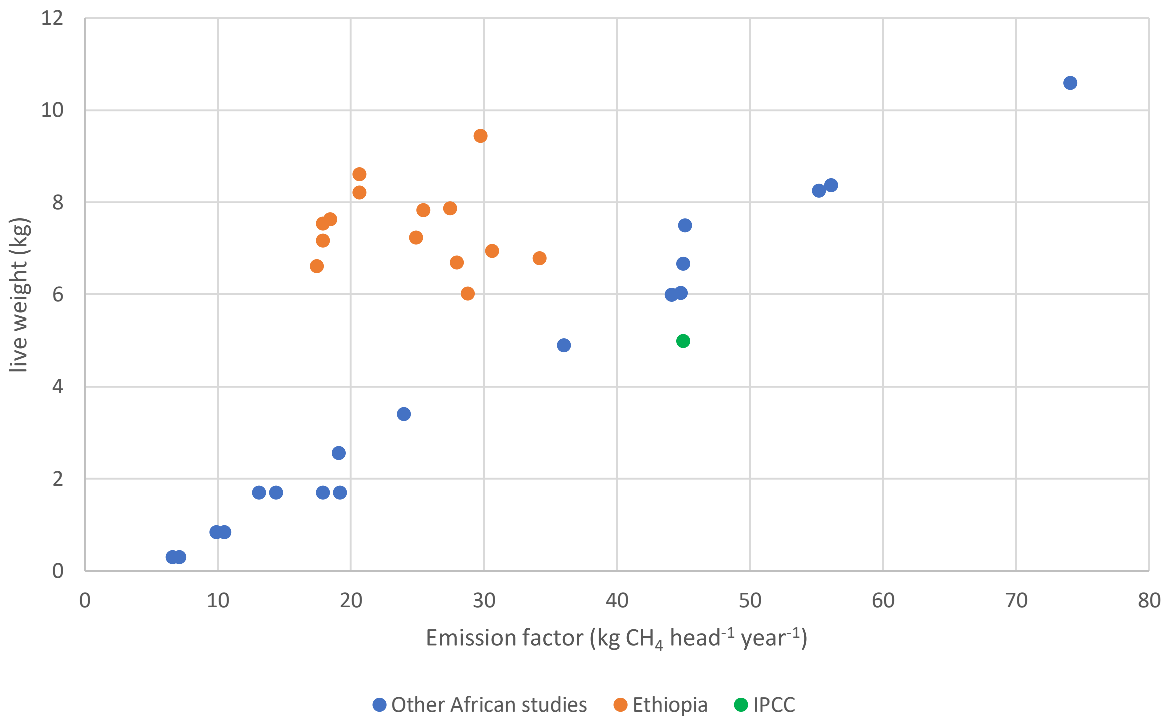

Figure 7. Comparison of sheep emission factors with emission factors from Africa and the IPCC default value

2.4 Source-specific recalculations

Ethiopia's SNC was submitted in 2015 and reports inventory emissions from 1994 to 2013 using the Tier 1 methodology from the 1996 Revised Guidelines (MEF 2015). Dairy cattle were not estimated separately from other cattle. The emission factors used were 31 kg CH_4 head^{-1} year^{-1} for all cattle, and 5 kg CH_4 head^{-1} year^{-1} for sheep and goats. The SNC Tier 1 time series was reconstructed using population data provided by the EFCCC and used to recalculate the Tier 1 emissions time series (see Annex 8). The Tier 1 time series for cattle enteric fermentation emissions are compared with the time series in this Tier 2 inventory (Table 34). Similar comparisons are presented for enteric fermentation from sheep and goats (Table 35).

Cattle enteric fermentation emissions calculated using the EFCCC activity data and Tier 1 method are 60%-70% lower than when using the revised population data and Tier 2 method in this inventory. The reasons for this are:

(a) The cattle population estimates in this Tier 2 inventory are on average 5.8% greater over the 1994-2013 time series than the activity data provided by EFCCC. This is because this inventory filled some data gaps and estimated cattle populations not reported in CSA data.

(b) The Tier 2 implied emission factors over the 1994-2013 time series are ~55% higher than the Tier 1 emission factor for other cattle, and ~67% higher for dairy cattle.

For sheep and goats, the estimated enteric fermentation emissions in this inventory are on average 57% higher than when estimated using the EFCCC population data and Tier 1 emission factors. This is due to:

(a) Differences in population data: the sheep and goat population in the Tier 2 inventory is on average 20% greater than the population in the EFCCC data due to gap filling CSA data and reporting sheep and goats in pastoral regions not reported in CSA data; and

(b) The implied emission factors for sheep are on average 17% higher than the IPCC default value and for goats they are 62% higher.

Table 34. Recalculated estimates of enteric fermentation from cattle, 1994-2013 (Gg CH_4)

Year	Tier 1	Tier 2, this inventory
1994	912.95	1453.96
1995	924.58	1567.07
1996	967.42	1637.03
1997	1096.52	1747.41
1998	1096.52	1752.00
1999	1087.95	1672.58
2000	1025.34	1782.23
2001	1096.88	2139.65
2002	1259.80	1825.49
2003	1209.00	1877.90
2004	1201.23	1947.28
2005	1252.09	2043.51
2006	1336.86	2173.62
2007	1519.00	2361.42
2008	1519.00	2469.82
2009	1577.40	2595.93
2010	1654.85	2718.07
2011	1616.00	2654.57
2012	1673.69	2795.67
2013	1674.00	2849.73

Table 35. Recalculated estimates of enteric fermentation from sheep and goat, 1994-2013 (Gg CH_4)

Year	Tier 1 with SNC population data	Tier 2, this inventory
1994	96.10	161.94
1995	96.00	163.07
1996	101.75	182.83
1997	119.44	182.76
1998	119.44	171.62
1999	108.90	161.97
2000	97.74	168.61
2001	105.30	258.90
2002	126.61	237.14
2003	140.00	214.18
2004	164.63	229.57
2005	185.49	257.68
2006	210.96	297.02
2007	239.13	332.07
2008	239.58	325.59
2009	239.70	335.32
2010	241.48	345.46
2011	234.17	333.34
2012	247.75	359.72
2013	257.50	401.27

3


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Manure management (Category 3A2)

3. Manure management (Category 3A2)

3.1 Source category description

Emissions sources	Sources included	Method	Emission factors
3A2ai	Dairy cattle manure management	T2	CS
3A2aii	Other cattle manure management	T2	CS
3A2c	Sheep manure management	T2	CS
3A2d	Goat manure management	T2	CS
Gases reported	CH_4, N_2O		
Completeness	All cattle, sheep and goats are accounted for. No known omissions.		
Improvements since last submission	This is the first inventory for dairy and other cattle, sheep and goats that uses a Tier 2 approach.		

This category reports emissions of CH_4 and direct N_2O emissions from management of manure from dairy and other cattle, sheep and goats. Data on manure management in Ethiopia is extremely limited (see Annex 5). The main types of manure management systems identified were:

- Daily spread: Manure is removed daily from where animals are kept and applied to fodder or food crops.
- Solid storage (i.e. manure is stored in heaps in or near the farm yard).
- Compost: Manure and other organic material in bedding is composted.
- Liquid slurry: Manure is stored in pits which may also be inundated with water
- Burned for fuel.
- Biogas.
- Deposited on pasture.

For sheep and goats, drylot management was also identified.

Manure management emissions reported in this category include CH_4 and N_2O emissions from all these manure management systems, except

- Methane emissions from 'burned for fuel', which is to be reported in the energy sector inventory; and
- Direct N_2O emissions from deposit of dung and urine on pasture, range or paddock, which is reported in Chapter 5 (reporting category 3C4), because it is classified as contributing to the 'N_2O emissions from managed soils' category.

These manure management systems may be associated with different housing types (e.g. traditional or improved kraals and zero-grazing units), but this association is currently not well documented. Specific manure management practices have also not been documented in detail in Ethiopia and Annex 5 describes the data sources and assumptions used to estimate the proportion of manure managed in different manure management systems.

3.2 Manure management emissions from cattle (Category 3A2a)

3.2.1 Methane emissions from cattle

Methane is produced by the decomposition of manure under anaerobic conditions. When stored in liquid or slurry form, anaerobic decomposition is greater and more methane is released, and when stored as a solid less methane is stored. Therefore, the manure management system used affects methane emission rates. The emission factors for manure management are calculated using the IPCC Tier 2 methodology using IPCC (2006) Equation 10.23:

$$EF_T = (VS_T \times 365) \times \left(B_{o,T} \times 0.67\ kg/m^3 \times \sum_{S,k} \frac{MCF_{S,k}}{100} \times MS_{T,S,k} \right)$$

where:

EF_T is the emission factor for a specific animal sub-category, T, kg CH_4 head^{-1} year^{-1}

VS_T is daily volatile solids excreted by animal sub-category, T, kg dry matter head^{-1} year^{-1}

$B_{o,T}$ is the maximum methane producing capacity for manure produced by sub-category T, m^3 CH_4 per kg VS excreted

0.67 is the conversion factor of m^3 CH_4 to kg CH_4

$MCF_{S,k}$ is the methane conversion factors for each manure management system, *S*, by climate region, *k*, %

$MS_{T,S,k}$ is the fraction of manure from livestock sub-category T handled using manure management system *S* in climate region *k*, dimensionless

The value of VS is estimated using IPCC (2006) Equation 10.24:

$$VS = \left[GE \times \left(1 - \frac{DE\%}{100}\right) + (UE \times GE)\right] \times \left[\frac{1 - ASH}{18.45}\right]$$

where:

GE is gross energy intake, MJ day^{-1}, as calculated in the enteric fermentation equations above

DE% is digestibility of feed as used in the enteric fermentation equations above

UE X GE is urinary energy expressed as a fraction of GE, assumed to be 0.04GE (IPCC 2006)

ASH is the ash content of manure, assumed to be 0.08 (IPCC 2006)

18.45 is the conversion factor for dietary GE per kg dry matter (MJ kg^{-1}).

No country specific data was identified for B_o or MCF. For B_o, the IPCC (2019) default value of 0.24 for dairy cows and 0.13 for all other dairy and other cattle were used (IPCC 2019, Table 10.16). For MCF values, the IPCC default values (IPCC 2019, Table 10.17) were used, assuming a tropical montane climate for the dairy and mixed crop-livestock systems and a tropical dry climate for the pastoral/agro-pastoral system (Table 36). Country specific manure management system activity data ($MS_{T,S,k}$) were estimated using data and methods described in Annex 5. Manure management system activity data available for this inventory did not vary between sub-categories within each production system. The implied emission factors for manure management methane emissions thus derived for each production system are shown in Table 37 and Table 38. The time series for methane emissions from cattle manure management is shown in Table 39.

Table 36. Manure management methane conversion factors

Manure management system	MCF value	Source
Compost	2.5%	IPCC (2019) Table 10.17
Solid storage	5%	IPCC (2019) Table 10.17
Liquid storage, 12 months	73%	IPCC (2019) Table 10.17
Daily spread	1%	IPCC (2019) Table 10.17
Burned for fuel	10%	IPCC (2019) Table 10.17
Biogas digesters	10%	IPCC (2019) Table 10A.11*
Pasture	0.47%	IPCC (2019) Table 10.17

*Assuming low quality biogas digesters, with low quality gas-tight storage. Note: The MCF is the percentage of the maximum methane production potential (B_o) that is achieved, and is specific to each manure management system. Therefore, the figures in the second column in this table cannot be added together.

Table 37: Manure management methane implied emission factors for dairy cattle in each production system, 1994-2018 (kg CH_4 $head^{-1}$ $year^{-1}$)

	Commercial dairy production system							Smallholder dairy production system						
Year	Adult cows >3 years	Adult males (3-10 years)	Calves < 6 months (male & female)	Calves 6 m-1 year (male & female)	Growing males 1-3 years	Growing females 1-3 years	National implied emission factor	Adult cows >3 years	Adult males used for breeding (3-10 years)	Calves < 6 months (male & female)	Calves 6 m-1 year (male & female)	Growing males 1-3 years	Growing females 1-3 years	National implied emission factor
1994	20.36	7.46	1.11	1.77	6.45	6.12	12.51	20.36	7.88	6.86	1.11	1.77	6.74	13.86
1995	20.45	7.46	1.11	1.77	6.45	6.12	12.56	20.45	7.88	6.86	1.11	1.77	6.74	13.91
1996	20.54	7.46	1.11	1.77	6.45	6.12	12.61	20.54	7.87	6.85	1.11	1.77	6.73	13.97
1997	20.64	7.46	1.11	1.77	6.45	6.12	12.65	20.64	7.87	6.85	1.11	1.77	6.73	14.02
1998	20.73	7.46	1.11	1.77	6.45	6.12	12.70	20.73	7.87	6.84	1.11	1.77	6.73	14.08
1999	20.83	7.46	1.11	1.77	6.45	6.12	12.75	20.83	7.86	6.84	1.11	1.77	6.73	14.13
2000	20.93	7.46	1.11	1.77	6.45	6.12	12.80	20.93	7.86	6.84	1.11	1.77	6.72	14.19
2001	21.03	7.46	1.11	1.77	6.45	6.12	12.85	21.03	7.85	6.83	1.11	1.77	6.72	14.25
2002	21.14	7.46	1.11	1.77	6.45	6.12	12.91	21.14	7.85	6.83	1.11	1.77	6.72	14.31
2003	21.25	7.47	1.11	1.77	6.45	6.13	12.96	21.25	7.85	6.83	1.11	1.77	6.72	14.38
2004	21.35	7.46	1.11	1.77	6.45	6.12	13.01	21.35	7.84	6.82	1.11	1.77	6.71	14.43
2005	21.47	7.47	1.11	1.77	6.45	6.13	13.08	21.47	7.84	6.83	1.11	1.77	6.71	14.51
2006	21.58	7.47	1.11	1.77	6.45	6.13	13.13	21.58	7.84	6.82	1.11	1.77	6.71	14.57
2007	21.67	7.46	1.11	1.77	6.44	6.12	13.18	21.67	7.82	6.81	1.11	1.77	6.70	14.62
2008	21.79	7.46	1.11	1.77	6.44	6.12	13.24	21.79	7.82	6.81	1.11	1.77	6.70	14.69
2009	21.97	7.48	1.11	1.78	6.43	6.14	13.32	21.97	7.84	6.82	1.11	1.78	6.71	14.78
2010	22.16	7.50	1.11	1.78	6.42	6.16	13.40	22.16	7.86	6.84	1.11	1.78	6.73	14.88
2011	22.35	7.53	1.12	1.79	6.41	6.18	13.49	22.35	7.88	6.86	1.12	1.79	6.75	14.98
2012	22.52	7.54	1.12	1.79	6.39	6.19	13.57	22.52	7.89	6.87	1.12	1.79	6.76	15.06
2013	22.63	7.56	1.12	1.79	6.37	6.20	13.61	22.63	7.90	6.88	1.12	1.79	6.77	15.11
2014	22.76	7.58	1.12	1.80	6.36	6.22	13.66	22.76	7.92	6.89	1.12	1.80	6.78	15.17
2015	22.89	7.59	1.13	1.80	6.35	6.23	13.71	22.89	7.93	6.90	1.13	1.80	6.80	15.23
2016	23.02	7.61	1.13	1.81	6.33	6.25	13.77	23.02	7.95	6.92	1.13	1.81	6.81	15.29
2017	23.16	7.63	1.13	1.81	6.32	6.26	13.82	23.16	7.97	6.93	1.13	1.81	6.83	15.36
2018	23.30	7.66	1.14	1.82	6.61	6.28	13.89	23.30	7.99	6.95	1.14	1.82	6.84	15.43

Table 38. Manure management methane implied emission factors for other cattle in each production system, 1994-2018 (kg CH_4 head-1 year-1)

	Pastoral and agro-pastoral system								Mixed crop-livestock system									
Year	Adult multi-purpose cows >3 years	Adult males used for draught (3-10 years)	Adult males used for breeding & other purpose (>3-10 years)	Calves < 6 months (male & female)	Calves 6 m-1 year (male & female)	Growing males 1-3 years	Growing females 1-3 years	National implied emission factor	Adult multipurpose cows >3 years	Adult males used for draught (3-10 years)	Adult males used for breeding & other purpose (>3-10 years)	Calves < 6 months (male & female)	Calves 6 m-1 year (male & female)	Growing males 1-3 years	Growing females 1-3 years	Small-holder fattening male	Commercial feedlot fed male	National implied emission factor
1994	3.33	3.55	3.78	0.66	1.01	3.17	2.53	2.75	3.88	4.27	4.50	0.74	1.05	3.92	3.01	3.45	3.64	3.48
1995	3.34	3.54	3.78	0.66	1.01	3.17	2.53	2.75	3.88	4.27	4.50	0.74	1.05	3.92	3.01	3.45	3.64	3.48
1996	3.34	3.54	3.78	0.66	1.01	3.17	2.53	2.68	3.89	4.26	4.50	0.74	1.05	3.92	3.01	3.45	3.64	3.41
1997	3.36	3.53	3.78	0.66	1.01	3.17	2.53	2.68	3.91	4.26	4.50	0.74	1.05	3.92	3.01	3.44	3.64	3.42
1998	3.39	3.53	3.77	0.66	1.01	3.17	2.53	2.69	3.95	4.25	4.49	0.74	1.05	3.92	3.01	3.44	3.63	3.43
1999	3.42	3.53	3.77	0.66	1.01	3.17	2.53	2.71	3.99	4.25	4.49	0.74	1.05	3.91	3.01	3.44	3.63	3.44
2000	3.45	3.52	3.77	0.66	1.01	3.17	2.52	2.72	4.02	4.24	4.49	0.74	1.05	3.91	3.01	3.44	3.63	3.45
2001	3.48	3.52	3.77	0.66	1.01	3.17	2.52	2.73	4.06	4.24	4.49	0.74	1.05	3.91	3.01	3.44	3.63	3.46
2002	3.52	3.52	3.77	0.66	1.01	3.17	2.52	2.74	4.10	4.23	4.49	0.74	1.05	3.91	3.00	3.44	3.63	3.48
2003	3.54	3.51	3.77	0.66	1.01	3.17	2.52	2.73	4.09	4.17	4.43	0.73	1.04	3.86	2.96	3.41	3.63	3.43
2004	3.56	3.51	3.77	0.66	1.01	3.16	2.52	2.76	4.14	4.20	4.46	0.74	1.05	3.89	2.99	3.42	3.63	3.51
2005	3.61	3.51	3.76	0.66	1.01	3.16	2.52	2.79	4.21	4.22	4.49	0.75	1.06	3.92	3.01	3.44	3.63	3.54
2006	3.58	3.50	3.76	0.66	1.01	3.16	2.52	2.81	4.16	4.18	4.45	0.74	1.05	3.88	2.98	3.42	3.63	3.48
2007	3.59	3.50	3.76	0.66	1.01	3.16	2.52	2.77	4.16	4.18	4.45	0.74	1.05	3.88	2.98	3.42	3.62	3.47
2008	3.54	3.49	3.76	0.66	1.01	3.16	2.52	2.76	4.14	4.20	4.47	0.74	1.05	3.90	2.99	3.43	3.62	3.50
2009	3.67	3.49	3.76	0.66	1.01	3.16	2.52	2.85	4.33	4.20	4.48	0.75	1.06	3.91	3.00	3.43	3.62	3.57
2010	3.59	3.49	3.76	0.66	1.01	3.16	2.52	2.82	4.22	4.22	4.50	0.75	1.06	3.93	3.02	3.44	3.62	3.52
2011	3.57	3.48	3.76	0.66	1.01	3.16	2.52	2.79	4.21	4.22	4.50	0.75	1.06	3.93	3.02	3.44	3.62	3.52
2012	3.62	3.48	3.75	0.66	1.01	3.16	2.52	2.84	4.25	4.20	4.49	0.75	1.06	3.92	3.01	3.44	3.62	3.54
2013	3.60	3.48	3.75	0.66	1.01	3.16	2.51	2.81	4.22	4.18	4.47	0.75	1.06	3.90	3.00	3.42	3.62	3.52
2014	3.57	3.47	3.75	0.66	1.01	3.15	2.51	2.81	4.19	4.19	4.48	0.75	1.06	3.91	3.00	3.43	3.62	3.50
2015	3.55	3.47	3.75	0.66	1.01	3.15	2.51	2.85	4.17	4.18	4.48	0.75	1.06	3.91	3.00	3.43	3.62	3.48
2016	3.59	3.47	3.75	0.66	1.01	3.15	2.51	2.84	4.21	4.17	4.47	0.75	1.06	3.90	3.00	3.43	3.61	3.48
2017	3.53	3.46	3.75	0.66	1.01	3.15	2.51	2.80	4.11	4.14	4.44	0.74	1.05	3.87	2.98	3.41	3.61	3.43
2018	3.58	3.46	3.75	0.66	1.01	3.15	2.51	2.80	4.19	4.16	4.47	0.75	1.06	3.90	3.00	3.42	3.61	3.45

Table 39. Methane emissions from manure management from dairy and other cattle, 1994-2018 (Gg CH_4)

	Commercial dairy	Smallholder dairy	Pastoral/agro-pastoral other cattle	Mixed crop livestock other cattle
1994	0.61	2.58	11.32	90.30
1995	0.61	2.78	12.18	97.36
1996	0.61	2.91	15.58	98.15
1997	0.94	3.11	16.32	105.10
1998	1.27	3.10	16.86	104.63
1999	1.61	2.95	16.73	98.95
2000	1.94	3.16	17.17	106.22
2001	2.28	3.77	20.45	127.74
2002	2.63	3.24	17.54	108.66
2003	2.97	3.44	12.14	118.98
2004	3.32	2.92	11.98	124.52
2005	3.68	4.09	12.50	130.76
2006	4.03	4.00	15.46	135.93
2007	4.38	4.72	15.26	149.64
2008	4.75	4.86	15.78	156.83
2009	5.12	4.56	16.64	165.28
2010	5.50	5.83	20.27	169.15
2011	5.88	8.16	19.15	165.28
2012	6.27	8.47	24.10	168.93
2013	6.64	10.72	25.11	170.47
2014	7.02	11.44	27.44	173.53
2015	7.40	12.40	27.95	175.56
2016	7.78	16.28	26.35	181.04
2017	8.17	15.72	26.16	181.50
2018	8.57	19.59	29.19	183.98

3.2.2 Direct N_2O emissions from cattle manure management

Manure also releases nitrous oxide with different rates for different manure management systems. This section only covers the nitrous oxide released during the storage and treatment of manure before it is applied to the land or used elsewhere. Therefore, this section does not include the nitrous emissions from manure deposited directly to pasture. Instead this is accounted for in Chapter 5. Emission factors for direct N_2O emissions were calculated using the IPCC Tier 2 approach by applying IPCC (2006) Equation 10.25:

$$NE_g = 22.02 \times \left(\frac{BW}{C \times MW}\right)^{0.75} \times WG^{1.097}$$

where:

$N_2O_{D(mm)}$ is direct N_2O emissions from manure management, kg N_2O $year^{-1}$

N_T is number of head of cattle sub-category T

Nex_T is average nitrogen excretion per head of sub-category T, kg N $head^{-1}$ $year^{-1}$

$MS_{T,S}$ is fraction of total annual nitrogen excretion for sub-category T that is managed in manure management system *S*, dimensionless

EF_{3S} is emission factor for direct N_2O emissions from manure management system *S*, kg N_2O-N/kg N

44/28 is the conversion of N_2O-N emissions to N_2O emissions.

N excretion was estimated as the balance of N intake and N retention calculated using IPCC (2019) Equations 10.31-10.33. The data sources and values used for crude protein content of the diet (CP%) are shown in Annex 4. Default values for milk protein content (milk PR%) were used (3.5% taken from IPCC 2006, page 10.60). Other values used in these calculations (i.e., GE, milk, WG, NE_g) were the values used in the calculation of methane emissions from enteric fermentation. Estimated nitrogen excretion (N_{ex}) is presented in Table 41 and Table 42.

Manure management system activity data are the same as those used to estimate methane manure management emissions (Annex 5). The emission factors, EF_3, used were the IPCC default emission factors from IPCC (2019) Table 10.21 (Table 40). The resulting time series for direct N_2O emissions is shown in Table 43.

Table 40. Emission factors (EF_3) used in estimating direct N_2O emissions from manure management

Manure management system	EF_3 [kg N_2O-N (kg Nitrogen excreted)$^{-1}$]	Source
Daily spread	0	IPCC 2019 Table 10.21
Solid storage (e.g. heap)	0.010	IPCC 2019 Table 10.21
Dry lot (e.g. periodic removal from confinement area)	0.02	IPCC 2019 Table 10.21
Composted (static pile)	0.010	IPCC 2019 Table 10.21
Liquid (e.g. pit)	0	IPCC 2019 Table 10.21
Biogas	0.0006	IPCC 2019 Table 10.21

Table 41. Nitrogen excretion (kg N head^{-1} year^{-1}) for dairy cattle, 1994-2018

Year	Commercial dairy production system							Smallholder dairy production system							
	Adult cows >3 years	Adult males (3-10 years)	Calves < 6 months (male & female)	Calves 6 m-1 year (male & female)	Growing males 1-3 years	Growing females 1-3 years	National weighted average	Adult cows >3 years	Adult males used for breeding (3-10 years)	Calves < 6 months (male & female)	Calves 6 m-1 year (male & female)	Growing males 1-3 years	Growing females 1-3 years	National weighted average
1994	65.97	50.80	4.67	20.34	41.22	39.27	48.60	65.97	53.64	4.67	20.34	43.21	41.01	51.65
1995	66.16	50.80	4.67	20.34	41.22	39.27	48.70	66.16	53.61	4.67	20.34	43.19	40.99	51.76
1996	66.35	50.80	4.67	20.34	41.22	39.27	48.79	66.35	53.59	4.67	20.34	43.17	40.97	51.86
1997	66.55	50.80	4.67	20.34	41.22	39.27	48.89	66.55	53.56	4.67	20.34	43.15	40.96	51.97
1998	66.74	50.80	4.67	20.34	41.22	39.27	48.99	66.74	53.53	4.67	20.34	43.13	40.94	52.09
1999	66.95	50.80	4.67	20.34	41.22	39.27	49.10	66.95	53.50	4.67	20.34	43.11	40.92	52.20
2000	67.15	50.80	4.67	20.34	41.22	39.27	49.20	67.15	53.48	4.67	20.34	43.09	40.91	52.32
2001	67.36	50.80	4.67	20.34	41.22	39.27	49.31	67.36	53.45	4.67	20.34	43.07	40.89	52.44
2002	67.58	50.80	4.67	20.34	41.22	39.27	49.42	67.58	53.42	4.67	20.34	43.06	40.87	52.56
2003	67.84	50.83	4.67	20.36	41.24	39.29	49.56	67.84	53.42	4.67	20.36	43.06	40.88	52.71
2004	68.07	50.83	4.67	20.36	41.24	39.30	49.68	68.07	53.40	4.67	20.36	43.04	40.86	52.84
2005	68.26	50.81	4.67	20.35	41.23	39.28	49.77	68.26	53.35	4.67	20.35	43.01	40.83	52.95
2006	68.48	50.80	4.67	20.34	41.22	39.27	49.88	68.48	53.32	4.67	20.34	42.98	40.81	53.07
2007	68.68	50.78	4.66	20.33	41.20	39.25	49.97	68.68	53.27	4.66	20.33	42.94	40.77	53.17
2008	68.93	50.79	4.66	20.34	41.21	39.26	50.10	68.93	53.25	4.66	20.34	42.93	40.76	53.32
2009	69.20	50.80	4.67	20.34	41.22	39.27	50.24	69.20	53.23	4.67	20.34	42.92	40.76	53.47
2010	69.41	50.78	4.67	20.33	41.20	39.26	50.35	69.41	53.18	4.67	20.33	42.88	40.72	53.59
2011	69.67	50.78	4.67	20.34	41.20	39.26	50.48	69.67	53.16	4.67	20.34	42.87	40.71	53.74
2012	69.94	50.79	4.67	20.34	41.21	39.26	50.62	69.94	53.14	4.67	20.34	42.86	40.70	53.89
2013	70.07	50.78	4.67	20.33	41.20	39.26	50.68	70.07	53.10	4.67	20.33	42.83	40.67	53.97
2014	70.21	50.78	4.67	20.33	41.20	39.25	50.75	70.21	53.07	4.67	20.33	42.81	40.65	54.04
2015	70.35	50.77	4.67	20.33	41.19	39.25	50.82	70.35	53.04	4.67	20.33	42.78	40.63	54.12
2016	70.50	50.77	4.67	20.33	41.19	39.25	50.90	70.50	53.01	4.67	20.33	42.76	40.62	54.20
2017	70.64	50.77	4.67	20.33	41.19	39.25	50.97	70.64	52.98	4.67	20.33	42.74	40.60	54.28
2018	70.79	50.77	4.67	20.33	41.19	39.25	51.04	70.79	52.95	4.67	20.33	42.72	40.58	54.36

Table 42. Nitrogen excretion (kg N head^{-1} year^{-1}) for other cattle, 1994-2018

	Pastoral and agro-pastoral system								Mixed crop-livestock system									
Year	Adult multi-purpose cows >3 years	Adult males used for draught (3-10 years)	Adult males used for breeding & other purpose (>3-10 years)	Calves < 6 months (male & female)	Calves 6 m-1 year (male & female)	Growing males 1-3 years	Growing females 1-3 years	National weighted average	Adult multi-purpose cows >3 years	Adult males used for draught (3-10 years)	Adult males used for breeding & other purpose (>3-10 years)	Calves < 6 months (male & female)	Calves 6 m-1 year (male & female)	Growing males 1-3 years	Growing females 1-3 years	Small-holder fattening male	Commercial feedlot fed male	National weighted average
1994	32.98	36.40	38.80	4.55	17.21	30.59	24.63	27.99	26.48	30.39	32.04	3.10	12.42	25.75	20.05	30.99	43.57	24.27
1995	32.99	36.36	38.78	4.55	17.21	30.58	24.62	27.99	26.49	30.35	32.02	3.10	12.42	25.74	20.04	30.98	43.56	24.26
1996	33.04	36.32	38.77	4.57	17.24	30.57	24.61	27.25	26.53	30.32	32.01	3.11	12.41	25.73	20.03	30.97	43.54	23.85
1997	33.14	36.28	38.76	4.57	17.24	30.56	24.60	27.27	26.61	30.28	31.99	3.11	12.41	25.72	20.02	30.95	43.53	23.87
1998	33.35	36.25	38.74	4.57	17.24	30.55	24.59	27.35	26.78	30.25	31.98	3.11	12.41	25.71	20.02	30.94	43.51	23.92
1999	33.57	36.21	38.73	4.57	17.24	30.54	24.59	27.47	26.96	30.21	31.97	3.11	12.41	25.70	20.01	30.93	43.50	23.97
2000	33.79	36.17	38.71	4.57	17.24	30.53	24.58	27.51	27.14	30.17	31.95	3.11	12.41	25.69	20.00	30.91	43.49	24.02
2001	34.01	36.13	38.70	4.57	17.24	30.52	24.57	27.58	27.32	30.14	31.94	3.11	12.41	25.68	19.99	30.90	43.47	24.07
2002	34.22	36.09	38.68	4.57	17.24	30.51	24.56	27.66	27.50	30.10	31.92	3.11	12.41	25.67	19.99	30.89	43.46	24.12
2003	34.46	36.08	38.70	4.56	17.22	30.52	24.57	27.44	27.80	30.19	32.04	3.03	12.46	25.74	20.04	30.70	43.44	24.05
2004	34.59	36.05	38.69	4.55	17.23	30.51	24.57	27.66	27.69	29.94	31.80	3.07	12.36	25.55	19.89	30.79	43.43	24.26
2005	34.82	36.00	38.66	4.55	17.21	30.49	24.55	27.85	27.75	29.80	31.67	3.12	12.32	25.46	19.83	30.88	43.41	24.26
2006	34.70	35.96	38.64	4.55	17.23	30.48	24.54	28.12	27.98	30.06	31.97	3.07	12.45	25.70	20.01	30.75	43.40	24.32
2007	34.75	35.93	38.63	4.56	17.21	30.47	24.54	27.67	27.74	29.77	31.70	3.07	12.33	25.46	19.83	30.74	43.38	23.97
2008	34.44	35.89	38.62	4.55	17.24	30.46	24.53	27.74	27.48	29.71	31.65	3.10	12.32	25.44	19.81	30.80	43.37	24.12
2009	35.30	35.85	38.60	4.55	17.24	30.45	24.52	28.39	28.24	29.69	31.65	3.12	12.33	25.45	19.82	30.84	43.35	24.27
2010	34.71	35.81	38.58	4.56	17.24	30.43	24.51	28.14	27.59	29.52	31.50	3.15	12.28	25.33	19.73	30.88	43.34	23.99
2011	34.57	35.76	38.56	4.55	17.21	30.42	24.49	27.94	27.75	29.72	31.73	3.15	12.40	25.53	19.89	30.88	43.32	24.17
2012	34.94	35.73	38.55	4.55	17.22	30.41	24.49	28.27	28.00	29.68	31.71	3.14	12.39	25.52	19.88	30.85	43.31	24.24
2013	34.84	35.70	38.54	4.55	17.22	30.41	24.48	28.04	28.15	29.85	31.92	3.11	12.49	25.69	20.01	30.76	43.29	24.42
2014	34.61	35.66	38.52	4.56	17.22	30.39	24.47	28.02	27.88	29.75	31.84	3.13	12.46	25.63	19.96	30.80	43.28	24.22
2015	34.45	35.62	38.51	4.55	17.21	30.38	24.46	28.48	27.74	29.69	31.80	3.13	12.45	25.59	19.94	30.79	43.27	24.11
2016	34.73	35.58	38.49	4.56	17.24	30.37	24.46	28.41	28.13	29.82	31.97	3.13	12.53	25.74	20.05	30.76	43.25	24.18
2017	34.31	35.54	38.48	4.55	17.22	30.36	24.45	28.09	28.02	30.03	32.22	3.08	12.64	25.94	20.20	30.64	43.24	24.31
2018	34.63	35.50	38.46	4.56	17.22	30.34	24.44	27.85	28.04	29.76	31.96	3.12	12.54	25.73	20.04	30.73	43.22	24.01

Table 43. Direct N_2O emissions from manure management from cattle, kg N_2O, 1994-2018

Year	Commercial dairy	Smallholder dairy	Pastoral/agro-pastoral other cattle	Mixed crop livestock other cattle
1994	22,472	92,737	974,102	3,727,054
1995	22,517	99,906	1,048,148	4,016,935
1996	22,564	104,178	1,333,902	4,039,594
1997	34,634	111,360	1,395,764	4,322,380
1998	46,756	110,859	1,440,032	4,297,514
1999	58,932	105,106	1,427,233	4,059,473
2000	71,163	112,411	1,462,544	4,350,920
2001	83,451	134,038	1,739,733	5,225,936
2002	95,798	114,849	1,490,550	4,439,789
2003	108,270	121,843	1,027,439	4,920,178
2004	120,755	103,074	1,013,359	5,085,886
2005	133,237	143,956	1,054,599	5,290,016
2006	145,813	140,545	1,309,022	5,601,242
2007	158,393	165,605	1,287,122	6,095,031
2008	171,141	170,281	1,337,101	6,371,905
2009	183,376	158,711	1,404,177	6,646,191
2010	195,460	201,442	1,714,211	6,786,864
2011	207,637	279,923	1,620,555	6,685,743
2012	219,811	288,597	2,035,771	6,832,558
2013	231,627	363,643	2,118,683	6,984,503
2014	243,402	385,558	2,320,137	7,080,291
2015	255,136	415,525	2,372,998	7,154,140
2016	266,843	542,143	2,231,642	7,410,753
2017	278,501	520,579	2,219,881	7,559,934
2018	290,107	644,522	2,458,208	7,538,469

3.3 Manure management emissions from sheep and goats (Categories 3A2c and 3A2d)

3.3.1 Methane emissions from sheep and goats

Similar to cattle, methane emissions from manure management were calculated using IPCC Equations 10.23 and 10.24. Default values for low productivity systems in Africa were used for B_o (i.e. 0.13) and MCF values used the IPCC default values assuming a tropical montane climate for the mixed crop-livestock systems and a tropical dry climate for the pastoral/agro-pastoral system (IPCC 2019, Table 10.17). Country specific manure management system activity data ($MS_{T,S,k}$) were estimated using data and methods described in Annex 5. Manure management system activity data available for this inventory did not vary between sub-categories within each production system. The implied emission factors for manure management methane emissions thus derived for each production system are shown in Table 42. These were multiplied by population numbers of the relevant sub-category in each year and the resulting time series for methane emissions from cattle manure management is shown in Table 43.

Table 44: Manure management methane implied emission factors for sheep and goats, 1994-2018 (kg CH_4 head^{-1} year^{-1})

Year	Sheep		Goats	
	Mixed crop-livestock	Pastoral/ Agro-pastoral	Mixed crop-livestock	Pastoral/ Agro-pastoral
1994	0.16	0.17	0.17	0.23
1995	0.16	0.18	0.17	0.23
1996	0.16	0.17	0.16	0.23
1997	0.16	0.17	0.16	0.23
1998	0.16	0.17	0.16	0.23
1999	0.16	0.17	0.16	0.23
2000	0.16	0.17	0.16	0.23
2001	0.16	0.17	0.16	0.23
2002	0.16	0.17	0.16	0.23
2003	0.16	0.17	0.16	0.23
2004	0.16	0.17	0.16	0.22
2005	0.16	0.17	0.16	0.23
2006	0.16	0.17	0.16	0.22
2007	0.16	0.17	0.16	0.23
2008	0.16	0.17	0.16	0.22
2009	0.16	0.17	0.16	0.22
2010	0.16	0.17	0.16	0.22
2011	0.16	0.17	0.16	0.22
2012	0.16	0.17	0.16	0.22
2013	0.16	0.17	0.16	0.22
2014	0.16	0.17	0.16	0.22
2015	0.16	0.17	0.16	0.22
2016	0.16	0.17	0.16	0.22
2017	0.16	0.17	0.16	0.22
2018	0.16	0.17	0.16	0.22

Table 45: Methane emissions from manure management from sheep and goats, 1994-2018 ($Gg\ CH_4$)

Year	Sheep	Goats
1994	2.17	1.88
1995	2.19	1.90
1996	2.44	2.14
1997	2.43	2.15
1998	2.26	2.04
1999	2.11	1.96
2000	2.14	2.10
2001	3.05	3.53
2002	3.08	2.88
2003	2.86	2.51
2004	3.06	2.69
2005	3.53	2.91
2006	4.02	3.41
2007	4.43	3.90
2008	4.24	3.95
2009	4.39	4.03
2010	4.44	4.26
2011	4.24	4.16
2012	4.48	4.60
2013	4.82	5.34
2014	5.21	5.57
2015	5.09	5.63
2016	5.35	5.65
2017	5.52	6.20
2018	5.85	7.57

3.3.2 Direct N_2O emissions from sheep and goat manure management

Similar to cattle, direct N_2O emissions from manure management for sheep and goats were estimated using IPCC (2006) Equation 10.25. N excretion was estimated as the balance of N intake and N retention calculated using IPCC (2019) Equations 10.31-10.33. The data sources and values used for crude protein content of the diet (CP%) are shown in Annex 4. The IPCC default values used for the fraction of N intake retained by sheep and goats were taken from IPCC (2019) Table 10.20 (i.e. 0.10). Other values used in these calculations (i.e., GE, WG, NE_g) were the values used in the calculation of methane emissions from enteric fermentation. Estimated nitrogen excretion (N_{ex}) is presented in Table 46 and Table 47. Manure management system activity data are the same as those used to estimate methane manure management emissions (Annex 5). The emission factors, EF_3, used were the IPCC default emission factors from IPCC (2019) Table 10.21. The resulting time series for direct N_2O emissions is shown in Table 48.

Table 46. Nitrogen excretion (kg N $head^{-1}$ $year^{-1}$) by sheep, 1994-2018

	Mixed crop livestock								Pastoral / agro-pastoral							
Year	Breeding ewes (>2 yrs)	Mature male (>2 yrs)	female (1-2 yrs)	Male (1-2 yrs)	Intact male (< 1 yr)	Castrated male (< 1 yr)	Female lamb (< 1yr)	National weighted average	Breeding ewes (>2 yrs)	Mature male (>2 yrs)	female (1-2 yrs)	Male (1-2 yrs)	Intact male (< 1 yr)	Castrated male (< 1 yr)	Female lamb (< 1 yr)	National weighted average
1994	3.47	3.15	3.78	4.10	3.94	3.75	3.46	3.41	3.51	3.36	3.89	4.67	4.26	4.06	3.77	3.79
1995	3.48	3.15	3.78	4.10	3.94	3.75	3.46	3.41	3.52	3.36	3.89	4.67	4.26	4.06	3.77	3.80
1996	3.49	3.15	3.78	4.10	3.94	3.75	3.46	3.43	3.53	3.36	3.89	4.67	4.26	4.06	3.77	3.77
1997	3.50	3.15	3.78	4.10	3.94	3.75	3.46	3.44	3.53	3.36	3.89	4.67	4.26	4.06	3.77	3.77
1998	3.50	3.15	3.78	4.10	3.94	3.75	3.46	3.44	3.53	3.36	3.89	4.67	4.26	4.06	3.77	3.77
1999	3.51	3.15	3.78	4.10	3.94	3.75	3.46	3.44	3.53	3.36	3.89	4.67	4.26	4.06	3.77	3.76
2000	3.52	3.15	3.78	4.10	3.94	3.75	3.46	3.45	3.53	3.36	3.89	4.67	4.26	4.06	3.77	3.77
2001	3.52	3.15	3.78	4.10	3.94	3.75	3.46	3.45	3.53	3.36	3.89	4.67	4.26	4.06	3.77	3.76
2002	3.53	3.15	3.78	4.10	3.94	3.75	3.46	3.45	3.52	3.36	3.89	4.67	4.26	4.06	3.77	3.77
2003	3.54	3.15	3.79	4.10	3.94	3.76	3.46	3.50	3.52	3.36	3.89	4.67	4.26	4.06	3.77	3.77
2004	3.54	3.15	3.79	4.11	3.94	3.76	3.46	3.50	3.50	3.36	3.89	4.67	4.26	4.06	3.77	3.75
2005	3.58	3.15	3.78	4.10	3.94	3.75	3.46	3.50	3.54	3.36	3.89	4.67	4.26	4.06	3.77	3.76
2006	3.55	3.15	3.78	4.10	3.94	3.75	3.46	3.49	3.52	3.36	3.89	4.67	4.26	4.06	3.77	3.76
2007	3.52	3.15	3.78	4.10	3.94	3.75	3.46	3.46	3.50	3.36	3.89	4.67	4.26	4.06	3.77	3.74
2008	3.48	3.15	3.78	4.10	3.94	3.75	3.46	3.43	3.49	3.36	3.89	4.67	4.26	4.06	3.77	3.74
2009	3.48	3.15	3.78	4.10	3.94	3.75	3.46	3.42	3.43	3.36	3.89	4.67	4.26	4.06	3.77	3.69
2010	3.54	3.14	3.78	4.09	3.93	3.75	3.45	3.46	3.46	3.36	3.89	4.67	4.26	4.06	3.77	3.72
2011	3.54	3.14	3.77	4.09	3.93	3.74	3.45	3.46	3.46	3.36	3.89	4.67	4.26	4.06	3.77	3.72
2012	3.54	3.14	3.78	4.09	3.93	3.75	3.45	3.46	3.44	3.36	3.89	4.67	4.26	4.06	3.77	3.70
2013	3.52	3.15	3.78	4.10	3.94	3.75	3.46	3.45	3.46	3.36	3.89	4.67	4.26	4.06	3.77	3.73
2014	3.56	3.14	3.78	4.09	3.93	3.75	3.46	3.47	3.45	3.36	3.89	4.67	4.26	4.06	3.77	3.72
2015	3.52	3.14	3.78	4.09	3.93	3.75	3.45	3.45	3.40	3.36	3.89	4.67	4.26	4.06	3.77	3.67
2016	3.55	3.14	3.78	4.09	3.93	3.75	3.45	3.46	3.47	3.36	3.89	4.67	4.26	4.06	3.77	3.71
2017	3.56	3.14	3.78	4.09	3.93	3.75	3.45	3.46	3.44	3.36	3.89	4.67	4.26	4.06	3.77	3.69
2018	3.49	3.14	3.77	4.09	3.93	3.74	3.45	3.41	3.43	3.36	3.89	4.67	4.26	4.06	3.77	3.67

Table 47. Nitrogen excretion (kg N $head^{-1}$ $year^{-1}$) by goats, 1994-2018

	Mixed crop livestock					Pastoral / agro-pastoral				
Year	Adult does (2+ yrs)	Bucks (2+ yrs)	Yearlings (1-2 yrs)	Kids (male & female, <1 yr)	National weighted average	Adult does (2+ years)	Bucks (2+ years)	Yearlings (1-2 yrs)	Kids (male & female, <1 yr)	National weighted average
1994	4.33	4.13	5.74	2.47	3.83	4.29	3.95	5.76	2.05	3.71
1995	4.33	4.13	5.74	2.47	3.83	4.30	3.95	5.76	2.05	3.72
1996	4.34	4.13	5.74	2.47	3.78	4.31	3.95	5.76	2.05	3.64
1997	4.34	4.13	5.74	2.47	3.79	4.32	3.95	5.76	2.05	3.64
1998	4.36	4.13	5.74	2.47	3.79	4.32	3.95	5.76	2.05	3.64
1999	4.37	4.13	5.74	2.47	3.79	4.31	3.95	5.76	2.05	3.65
2000	4.38	4.13	5.74	2.47	3.80	4.31	3.95	5.76	2.05	3.65
2001	4.39	4.13	5.74	2.47	3.80	4.30	3.95	5.76	2.05	3.65
2002	4.40	4.13	5.74	2.47	3.68	4.30	3.95	5.77	2.05	3.54
2003	4.42	4.14	5.75	2.48	3.69	4.30	3.95	5.77	2.05	3.55
2004	4.37	4.14	5.75	2.48	3.72	4.28	3.95	5.77	2.05	3.59
2005	4.41	4.13	5.74	2.47	3.71	4.31	3.95	5.77	2.05	3.58
2006	4.38	4.14	5.74	2.47	3.72	4.25	3.95	5.77	2.05	3.63
2007	4.36	4.14	5.74	2.47	3.74	4.27	3.95	5.77	2.05	3.63
2008	4.37	4.14	5.74	2.47	3.74	4.25	3.95	5.77	2.05	3.64
2009	4.33	4.14	5.74	2.47	3.79	4.24	3.95	5.77	2.05	3.67
2010	4.35	4.13	5.73	2.47	3.73	4.26	3.95	5.76	2.05	3.63
2011	4.42	4.13	5.73	2.47	3.68	4.25	3.95	5.77	2.05	3.66
2012	4.38	4.13	5.73	2.47	3.71	4.20	3.95	5.77	2.05	3.68
2013	4.37	4.13	5.74	2.47	3.71	4.22	3.95	5.77	2.05	3.65
2014	4.40	4.13	5.74	2.47	3.69	4.22	3.95	5.77	2.05	3.66
2015	4.39	4.13	5.73	2.47	3.69	4.21	3.95	5.77	2.05	3.66
2016	4.39	4.13	5.73	2.47	3.68	4.22	3.95	5.77	2.05	3.69
2017	4.39	4.13	5.73	2.47	3.69	4.22	3.95	5.76	2.05	3.72
2018	4.37	4.13	5.73	2.47	3.72	4.21	3.95	5.77	2.05	3.69

Table 48. Direct N_2O emissions from sheep and goat manure management, 1994-2018 (kg N_2O)

Year	Sheep		Goat	
	Mixed crop-livestock	Pastoral/Agro-pastoral	Mixed crop-livestock	Pastoral/Agro-pastoral
1994	151,032	26,052	110,757	43,619
1995	151,205	27,058	110,135	45,218
1996	153,093	44,802	103,722	70,370
1997	152,739	44,455	104,276	70,519
1998	139,303	44,299	95,256	70,349
1999	124,783	45,871	85,858	72,908
2000	130,446	43,292	96,256	74,305
2001	196,075	51,406	178,262	109,004
2002	192,807	56,838	165,788	70,465
2003	197,139	35,,854	145,512	60,392
2004	217,452	32,803	157,922	62,928
2005	252,963	34,987	181,253	57,957
2006	282,427	45,475	194,397	84,703
2007	306,720	53,988	232,841	87,001
2008	291,609	53545	233,565	90,229
2009	301,466	56,310	232,049	98,242
2010	290,796	69,547	227,934	119,330
2011	270,684	72,915	217,586	121,231
2012	284,643	78,663	226,752	147,603
2013	292,130	98,560	246,122	187,447
2014	319,468	103,305	255,592	196,771
2015	312,062	100,637	261,030	196,119
2016	333,392	100,749	269,596	189,550
2017	334,197	112,864	291,743	211,538
2018	323,685	148,494	284,469	326,061

3.4 Uncertainties and time-series consistency

Annex 6 gives the main results of uncertainty analysis conducted using Monte Carlo simulation for cattle manure management emissions. The uncertainty of 2018 total methane emissions from manure management for cattle was (+47.7%, -36.7%), and for direct nitrous oxide emissions it was (+61.1%, -46.9%). Since population activity data uncertainty for cattle in 2018 was ±3.23%, the average emission factor uncertainty was about ±47.6% for manure management methane emissions. Population activity data uncertainty was higher for sheep (±7.81%) and goats (±10.16%), so assuming a similar level of uncertainty for sheep and goat manure management emission factors, sheep and goat manure management methane emission uncertainty can be estimated by error propagation as ±48.2% and ±48.7%, respectively.

For direct N_2O emissions from manure management for cattle, analysis in Annex 6 estimates uncertainty of total direct N_2O emissions as (+61.1%, -46.9%). With activity data uncertainty of ±3.23%, by error propagation, average emission factor uncertainty is about +60.0%. Assuming a similar emission factor uncertainty for sheep and goats, estimated total direct N_2O emission uncertainty for sheep and goats would be ±61.5% and ±61.8%, respectively.

The uncertainty levels estimated here are higher than the default estimates in IPCC (2006). However, it is important to note that the estimates in this inventory are empirically derived from data used to compile this inventory, while there is no evidence that the IPCC default uncertainty estimate is appropriate to the Ethiopian context. Analysis of the sources of uncertainty in Annex 6 shows that the key variables affecting uncertainty of manure management methane emissions from cattle are the methane conversion factor for burning and solid storage, the proportions of manure managed by burning and in solid storage in the mixed crop-livestock system, and feed digestibility for cows and oxen in the mixed crop-livestock system. Together with cattle LW, these factors are also the most important factors affecting nitrous oxide manure management emissions. Improved data on the proportions of manure managed in different systems, LW and feed digestibility data can be collected through surveys and would reduce the uncertainty of cattle manure management methane and nitrous oxide emissions.A consistent method was used to estimate emissions in each year of the time series.

3.5 Source-specific QAQC and verification

Tier 1 and Tier 2 QAQC activities have been implemented. This inventory was compiled in an Excel spreadsheet. Quality control activities included:

- Checking that the equations programmed in the spreadsheet were correctly input
- Checking that inputs to summed totals were obtained from the correct fields
- Checking that all data sources were fully documented
- Checking that the figures in the inventory report were correctly transcribed
- Reconstructing a number of the calculations to cross-check the intermediate calculations and results in the inventory spreadsheet.

QAQC activities identified and addressed the following issues:

- Implied emission factors disaggregated by production system were not presented in the inventory report for all animal categories, which has now been rectified;
- A methane conversion factor for biogas technologies inappropriate for Ethiopian biogas technologies had been used, and the appropriate MCF value has now been used;
- Data sources were not given for relevant tables in the inventory report and this has now been rectified.

The inventory was also reviewed by members of the Tier 2 livestock inventory advisory group and all comments and queries have been responded to and addressed in the revised inventory report. Most comments related to increasing the transparency of emission estimates and explaining the reason for trends in input parameters and emission factors.

To verify the inventory estimates, the estimated values for VS used to calculate manure management methane emissions were cross-checked against the default values in IPCC (2019). IPCC (2019, Table 10.13A) gives values of 15.2-21.7 kg VS per 1000 kg animal mass for dairy cattle, and 10.3-12.7 kg VS per 1000 kg animal mass for other cattle. Applying the LW values used in this inventory, the default values are within the range estimated in this inventory for other cattle (i.e. 1.5 – 3.5 kg VS head^{-1} day^{-1}), but the inventory estimates for dairy cattle (i.e. 1.0 – 3.8 kg VS head^{-1} day^{-1}) are slightly lower than the IPCC (2019) default values, most likely because of the higher feed digestibility values used in this inventory.

The MMS% values were also compared with the IPCC default values and the values in the FAO GLEAM model, which were used to derive the IPCC (2019) default emission factors. IPCC (2019) assumed for Sub-Saharan Africa that 5% of cattle dung is burned, 50% deposited on pasture, 30% managed in drylot and 15% in solid storage. These percentages differ from those used for both the mixed crop-livestock and pastoral/agro-pastoral other cattle in this inventory (Annex 5). For dairy cattle, IPCC (2019) default values are 6% burned, 45% deposited on pasture, 29% managed in drylot and 20% in solid storage, which also differ from the values used here. Methane emissions from manure management are likely to be very sensitive to the MMS% values used.

3.6 Source-specific recalculations

Tier 1 emissions using activity data reported in the SNC were reconstructed for methane and direct nitrous oxide emissions from manure management (Table 45 and Table 46). For details of the Tier 1 reconstruction, see Annex 8. For cattle, Tier 2 estimates of methane emissions from manure management are much higher than Tier 1. This is because the Tier 2 emission factor averages about 3.38 kg CH_4 head^{-1} year^{-1} across the 1994-2013 time series, whereas the IPCC (1996) Tier 1 default value is 1 kg CH_4 head^{-1} year^{-1}. IPCC (2019) has refined default estimates of methane emissions to values closer to those used in this inventory.

For nitrous oxide, the Tier 1 estimate is much higher than the Tier 2 estimate for cattle. Firstly, the nitrogen excretion rate values used in the current inventory were much lower than those calculated using IPCC default values (40 kg N head^{-1} year^{-1}) in the Tier 1 method (see Annex 8). Secondly, fractions of manure managed in different manure management systems also differ between the Tier 2 and Tier 1 calculations for cattle, but are more similar for sheep and goats.

Table 49. Recalculated estimates of methane and direct nitrous oxide emissions from manure management from cattle, 1994-2013

	Methane (Gg CH_4)		Nitrous Oxide (kg N_2O)	
Year	Tier 1	Tier 2	Tier 1	Tier 2
1994	29.45	104.81	16,578,442	4,793,893
1995	29.83	112.94	16,789,543	5,164,989
1996	31.21	117.25	17,567,520	5,477,674
1997	35.37	125.47	19,912,014	5,829,504
1998	35.37	125.87	19,912,014	5,848,405
1999	35.10	120.23	19,756,342	5,591,812
2000	33.08	128.49	18,619,268	5,925,875
2001	35.38	154.25	19,918,513	7,099,706
2002	40.64	132.07	22,877,012	6,045,188
2003	39.00	137.54	21,954,474	6,069,459
2004	38.75	142.74	21,813,346	6,202,319
2005	40.39	151.03	22,737,010	6,488,570
2006	43.12	159.42	24,276,356	7,050,809
2007	49.00	174.01	27,583,826	7,547,758
2008	49.00	182.22	27,583,826	7,879,286
2009	50.88	191.60	28,644,399	8,209,079
2010	53.38	200.76	30,050,721	8,702,516
2011	52.13	198.47	29,345,250	8,793,858
2012	53.99	207.76	30,392,929	9,376,737
2013	54.00	212.94	30,398,502	9,698,455

Table 50. Recalculated estimates of methane and direct nitrous oxide emissions from manure management from sheep and goats, 1994-2013

	Methane (Gg CH_4)		Nitrous Oxide (kg N_2O)	
Year	Tier 1	Tier 2	Tier 1	Tier 2
1994	3.76	4.06	1,604,362	331,459
1995	3.75	4.08	1,601,902	333,616
1996	3.97	4.58	1,690,251	371,987
1997	4.67	4.58	1,995,662	371,989
1998	4.67	4.30	1,995,662	349,207
1999	4.26	4.06	1,819,575	329,418
2000	3.82	4.24	1,633,791	344,299
2001	4.12	6.57	1,766,907	534,747
2002	4.95	5.96	2,113,685	485,899
2003	5.47	5.37	2,334,115	438,896
2004	6.45	5.75	2,758,848	471,104
2005	7.26	6.44	3,101,422	527,160
2006	8.25	7.43	3,526,365	607,002
2007	9.36	8.32	4,010,088	680,549
2008	9.38	8.18	4,018,490	668,947
2009	9.39	8.42	4,023,459	688,067
2010	9.47	8.69	4,065,971	707,607
2011	9.19	8.39	3,952,805	682,416
2012	9.73	9.08	4,184,605	737,661
2013	10.11	10.16	4,349,140	824,259

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Indirect emissions of nitrous oxide from manure management (Category 3C6)

4. Indirect emissions of nitrous oxide from manure management (Category 3C6)

4.1 Source category description

Emissions sources	Sources included	Method	Emission factors
	Cattle, sheep and goat manure management	T2	CS
Gases reported	N_2O		
Completeness	All cattle, sheep and goats are accounted for. No known omissions.		
Improvements since last submission	This is the first inventory for dairy and other cattle, sheep and goats that uses a Tier 2 approach.		

This category reports indirect emissions of N_2O from management of manure from cattle, sheep and goats. IPCC 2006 (Chapter 8.8) Reporting Guidelines and Tables does not require separate reporting of indirect N_2O emissions from different animal species, so the total for all species is reported together with the total for each species.

4.2 Methodological issues

IPCC (2006, page 10.56) indicates that this source category should only include N losses from volatilization because there is no country-specific information on N losses from leaching. However, IPCC (2019) provides equations and default factors for indirect emissions from N leaching that may be used when manure is uncovered on permeable soil or where runoff may occur to permeable soil and runoff is not collected in an impermeable basin and redistributed to fields. These conditions apply throughout the highlands of Ethiopia and therefore N losses due to leaching and runoff are included in this inventory. IPCC (2019) updated the equations for calculating N losses due to volatilization and leaching/runoff by including a variable $N_{cdg(s)}$, which represents co-digestates added to biogas plants such as food waste or other materials. Due to a lack of detailed information on co-digestates, this variable has not been estimated and the IPCC (2006) equations are implemented.

4.2.1 N losses from volatilization

Nitrous oxide emissions due to volatilization were calculated using IPCC Equations 10.26 and 10.27:

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

where:

$N_{volatilization - MMS}$ is amount of manure nitrogen lost due to volatilization of NH_3 and NO_x, kg N year^{-1}

N_T is number of head of cattle sub-category T

Nex_T is average nitrogen excretion per head of sub-category T, kg N head^{-1} year^{-1}

$MS_{T,S}$ is fraction of total annual nitrogen excretion for sub-category T that is managed in manure management system *S*, dimensionless

$Frac_{GasMS}$ is percent of managed manure nitrogen for each sub-category that volatilizes as NH_3 and NO_x in manure management system *S*, %.

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

where

is indirect N_2O emissions due to volatilization of N from manure management, kg N_2O year^{-1}

EF_4 is emission factor for N_2O emissions from atmospheric deposition of nitrogen on soils and water surfaces, kg N_2O-N (kg NH_3-N + NO_x-N volatilised) $^{-1}$.

N excretion was estimated as the balance of N intake and N retention calculated using IPCC (2006) Equations 10.31-10.33:

$$Nex_{(T)} = N_{intake(T)} \times (1 - N_{retention_{frac(T)}}) \times 365$$

Where

$Nex_{(T)}$ is annual N excretion for animal sub-category T, kg N head^{-1} year^{-1}

$N_{intake(T)}$ is daily N intake per head for animal sub-category T, kg N head^{-1} day^{-1}

$N_{retention\_frac(T)}$ is fraction of N intake that is retained by animal sub-category T.

N intake (kg N head^{-1} day^{-1}) was calculated as:

$$N_{intake(T)} = \frac{GE}{18.45} \times \left(\frac{\frac{CP\%}{100}}{6.25}\right)$$

where

GE is gross energy intake, MJ head^{-1} day^{-1}, which used the values estimated for enteric fermentation;

18.45 is conversion of dietary GE per kg dry matter, MJ kg^{-1}

CP% is crude protein content of the diet

6.25 is conversion from kg of dietary protein to dietary N, kg feed protein (kg N)$^{-1}$.

For cattle, nitrogen retention (kg N head^{-1} day^{-1}) was calculated as:

$$N_{retention(T)} = \left(\frac{Milk \times \left(\frac{Milk\ PR\%}{100} \right)}{6.38} \right) \times \left(\frac{WG \times \left[268 - \left(\frac{7.03 \times NE_g}{WG} \right) \right]}{1000 \times 6.25} \right)$$

Where

Milk is milk production, kg head^{-1} day^{-1}

Milk PR% is protein content of milk, %

6.38 is conversion from milk protein to milk N, kg protein (kg N)$^{-1}$

WG is weight gain, kg day^{-1}

268 is a constant, g protein kg^{-1} head^{-1}

7.03 is a constant, g protein MJ^{-1} head^{-1}

NEg is net energy for growth, MJ head^{-1} day^{-1}, which used the value estimated for enteric fermentation

6.25 is conversion from kg of dietary protein to dietary N, kg feed protein (kg N)$^{-1}$.

For sheep and goats, the IPCC (2019) default value for N retention (i.e. 0.10) was used.

The data sources and values used for crude protein content of the diet (CP%) are shown in Annex 4. Milk protein content (milk PR%) used a default value of 3.5% (IPCC 2006, page 10.60). Other values used in these calculations (e.g. GE, milk, WG, NE_g) were the values used in the calculation of methane emissions from enteric fermentation. Manure management system activity data are the same as those used to estimate methane manure management emissions (Annex 5). For all types of cattle, sheep and goats, the emission factor, EF_4, used the IPCC default emission factors from IPCC (2019) Table 11.3 (i.e. 0.014 in dairy and mixed crop-livestock systems and 0.005 in the pastoral/agro-pastoral system). Fracgas was taken from IPCC (2019) Table 10.22 (see Table 48).

Table 51. Fraction of nitrogen lost due to volatilization ($Frac_{gas\_MS}$) used in estimating indirect N_2O emissions from manure management

Manure management system	$Frac_{gas\_MS}$	Source
Daily spread	0.07	IPCC 2019 Table 10.22
Solid storage – dairy cows	0.3	IPCC 2019 Table 10.22
Solid storage – other cattle	0.45	IPCC 2019 Table 10.22
Solid storage – sheep & goats	0.12	IPCC 2019 Table 10.22
Drylot – sheep & goats	0.30	IPCC 2019 Table 10.22
Composted (static pile) – dairy cows	0.50	IPCC 2019 Table 10.22
Composted (static pile) – other cattle	0.65	IPCC 2019 Table 10.22
Liquid (e.g. pit)	0.48	IPCC 2019 Table 10.22
Biogas	0.225	Midpoint of the range given in IPCC 2019 Table 10.22

4.2.1 N losses from leaching

Nitrous oxide emissions due to leaching were calculated using IPCC Equations 10.28 and 10.29:

$$N_{leaching-MMS} = \left[\sum_{S}\left[\sum_{T}(N_T \times Nex_T \times MS_{T,S})\right] \times \frac{Frac_{leachMS}}{100}\right]_{(T,S)}$$

where:

$N_{leaching-MMS}$ is amount of manure nitrogen lost due to leaching of N, kg N year^{-1}

N_T is number of head of cattle sub-category T

Nex_T is average nitrogen excretion per head of sub-category T, kg N head^{-1} year^{-1}

$MS_{T,S}$ is fraction of total annual nitrogen excretion for sub-category T that is managed in manure management system *S*, dimensionless

$Frac_{leachMS}$ is percent of managed manure nitrogen losses for each sub-category due to runoff and leaching, %.

$$N_2O_{L(mm)} = (N_{leaching-MMS} \times EF_5) \times \frac{44}{28}$$

where

is indirect N_2O emissions due to volatilization of N from manure management, kg N_2O year^{-1}

EF_5 is emission factor for N_2O emissions from nitrogen leaching and runoff, kg N_2O-N (kg N leached/runoff) $^{-1}$.

In the pastoral/agro-pastoral system, the value of $Frac_{leach\_MS}$ was 0. In other production systems, the values used in Table 49 were used. For EF_5, the value used was 0.011 taken from IPCC (2019, Table 11.3).

Table 52. Fraction of nitrogen lost due to leaching ($Frac_{leach\_MS}$) used in estimating indirect N_2O emissions from manure management

Manure management system	Fracleach	Source
Daily spread	0	IPCC 2019 Table 10.22
Solid storage – dairy cows	0.02	IPCC 2019 Table 10.22
Solid storage – other cattle	0.02	IPCC 2019 Table 10.22
Solid storage – sheep & goats	0.02	IPCC 2019 Table 10.22
Drylot – sheep & goats	0.035	IPCC 2019 Table 10.22
Composted (static pile) – dairy cows	0.06	IPCC 2019 Table 10.22
Composted (static pile) – other cattle	0.06	IPCC 2019 Table 10.22
Liquid (e.g. pit)	0	IPCC 2019 Table 10.22
Biogas	0	IPCC 2019 Table 10.22

4.3 Indirect N_2O emissions

Table 53. Indirect N_2O emissions from manure management, 1994-2018 (Kg N_2O)

Year	Dairy cattle	Other cattle	Sheep	Goats	Total
1994	59041	2,334,230	17972	25894	2,437,137
1995	62739	2,514,982	18061	25906	2,621,688
1996	64952	2,659,295	19429	26764	2,770,440
1997	74818	2,830,800	19373	26888	2,951,879
1998	80773	2,838,834	17891	25067	2,962,565
1999	84063	2,712,728	16393	23403	2,836,587
2000	94075	2,876,259	16870	25605	3,012,809
2001	111455	3,446,826	24610	44982	3,627,873
2002	107948	2,934,139	24548	39201	3,105,836
2003	117924	2,961,274	22686	34282	3,136,166
2004	114703	3,038,370	25004	36983	3,215,060
2005	142050	3,160,584	28582	41232	3,372,447
2006	146746	3,435,985	33015	46142	3,661,888
2007	166035	3,675,048	36484	54036	3,931,603
2008	174975	3,838,043	36234	54456	4,103,708
2009	175739	4,007,682	37659	54835	4,275,916

2010	204395	4,222,854	36093	55808	4,519,149
2011	251695	4,128,262	33392	53898	4,467,247
2012	263100	4,395,444	35270	57980	4,751,794
2013	308810	4,510,694	37259	65253	4,922,016
2014	327094	4,652,720	39985	67944	5,087,743
2015	349646	4,714,577	39780	68977	5,172,980
2016	422814	4,778,375	41145	70132	5,312,466
2017	418682	4,848,207	42151	76440	5,385,480
2018	490936	4,948,194	43600	84741	5,567,470

4.3 Uncertainties and time-series consistency

Annex 6 gives the main results of uncertainty analysis conducted using Monte Carlo simulation for cattle. Uncertainty of 2018 for total indirect nitrous oxide emissions from manure management for cattle was (+56.2%, -42.8%). With population activity data uncertainty for cattle in 2018 of ±3.23%, average emission factor uncertainty was about ±56.1%. Population activity data uncertainty was higher for sheep (±7.81%) and goats (±10.16%), so assuming a similar level of uncertainty for sheep and goat manure management emission factors, sheep and goat manure management methane emission uncertainty can be estimated by error propagation as ±56.6% and ±57.0%, respectively.

A consistent method was used to estimate emissions in each year of the time series.

4.4 Source-specific QAQC and verification

Tier 1 QC activities have been implemented. This inventory was compiled in an Excel spreadsheet. Quality control activities included:

- Checking that the equations programmed in the spreadsheet were correctly input
- Checking that inputs to summed totals were obtained from the correct fields
- Checking that all data sources were fully documented
- Checking that the figures in the inventory report were correctly transcribed
- Reconstructing a number of the calculations to cross-check the intermediate calculations and results in the inventory spreadsheet.

QAQC activities identified and addressed the following issue:

- Total emissions were not presented disaggregated by species, which has now been rectified.

The inventory was also reviewed by members of the Tier 2 livestock inventory advisory group and there were no comments or queries about this emission source.

4.5 Source-specific recalculations

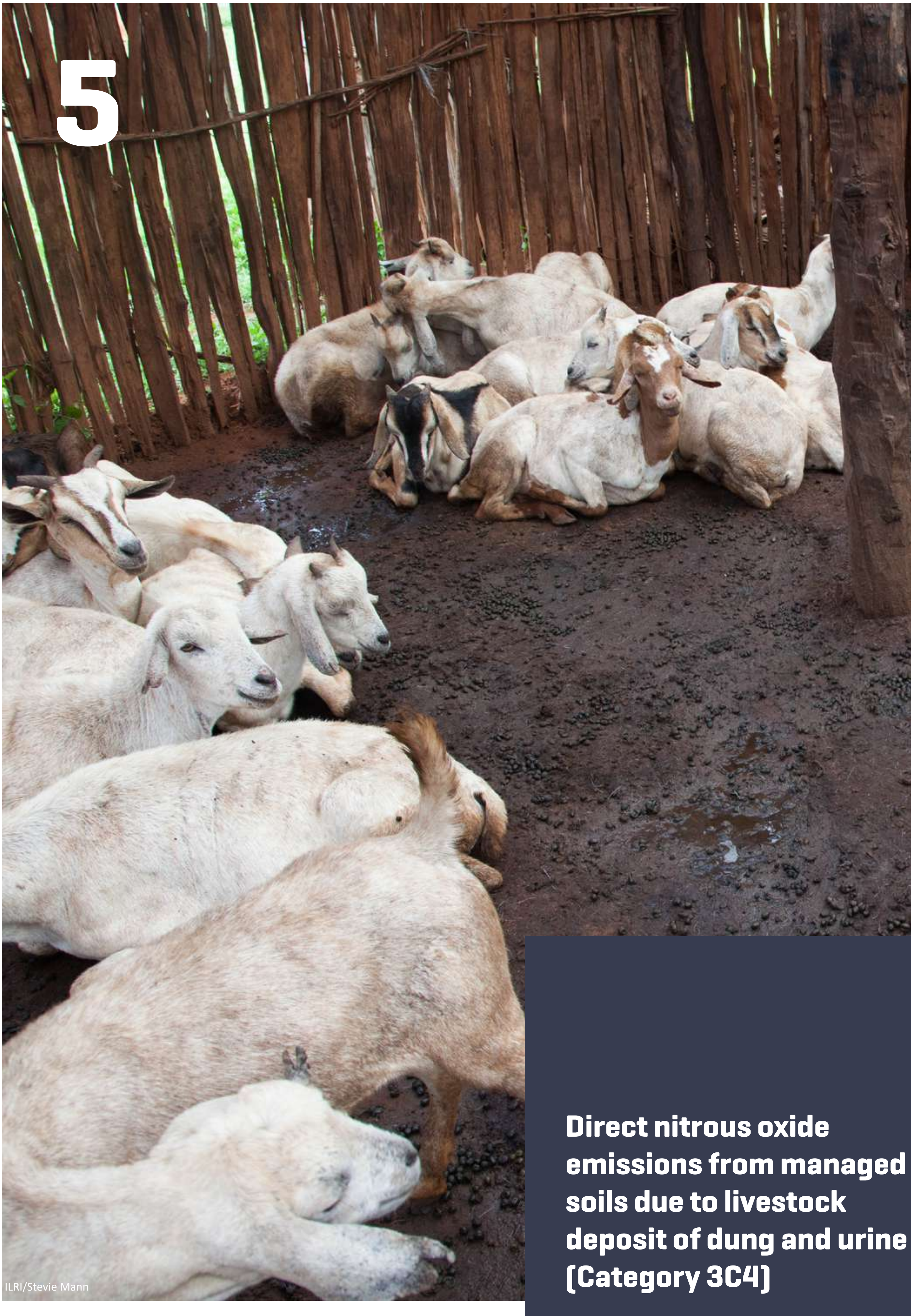
Tier 1 emissions using activity data reported in the SNC were reconstructed for indirect nitrous oxide emissions from manure management (Table 51). The Tier 1 emission estimate includes only indirect emissions from volatilization and does not include indirect emissions from leaching (see explanation in Annex 8). The reconstructed Tier 1 estimate is about 13% lower than the Tier 2 estimate, because although the Tier 1 default value for N_{ex} is higher than the Tier 2 estimates for cattle, the Tier 2 estimate includes leaching for ruminants in all production systems except the pastoral/agropastoral production system.

Table 54. Recalculated estimates of indirect nitrous oxide emissions from manure management for cattle, sheep and goats, 1994-2013

	Nitrous oxide (Kg N_2O)	
Year	SNC 2 Tier 1	Tier 2
1994	2,001,463	2,437,137
1995	2,024,659	2,621,688
1996	2,119,888	2,770,440
1997	2,410,784	2,951,879
1998	2,410,784	2,962,565
1999	2,375,888	2,836,587
2000	2,231,038	3,012,809
2001	2,388,630	3,627,873
2002	2,751,847	3,105,836
2003	2,671,443	3,136,166
2004	2,698,244	3,215,060
2005	2,835,074	3,372,447
2006	3,048,512	3,661,888
2007	3,464,177	3,931,603
2008	3,465,017	4,103,708
2009	3,583,290	4,275,916
2010	3,743,712	4,519,149
2011	3,654,053	4,467,247
2012	3,793,578	4,751,794
2013	3,810,650	4,922,016

4.6 Source-specific planned improvements

Annex 7 discusses data quality and inventory improvement priorities. For manure management, the priority is to improve the availability of representative data on manure management systems that are collected using classifications and methods in line with the IPCC categories.



ILRI/Stevie Mann

Direct nitrous oxide emissions from managed soils due to livestock deposit of dung and urine (Category 3C4)

5. Direct nitrous oxide emissions from managed soils due to livestock deposit of dung and urine (Category 3C4)

5.1 Source category description

Emissions sources	Sources included	Method	Emission factors
	Cattle, sheep and goat deposit of dung and urine on pasture	T2	CS
Gases reported	N_2O		
Completeness	All cattle, sheep and goats accounted for. No known omissions.		
Improvements since last submission	This is the first inventory that uses a Tier 2 approach.		

Direct N_2O emissions from urine and dung N deposited on pasture, range and paddock by grazing animals is categorized under reporting category 3C4. Indirect N_2O emissions from urine and dung N deposited on pasture, range and paddock by grazing animals is categorized under reporting category 3C5. There is very little documentation of specific management practices for dung deposited on pasture. Here, we assume that it lies unmanaged. Any portion that may be collected from paddocks near to farms and then stored in farm yards is assumed to be included in manure management emissions in Chapters 3 and 4.

5.2 Methodological issues

Emissions were calculated using the IPCC Tier 2 approach using equations modified from IPCC (2006) Equations 11.1 and 11.5:

$$N_2O - N_{PRP,SO} = (F_{PRP} \times EF_{3,PRP}) + (F_{SO} \times EF_{3,SO})$$

where

is annual direct N_2O-N emissions from urine and dung inputs to grazed soils, kg N_2O-N year^{-1}

F_{PRP} is annual amount of urine and dung N deposited by grazing cattle on pasture and paddock, kg N year^{-1}

EF_{3PRP} is the emission factor for N2O emissions from urine and dung N deposited by cattle on pasture and paddock, kg N_2O-N (kg N input)$^{-1}$.

F_{SO} is annual amount of urine and dung N deposited by grazing sheep and goats on pasture and paddock, kg N year^{-1}

EF_{3SO} is the emission factor for N2O emissions from urine and dung N deposited by sheep and goats on pasture and paddock, kg N_2O-N (kg N input)$^{-1}$.

and

$$F_{PRP,SO} = \sum\left[\left(N_{(T)} \times Nex_{(T)}\right) \times MS_{(T,PRP,SO)}\right]$$

Where

$N_{(T)}$ is the number of animals in each sub-category

$Nex_{(T)}$ is annual average nitrogen excretion per head of sub-category T, kg N head^{-1} year^{-1}

$MS_{(T,PRP)}$ is the fraction of annual N excretion for sub-category T that is deposited on pasture or paddock.

was then converted to N_2O by multiplying it by (44/28).

The same values for N excretion (Nex) were used as for N_2O emissions from manure management, together with the proportions of Nex deposited on pasture that was derived when estimating manure management systems. For the emission factor for cattle, $EF_{3,PRP, CPP}$, a value of 0.006 was used for the dairy and mixed crop-livestock systems and 0.002 for the pastoral/agro-pastoral system (IPCC 2019 Table 11.1). For sheep and goats, $EF_{3PRP,SO}$ used a value of 0.003 (IPCC 2019, Table 11.1). The resulting time series for direct N_2O emissions from pasture deposit of dung and urine is shown in Table 51.

Table 55. Direct N_2O emissions from dung and urine deposited on pasture by cattle, sheep and goats, 1994-2018 (kg N_2O)

Year	Dairy cattle	Other cattle	Sheep	Goats	Total
1994	0	2,472,474	184,783	161,088	2,818,345
1995	0	2,664,510	186,014	162,108	3,012,631
1996	0	2,723,071	206,499	181,661	3,111,231
1997	0	2,908,793	205,767	182,395	3,296,956
1998	0	2,900,194	191,585	172,805	3,264,584
1999	0	2,749,968	178,073	165,668	3,093,709
2000	0	2,936,953	181,292	177,977	3,296,222
2001	0	3,524,970	258,241	299,756	4,082,967
2002	0	2,996,651	260,499	246,526	3,503,676
2003	0	3,223,764	243,123	214,856	3,681,743
2004	0	3,324,766	261,136	230,451	3,816,353
2005	0	3,458,298	300,470	249,610	4,008,378
2006	0	3,691,685	342,159	291,234	4,325,079
2007	0	3,995,776	376,390	333,747	4,705,914
2008	0	4,175,967	360,160	337,872	4,873,999
2009	0	4,357,208	373,332	344,651	5,075,191
2010	0	4,493,036	376,010	362,362	5,231,409
2011	0	4,415,497	358,539	353,548	5,127,583
2012	0	4,571,512	379,102	390,631	5,341,245
2013	0	4,679,030	407,677	452,420	5,539,127
2014	0	4,770,017	441,154	472,031	5,683,202
2015	0	4,824,228	430,643	477,025	5,731,896
2016	0	4,962,040	453,016	479,109	5,894,165
2017	0	5,053,110	466,498	525,162	6,044,770
2018	0	5,076,816	492,709	637,075	6,206,600

5.3 Uncertainties and time-series consistency

Annex 6 gives the main results of uncertainty analysis conducted using Monte Carlo simulation for cattle. Uncertainty of 2018 for total direct nitrous oxide emissions from managed soils was (+156.2%, -81.0%). With population activity data uncertainty for cattle in 2018 of ±3.23%, average emission factor uncertainty was about ±156.2%. Population activity data uncertainty was higher for sheep (±7.81%) and goats (±10.16%), so assuming a similar level of uncertainty for sheep and goat manure management emission factors, sheep and goat manure management methane emission uncertainty can be estimated by error propagation as ±156.3% and ±156.5%, respectively. The high level of uncertainty is mainly due to the default uncertainty range associated with the emission factor in the IPCC Guidelines. Annex 6 highlights the factors associated with uncertainty in the trend of direct nitrous oxide emissions from soils, for which improved data availability can partially reduce the overall uncertainty.

A consistent method was used to estimate emissions in each year of the time series.

5.4 Source-specific QAQC and verification

Tier 1 QC activities have been implemented. This inventory was compiled in an Excel spreadsheet. Quality control activities included:

- Checking that the equations programmed in the spreadsheet were correctly input
- Checking that inputs to summed totals were obtained from the correct fields
- Checking that all data sources were fully documented
- Checking that the figures in the inventory report were correctly transcribed
- Reconstructing a number of the calculations to cross-check the intermediate calculations and results in the inventory spreadsheet.

QAQC activities identified and addressed the following issue:

- Emissions were not presented disaggregated by species, which has now been rectified.

The inventory was also reviewed by members of the Tier 2 livestock inventory advisory group and there were no comments or queries about this emission source.

5.5 Source-specific recalculations

Tier 1 emissions using activity data reported in the SNC were reconstructed for direct nitrous oxide emissions from dung and urine deposited on pasture (Table 52). Tier 1 estimates of direct N_2O emissions from dung and urine deposited on pasture are much higher than the Tier 2 estimates. This is because (a) Tier 1 default values for N excretion (N_{ex}) are higher than the Tier 2 estimates, and (b) the Tier 2 estimation uses IPCC (2019) values for $EF_{3,PRP}$ (i.e. 0.002-0.003), which are much lower than the IPCC (1996) default value of 0.02. Other issues related to reconstruction of the Tier 1 estimate are described in Annex 8.

Table 56. Recalculated estimates of direct N_2O emissions from dung and urine deposited on pasture by cattle, sheep and goats 1994-2013

	Nitrous oxide (Kg N_2O)	
Year	SNC 2 Tier 1	Tier 2
1994	24,890,585	2,818,345
1995	25,148,565	3,012,631
1996	26,206,529	3,111,231
1997	30,058,264	3,296,956
1998	30,058,264	3,264,584
1999	29,508,587	3,093,709
2000	27,660,397	3,296,222
2001	29,750,140	4,082,967
2002	34,150,117	3,503,676
2003	33,317,472	3,681,743
2004	34,207,587	3,816,353
2005	35,989,714	4,008,378
2006	38,836,603	4,325,079
2007	44,362,055	4,705,914
2008	44,395,662	4,873,999
2009	45,847,688	5,075,191
2010	48,003,577	5,231,409
2011	47,012,862	5,127,583
2012	48,932,842	5,341,245
2013	49,294,399	5,539,127

5.6 Source-specific planned improvements

Annex 7 discusses data quality and inventory improvement priorities. For manure management, the priority is to improve the availability of representative data on manure management systems that are collected using classifications and methods in line with the IPCC categories. This will include estimation of the proportion of dung and urine deposited on pasture.

ILRI/ Camille Hanotte

Indirect emissions of nitrous oxide from managed soils due to cattle, sheep and goats (Category 3C5)

6. Indirect emissions of nitrous oxide from managed soils due to cattle, sheep and goats (Category 3C5)

6.1 Source category description

Emissions sources	Sources included	Method	Emission factors
	Cattle, sheep and goat dung and urine deposit on pasture	T1	CS
Gases reported	N_2O		
Completeness	All cattle, sheep and goats accounted for. No known omissions.		
Improvements since last submission	This is the first inventory for dairy cattle that uses a Tier 2 approach.		

This category reports indirect emissions of N_2O from dung and urine deposited on pasture by dairy cattle. There is very little documentation of specific management practices for dung deposited on pasture. Here, we assume that it lies unmanaged. Any portion that may be collected from paddocks near to farms and then stored in farm yards is assumed to be included in manure management emissions in Chapters 3 and 4.

6.2 Methodological issues

Indirect N_2O emissions from deposit of dung and urine on pasture by cattle, sheep and goats were calculated using IPCC equations 11.9 (for volatilization) and 11.10 (for leaching):

$$N_2O_{ATD} - N = (F_{PRP} \times Frac_{GASM} \times EF_4)$$

Where

is annual amount of N_2O-N produced from atmospheric deposition of N volatilized from pasture and paddock, kg N_2O-N year^{-1}

F_{PRP} is annual amount of urine and dung N deposited by grazing cattle on pasture and paddock, kg N year^{-1}

$Frac_{GASM}$ is fraction of urine and dung N deposited by dairy cattle that volatilizes as NH_3 and NO_x, kg N volatilized (kg N input)$^{-1}$

EF_4 is emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces, [kg N–N_2O (kg NH_3–N + NO_x–N volatilised)$^{-1}$]

For leaching the equation used was:

$$N_2O_{(L)} - N = (F_{PRP} \times Frac_{LEACH} \times EF_5)$$

where

is annual amount of N_2O-N produced from leaching and runoff from deposit of urine and dung on pasture and paddock, kg N_2O-N year^{-1}

F_{PRP} is annual amount of urine and dung N deposited by grazing cattle on pasture and paddock, kg N year^{-1}

$Frac_{LEACH}$ is fraction of N deposited on pasture and paddock that is lost through leaching and runoff, kg N (kg of N deposited)$^{-1}$

EF_5 is emission factor for N_2O emissions from N leaching and runoff, kg N_2O–N (kg N leached and

runoff)$^{-1}$

Both $N_2O_{(ATD)}$-N and $N_2O_{(L)}$-N were converted to N_2O by multiplying by (44/28).

Default emission factors for EF_4 (0.014 in dairy and mixed crop livestock system, 0.005 in the pastoral/agro-pastoral systems) and EF_5 (0.011 in all systems) and default fractions for $Frac_{GASM}$ (0.21) and $Frac_{Leach}$ (0.24, but 0 in the pastoral/agro-pastoral system) were used (IPCC Table 11.3). F_{PRP} used the value calculated for direct nitrous oxide emissions from urine and dung deposited on pasture in Section 5. Table 53 presents the resulting estimated indirect N_2O emissions from deposit of dung and urine on pasture by cattle, sheep and goats.

Table 57. Indirect N_2O emissions from dung and urine deposited on pasture by cattle, sheep and goats, 1994-2018 (kg N_2O)

Year	Dairy cattle	Other cattle	Sheep	Goats	Total
1994	0	2,238,032	319,774	259,570	2,817,375
1995	0	2,411,961	321,139	259,999	2,993,099
1996	0	2,448,420	342,948	273,272	3,064,640
1997	0	2,617,245	341,907	274,500	3,233,652
1998	0	2,606,458	315,669	256,819	3,178,946
1999	0	2,467,555	289,094	241,195	2,997,844
2000	0	2,639,226	297,449	262,806	3,199,481
2001	0	3,168,619	433,125	457,452	4,059,196
2002	0	2,692,981	432,337	393,832	3,519,150
2003	0	2,933,372	419,285	344,177	3,696,834
2004	0	3,028,191	455,590	370,856	3,854,637
2005	0	3,149,778	526,747	411,056	4,087,581
2006	0	3,350,799	594,658	463,916	4,409,373
2007	0	3,634,983	650,511	540,881	4,826,375
2008	0	3,799,412	620,730	545,588	4,965,729
2009	0	3,963,740	642,690	550,840	5,157,270
2010	0	4,070,528	635,517	564,417	5,270,462
2011	0	4,004,317	599,926	546,278	5,150,521
2012	0	4,123,252	632,897	591,036	5,347,185
2013	0	4,218,021	667,775	669,376	5,555,172
2014	0	4,289,947	725,686	697,291	5,712,923
2015	0	4,337,033	708,584	707,178	5,752,796
2016	0	4,474,104	750,097	717,086	5,941,287
2017	0	4,559,540	764,048	782,555	6,106,143
2018	0	4,566,572	780,082	885,551	6,232,204

6.3 Uncertainties and time-series consistency

Annex 6 gives the main results of uncertainty analysis conducted using Monte Carlo simulation for cattle. Uncertainty of 2018 for total indirect nitrous oxide emissions from managed soils due to cattle was (+105.0%, -64.1%). The high level of uncertainty is mainly due to the default uncertainty range associated with the emission factor in the IPCC Guidelines. Annex 6 highlights the factors associated with uncertainty in the trend of direct nitrous oxide emissions from soils, for which improved data availability can partially reduce the overall uncertainty.

A consistent method was used to estimate emissions in each year of the time series. The values of $Nex_{(T)}$ and $MS_{(T,PRP)}$ used in calculating F_{PRP} were the same values used for calculating direct nitrous oxide emissions from manure management and deposit of urine and dung on pasture.

6.4 Source-specific QAQC and verification

Tier 1 QC activities have been implemented. This inventory was compiled in an Excel spreadsheet.

Quality control activities included:

- Checking that the equations programmed in the spreadsheet were correctly input
- Checking that inputs to summed totals were obtained from the correct fields
- Checking that all data sources were fully documented
- Checking that the figures in the inventory report were correctly transcribed
- Reconstructing a number of the calculations to cross-check the intermediate calculations and results in the inventory spreadsheet.

QAQC activities identified and addressed the following issue:

- Emissions were not presented disaggregated by species, which has now been rectified.

The inventory was also reviewed by members of the Tier 2 livestock inventory advisory group and there were no comments or queries about this emission source.

6.5 Source-specific recalculations

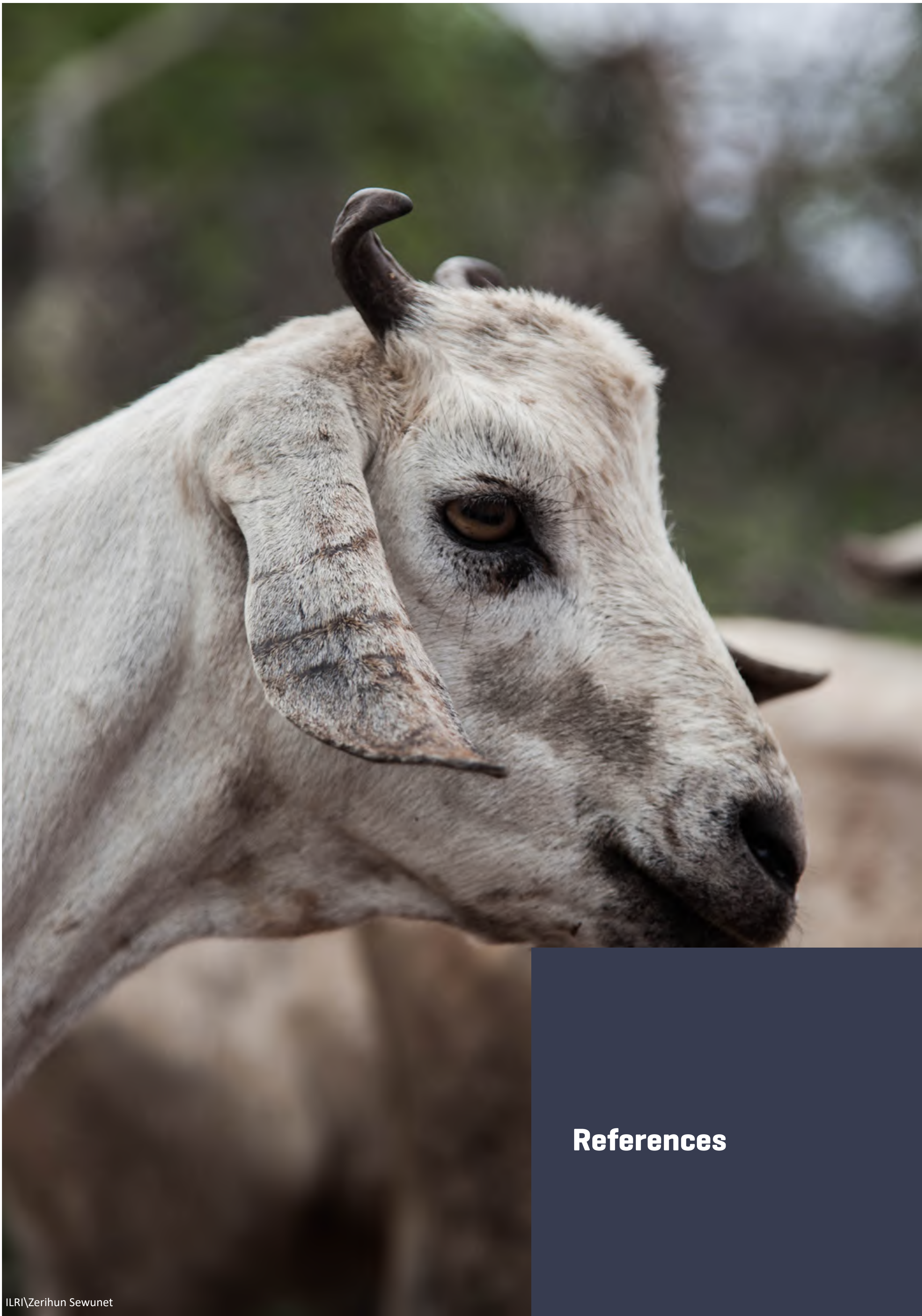
Tier 1 emissions using activity data reported in the SNC (2012) were reconstructed for direct nitrous oxide emissions from dung and urine deposited on pasture (Table 54). For details of issues relating to the recalculation, see Annex 8. Tier 1 estimates of indirect N_2O emissions from dung and urine deposited on pasture are on average 27% lower than the Tier 2 estimates. Although the Tier 1 default value for N_{ex} is higher than the Tier 2 estimates for cattle, the Tier 2 estimate includes leaching for ruminants in all production systems except the pastoral/agropastoral production system.

Table 58. Indirect N_2O emissions from dung and urine deposited on pasture by cattle, sheep and goats 1994-2013

Year	Nitrous oxide (Kg N_2O)	
	Tier 1	Tier 2
1994	1,930,463	2,817,375
1995	1,945,889	2,993,099
1996	2,041,704	3,064,640
1997	2,346,117	3,233,652
1998	2,346,117	3,178,946
1999	2,263,581	2,997,844
2000	2,100,878	3,199,481
2001	2,255,120	4,059,196
2002	2,623,809	3,519,150
2003	2,640,268	3,696,834
2004	2,799,191	3,854,637
2005	3,008,021	4,087,581
2006	3,297,659	4,409,373
2007	3,748,253	4,826,375
2008	3,751,613	4,965,729
2009	3,836,044	5,157,270
2010	3,962,369	5,270,462
2011	3,862,263	5,150,521
2012	4,036,424	5,347,185
2013	4,102,671	5,555,172

6.6 Source-specific planned improvements

Annex 7 discusses data quality and inventory improvement priorities. For manure management, the priority is to improve the availability of representative data on manure management systems that are collected using classifications and methods in line with the IPCC categories. This will include estimation of the proportion of dung and urine deposited on pasture.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Annex 1: Cattle, sheep and goat sub-categories and population data

Annex 1: Cattle, sheep and goat sub-categories and population data

This annex explains how cattle, sheep and goat sub-categories populations and production systems are defined.

Cattle: IPCC (2006) recommends that cattle populations "should be classified into at least three main subcategories: mature dairy, other mature, and growing cattle. Depending on the level of detail in the emissions estimation method, subcategories can be further classified based on animal or feed characteristics." The classification used in this inventory reflects cattle type (i.e., dairy, other), feed characteristics (i.e. production systems and fattening feeding systems) and animal charateristics (i.e. age, sex, utilization). Table A.1.2 shows how the classification of cattle sub-categories maps to both the IPCC (2006) animal category definitions and the categories in CSA annual livestock sample surveys.

This inventory distinguishes between dairy cattle (i.e. exotic or cross-bred breeds) and dual purpose (i.e. indigenous breed) other cattle. The dairy cattle category includes dairy cows as well as other sub-categories of exotic or cross-bred breeds because there are significant differences in animal performance between exotic or cross-bred and indigenous cattle.

Other cattle in different production systems differ in both feeding and animal performance. In each region of the country, some cattle are identified as being in the mixed crop livestock production system and some are in the pastoral/agro-pastoral system. The populations in each of these systems in each region were based on the population in zones shown in Table A.1.1. Cattle that are fattened in smallholder fattening operations or commercial feedlots also differ in feeding and animal performance (e.g. weight gain) and are identified as separate sub-categories within the mixed crop-livestock production system.

Table A1.1 Zones in each of the main production systems defined

Region	Zones in the pastoral / agro-pastoral production system	Zones in the mixed crop livestock production system
Tigray	West Tigray	North West Tigray, Central Tigray, East Tigray, South Tigray
Afar	All zones	
Ahmara		North Gonder, South Gonder, North Wello, South Wello, North Shewa, East Gojam, West Gojam, Waghmera, Awi, Oromia and Argoba Special Woreda
Oromia	Borena	West Wellega, East Wellega, Illubaabor, Jima, West Shewa, East Shewa, North Shewa, Arsi, West Hararghe, East Hararghe, Bale, South West Shewa, Guji. West Arsi, Kelem Wellega and Horroguduru Wellega
Somali	All zones	
B/Gumuz	Metekel	Asosa, Kemeshi, Pawi Special Woreda, Mao Kpmo
SNNP	South Omo	Gurage, Hadiya, Kembata Tembaro, Sedama, Gedio, Walayta, Shaka, Kaffa, Gamo Goffa, Bench Maji, Yem Special Woreda, Amaro Special Woreda, Burji Special Woreda, Konso Special Woreda, Derashe Special Woreda, Dawero, Basketo Special Woreda, Konta Special Woreda, Silite and Alaba Special Woreda
Gambella	Angnuwak, Nuwar, Mezhenger and Itang Special Woreda	
Harari		Hundene
Dire Dewa		Dire Dewa
Addis Ababa		Addis Ababa

IPCC (2019) provides updated guidance on livestock characterization. For the Tier 1a approach, IPCC (2019) recommends categorization by high and low productivity systems. For dairy cattle, this inventory identifies a smallholder dairy system and a commercial dairy system, which may correspond to low and high productivity systems, respectively, although data to characterize the differences in performance were not available for this inventory. Characterizing these differences in performance is an option for future improvement. The distinction between commercial and smallholder dairy systems is retained in this inventory so that the inventory structure does not have to be changed when better animal performance data is available.

Animal characteristics also differ by age and sex. The classification by age and sex used in this inventory is more detailed than the IPCC minimum recommendation because for the mixed crop-livestock and pastoral/agro-pastoral production systems, CSA data is available with a more detailed categorization. Using this more detailed classification supports more accurate estimation of animal performance and emission factors.

Table A1.2 Correspondence of cattle sub-categories to IPCC and CSA categories

IPCC (2006) categories		Tier 2 inventory categories		CSA categories
Dairy	Mature cow	Smallholder intensive	Adult crossbred & pure exotic dairy cows (3-10 & above years)	Crossbred & pure exotic cows (3-10 years & above)
		Commercial intensive	Adult crossbred & pure exotic dairy cows (3-10 & above years)	(not enumerated)
	Other mature	Smallholder intensive	Adult crossbred & pure exotic males (3 & above years)	Adult crossbred & pure exotic males (3 & above years)
		Commercial intensive	Adult crossbred & pure exotic males (3 & above years)	(not enumerated)
	Growing cattle	Smallholder intensive	Crossbred & Pure exotic calves (<6 months) male & female	Crossbred & Pure exotic calves (<6 months) male
				Crossbred and pure exotic calves (<6 months) female
			Crossbred & Pure exotic calves (6 m - < 1 yr) male & female	Crossbred & Pure exotic calves (6 m - < 1 yr) male
				Crossbred & Pure exotic calves (6 m - < 1 yr) female
			Crossbred & Pure exotic growing males (1 - < 3 years)	Crossbred & Pure exotic growing males (1 - < 3 years)
			Crossbred & Pure exotic growing females (1 -< 3 years)	Crossbred & Pure exotic growing females (1 -< 3 years)
		Commercial intensive	Crossbred & Pure exotic calves (<6 months) male & female	(not enumerated)
			Crossbred & Pure exotic calves (6 m - < 1 yr) male & female	(not enumerated)
			Crossbred & Pure exotic growing males (1 - < 3 years)	(not enumerated)
			Crossbred & Pure exotic growing females (1 -< 3 years)	(not enumerated)
Other cattle	Other mature	Mixed crop-livestock	Adult multipurpose cows (>3 years)	Indigenous cows (3-10 years & above) in mixed crop-livestock zones
			Adult males used for draught (3-10 years)	Indigenous males (3-10 years) used for draught in mixed crop-livestock system zones
			Adult males used for breeding & other purpose (>3-10 years)	Indigenous males (3-10 years) used for breeding purpose in mixed crop-livestock system zones
				Indigenous males (3-10 years) used for other purpose in mixed crop-livestock system zones
			Smallholder fattening cattle (male 3-10 years)	Indigenous males (3-10 years) used for beef in mixed crop-livestock system zones
			Commercial feedlot-fed cattle (male 3-10 years)	(not enumerated)
		Pastoral/agro-pastoral	Adult multipurpose cows (>3 years)	Indigenous cows (3-10 years & above) in pastoral /agro-pastoral zones
			Adult males used for draught (3-10 years)	Indigenous males (3-10 years) used for draught in pastoral / agro-pastoral zones
			Adult males used for breeding & other purpose (>3-10 years)	Indigenous males (3-10 years) used for breeding purposes in pastoral /agro-pastoral zones
				Indigenous males (3-10 years) used for other purposes in pastoral /agro-pastoral zones

	Growing cattle	Mixed crop-livestock	Calves (<6 months) male & female	Indigenous male calves (<6 months) in mixed-crop livestock zones
				Indigenous female calves (<6 months) in mixed-crop livestock zones
			Calves (6 m - < 1 yr) male & female	Indigenous male calves (6 m -<1 year) in mixed-crop livestock zones
				Indigenous female calves (6 m -<1 year) in mixed-crop livestock zones
			Growing males (1-<3 years)	Indigenous growing males (1-<3 years) in mixed-crop livestock zones
			Growing females (1-<3 years)	Indigenous growing males (1-<3 years) in mixed-crop livestock zones
		Pastoral / agro-pastoral	Calves (<6 months) male & female	Indigenous male calves (<6 months) in mixed-crop livestock zones
				Indigenous female calves (<6 months) in mixed-crop livestock zones
			Calves (6 m - < 1 yr) male & female	Indigenous male calves (6 m -<1 year) in mixed-crop livestock zones
				Indigenous female calves (6 m -<1 year) in mixed-crop livestock zones
			Growing males (1-<3 years)	Indigenous growing males (1-<3 years) in mixed-crop livestock zones
			Growing females (1-<3 years)	Indigenous growing males (1-<3 years) in mixed-crop livestock zones

A1.1 Dairy cattle sub-category populations

Two dairy cattle production systems were identified: 1) smallholder intensive dairy cattle population, located in rural areas characterized by mixed crop-livestock production, and 2) commercial dairy cattle population, which includes cattle raised in urban and peri-urban areas and on commercial farms. Smallholder dairy cattle are enumerated in the CSA annual livestock sample surveys, while cattle in urban or peri-urban and commercial farms are not.

A1.1.1 Smallholder intensive dairy cattle sub-category populations: Six dairy cattle population sub-categories were defined based on sub-categories reported in the annual CSA agricultural sample survey: adult pure exotic dairy cows (3-10 years), adult pure exotic males (3-10 years), pure exotic calves (<6 months, male and female), pure exotic calves (6 m – <1 year, male and female), pure exotic growing males (1-<3 years) and pure exotic growing females (1-<3 years).

The total population of cross-bred and pure exotic dairy cattle was taken from the CSA agricultural sample survey for the years 2003-2018. The herd structure was taken from Holetta Agricultural Research Centre Annual Research Report (2018). Sub-category populations were derived by multiplying total dairy cattle population (crossbred and pure exotic) by the proportion of dairy cattle in each sub-category as in Table A1.3.

Table A1.3 Smallholder intensive dairy cattle herd structure

Sub-category	Proportion in the herd
Adult dairy cows	0.587
Adult males	0.042
Calves <6 months	0.080
Calves 6 m -<1yr	0.080
Growing males	0.009
Growing females	0.202

Source: Holetta Agricultural Research Centre Annual Research Report (2018)

For the years 1994-2002, due to missing population data for cross-bred and pure exotic cattle in the CSA reports, sub-category populations were interpolated using the average annual growth rate of the total national cattle population for each year. The resulting smallholder intensive dairy cattle sub-populations are shown in Table A1.4.

Table A1.4 Smallholder intensive dairy cattle sub-category populations

Year	Adult dairy cows (>3 years)	Adult males used for breeding & other purpose (3-10 years)	Calves < 6 months (male & female)	Calves (6 m-1 yr) male & female	Growing males (1-3 years)	Growing females (1-3 years)
1994	109,105	7,806	14,869	14,869	1,673	37,545
1995	117,295	8,392	15,986	15,986	1,798	40,364
1996	122,051	8,733	16,634	16,634	1,871	42,000
1997	130,185	9,315	17,742	17,742	1,996	44,800
1998	129,315	9,253	17,624	17,624	1,983	44,500
1999	122,331	8,753	16,672	16,672	1,876	42,097
2000	130,537	9,340	17,790	17,790	2,001	44,921
2001	155,291	11,111	21,164	21,164	2,381	53,439
2002	132,748	9,498	18,092	18,092	2,035	45,682
2003	140,411	10,046	19,136	19,136	2,153	48,318
2004	118,457	8,476	16,144	16,144	1,816	40,764
2005	165,158	11,817	22,509	22,509	2,532	56,835
2006	160,852	11,509	21,922	21,922	2,466	55,353
2007	189,160	13,534	25,780	25,780	2,900	65,094
2008	193,971	13,879	26,436	26,436	2,974	66,750
2009	180,849	12,940	24,647	24,647	2,773	62,234
2010	229,809	16,443	31,320	31,320	3,523	79,083
2011	319,616	22,869	43,559	43,559	4,900	109,987

2012	329,391	23,568	44,891	44,891	5,050	113,351
2013	416,020	29,766	56,698	56,698	6,379	143,162
2014	442,146	31,636	60,258	60,258	6,779	152,152
2015	476,781	34,114	64,979	64,979	7,310	164,071
2016	624,085	44,653	85,054	85,054	9,569	214,762
2017	600,374	42,957	81,823	81,823	9,205	206,602
2018	744,200	53,248	101,424	101,424	11,410	256,096

A1.1.2 Commercial dairy cattle sub-category populations: CSA data is only sampled from rural households. It does not include households in urban or peri-urban areas or commercial farms. The commercial dairy production system is defined as dairy cattle on urban and peri-urban farms and on small, medium or large commercial farms.

There is no official data source on the commercial dairy population in Ethiopia. For this initial inventory, we estimated commercial dairy populations for 1996 and 2017 and filled in missing years using linear interpolation. In 1996 a census of cattle populations was conducted in Addis Ababa, and enumerated 27,000 exotic cattle (reported in Feleke 2003, p.7). A 1990s farm survey reported in Staal (1996) suggested that some urban and peri-urban farms also include indigenous cattle (ca. 16% of total urban/peri-urban cattle population). Therefore, for Addis Ababa, we estimate a total 1996 commercial dairy population of 32,385 (i.e. including 16% indigenous breed). The 1996 census referred to the Addis Ababa region before it became a municipality in 1996, and includes woredas that are now part of the wider Addis Ababa milk shed and that are now in Oromia Region. Land O'Lakes (2010) estimated that the Addis Ababa milk shed was about 66% of national milk supply. Assuming that in 1996 the Addis Ababa milkshed was 66% of the commercial dairy herd, then the total national commercial dairy population in 1996 would be 48,579 head.

For 2017, a survey in the Addis Ababa milkshed estimated a population of 394,000 dairy cattle in urban/peri-urban and commercial farms (Minten et al. 2018).[1] Land O'Lakes (2010) estimated that the Addis Ababa milk shed was about 66% of national milk supply. Therefore, we assume that the total national commercial dairy population was 591,000 cattle in 2017.

To allocate the total commercial dairy herd in between regions in 1996 and 2017, we assume the distribution of cattle shown in Table A1.5, based on the distribution of CSA-enumerated dairy cattle in each milkshed and each region taken from Brandsma et al. (2013).[2] Within each region, the herd structure was estimated based on a survey reported by Mekasha et al. (2003), as shown in Table A1.6. Missing data between 1996 and 2017 were linearly interpolated, and before 1996 and after 2017 were linearly extrapolated. The resulting sub-category populations are shown in Table A1.7.

2. The study report refers to 'dairy cows' as the unit of herd size, and therefore we interpret that the cattle enumerated in that study include cows as well as other dairy cattle.
3. This source was chosen because CSA-enumerated dairy cattle are presented by milk shed.

Table A1.5 Assumed distribution of commercial dairy cattle by region

	Addis	Oromia	Amhara	SNNPR	Tigray	Dire Dawa
Addis Milk Shed (66.6% of total)	5.0%	69.0%	26.0%	0%	0%	0%
Other milk sheds (33.3% of total)	0%	27.4%	38.3%	33.8%	0.5%	0.001%
Total per region	1.65%	41.14%	34.22%	22.6%	0.33%	0.06%

Table A1.6 Assumed herd structure for commercial dairy cattle

Sub-category	Proportion of herd
Adult dairy cows	0.51
Adult males used for reproduction	0.02
Adult males used for beef	0
Calves <6 months	0.05
Calves 6 m -<1yr	0.14
Growing males	0.02
Growing females	0.25

Source: Mekasha et al. (2002)

Table A1.7 Commercial dairy cattle sub-category populations, 1994-2018

Year	Adult dairy cows (>3 years)	Adult males used for breeding & other purpose (3-10 years)	Calves < 6 months (male & female)	Calves (6 m-1 yr) male & female	Growing males (1-3 years)	Growing females (1-3 years)
1994	24,721	911	2,497	7,030	1,101	12,318
1995	24,721	911	2,497	7,030	1,101	12,318
1996	24,721	911	2,497	7,030	1,101	12,318
1997	37,865	1,396	3,825	10,768	1,687	18,867
1998	51,009	1,881	5,153	14,506	2,273	25,416
1999	64,154	2,365	6,481	18,245	2,858	31,966
2000	77,298	2,850	7,809	21,983	3,444	38,515
2001	90,442	3,335	9,136	25,721	4,029	45,065
2002	103,587	3,819	10,464	29,459	4,615	51,614
2003	116,731	4,304	11,792	33,197	5,200	58,164
2004	129,875	4,789	13,120	36,935	5,786	64,713
2005	143,019	5,273	14,448	40,673	6,372	71,262
2006	156,164	5,758	15,776	44,411	6,957	77,812
2007	169,308	6,242	17,103	48,149	7,543	84,361
2008	182,452	6,727	18,431	51,887	8,128	90,911
2009	195,597	7,212	19,759	55,625	8,714	97,460
2010	208,741	7,696	21,087	59,364	9,300	104,009
2011	221,885	8,181	22,415	63,102	9,885	110,559
2012	235,030	8,666	23,743	66,840	10,471	117,108
2013	248,174	9,150	25,070	70,578	11,056	123,658
2014	261,318	9,635	26,398	74,316	11,642	130,207
2015	274,462	10,120	27,726	78,054	12,228	136,756
2016	287,607	10,604	29,054	81,792	12,813	143,306
2017	300,751	11,089	30,382	85,530	13,399	149,855
2018	313,895	11,574	31,710	89,268	13,984	156,405

A1.2 Other cattle sub-category populations

Other cattle include dual purpose cattle (i.e. indigenous breeds) in the mixed crop-livestock production system and the pastoral/agro-pastoral production system. A total of 16 sub-categories were defined (Table A1.8).

Table A1.8 Other cattle sub-categories

Mixed crop-livestock system	Pastoral/agro-pastoral system
Adult multipurpose cows ≥3 years	Adult multipurpose cows ≥3 years
Adult males used for draught (3-10 years)	Adult males used for draught (3-10 years)
Adult males used for breeding & other purpose (>3-10 years)	Adult males used for breeding & other purpose (>3-10 years)
Calves < 6 months (male & female)	Calves < 6 months (male & female)
Calves (6 m-<1 yr) male & female	Calves (6 m-<1 yr) male & female
Growing males 1-<3 years	Growing males 1-<3 years
Growing females 1-<3 years	Growing females 1-<3 years
Smallholder fattening cattle (male 3-10 years)	
Commercial feedlot-fed cattle (male 3-10 years)	

The main data source for populations was the CSA annual livestock sample survey. Some adjustments were needed to align sub-categories and to fill missing data. For 1995, sub-category populations were available from CSA reports as < 1 year age class, 1 - < 2 years age class and 2 years and above age class for both males and females, which was slightly different from cattle population sub-category reported starting from 1997 (i.e., < 6 months, 6 months to < 1 year, 1 to < 3 years and 3 years to < 10 years and 10 years and above). Therefore, sub-categories reported in 1995 were aligned to the 1997 sub-categories using coefficients developed from the more detailed 1997 age and sex classes. Specifically:

- The proportions of other cattle '< 6 months' and '6 months to < 1 year' in the 1997 data were applied to the 1995 '<1 year' age class to estimate the proportions in each age class in 1995;
- Other cattle '1-<2 years' and '>2 years' in the 1995 data were summed, and the proportions of other cattle in the '1-<3 years' and '>3 years' in the 1997 data were applied to estimate the proportions in each age class in 1995.

For 1995, 1997, and 2003-2018 in the mixed crop-livestock system, and for 1997, 2003-2008 and 2010-2016 in the pastoral/agro-pastoral system, sub-category populations were derived from CSA livestock survey reports as follows. The population for adult males used for breeding and other purposes derived from the CSA data for '3 to < 10 years' and '10 year and above' male age classes. 'Adult males used for draught' derived from the CSA data for '3 to < 10 years males used for draft purpose'. The smallholder fattening cattle sub-category population derived from the CSA data for '3 to < 10 years males used for meat purpose'. Population data on the 'Adult multipurpose cows' sub-category derived from CSA data on the '3 to 10 years' and '10 years and above' female age classes. For growing male and growing female sub-categories, population data came from the '1 to < 3 years' male and female age classes, respectively. The populations of calves <6 months and 6 months to <1 year came from those same categories in the CSA reports. For the mixed crop-livestock production system, sub-category population numbers for 1994, 1996 and 1998-2002 were interpolated using the annual growth rate of the national total cattle population of CSA livestock sample survey reports.

CSA annual livestock sample surveys do not include commercial farms. The commercial feedlot cattle population was estimated using reported exports of live cattle and meat as a proxy variable. There are four datasets on Ethiopia's exports of live cattle and beef (Table A1.9). Prior to 2001, FAOSTAT reports low numbers of cattle and beef export (averaging 919 head per year from 1994-2000, which is slightly higher than the COMTRADE average of 699 head per year). From 2004, FAOSTAT shows much higher exports than the other datasets (Figure A1.1), COMTRADE reports the lowest number and Trademap (using ERCA data since 2011) reports a value in between these other data sources. Considering that Trademap now uses ERCA, which means that future updating of the inventory can also use ERCA data, the Trademap dataset was selected to use for 2001-2018. Trademap.org data are produced by the International Trade Centre, a multilateral agency with a joint mandate from WTO and UNCTAD. For consistency with the Trademap data, COMTRADE data was used for the period 1995-2001, with missing years (1994 and 1996) filled using linear interpolation and extrapolation. Consistent with the animal performance data used to estimate emission factors, we assume a finishing LW of 362 kg per cow and a 50% carcass ratio to convert tonnes of bovine meat exported to numbers of cattle, considering that most exported meat is carcass or half-carcasses containing bones.[1] The ERCA data show a decline in exported live animal numbers in recent years, most likely reflecting changes in national and overseas export policies and regulations. Reportedly, 70% of commercial feedlot cattle are from Oromia Region,[2] and because there are also northern and southern export routes,[3] we assume 10% of the total commercial feedlot population is in SNNPR, 10% in Amhara Region and 10% in Tigray Region.

1 Trademap.org data for product categories HS0201 and HS0202 examined at 6-digit level.

2 FAO. 2015. Analysis of price incentives for Live Cattle in Ethiopia. Technical notes series, MAFAP. FAO, Rome.

3 Gebre Mariam S, Amare S, Baker D, Solomon A, Davies R. 2013. *Study of the Ethiopian live cattle and beef value chain*. ILRI Discussion Paper 23. Nairobi: International Livestock Research Institute.

Table A1.9 Cattle and beef export data sources

Data source	Notes
FAOSTAT[a]	Data available 1994-2017; "official data", but original source not known
COMTRADE[b]	Data available 1995-2018 with gaps (1994, 1996); data reported by Ethiopia, specific source not known
Trademap[c]	Data available 2001-2018; 2001-2010 from COMTRADE, 2011-2018 from Ethiopia Revenue and Customs Authority (ERCA)
National Bank of Ethiopia[d]	Data cited in Teklewold et al. (2009), but original dataset could not be obtained. Literature reports suggest that this dataset gives much higher export estimates than the other datasets in most years

a http://www.fao.org/faostat/en/; b https://comtrade.un.org/data; c https://www.trademap.org/ d https://nbebank.com/statistical-data-series/

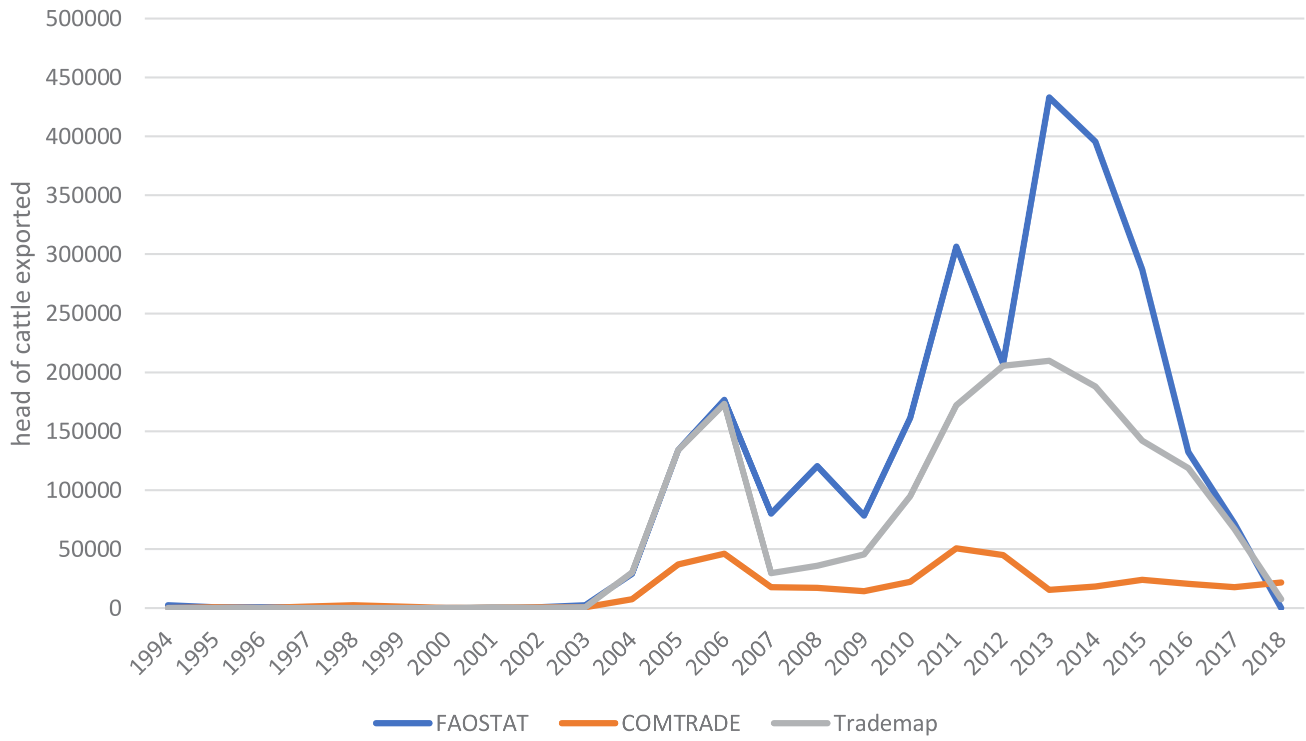

Figure A1.1: Estimated cattle exports (live, meat) from different datasets

For the pastoral/agro-pastoral production system, data issues included missing data in the CSA time series, and incomplete sampling of pastoral/agropastoral zones in Somali and Afar Region by CSA. For the pastoral/agro-pastoral production system, CSA-enumerated sub-category populations for 1994, 1995, 1996, 1998-2002, 2009, 2017 and 2018 were interpolated using the annual growth rate of national total cattle populations from CSA sample survey reports.

The CSA annual livestock survey only samples in two of the five zones in Afar Region and three of the nine zones in Somali Region. To estimate the population of cattle in the non-sampled zones, we followed the analysis of Tilahun and Schmidt (2012) as follows. For Somali Region, a 2003 aerial census estimated a total cattle population of 670,000 in the zones not covered by CSA, which is similar to the 643,000 estimated in Ethiopian Agricultural Sample Enumeration (EASE) data for 2001. The total 2003 estimate for Somali Region was 1.0161 million cattle, so the CSA enumerated zones accounted for 45% of the total cattle population. In 2006, preparations for the Livestock Masterplan Study estimated a total population of 1.39 million, of which CSA enumerated 44%, and in 2001 EASE estimated 1.23 million, of which CSA enumerated 47.8%. On average, CSA enumerated 46% of the total population in Somali Region. Assuming that this percentage remained constant from 1994-2018, we estimated the total Somali Region population by dividing the CSA enumerated populations by 0.46. We assume that the herd structure of the total population is the same as the herd structure enumerated by CSA. For Afar Region, the only possible comparison is with the 2001 EASE data. This suggests that total cattle population in 2001 in Afar was 2.34

million, of which CSA enumerated 0.92 million, or 39% of the total. Assuming this proportion to be constant, we estimate the total population in Afar by dividing the CSA data by 0.39 and assume that the herd structure is the same as the herd structure shown in the CSA data for Afar Region.

As a cross-check, there has been one other reported estimate for Somali and Afar regions (Benkhe et al. 2010). They analyzed that in the Livestock Masterplan (2006) data, Somali and Afar populations account for 8.2% of the total national cattle herd. Removing Afar and Somali from the CSA totals and then estimating their values using a fixed 8.2% also gives an estimate of national populations. The result is not fully consistent with the method used above (see Figure A1.2). The reason for the different trend is that the Benkhe method follows the overall trend in national livestock populations, while the inventory method used here follows the trend in CSA enumerated zones of Afar and Somali. A comparison of the two methods can be used to estimate uncertainty of the population estimates. In 2020, CSA undertook a survey that includes previously unenumerated zones in Afar and Somali regions, and the estimate from that survey can be used to update and revise the inventory estimate in future revisions.

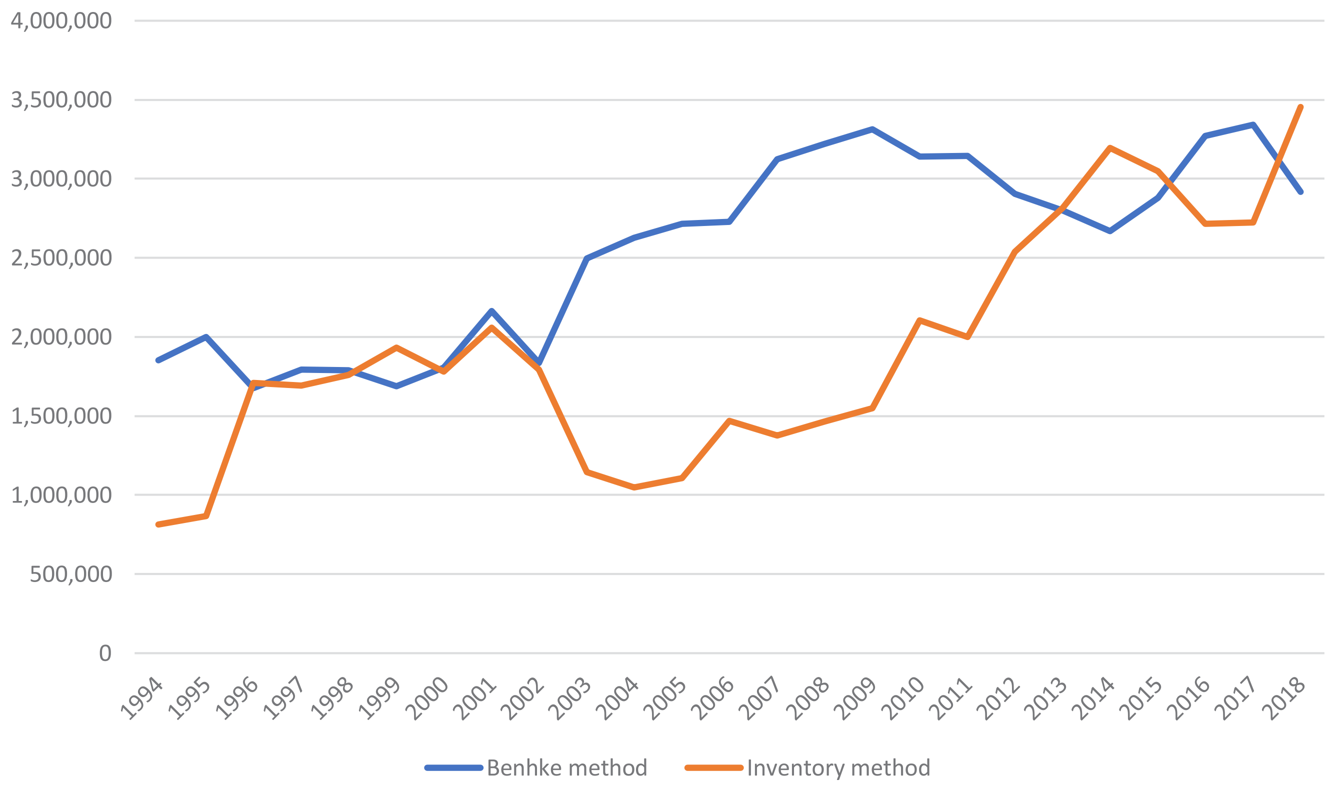

Figure A1.2 Additional cattle population estimated in Afar and Somali Regions using this inventory method and the Benkhe et al. (2010) method

The resulting total national dual purpose cattle populations are shown in Table A1.10.

Table A1.10 Dual purpose cattle sub-category populations

	Pastoral and agro-pastoral system							Mixed crop-livestock system								
Year	Adult multipurpose cows ≥3 years	Adult males used for draught (3-10 years)	Adult males used for breeding & other purpose (>3-10 years)	Calves < 6 months (male & female)	Calves (6 m-<1 yr) male & female	Growing males 1-<3 years	Growing females 1-<3 years	Adult multi purpose cows ≥3 years	Adult males used for draught (3-10 years)	Adult males used for breeding & other purpose (>3-10 years)	Calves < 6 months (male & female)	Calves (6 m-<1 yr) male & female	Growing males 1-<3 years	Growing females 1-<3 years	Smallholder fattening male	Commercial feedlot fed male
1994	1,596,461	569,432	263,184	430,810	450,072	342,603	458,347	9,410,904	7,172,757	781,616	1,966,716	1,920,733	2,067,591	2,482,679	163,829	277
1995	1,717,453	612,793	283,368	463,573	484,330	368,824	493,313	10,148,151	7,734,400	842,843	2,120,762	2,071,179	2,229,493	2,677,200	176,658	449
1996	2,261,400	671,969	340,841	687,444	708,954	440,802	707,606	10,104,274	7,788,235	819,081	2,471,101	2,468,416	2,254,885	2,677,134	183,073	793
1997	2,359,148	699,805	357,973	720,886	743,699	462,092	743,050	10,803,695	8,327,100	875,775	2,642,118	2,639,248	2,410,904	2,862,470	195,740	1,137
1998	2,433,531	709,626	371,825	740,824	760,956	477,064	764,327	10,718,941	8,261,890	868,906	2,621,407	2,618,559	2,392,022	2,840,003	194,207	2,288
1999	2,413,050	706,779	363,562	726,947	746,295	468,361	747,859	10,101,521	7,786,352	818,861	2,470,461	2,467,777	2,254,335	2,676,380	183,029	995
2000	2,457,165	716,614	375,279	747,785	768,093	481,554	771,443	10,806,743	8,329,690	876,025	2,642,897	2,640,026	2,411,649	2,863,253	195,801	23
2001	2,911,852	848,357	446,138	888,267	912,502	571,956	916,962	12,952,908	9,983,033	1,049,988	3,167,638	3,164,197	2,890,350	3,431,973	234,665	494
2002	2,488,990	725,696	380,466	757,956	778,567	488,089	782,073	10,980,099	8,463,399	890,079	2,685,305	2,682,388	2,450,359	2,909,175	198,944	366
2003	1,867,159	481,507	204,868	608,291	499,929	287,619	493,654	12,581,836	8,855,742	1,016,157	3,299,453	2,878,488	2,682,543	3,229,670	193,274	693
2004	1,892,157	476,142	203,634	608,971	454,818	275,767	424,790	13,199,277	9,199,569	1,170,378	3,144,487	2,555,836	2,705,096	3,289,811	168,840	29,931
2005	1,935,648	485,660	240,703	619,150	464,660	293,620	438,206	13,630,879	9,834,796	1,265,198	3,356,074	2,816,945	2,575,089	3,135,702	193,147	133,837
2006	2,445,034	555,398	332,869	707,874	557,130	336,405	560,392	14,293,460	10,145,736	1,423,051	3,673,834	3,180,515	2,714,724	3,256,441	210,210	173,136
2007	2,378,464	528,907	335,252	779,529	591,685	358,355	539,202	15,775,165	10,990,446	1,515,699	4,006,556	3,658,684	3,151,047	3,770,818	277,636	29,695
2008	2,498,951	567,639	306,436	725,988	645,960	341,975	626,716	16,409,483	11,850,688	1,475,007	3,788,081	3,614,300	3,290,426	4,016,242	307,175	36,125
2009	2,609,230	565,399	339,541	706,715	640,358	353,222	631,658	16,710,660	12,256,971	1,901,678	4,496,573	3,367,713	3,250,842	4,048,312	279,146	45,707
2010	3,234,130	639,367	501,944	899,766	767,179	399,205	759,137	17,351,435	12,824,183	1,726,283	4,295,944	4,091,775	3,297,794	4,029,742	316,037	94,982
2011	3,035,535	622,598	436,716	867,627	728,078	416,816	749,745	17,201,494	12,293,382	1,439,163	4,213,281	3,881,193	3,411,450	3,959,917	361,332	172,205
2012	3,827,822	754,514	618,906	1,112,628	795,100	475,219	895,213	17,272,052	12,599,175	1,510,056	4,499,715	3,539,126	3,607,174	4,187,057	310,861	205,357
2013	4,188,434	785,683	480,342	1,176,692	930,274	502,432	866,844	17,337,910	12,914,533	1,572,731	4,437,434	3,701,698	3,721,265	4,214,923	340,815	209,744
2014	4,487,769	886,630	521,888	1,217,349	1,006,685	587,867	1,067,926	17,623,475	13,412,696	1,350,927	4,445,533	4,049,670	3,782,931	4,404,613	341,382	187,884
2015	4,718,866	801,304	731,985	1,154,372	977,554	528,436	902,135	17,782,260	13,661,066	1,356,130	4,330,671	4,493,762	3,840,335	4,471,209	354,737	142,242
2016	4,323,830	761,386	769,972	1,132,337	1,012,978	486,094	797,471	18,214,724	14,021,581	1,328,434	4,873,223	4,279,652	4,031,973	4,780,273	367,643	118,947
2017	4,282,365	792,776	751,564	1,160,170	1,033,077	506,341	825,997	18,192,536	14,739,174	1,189,712	4,607,730	4,639,693	4,184,848	4,858,250	377,322	66,858
2018	5,008,576	714,204	811,916	1,557,763	988,751	563,201	774,502	18,442,905	14,084,884	1,317,665	4,851,003	4,796,332	4,280,071	5,085,527	461,414	7,707

A1.3 Sheep sub-category populations

IPCC (2006) recommends to classify sheep into mature ewes, other sheep >1 year, and growing lambs (intact, castrates and females). In this inventory, fourteen sheep sub-categories were defined based on age, sex, physiological state (i.e. intact/castrated) and production system in line with the classifications in CSA annual livestock survey reports (Table A1.11). The population of the breeding ewes sub-category is derived from the CSA '2 years and above' female age classes; the population of the adult male sub-category derived from the '2 years and above' male age class; the males 1-< 2 years sub-category derived from the CSA '1 to < 2 years' male age class; the females 1- < 2 years sub-category derived from the '1- < 2 years' female age class. The intact male sub-category was derived from the sum of the CSA '< 6 months males' and '6 months-< 1-year males' age classes divided by the number of castrated males of a similar age. A fixed coefficient of 10% for the number of castrated males (< 6 months males plus 6 months to < 1-year males age class) was used and was constant for all years in the time series (ILRI 2004). The population data for 'females < 1 year' sub-category came from sum of CSA '< 6 months females' and '6 months to < 1-year female' age classes.

Table A1.11 Correspondence of sheep sub-categories to IPCC and CSA categories

IPCC (2006)	This inventory		CSA
Mature ewes	Mixed crop-livestock	Breeding ewes (≥2 yrs)	Sheep > 2 years, female in mixed crop-livestock zones
	Pastoral/agro-pastoral	Breeding ewes (≥2 yrs)	Sheep > 2 years, female in pastoral / agro-pastoral zones
Other sheep > 1 year	Mixed crop-livestock	Mature male (≥2 years)	Sheep > 2 years, male in mixed crop-livestock zones
		female (1-<2 yrs)	Sheep 1-<2 years, female in mixed crop-livestock zones
		Male (1-<2 years)	Sheep 1-<2 years, male in mixed crop-livestock zones
	Pastoral/agro-pastoral	Mature male (≥2 years)	Sheep > 2 years, male in pastoral/ agro-pastoral zones
		female (1-<2 yrs)	Sheep 1-<2 years, female in pastoral/ agro-pastoral zones
		Male (1-<2 years)	Sheep 1-<2 years, male in pastoral/ agro-pastoral zones
Growing lambs	Mixed crop-livestock	Intact male (< 1 yr)	Sheep < 6 m, male mixed crop livestock zones
			Sheep 6m-<1 year, male mixed crop livestock zones
		Castrated male (< 1 yr)	Sheep < 6 m, male mixed crop livestock zones
			Sheep 6m-<1 year, male mixed crop livestock zones
		Female (< 1 yr)	Sheep < 6 m, female mixed crop livestock zones
			Sheep 6m-<1 year, female mixed crop livestock zones
	Pastoral/agro-pastoral	Intact male (< 1 yr)	Sheep < 6 m, male in pastoral/ agro-pastoral zones
			Sheep 6m-<1 year, male in pastoral/ agro-pastoral zones
		Castrated male (< 1 yr)	Sheep < 6 m, male in pastoral/ agro-pastoral zones
			Sheep 6m-<1 year, male in pastoral/ agro-pastoral zones
		Female (< 1 yr)	Sheep < 6 m, female in pastoral/ agro-pastoral zones
			Sheep 6m-<1 year, female in pastoral/ agro-pastoral zones

For the mixed crop-livestock production system, data on sub-category populations in the mixed crop livestock system for 1995, 1997 and 2003-2018 came from CSA annual agricultural sample survey reports, and sheep sub-category populations for 1994, 1996 and 1998-2002 were interpolated using the annual growth rate of the total national sheep population.

For the pastoral/agro-pastoral production system, data on sub-category populations were first taken from the CSA annual agricultural sample survey reports for 1997, 2003-2008 and 2010-2016. Missing data for 1994, 1995, 1996, 1998-2002, 2009, 2017 and 2018 were then interpolated using the annual average growth rate of the national total sheep population. The CSA annual livestock survey only samples in two of the five zones in Afar Region and three of the nine zones in Somali Region. To estimate the population of sheep in the non-sampled zones, we followed the analysis of Tilahun and Schmidt (2012) who analyzed that in the EASE 2001 census, the ratio of combined sheep and goats to cattle was 2.27 in Somali and 2.88 in Afar. We used the CSA-enumerated total populations of sheep and goats to estimate the proportions of sheep and goats, and assumed that the flock structure of sheep and goats in each region is the same as the structure enumerated in the CSA data. Some studies have reported a shift in pastoralists' preferences towards keeping sheep or goats compared to cattle in some other pastoralist areas of Ethiopia (Megersa et al. 2014), so it is possible that the numbers of sheep and goats are underestimated by assuming a fixed ratio of sheep and goats to cattle, but this cannot be verified. The resulting estimates of total national sheep sub-category populations is shown in Table A1.12.

Table A1.12 Sheep sub-category populations, 1994-2018 (head)

Year	Pastoral and agro-pastoral system							Mixed crop-livestock system						
	Breeding ewes ≥ 2 years	Mature male sheep ≥ 2 years	Female 1-<2 years	Male 1-< 2 year	Intact male < 1 yr	Castrated male < 1 yr	Females <1 yr	Breeding ewes	Mature male sheep ≥ 2 years	Female 1-<2 years	Male 1-< 2 year	Intact male < 1 yr	Castrated male < 1 yr	Females <1 yr
1994	733,541	190,371	238,622	193,449	213,386	23,710	307,016	5,600,600	651,248	955,647	486,764	1,771,920	196,880	2,021,758
1995	760,170	198,617	250,541	201,619	220,201	24,467	316,382	5,600,718	651,262	955,667	486,775	1,771,958	196,884	2,021,801
1996	1,194,014	426,586	427,343	224,066	372,444	41,383	606,493	5,603,267	717,100	917,361	418,670	1,759,601	195,511	2,221,815
1997	1,173,231	428,002	426,747	225,664	370,097	41,122	600,992	5,587,870	715,130	914,840	417,520	1,754,766	194,974	2,215,710
1998	1,175,340	424,169	423,596	225,455	367,594	40,844	598,113	5,091,836	651,648	833,630	380,457	1,598,996	177,666	2,019,022
1999	1,240,166	434,335	430,994	229,752	378,075	42,008	618,132	4,557,102	583,213	746,084	340,502	1,431,073	159,008	1,806,988
2000	1,150,296	410,760	412,713	223,684	359,310	39,923	584,215	4,759,760	609,149	779,263	355,644	1,494,714	166,079	1,887,347
2001	1,369,294	484,601	489,428	261,585	429,477	47,720	695,939	7,148,212	914,821	1,170,298	534,107	2,244,762	249,418	2,834,419
2002	1,486,491	540,545	560,715	295,113	472,011	52,446	767,640	7,022,933	898,788	1,149,787	524,746	2,205,421	245,047	2,784,743
2003	1,059,453	216,586	277,522	156,801	321,785	35,754	564,651	7,162,448	627,187	1,131,346	407,000	2,394,464	266,052	3,125,997
2004	1,051,170	217,630	200,134	144,870	302,990	33,666	471,658	8,004,997	681,422	1,294,133	446,349	2,663,373	295,930	3,259,690
2005	1,110,421	229,125	214,116	137,835	352,737	39,193	488,027	9,013,700	853,813	1,409,564	592,377	3,136,444	348,494	3,951,043
2006	1,394,367	329,186	299,257	214,897	429,423	47,714	630,969	10,283,038	1,048,902	1,505,343	639,152	3,563,285	395,921	4,193,951
2007	1,596,534	469,906	383,820	234,310	497,764	55,307	754,229	11,233,241	1,245,840	1,733,660	792,751	3,651,728	405,748	4,540,159
2008	1,562,598	522,279	364,702	256,633	497,630	55,292	699,910	11,064,401	1,359,209	1,507,079	778,563	3,351,348	372,372	4,157,357
2009	1,845,548	524,019	391,122	238,791	469,650	52,183	699,939	11,444,807	1,412,221	1,457,590	846,933	3,535,989	392,888	4,252,017
2010	2,145,851	632,554	493,941	325,207	597,728	66,414	913,092	10,610,485	1,266,460	1,354,832	754,542	3,562,160	395,796	4,411,275
2011	2,298,297	586,306	565,769	344,723	613,426	68,158	945,944	9,932,330	986,265	1,321,057	702,895	3,406,448	378,494	4,059,639
2012	2,629,330	570,396	606,776	307,821	641,669	71,297	1,057,112	10,396,657	1,059,861	1,362,341	760,687	3,503,149	389,239	4,367,677
2013	3,175,353	700,198	688,681	431,738	911,101	101,233	1,307,923	10,642,747	1,182,179	1,483,719	820,480	3,612,360	401,373	4,320,928
2014	3,416,156	695,891	768,581	474,540	876,150	97,350	1,359,011	11,372,818	1,251,281	1,515,688	846,269	4,050,894	450,099	4,962,137
2015	3,540,843	774,525	729,119	365,522	804,323	89,369	1,288,388	11,317,762	1,284,242	1,522,465	891,247	3,899,296	433,255	4,648,028
2016	3,191,889	901,670	620,685	384,275	919,618	102,180	1,387,417	11,859,558	1,237,550	1,667,517	988,229	4,216,668	468,519	5,088,833
2017	3,687,374	1,055,173	744,041	417,092	995,575	110,619	1,448,743	11,843,281	1,276,220	1,565,794	984,840	4,306,656	478,517	5,115,456
2018	5,323,540	1,277,805	779,262	425,383	1,287,233	143,026	1,973,700	11,762,157	1,239,535	1,772,745	1,090,010	3,970,342	441,149	4,690,621

A1.4 Goat sub-category populations

IPCC (2006) recommends to classify goats by production system, age and sex into mature does, yearlings, bucks and kids (<1 year). Eight sub-categories of goat were identified based on age, sex and production system: does, yearlings, bucks and kids in the mixed crop-livestock and pastoral/agro-pastoral systems (Table A1.13). Goat sub-category populations derived from CSA annual livestock survey reports.

Population data for adult does came from the CSA '2 year and above' female age class; for the yearling goat sub-category, population data came from the sum of the CSA '1 to < 2 years' male and female age classes; population data for the adult bucks sub-category derived from the CSA '2 years and above' male age class. For the kids sub-category, population data was derived from the sum of the CSA '< 6 months' and '6 months to < 1-year' male and female age classes.

Table A1.13 Correspondence of goat sub-categories to IPCC and CSA categories

IPCC (2006)	This inventory		CSA
Mature does	Mixed crop-livestock	Adult does (≥2 yrs)	Goats > 2 years, female in mixed crop-livestock zones
	Pastoral/ agro-pastoral	Adult does (≥2 yrs)	Goats > 2 years, female in pastoral / agro-pastoral zones
Bucks	Mixed crop-livestock	Mature male (≥2 years)	Goat > 2 years, male in mixed crop-livestock zones
	Pastoral/ agro-pastoral	Mature male (≥2 years)	Goat > 2 years, male in pastoral/ agro-pastoral zones
Yearlings	Mixed crop-livestock	Female (1-<2 yrs)	Goat 1-<2 years, female in mixed crop-livestock zones
		Male (1-<2 years)	Goat 1-<2 years, male in mixed crop-livestock zones
	Pastoral/ agro-pastoral	Female (1-<2 yrs)	Goat 1-<2 years, female in pastoral/ agro-pastoral zones
		Male (1-<2 years)	Goat 1-<2 years, male in pastoral/ agro-pastoral zones
Kids	Mixed crop-livestock	Male (< 1 yr)	Goat < 6 m, male mixed crop livestock zones
			Sheep 6m-<1 year, male mixed crop livestock zones
		Female (< 1 yr)	Goat < 6 m, female mixed crop livestock zones
			Goat 6m-<1 year, female mixed crop livestock zones
	Pastoral/ agro-pastoral	Male (< 1 yr)	Goat < 6 m, male in pastoral/ agro-pastoral zones
			Goat 6m-<1 year, male in pastoral/ agro-pastoral zones
		Female (< 1 yr)	Goat < 6 m, female in pastoral/ agro-pastoral zones
			Goat 6m-<1 year, female in pastoral/ agro-pastoral zones

For the pastoral/agro-pastoral production system, goat sub-category populations for 1997, 2003-2008 and 2010-2016 were taken from CSA annual agricultural sample survey reports. The goat sub-category populations for the pastoral/agro-pastoral system for 1994-1996, 1998-2002, 2017 and 2018 were interpolated using the annual growth rate of the total national goat population and for 2009 linear interpolation was used. Regional data on goat sub-category populations was estimated from zonal level CSA livestock reports. Then, for goat populations in zones of Afar and Somali that are not enumerated in the CSA annual sample surveys, the same methods used to estimate sheep populations were applied to estimate goat populations. Tilahun and Schmidt (2012) report that in the EASE 2001 census, the ratio of combined sheep and goats to cattle was 2.27 in Somali and 2.88 in Afar. We used the CSA-enumerated total populations of sheep and goats to estimate the proportions of sheep and goats, and assume that the flock structure of sheep and goats in each region is the same as the structure enumerated in the CSA data.

For the mixed crop-livestock production system, for 1995, 1997 and 2003-2018 data were taken from the CSA annual agricultural sample survey reports. For 1994, 1996 and 1998-2002 populations were estimated using the annual growth rate of the total national sheep population. Missing values in the CSA livestock survey reports were estimated using trend analysis and linear interpolation.

The resulting estimates of total national goat sub-category populations is shown in Table A1.14.

Table A1.14 Goat sub-category populations, 1994-2018 (head)

	Pastoral & agro-pastoral system				Mixed crop-livestock system			
Year	Does	Yearling	Bucks	Kids	Does	Yearling	Bucks	Kids
1994	1,259,080	552,858	411,751	1,028,841	3,295,381	1,274,410	805,319	2,625,382
1995	1,301,398	574,084	429,878	1,060,145	3,275,648	1,266,779	800,497	2,609,661
1996	2,057,384	870,156	590,488	1,835,500	3,183,422	1,045,601	691,573	2,667,072
1997	2,054,006	872,636	593,274	1,837,647	3,197,910	1,050,360	694,720	2,679,210
1998	2,047,261	875,088	594,867	1,824,501	2,917,755	958,342	633,859	2,444,496
1999	2,124,072	910,490	619,872	1,874,565	2,626,713	862,749	570,632	2,200,661
2000	2,161,493	931,676	632,756	1,912,524	2,941,295	966,074	638,972	2,464,218
2001	3,198,227	1,354,602	921,802	2,797,113	5,440,616	1,786,981	1,181,930	4,558,150
2002	2,181,454	879,486	433,445	2,017,134	5,124,114	1,441,944	851,967	5,044,157
2003	1,851,496	762,646	385,956	1,711,704	4,486,896	1,261,292	745,002	4,419,581
2004	2,027,685	743,939	410,373	1,666,943	5,088,315	1,417,452	789,729	4,458,031
2005	1,831,223	675,278	384,695	1,591,836	5,521,960	1,665,184	996,914	5,339,584
2006	2,760,641	1,045,671	574,909	2,070,117	6,088,692	1,753,593	1,079,879	5,528,084
2007	2,659,429	1,030,902	705,667	2,227,413	7,144,129	2,233,293	1,424,086	6,407,787
2008	2,830,844	1,126,486	682,121	2,219,277	7,236,522	2,174,349	1,390,649	6,474,800
2009	3,145,243	1,139,645	800,938	2,310,741	7,305,887	1,925,196	1,693,675	6,004,812
2010	3,825,673	1,362,990	904,394	2,991,835	7,198,767	1,972,192	1,369,135	6,372,540
2011	3,837,407	1,462,576	955,220	2,906,937	6,898,126	1,767,535	1,046,970	6,657,112
2012	5,116,176	1,682,361	1,045,294	3,254,065	7,187,132	2,002,888	1,174,603	6,564,808
2013	6,347,539	2,116,936	1,339,834	4,394,433	7,873,551	2,182,429	1,261,364	7,054,349
2014	6,586,923	2,392,690	1,387,479	4,495,996	7,993,231	2,250,526	1,287,541	7,639,164
2015	6,973,216	2,077,171	1,304,079	4,487,254	8,346,885	2,181,657	1,318,348	7,699,098
2016	6,128,735	2,139,695	1,597,773	4,334,240	8,554,562	2,528,313	1,212,799	7,963,010
2017	7,000,967	2,338,109	1,792,061	4,609,077	8,946,133	2,779,539	1,502,353	8,632,054
2018	11,696,096	3,017,412	2,463,288	7,263,320	8,702,961	2,732,389	1,636,196	8,100,325

A1.5 Comparison of livestock population data with the Second National Communication

There are differences in the livestock population data used in this inventory, the data directly reported by CSA and the data used in the SNC.

Figure A1.3 compares the total national cattle population data reported in the SNC and the data obtained directly from CSA. Two key differences are:

(1) There is a 1-year time lag between the CSA data and the data reported in the SNC. For example, the CSA data for 1995 and reported in the SNC as 1996, and CSA data for 1997 are reported in the SNC as 1998 and so on.

(2) The CSA cattle population data for 2001 are 20% higher than the SNC figure for 2001 and 5% higher than the SNC figure for 2002. It appears that the SNC time series has interpolated the missing CSA population data for 2002 and at the same time may have smoothed the trend between 2000 and 2003.

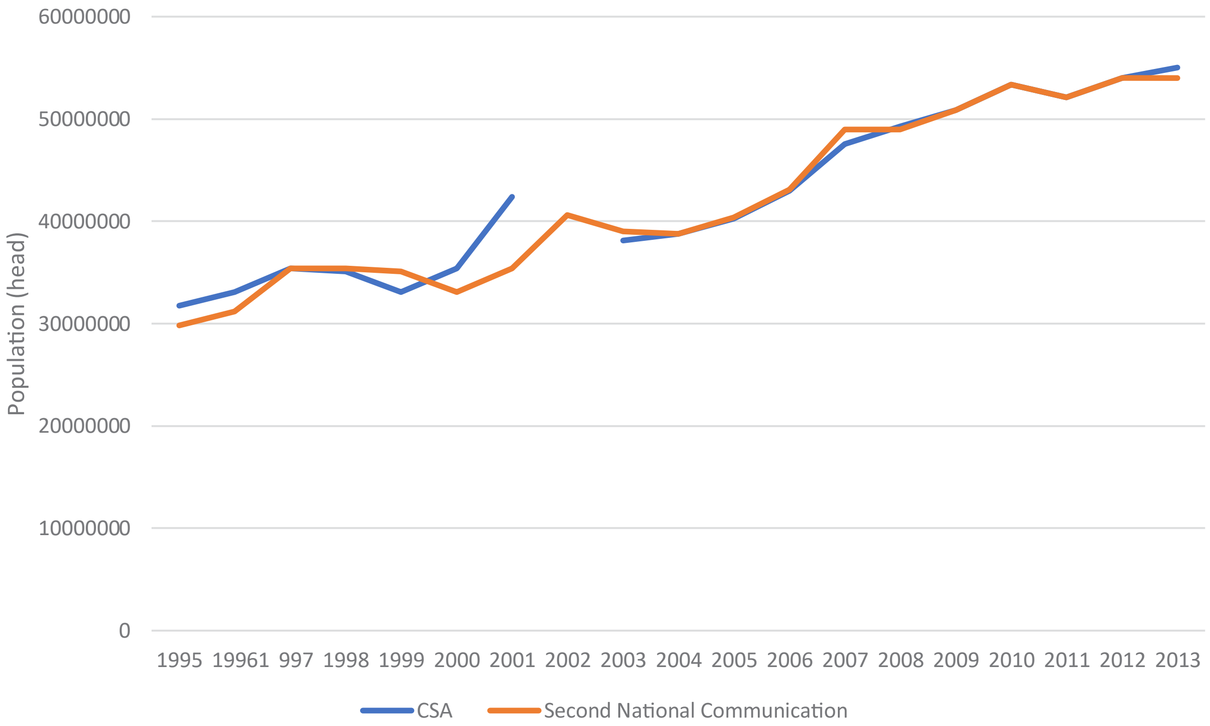

Figure A1.3 Comparison of total cattle populations reported by CSA and in the Second National Communication (1995-2013)

There are also differences between the data used in this inventory and in the SNC. Figures A1.4 to A1.6 show that the trend in cattle, sheep and goat populations reported in the SNC and in this inventory are broadly similar, with correlation coefficients (r^2) of between 0.93 and 0.97. Across most of the time series, this inventory reports higher livestock populations because cattle, sheep and goat populations in zones of Afar and Somali regions that are not enumerated by CSA are included, and for cattle, populations in the commercial dairy production system and commercial feedlots are also included. The main difference in each time series is for the year 2001. This inventory follows the same trend as shown in CSA data (i.e. cattle populations peaking in 2001), which is different from the data used in the SNC, which may have smoothed the trend between 2000 and 2003 when filling the gap in CSA data for 2002.

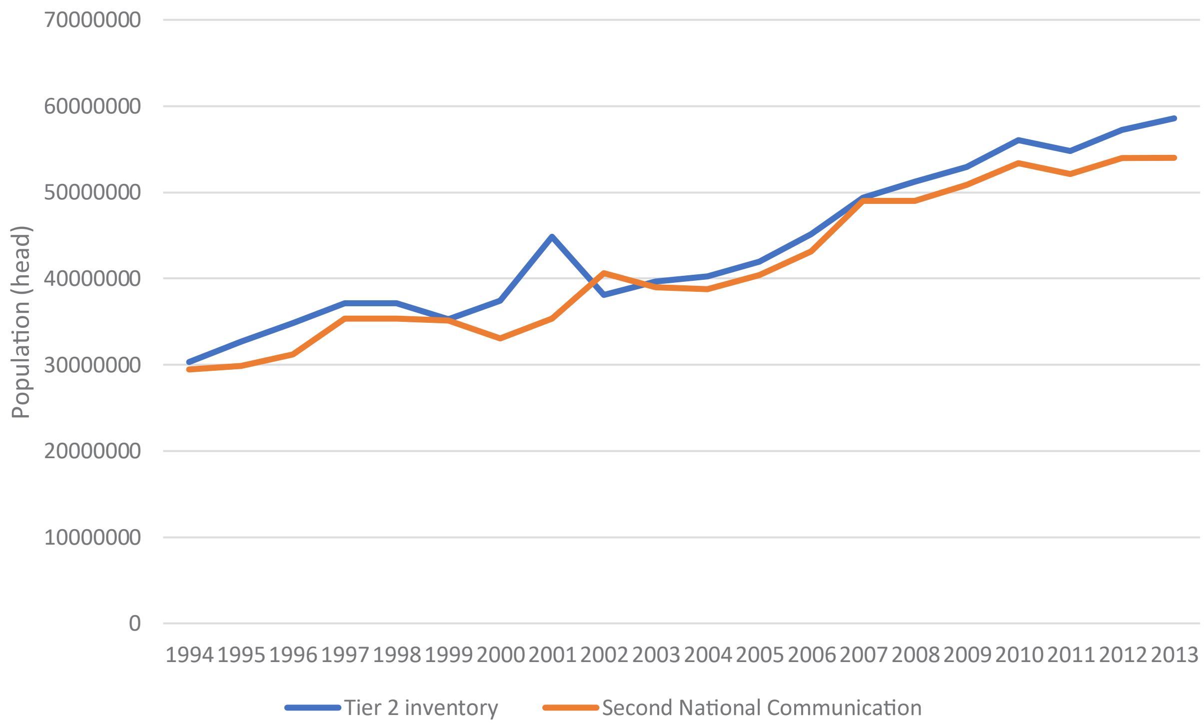

Figure A1.4 Comparison of total cattle populations between this inventory and the Second National Communication (1994-2013)

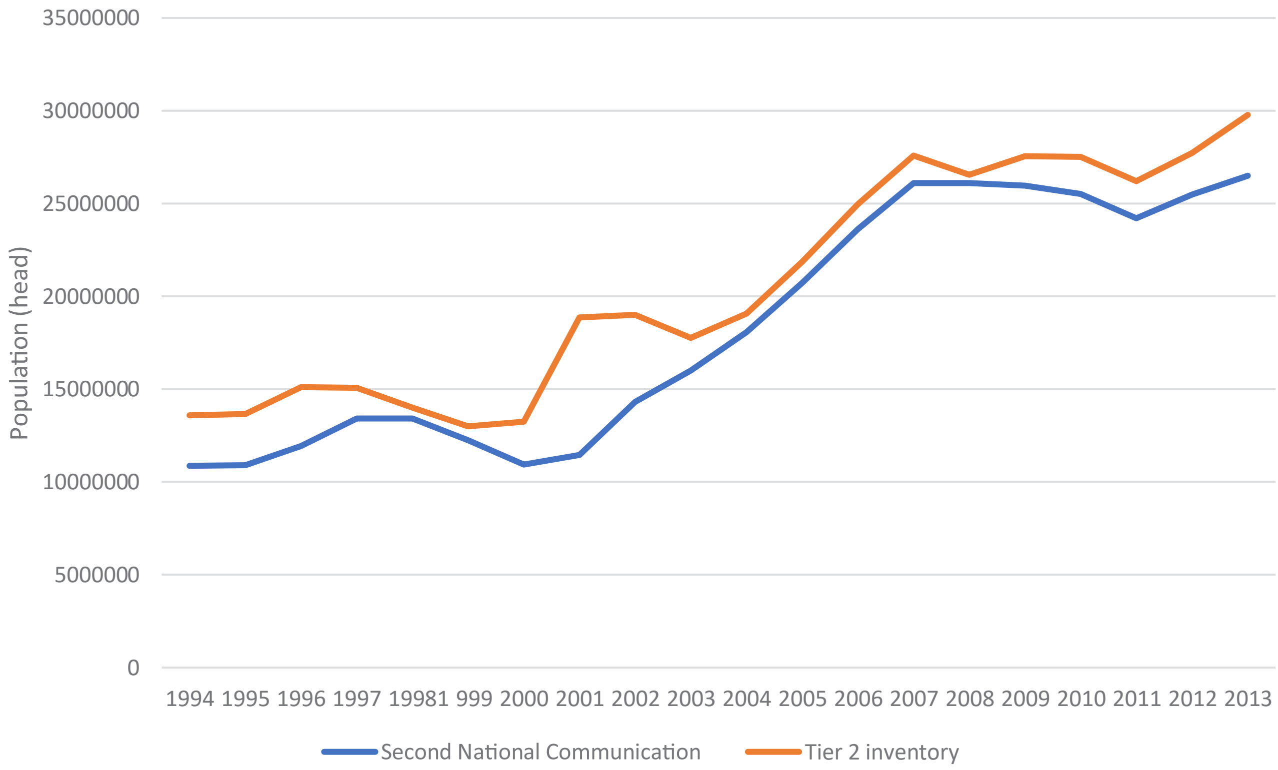

Figure A1.5 Comparison of total sheep populations between this inventory and the Second National Communication (1994-2013)

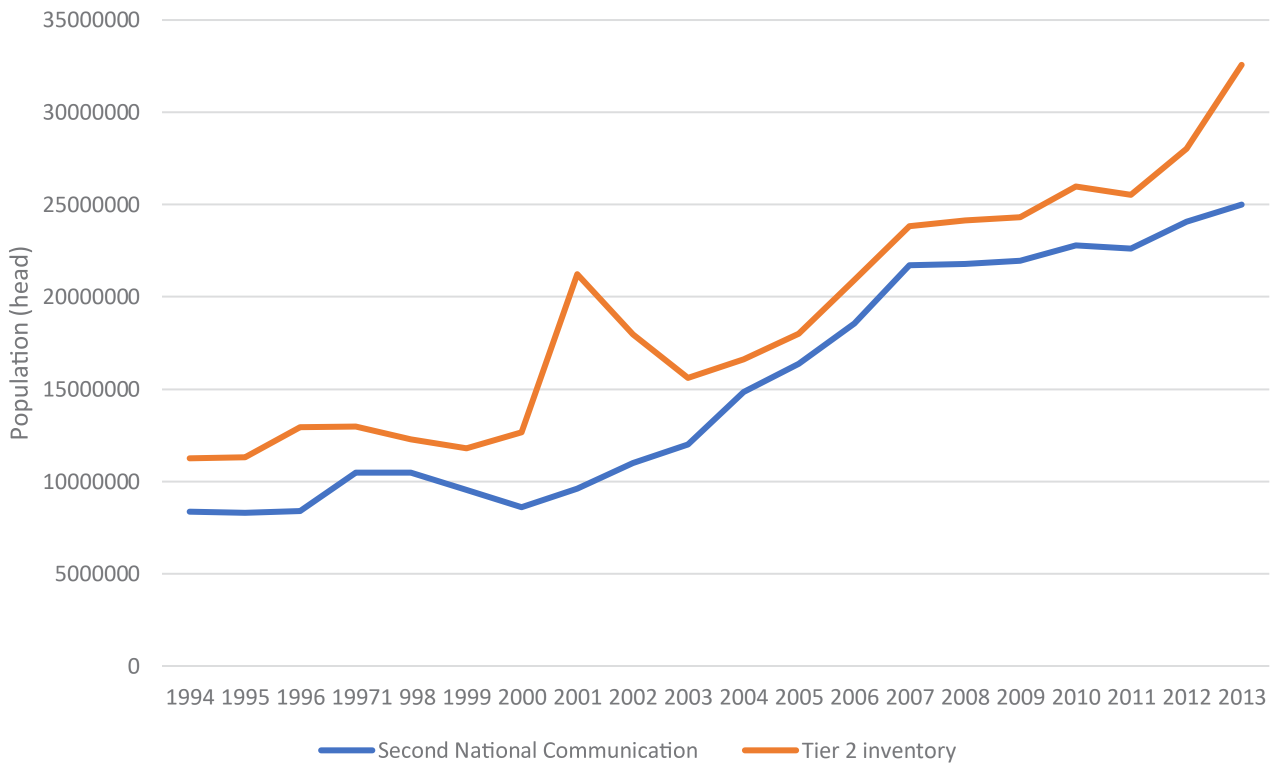

Figure A1.6 Comparison of total goat populations between this inventory and the Second National Communication (1994-2013)

ILRI/Zerihun Sewunet

Annex 2: Data sources and methods used to estimate live weight, mature weight and weight gain

Annex 2: Data sources and methods used to estimate live weight, mature weight and weight gain

A comprehensive literature review was made in order to assess livestock activity data availability in Ethiopia. Studies were obtained through systematic web searches using Google Scholar and examination of bibliographic references, including scientific publications, research reports, official government reports, and M.Sc. and Ph.D. theses. Studies were used if they were conducted on cattle, sheep or goats from 1994 onwards (i.e. the base year for Ethiopia's national inventory) and also if they reported parameter values related to one or more of the following variables: production system, LW, mature weight, weight gain, feed type, diet digestibility as well as the nutritional composition of the overall diet. Data sources were preferred if they were nationally representative or based on large samples at national, agro-ecological zone or region level and if multi-year values were reported to support time series consistency. One hundred and four publications on cattle (6 in commercial dairy, 60 in mixed crop-livestock, and 38 in pastoral/agro-pastoral production system) reported estimates of LW and weight gain at different ages. Seventy publications were reviewed for sheep (60 in mixed crop-livestock and 10 in pastoral/agro-pastoral production system), and 61 publications for goat (47 in mixed crop-livestock and 14 in pastoral/agro-pastoral production system) reporting estimates of weight at different ages from which LW, weight gain and mature weight can be estimated. After review it was identified that there is no existing time series of nationally representative LW measurements. Therefore, available data on LW, weight gain and/or mature weight is based on the average values of relevant studies conducted in specific years and locations. Summaries of the values for key parameters on LW and weight gain for cattle, sheep and goat in the different production system are presented in Appendix Tables 1-8.

A2.1 Dairy cattle live weight, mature weight and weight gain

A2.1.1 Dairy cattle in commercial and smallholder intensive dairy cattle production systems

For commercial and smallholder intensive production systems, the main data source used for the LW estimate was Aynalem et al. (2011). That publication reports LW at birth (n=2481), weaning (n=2228), six months (n=2151), yearling (n=1688), eighteen months (n=938) and two years old (n=562) measured over fifteen years from 1990 to 2004 at two research locations: Debre Zeit Research Station of the International Livestock Research Institute (ILRI) and Holetta Agricultural Research Center of EIAR (Appendix Table 1). The published paper reports on four genotypes (i.e. 50%, 62.5%, 75% and 87.5% cross-breed). The LW of each animal was recorded once every week using a digital platform weighing scale but the LW measurements were not reported separately for male and female animals in the publication.

For the LW estimate of calves, young and growing animals, the following methods were used. For calves < 6 months old, the median age in this age category is 3 months. LW at 3 months was estimated as the average of LW at birth and six months old weight across the four genotypes (Table A2.1a). For calves 6 months - < 1 year, the median age is 9 months. LW was calculated as the average LW of calves at six months old and yearling weight across the four genotypes. For heifers and growing male animals together, the median age is 24 months and LW was calculated as the average LWs at 24 months across the four genotypes. The LW estimates of each sub-category represented in the inventory are shown in Table A2.1a.

Since LW of adult cows and males were not given in that publication, other small-scale studies were used to estimate the average LW of the adult cow and male sub-categories represented in the inventory. LW for adult cows was taken from Fekade and Mekasha (2016), Kassu Tsegaye (2016), Kurtu and Waal (2009). These small-scale studies measured heart girth of 24, 15, and 82 animals, respectively. The LW of the adult cows was then estimated from the heart girth measurements using the regression equation: $Y=-423.405+4.834X$ ($R^2=0.86$; CV=10%) where Y=estimated live weight (kg), X=heart girth (cm). The equation was developed at ILRI's Debre Zeit Station using body measurements (heart girth) and actual body weight of crossbred dairy cows (ILRI 1996). Similarly, LW estimate for adult males was taken from a small-scale study by Astatke et al. (1986). The LW estimates of the adult cow and male sub-categories are shown in Table A2.1a. To estimate the time series for LW (1994 to 2018) we assumed no change in LW over time for each sub-category, since there are no large scale surveys or multi-year studies covering this period on crossbred cattle with which to estimate a trend in live weight over time. Supporting the assumption of no change over time, it is noteworthy that the fifteen year performance record Aynalem et al. (2011) has a very small standard deviation suggesting that there has been no significant change in LW for each sub-category (Table A2.1a). Weight gain per day was calculated as the change in weight between LWs at the median age of each adjacent age class divided by the number of days between the median ages. Although this leads to some difference with literature reports of daily weight gain, it ensures that the LW and weight gain values are biologically feasible. For adult cattle, no report of body weight gain was identified so weight gain for adult cattle was assumed to be zero, which is consistent with the recommendation in IPCC (2006).

Table A2.1a: Live weight and weight gain of dairy cattle in commercial and smallholder dairy production systems

Sub-category	Mean LW (kg)	Sources	Weight gain[d] (kg/d)
Adult exotic dairy cows (3-10 years)	428.6	a	
Adult exotic males 3-10 years	418.5	b	
Exotic calves (<6 months) male & female	60.0	c	0.340
Exotic calves (6 m - < 1 year) male & female	117.6	c	0.300
Exotic growing males (1 - < 3 year)	261.0	c	0.254
Exotic growing females (1 -< 3 years)	261.0	c	0.263

a) Fekade and Mekasha (2016), Gelane Kumsa (2017), Kassu Tsegaye (2016), Kurtu and Waal (2009); b) Astatke et al. (1986); c) Aynalem et al. 2010. d) calculated.

To estimate mature weight for female animal sub-categories represented in the inventory, LW of adult cows from Fekade and Mekasha, (2016), Gelane Kumsa (2017), Kassu Tsegaye (2016) and Kurtu and Waal (2009) were used since all the cows in these studies were on their third parity or greater, which can be considered as a mature animal. Similarly, to estimate mature weight of male animals, LW of adult males was used (Astatke et al. 1986). Mature weight for growing heifers (1-3 year) used the estimated mature weight for adult cows and the mature weight for growing male animal (1-3 year) used the estimated mature weight for adult male animals consistently throughout the time series. Mature weight for calves <6 months and calves 6 m – 1 year used the average of the mature weights of adult cows and males consistently throughout the time series.

A2.2 Other cattle live weight, mature weight and weight gain

Other cattle include indigenous breed multipurpose cattle in mixed crop-livestock and pastoral/agro-pastoral production systems. There are around 27 indigenous breeds of cattle in Ethiopia adapted to a wide range of ecological conditions (Workneh et al. 2004).

Other cattle in the mixed crop-livestock production system

Studies used to estimate LW, mature weight and weight gain of other cattle in the mixed crop-livestock production system are presented in Appendix Table 2. It is noteworthy that most studies used for the review did not report the sample size or the standard deviation or errors. Most of these studies report LW of male and female animals separately but some report the overall mean of male and female animals together (both).

For calves < 6 months, which includes both male and female calves in the same age class, LW at the median age of 3 months was calculated as the average of studies reporting LW at birth and 6 months old, including both studies that reported male and female calves separately and studies reporting LW male and female calves together. For calves 6 months - <1 year, LW at the median age of 9 months was calculated as the average LW at 6 and 12 months old, including both studies that reported male and female calves separately and studies reporting LW for male and female calves together. For heifers (1-<3 year), LW was calculated as average LW at 24 months from studies that reported separately for female animals, and from studies that reported female and male animals together (Table A2.2a). For growing male (1-<3 years) animals, LW was growing calculated as the average LW at 24 months from studies that reported separately for male animals and from studies that reported for female and male animals together (Table A2.2a). The estimated LW values in Table A2.2a were used consistently throughout the time series.

For multipurpose cows and adult males, LW was taken from studies presented in Appendix Table 2, the Domestic Animal Diversity Information System (DADIS FAO 1996) and the Domestic Animal Genetic Resources Information System (DAGRIS ILRI 1999). These two databases (DADIS and DAGRIS) are national electronic sources of systematic information on indigenous farm animal genetic resources, including adult weight, color and purpose. For adult multipurpose cows, LW was calculated as the total average LW of adult cows from studies reporting LW for female animals and from studies reporting LW for adult female and male animals together (Table A2.2a). For adult males used for draught and breeding purposes, LW was calculated as the average LW of adult male animals from studies reporting LW for male animals and from studies reporting LW for female and male animals together (Table A2.2a).

The same mature weight estimate was used for growing heifers (1-<3 year) and for multipurpose cows consistently throughout the time series. Mature weight for growing males (1-<3 year) and adult males used the same estimate of mature weight consistently throughout the time series. Mature weight for calves used the average of mature weights for multipurpose cows and adult males throughout the time series.

For weight gain, to ensure consistency with the LW data used, the average daily weight gain for each category was calculated by dividing the change in live weight between two age classes by the number of days between the me dian age of each age class. These weight gain values were used consistently throughout the time series. For adult cattle, no report of body weight gain was identified so weight gain for adult cattle was assumed to be zero, which is consistent with the recommendation in IPCC (2006). These values compare well with the daily weight gain estimates reported in the literature (Appendix Table 2). Table A2.2a shows the live weight and weight gain values used.

Table A2.2a: Live weight (kg) and weight gain (kg/d) of other cattle sub-categories in the mixed crop-livestock production system

Sub-category	Live weight (kg)	Weight gain (kg/d)
Mature multipurpose cows (≥ 3 years)	285.8	-
Mature males used for draught (3-10 yrs)	342.8	-
Mature males for breeding & other (≥3 yrs)	342.8	-
Calves < 6 months (male & female)	53.8	0.362
Calves 6 m-<1 year (male & female)	105.5	0.213
Growing males 1-<3 years	226.9	0.202
Heifers (1-<3 years)	181.4	0.149
Smallholder fattening	281.2	0.146
Commercial feedlot	281.3	0.257

Other cattle in the pastoral/agro-pastoral production system

The pastoral/agro-pastoral production system is found in seven regions of Ethiopia, including Afar, Somali, Tigray, SNNPR, Oromia, Dire Dawa, Benshangul Gumuz and Gambella Regional States. There have been very few studies on LW and weight gain in these areas. To estimate LW, mature weight, and weight gain, only studies conducted using cattle breeds in pastoral or agro-pastoral areas (i.e. Kereyu, Begait, Ogaden, Boran or Danakil) were considered (Appendix Table 3).

For calves (< 6 months), LW was calculated as average LW at birth and 6 months from studies reporting LW for females and males together (both), and from studies reporting LW of male and female animal separately. For calves 6 months - <1 year, LW was calculated as the average LW of 6 and 12 months old animals from studies reporting LW of male and female animals separately and studies reporting LW of male and female animals together. For heifers (1-<3 year), LW was calculated as the average of LW at 24 months old from studies reporting LW for female animals, and from studies reporting LW for male and female animals together (Table A2.2b). For growing males (1-3 years), LW was calculated as the average of LW at 24 months from studies reporting LW for male animals and studies reporting LW for female and male animals together (Table A2.2b). These values were then used consistently throughout the time series.

Table A2.2b: Live weight (kg) of other cattle sub-categories in pastoral and agro-pastoral production system

Sub-category	Live weight (kg)	Wt gain(g/d)
Adult multipurpose cows (≥ 3 years)	295.0	
Adult males used for draught (3-10 yrs)	339.8	
Adult males for breeding & other (≥3 yrs)	339.8	
Calves < 6 months (male & female)	58.8	0.402
Calves 6 m-<1 year (male & female)	117.0	0.298
Growing males 1-<3 years	225.1	0.186
Heifers (1-<3 years)	190.2	0.144

For adult multipurpose cows, LW was calculated as total average of LW animals from studies reporting LW for adult female animals and from studies reporting LW for adult female and male animals together (Table A2.2b). For adult males used for draught and breeding purposes, LW was calculated as the total average of LW of animals from studies that reported LW for adult male animals and from studies that reported LW for female and male animals together (Table A2.2b). Mature weight for growing heifers (1-<3 year), the estimated adult weight for multipurpose cows was consistently used throughout the time series. Mature weight for growing male animal (1-<3 year), the estimated adult weight for males animals are consistently used throughout the time series. Mature weight for calves, the average mature weight of multipurpose cows and adult males are consistently used throughout the time series.

For weight gain, to ensure consistency with the live weight data used, the average daily weight gain for each category was calculated by dividing the change in live weight between two age classes by the number of days between the median age of each age class. These weight gain values were used consistently throughout the time series. For adult cattle, no report of body weight gain was identified so weight gain for adult cattle was assumed to be zero, which is consistent with the recommendation in IPCC (2006). These values compare well with the daily weight gain estimates reported in the literature (Appendix Table 3). Table A2.2b shows the live weight and weight gain values used.

Smallholder fattening and commercial feedlot fed cattle

Smallholder fattening operations in the mixed crop-livestock system and feedlots in the pastoral and agro-pastoral system mainly use retired oxen. Cattle used for fattening purposes spent 8.5 months in their respective production system and 3.5 months in the fattening operation.

For smallholder fattening cattle, reports of initial weight, final body weight, and weight gain of fattened cattle were obtained from the published literature (Tesfaye et al. 2002; Nega et al. 2003; Nega et al. 2008; Haile et al. 2009; Shitahun 2009; Yoseph et al. 2010; Kebede et al. 2014; Bezahegn Abebe 2014; Mohammed and Hailu 2015; Tesfaye 2016; Guyo 2016, Appendix Table 4). The LW for smallholder fattening cattle was calculated as follows. Averaging across all literature reports of initial and final LW, total weight gain in the feedlot over 3.5 months is 52.65 kg, and average daily weight gain is 0.501 kg. Initial weight at feedlot is 273.56 kg, and final weight is 326.22 kg, so assuming no growth prior to entering the feedlot, annual average weight = ((299.89 * 105) + (273.56 * (365-105))/365 = 281.24 kg, and annual average daily weight gain = ((0 * (365-105)) + (0.501 * 105))/365 = 0.146 kg. A LW value of 281.24 kg and weight gain of 0.146 kg is used consistently throughout the time series (Table A2.2a and A2.2b).

The commercial feedlot category in the mixed crop-production system involves growing male animals (2-3 years old) and uses higher quality industrial by-product feeds compared to smallholder fattening operations. For the commercial feedlot category, reports of LW and weight gain were obtained from the published literature (Fikadu 1999; Aberash 2000; Nega et al. 2002; Tsigereda 2010; Yohannes 2011; Tesfaye 2016; Dadi et al. 2017). LW and weight gain for commercial feedlot cattle were estimated as follows. Average initial weight in the literature was 269.75 kg and final weight was 362.28 kg, so total weight gain in the feedlot was 92.53 kg and average daily weight gain over 3 months was 1.03 kg. This gives an annual average LW of 281.32 kg, and annual average daily weight gain of 0.257 kg, which was used consistently throughout the time series (Table A2.2a).

A2.3 Sheep live weight, mature weight and weight gain

The inventory uses animal performance data for indigenous sheep breeds from the mixed crop-livestock and pastoral/agro-pastoral production systems. Ethiopia has 15 indigenous sheep breeds (Gizaw et al. 2007) distributed in a wide range of ecological conditions of the country (Tibbo 2006; Solomon et al. 2011).

A2.3.1 Sheep in the mixed crop-livestock production system

For sheep, LW was taken from studies conducted using different indigenous sheep breeds (Appendix Table 5). Most of these studies report LW of male and female animals separately but some report overall mean of male and female animals together (both) in different age classes.

For breeding ewes (2 years and above), LW was calculated as the average LW of adult sheep from studies reporting the LW of female sheep and studies reporting LW for male and female sheep together. For adult male sheep (2 years and above), LW was calculated as the average LW of adult sheep from studies reporting LW of male sheep, and studies reporting LW for male and female sheep together. For female sheep (1-<2 years), LW (kg) was calculated as the average LW of '12 months' old and adult animals from studies reporting LW of female sheep, and from studies reporting LW for male and female sheep together. For male sheep (1-<2 years), LW (kg) was calculated as the average LW of 12 month old and adult animals from studies reporting LW for male sheep, and from studies reporting LW for male and female sheep together. For intact sheep (< 1 year), LW (kg) was calculated as the average LW of sheep at 6 months from studies reporting LW for male sheep, and from studies reporting LW for female and male sheep together. Since no LW reports are available on castrated and intact sheep separately, the estimated LW for intact sheep was used for castrated sheep (< 1 year). For female < 1 year, LW was calculated as the average LW at 6 months from studies reporting LW of female sheep, and from studies reporting LW for male and female sheep together. The estimated LW of adult sheep (2 year and above), female and male sheep (1-<2 years), and castrated and intact sheep (< 1 year) are then consistently used throughout the time series (Table A2.3a).

Table A2.3a: Live weight (kg) of sheep in the mixed crop-livestock production system

	Live weight (kg)	WG_{wean} (kg)	Initial body weight (kg)	Final body weight (kg)	WG_{lamb} (kg)
Breeding ewes 2 years and above	27.95	-	27.95	27.95	0
Adult male ≥ 2years	28.81	-	28.81	28.81	0
female 1-<2 years	24.89	-	22.12	27.95	6.69
Male 1-<2 years	25.47	-	21.82	28.81	6.99
Intact male lamb (< 1years)	17.89	8.81	11.35	22.12	10.77
Castrated lamb (< 1 year)	17.89	8.81	11.35	22.12	10.77
Female lamb (< 1 year)	17.46	8.49	10.99	20.96	9.97

Body weight initial: weaning weight; Body weight final: weight at 1 year old.

WG_{wean} is the increase in LW between birth and weaning and is used to estimate milk yield of ewes. WG_{wean} was calculated separately for male and female lambs (Table A2.3a) and the value used in the inventory is weighted by the proportion of male and female lambs in the CSA data, which varies slightly from year to year. WG_{lamb} is the increase in LW between weaning and 1 year old and is used to estimate net energy for growth. For adult male and female sheep, no growth is assumed. For male lambs, the value of the initial body weight at weaning used the average LW at weaning from studies reporting LW at weaning for male lambs and studies reporting LW at weaning for male and female lambs together (Appendix Table 5). Similarly for the final LW at 12 months old. For female and male sheep 1-<2 years, the initial weight used LW for male and female lambs at 12 months and the final weight used the LW of male and female adults, respectively. WG_{lamb} was calculated as the difference between the two (Table A2.3a).

A2.3.2 Sheep in the pastoral/agro-pastoral production system

For sheep in the pastoral and agro-pastoral production system, the same methods and assumptions used to estimate LW, WG_{wean} and WG_{lamb} for sheep in the mixed crop-livestock production system are also applied, but only studies conducted using pastoral/agropastoral system sheep breeds (i.e., Afar, Black head Somali, Begait) were considered (Appendix Table 6). The values used are shown in Table A2.3b.

Table A2.3b: Live weight (kg) of sheep in the pastoral and agro-pastoral production system

Sub-category	Live weight (kg)	WG_{wean} (kg)	Initial body weight (kg)	Final body weight (kg)	WG_{lamb} (kg)
Breeding ewes 2 years and above	30.63	-	30.63	30.63	0
Mature male ≥ 2years	34.20	-	34.20	34.20	0
female 1-<2 years	27.48	-	24.32	30.63	6.31
Male 1-<2years	29.75	-	25.30	34.20	8.90
Intact sheep (male < 1years)	20.63	10.80	13.40	25.30	11.90
Castrated (< 1 year)	20.63	10.80	13.40	25.30	11.90
Female grassfed (< 1 year)	18.46	9.36	12.02	24.32	12.30

A2.4 Goat live weight, mature weight and weight gain

Indigenous goat breeds in the mixed crop-livestock and pastoral/agro-pastoral production systems are represented in the GHG inventory. Ethiopia has 11 indigenous goat breeds (Farm Africa 1996). The indigenous goats of Ethiopia are found in all agro-ecological zones of the country.

A2.4.1 Goat in the mixed crop-livestock production system

For goats, LW was taken from studies conducted using different indigenous goat breeds (Appendix Table 7). Most of these studies report LW of male and female goats separately but some report the overall mean of male and female goats together (both) at different age classes.

For does (2 year and above), LW was calculated as the average LW of adult goats from studies reporting LW for female goats, and from studies reporting LW for male and female goats together. For bucks (2 year and above), LW was calculated using the average LW of adult goats from studies reporting LW of male goats, and from studies reporting LW for male and female goats together. For yearlings (1-2 year), LW (kg) was calculated as the average LW of 12 months of age and adult goats from studies reporting LW for female and male goats separately, and from studies reporting for male and female goats together. For kids (< 1 year), LW was calculated as the average LW of goats at 6 months of age from studies reporting LW for male and female goats separately, and from studies reporting LW for male and female goats together. The estimated LW of does, bucks, yearlings and kids were then consistently used throughout the time series (Table A2.4a).

WG_{wean} is the increase in LW between birth and weaning and is used to estimate the milk yield of does. LW at birth and LW at 3 months for male and female goats together were used to calculated WG_{wean}. WG_{lamb} is the increase in LW between weaning and 1 year old and is used to estimate net energy for growth. For kids, LW at 3 months old was taken as the initial body weight and weight at 12 months old as the final body weight, using data from studies report ing for males, females and both together. For yearlings 1-<2 years old (male and female), LW at 12 months was taken as the initial body weight, and weight of adults was taken as the final body weight using data from studies reporting for males, females and both together. The values of LW, WGwean and WGlamb are shown in Table A2.4a, and these values were used consistently throughout the time series.

Table A2.4a: Live weight (kg) of goats in the mixed crop-livestock production system

	Live weight (kg)	WG_{wean} (kg)	Initial body weight (kg)	Final body weight (kg)	WG_{lamb} (kg)
Adult does 2 years and above	26.72	-	26.72	26.72	0
Bucks 2 years and above	27.90	-	27.90	27.90	0
Yearling (male & female 1-< 2 years)	20.95	-	14.04	27.85	13.81
Kids (male & female < 1 year)	10.5	6.38	8.68	14.04	5.38

A2.4.2 Goats in the pastoral/agro-pastoral production system

For goats in the pastoral/agro-pastoral production system, the same methods and assumptions used to estimate LW, initial and final body weight, and young goat weight gain for goats in the mixed crop-livestock production system were also applied, but only studies conducted using pastoral/agro-pastoral system goat breeds (i.e., Boran, Short-eared Somali, Abergelle, Afar) were considered (Appendix Table 8). The values of LW, WG_{wean} and WG_{lamb} are shown in Table A2.4b, and these values were used consistently throughout the time series.

Table A2.4b: Live weight (kg) of goats in the pastoral and agro-pastoral production system

Sub-category	Live weight (kg)	WG_{wean} (kg)	Initial body weight (kg)	Final body weight (kg)	WG_{lamb} (kg)
Adult does 2 years and above	29.45	-	29.45	29.45	0
Bucks 2 years and above	29.45	-	29.45	29.45	0
Yearling (male & female 1-< 2 years)	21.34	-	13.22	29.45	16.23
Kids (male & female < 1 year)	9.62	5.77	8.10	13.22	5.12

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Annex 3: Data sources and methods for proportions of females giving birth and milk yield

Annex 3: Data sources and methods for proportions of females giving birth and milk yield

A3.1 Dairy cows: Proportions giving birth and milk yield

A3.1.1 Proportions of cows giving birth

For the commercial and smallholder intensive dairy production system, the proportion of dairy cows giving birth was estimated from calving intervals because there was no reliable time series data on the numbers of cows in milk and calves born. The calving rate was calculated as:

Calving rate = 365 * (100/calving interval in days)

Reports of calving interval were obtained from a longitudinal study from 1987 – 2007 using 493 crossbred Holstein Frisian dairy cows (1750 observations) in urban and peri-urban dairy production systems (Million et al. 2010). That publication estimated an overall mean calving interval of 445 days (Table A3.1a). Also, Dereje and Baars (1998), Million et al. (2001), and Shiferaw et al. (2003), Goshu et al. (2007), Mureda and Mekuriaw (2008), Demberga et al. (2009), Alemayehu et al. (2009), Duguma et al. (2012), and Melku (2016, MSc. Thesis) provide estimates of calving interval ranging from 421-660 days (Table A3.1a). The longer calving intervals are an indicator of poor feeding and management systems. The calving interval was calculated as the average of all studies (i.e., 507.3 days). The proportion of cows giving birth was then calculated using the formula above, which gives an estimate for the proportion of cows giving birth of 71.9%. This estimate was consistently used throughout the times series. It is noteworthy that some other surveys conducted in the early 1990s also estimated a similar range of calving interval (e.g. Staal 1996 reported a range of 450-504 days from one survey).

Table A3.1a Calving interval and calculated calving rate of crossbred dairy cows in urban and peri-urban areas of different cities and town of Ethiopia

Calving interval (days)	Breed	Urban & per-urban	Calculated calving rate (%)	Sources
421	Crossbred	Addis ababa	86.7	Dereje and Baars, 1998
445	Crossbred	Holeta	82.0	Million et al. 2001
462	Crossbred	Holleta	79.0	Shiferaw et al. 2003
456	Crossbred	Addis ababa	80.0	Goshu et al. 2007
534	Crossbred	Dire Dawa	68.4	Mureda and Mekuriaw, 2008
406	Crossbred	Zeway	89.9	Demberga et al. 2009
555	Crossbred	Bahirdar & Gondar	65.8	Alemayehu et al. 2009
493	Crossbred	Holeta	74.0	Million et al. 2010
642	Crossbred	Jimma	56.9	Duguma et al. 2012
660	Crossbred	Bahirdar	55.3	Melku, 2016 (Thesis)
Av=507.4			**Av=71.9**	

A3.1.2 Milk yield

Milk yield estimates for dairy cattle in commercial and smallholder intensive production systems were obtained from various studies conducted across four regions of Ethiopia (Table A3.1b). These studies record milk off-take (i.e. volume of milk obtained by milking) and do not include estimates of calf suckling. The average daily milk off-take per head in commercial and smallholder production systems was estimated to be 8.19 liters, which was converted to kg using a standard conversion of 1.031 kg per litre, so that dairy cow milk off-take equates to 8.45 kg cow^{-1} day^{-1}. In addition, Gedefa et al. (2019), Asaminew and Eyasu (2009) and Adebabay (2009), Kefena et al. (2011), and Zelalem (1999) provide estimates of lactation length ranging from 303-351 days, with an average value of 325 days for crossbred cattle in Ethiopia. Studies summarized in Table A3.1a estimate average calving rates of 71.9%. Therefore, the estimated daily off-take converted to an annual average daily off-take (i.e. average over 365 days) for the average cow (i.e. including lactating and non-lactating) by multiplying the average lactation day milk off-take by the proportion of the year in lactation and the proportion of cows giving birth: 8.45*(325 day/360 days) * 0.719= 5.48 kg cow^{-1} day^{-1}. This value was taken to represent milk off-take in 2013, which is the average year of the studies in Table A3.1b.

Minten et al. (2018) surveyed farms in the commercial dairy production system in the Addis Ababa milkshed in early 2018, obtaining estimates of milk yield at the time of the survey and 10 years previously. The average annual growth rate of milk yield in their data was 1.04% over the ten years. This growth rate was applied to the whole time series for milk off-take to estimate milk off-take for each year back to 1994.

Table A3.1b. Average daily milk yield for crossbred dairy cows in urban and peri-urban areas of different cities and towns of Ethiopia

Source	Type of study	Region	Production system	Breed	Milk yield (Liter/d)
Fita et al. 2003	Survey	Oromia	Urban-Peri	Crossbred	5.80
Mirkena et al. 2003	Monitoring	Oromia	Urban-Peri	Crossbred	4.61
Wondatir 2010	Monitoring	Oromia	Urban-Peri	Crossbred	7.60
Duguma et al. 2012	Monitoring	Oromia	Urban-Peri	Crossbred	8.52
Galmessa et al. 2013	Survey	Oromia	Urban-Peri	Crossbred	6.50
Alewya Heyredin 2014	Monitoring	Oromia	Urban-Peri	Crossbred	13.30
Fekade and Mekasha 2016	Monitoring	Oromia	Urban-Peri	Crossbred	14.10
Kefelegn Seyoum et al. 2014	Survey	Oromia	Urban-Peri	Crossbred	11.02
Assaminew and Ashenafi 2015	Monitoring	Oromia	Urban-Peri	Crossbred	10.19
Abera 2016	Monitoring	Oromia	Urban-Peri	Crossbred	14.16
Tolosa et al. 2016	on farm	Oromia	Urban-Peri	Crossbred	9.4
Fekade and Mekasha 2016	Monitoring	Oromia	Urban-Peri	Crossbred	14.6
Hordofa 2016	Survey	Oromia	Urban-Peri	Crossbred	7.10
Degefa 2017	Survey	Oromia	Urban-Peri	Crossbred	7.88
Mamo and Tefera 2017	Survey	Oromia	Urban-Peri	Crossbred	6.00
Desalegn Genzebu 2017	Monitoring	Oromia	Urban-Peri	Crossbred	11.19
Gelane Kumsa 2017	Monitoring	Oromia	Urban-Peri	Crossbred	9.45
Tamrat Gebiso 2018	Survey	Oromia	Urban-Peri	Crossbred	3.16
Ayenew 2008	Monitoring	Amhara	Urban-Peri	Crossbred	7.7
Abraha et al. 2009	Monitoring	Amhara	Urban-Peri	Crossbred	3.57
Tasew and Seifu 2009	Survey	Amhara	Urban-Peri	Crossbred	5.43
Zewdie Wondatir 2010	Monitoring	Amhara	Urban-Peri	Crossbred	6.10
Anteneh et al. 2010	Monitoring	Amhara	Urban-Peri	Crossbred	8.00
Bitew 2011	Monitoring	Amhara	Urban-Peri	Crossbred	8.27
Ayalew and Asefa 2013	Survey	Amhara	Urban-Peri	Crossbred	4.73
Ayalew and Badasso 2014	Survey	Amhara	Urban-Peri	Crossbred	2.96
Alemayehu and Kebede 2015	Survey	Amhara	Urban-Peri	Crossbred	7.42
Melku Muluye Kassahun 2016	Monitoring	Amhara	Urban-Peri	Crossbred	6.87
Assefa and Tegegn 2018	Survey	Amhara	Urban-Peri	Crossbred	9.35
Haftu Kebede 2015	Survey	SNNP	Urban-Peri	Crossbred	8.38
Beriso et al. 2015	Survey	SNNP	Urban-Peri	Crossbred	4.69
Tsegaye 2016	Monitoring	SNNP	Urban-Peri	Crossbred	5.88
Beyene et al. 2018	Survey	SNNP	Urban-Peri	Crossbred	7.61
Tsegaye 2010	Survey	Tigray	Urban-Peri	Crossbred	9.14
Weldeslasse et al. 2012	Survey	Tigray	Urban-Peri	Crossbred	7.31
Girmay and Gebrekidan 2014	Monitoring	Tigray	Urban-Peri	Crossbred	9.62
Tekelyesus 2015	Survey	Tigray	Urban-Peri	Crossbred	8.2
Mekonnin 2016	Monitoring	Tigray	Urban-Peri	Crossbred	15.0
Bahita and Hailay 2018	Survey	Tigray	Urban-Peri	Crossbred	9.43
Gebrehiwot 2018	Survey	Tigray	Urban-Peri	Crossbred	7.50
					8.19

SNNP: Southern Nations, Nationalities and People’s

The average daily milk off-take thus calculated does not take into account the milk suckled by calves. Calf milk consumption can be estimated following the methods and assumptions described by NRC (2001, Table 10-1). NRC (2001) estimates energy requirements of calves based on metabolizable energy for maintenance and growth:

Metabolizable energy (Mcal) = $(0.1*(LW^{0.75})) + (((0.84*(LW^{0.355}))* (LWG^{1.2})))$

where LW is average live weight of a calf between birth and weaning, and LWG is calf live weight gain before weaning (kg day^{-1}). The inventory used the average LW values between birth and weaning weight shown in Appendix Table 1 and LW gain values for calves < 6 months shown in Table A2.1a. Then the estimated calf milk consumption (2.54 Mcal), was converted into 3.78 kg/d on the basis of assumed metabolizable energy (5.37 Mcal/kg DM) and dry matter (12.5%) content of milk (NRC 2001). The estimated milk consumption (3.78 kg day^{-1}) was converted into annual average daily milk yield (i.e. average over 365 days) by assuming the calves are weaned at 90 days, so the kg milk consumption required by calves is multiplied by (90/365), resulting in estimated calf milk consumption of 0.93 kg/day. With a calving rate of 0.719, 0.93 kg/day was then multiplied by 0.719, i.e. 0.67 kg/day. Cow milk yield was then calculated as the sum of milk off-take and estimated calf milk consumption in each year of the time series. For example, in 2013, milk yield was calculated as the sum of milk off-take (5.48 kg day^{-1}) and estimated calf milk consumption (0.67 kg/day), which equates to an average milk yield of 6.15 kg cow^{-1} day^{-1} in 2013. The resulting estimate for 1994 is 4.54 kg cow^{-1} day^{-1}. This is slightly higher than an average of 4.11 kg reported from a large but non-random sample surveyed in 1992/93 (Staal 1996), which did not include calf suckling. The time series for commercial and smallholder dairy milk yields, including calf suckling, is shown in Table A3.1c.

Table A3.1c. Average daily milk yields for dairy cows in the commercial and smallholder production systems, 1994-2018 (kg $head^{-1}$ day^{-1})

Year	1994	1995	1996	1997	1998	1999	2000	2001	2002
Commercial	4.54	4.61	4.68	4.76	4.84	4.92	5.00	5.08	5.17
Smallholder	4.54	4.61	4.68	4.76	4.84	4.92	5.00	5.08	5.17
Year	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Commercial	5.25	5.34	5.43	5.52	5.61	5.70	5.80	5.90	6.00
Smallholder	5.25	5.34	5.43	5.52	5.61	5.70	5.80	5.90	6.00
Year	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**		
Commercial	6.10	6.15	6.21	6.27	6.33	6.38	6.44		
Smallholder	6.10	6.15	6.21	6.27	6.33	6.38	6.44		

A3.2 Other cows: Proportions giving birth and milk yield

A3.2.1 Proportions of cows giving birth

The proportion of dual purpose cows giving birth (calving rate) in mixed crop-livestock and pastoral production system was estimated using the number of total calves born and number of cows in milk in the reference year as a proxy indicator. Data was taken from the CSA annual agricultural sample survey.

The livestock production system in Ethiopia is characterized by high mortality. A one-year retrospective large-scale survey study in Ethiopia indicated high calf mortalities (21.3%) both in the mixed-crop livestock and in pastoral and agro-pastoral production systems (Fentie et al. 2016). This may lead to a higher number of calves born than what is reported by CSA in the reference year. Accordingly, the total number of calves born in the reference year was estimated by multiplying the CSA-reported calves by mortality rate (21.3%) and adding this to the CSA-reported calf population. The proportion of cows giving birth was then calculated as:

= [total number of calves (dead + CSA-reported)/ number of cows in milk] * 100

Number of total calves born (< 6 months) and cows in milk for year 1997, and 2003-2018 in the mixed crop-livestock system was provided by CSA. The estimated proportion of cows giving birth for 1997, and 2003-2018 are shown in Table A3.2a. Linear extrapolation and linear interpolation procedures were employed to fill in the missing years from 1994-1996, and 1998-2002, respectively.

Table A3.2a. Time series for proportion of cows giving birth for other cattle in mixed crop-livestock production system

Year	No. of calves born (< 6 month)	No. of calves mortality (< 6 months)	Total calves (< 6 months)	No. of cows in milk	% of cows giving birth
1994					32.6%
1995					33.0%
1996					33.7%
1997	3151088	671182	3822269	10894420	35.1%
1998					37.9%
1999					40.7%
2000					43.5%
2001	3,239,030				46.3%
2002	3730261	794545	4524806	8712548	49.1%
2003	3573604	761178	4334782	8048148	51.9%
2004	3798032	808981	4607013	8194238	53.9%
2005	4159582	885991	5045572	9113467	56.2%
2006	4562499	971812	5534312	9923124	55.4%
2007	4302878	916513	5219391	9919360	55.8%
2008	5010386	1067212	6077599	9627747	52.6%
2009	4918260	1047589	5965849	10676783	63.1%
2010	4787579	1019754	5807333	10577781	55.9%
2011	5229523	1113888	6343412	10711484	54.9%
2012	5173668	1101991	6275659	10731656	59.2%
2013	5215411	1110883	6326294	11381972	58.5%
2014	5053207	1076333	6129540	11326490	55.6%
2015	5628494	1198869	6827364	11833179	54.1%
2016	5381937	1146353	6528290	12392707	57.7%
2017	5780302	1231204	7011506	12405035	52.7%
2018	3730261	794545	4524806	8712548	56.5%

To cross-check the credibility of the low calving rate estimates for 1994-2001, literature was searched from before 2001. Mukasa-Mugerwa and Tegegne (1993)[1] estimated 45%; Galal et al. (1981)[2] estimated 33%-37% for local cows; and Lesnoff et al. (2002) estimated 37%.[3] Mukasa-Mugerwa et al. (1989) estimated 46%.[4] Therefore, while the estimates for this period remain highly uncertain, they are within the range of reported calving rates for earlier periods. For the pastoral and agro-pastoral production system, because it is not possible to estimate numbers of cows in milk specifically for this production system from the CSA annual livestock data, the proportions of cows giving birth in each year for mixed crop-livestock production systems were also applied to the pastoral and agro-pastoral system.

A3.2.2 Milk yield

A time series from 2003-2018 for average national daily milk yield for mixed crop-livestock and pastoral and agro-pastoral production was provided by CSA annual livestock sample surveys. Missing values for 1994-2002 were filled using the average of 2003-2008 since there was no clear trend during this 5 year period. The CSA-reported daily milk yield was converted to annual average daily milk production (i.e. average over 365 days) by multiplying the reported daily milk yield by the average lactation length of milking cows, which was taken from published literature (Table A3.2b), and by the proportion of cows giving birth (Table A3.2a). This average daily milk yield in litres was converted to kg using a standard conversion of 1.031 kg per litre.

1 http://agris.fao.org/agris-search/search.do?recordID=QT2016105180
2 http://agris.fao.org/agris-search/search.do?recordID=ET2010000042
3 https://agritrop.cirad.fr/514864/1/ID514864.pdf
4 https://doi.org/10.1007/BF02236190

Table A3.2b. Average lactation length (LL) of milking cows of indigenous breeds of Ethiopia (months)

Breed	LL	Source	Breed	LL	Source	Breed	LL	Source
Horro	10.5	Laval and Assegid 2002	Fogera	23.3	Aynalem et al. 2011	Begait	6.1	DADIS 2004
Horro	9.6	Agere et al. 2012	Boran	10.1	Solomon et al. 2011	Boran	5.7	DADIS 2004
Horro	5.8	Aynalem et al. 2011	Boran	8.0	Haile et al. 2010	Danakil	6.7	DADIS 2004
Arsi	9.6	Chali 2014	Sheko	9.9	Takele et al. 2005	Boran	7.0	DADIS 2004
Arsi	9.1	Gabriel et al. 1983	Sheko	10.3	Bayou et al. 2015	Fogera	9.1	DADIS 2004
Begait	6.4	Mulugeta 2015	Mursi	7.8	Endashaw et al. 2011	Horro	5.8	DADIS 2004
Begait	6.6	Teweldemedhn 2016	Zebu	10.1	Gabriel et al. 1983	Sheko	7.0	DADIS 2004
Begait	4.9	Tewelde et al. 2016	Arado	8.2	Niraj et al. 2014	Average	**7.90 months (248 days)**	
Begait	6.1	Aynalem et al. 2011	Abigar	6.0	DADIS 2004			
Fogera	10.5	Damitie et al. 2015	Arsi	3.9	DADIS 2004			

The CSA-reported daily milk however, did not take into account the portion of milk suckled by calves. Calf milk consumption was calculated following the methods and assumption described for calves in the commercial and smallholder intensive dairy production system (NRC 2001). This inventory used average LW values between birth and weaning weight shown in Appendix Table 2 and Appendix Table 3, and LW gain values for calves < 6 months shown in Table A2.2a, and Table A2.2b for the mixed crop-livestock and pastoral and agro-pastoral production system, respectively. The calf milk consumption was calculated to be 0.72 and 0.8 kg/day for the mixed crop-livestock production system and pastoral/agro-pastoral production system, respectively. This estimate of milk consumption per calf was then multiplied by the proportion of cows giving birth (Table A3.2a) and added to the adjusted CSA estimate. The resulting daily milk yields for 2003-2018 are presented in Table A3.2c.

Table A3.2c. Average daily milk yields for milking cows in, 1994-2018 (kg $head^{-1}$ day^{-1})

Year	1994	1995	1996	1997	1998	1999	2000	2001	2002
Mixed crop-livestock	0.56	0.57	0.58	0.60	0.65	0.70	0.75	0.80	0.84
Pastoral/agro pastoral	0.62	0.62	0.64	0.66	0.71	0.77	0.82	0.88	0.93
Year	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Mixed crop-livestock	0.90	0.91	0.97	0.96	0.95	0.90	1.15	0.98	0.98
Pastoral/agro pastoral	0.97	0.99	1.11	1.04	1.08	0.98	1.19	1.08	1.02
Year	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**		
Mixed crop-livestock	1.01	1.01	0.95	0.93	0.98	0.90	0.96		
Pastoral/agro pastoral	1.12	1.08	1.04	0.99	1.05	0.97	1.06		

A3.3 Sheep: Proportions giving birth

The proportions of breeding ewes giving birth in the mixed crop-livestock and pastoral production system were estimated using the number of breeding ewes (> 2 year old) divided by the number of lambs (< 6 months old) in the given year, with adjustment for lamb mortality.

High mortality rates are commonly reported for lambs both in mixed crop-livestock (26.9%) and in pastoral/agro-pastoral production systems (31.5%) (Fentie et al. 2016). When applying these mortality rates to the CSA-reported numbers of lambs, this leads to a higher number of lambs born than that reported by CSA for both mixed crop-livestock and pastoral and agro-pastoral production systems. To make this calculation, data on the number of lambs (< 6 months) and breeding ewes for 1995, 1997, and 2003-2018 in the mixed crop-livestock and pastoral and agro-pastoral system was taken from CSA annual agricultural sample survey reports. The proportion of breeding ewes giving birth was then calculated as:

= [total number of lambs (dead + CSA-reported)/ number of breeding ewes] * 100

The resulting proportions of ewes giving birth in the mixed crop-livestock and pastoral/agro-pastoral production systems are presented in Table A3.3b and Table A3.3b, respectively. Linear extrapolation was applied to fill in the missing data for 1994 and linear interpolation for 1996, and 1998-2002 in the mixed crop-livestock and pastoral and agro-pastoral production systems. The time series shows some variation in lambing rate. From 1994 to 2002, variability is low because linear interpolation was used to fill years with missing data. From 2003, variability is most likely due to the effects of drought on feed resources and thus reproduction (e.g. in 2008 and 2014-15).

Table A3.3a. Time series for proportion of ewes giving birth in mixed crop-livestock production system

Year	No. of lambs born (< 6 month)	No. of dead lambs (26.9%)	Total No. of lambs	No. of ewes (2 year and above)	% of ewes giving birth
1994					63.2%
1995	2857228	770023	3627251	5629768	64.4%
1996					66.9%
1997	2966850	799566	3766416	5587870	67.4%
1998					68.4%
1999					69.4%
2000					70.3%
2001					71.3%
2002					72.3%
2003	4134908	1114358	5249266	7162448	73.3%
2004	4637301	1249753	5887054	8004997	73.5%
2005	5645215	1521385	7166600	9013700	79.5%
2006	6128131	1651531	7779662	10283038	75.7%
2007	6266449	1688808	7955258	11233580	70.8%
2008	5702976	1536952	7239927	11064988	65.4%
2009	5876528	1583724	7460252	11442223	65.2%
2010	6216459	1675336	7891794	10611369	74.4%
2011	5839331	1573700	7413030	9933289	74.6%
2012	6136149	1653692	7789841	10397658	74.9%
2013	5985253	1613026	7598279	10643762	71.4%
2014	6941814	1870819	8812632	11373828	77.5%
2015	6431081	1733176	8164257	11318750	72.1%
2016	7094726	1912029	9006755	11860514	75.9%
2017	7123837	1919874	9043710	11722097	77.2%
2018	6095546	1642750	7738295	11376128	68.0%

Table A3.3b. Time series for proportion of ewes giving birth in pastoral and agro-pastoral production system

Year	No. of lambs born (< 6 month)	No. of dead lambs (26.9%)	Total No. of lambs	No. of ewes (2 year and above)	% of ewes giving birth
1994					65.8%
1995	192472	67557.67	260029.67	389102	66.8%
1996					68.8%
1997	299580	105152.6	404732.58	588840	68.7%
1998					68.5%
1999					68.3%
2000					68.1%
2001					67.9%
2002					67.7%
2003	292368	102621	394989	584850	67.5%
2004	296033	103907	399940	622473	64.3%
2005	321517	112852	434369	624910	69.5%
2006	412679	144850	557529	838709	66.5%
2007	472822	165961	638783	1007547	63.4%
2008	452869	158957	611826	973058	62.9%
2009	458966	161097	620062	1147517	54.0%
2010	563841	197908	761749	1310969	58.1%
2011	625534	219562	845096	1462505	57.8%
2012	665137	233463	898600	1616838	55.6%
2013	917639	322091	1239730	2109881	58.8%
2014	907646	318584	1226230	2147932	57.1%
2015	856782	300730	1157512	2286852	50.6%
2016	957841	336202	1294043	2164911	59.8%
2017	1066280	374264	1440545	2582360	55.8%
2018	1615190	566932	2182122	3991937	54.7%

A3.4 Goat: Proportions giving birth

To estimate the proportions of does giving birth in the mixed crop-livestock and pastoral/agro-pastoral production systems, the same assumptions as for sheep were made, and mortality rates of 21.2% and 38.5% were applied for kids in the mixed crop-livestock and pastoral/agro-pastoral production systems, respectively (Fentie et al. 2016).

The number of kids (< 6 months) and does for 1995, 1997, and 2003-2018 in the mixed crop-livestock and pastoral and agro-pastoral systems were taken from CSA agricultural sample survey reports. The resulting proportions of does giving birth for mixed crop-livestock and pastoral/agro-pastoral production systems are presented in Table A3.4a and Table A3.4b. Linear extrapolation and linear interpolation were applied to fill in missing data for 1994, and intervening years (1996, 1998-2002), respectively. The time series shows some variation in kidding rate. From 1994 to 2002, variability is low because linear interpolation was used to fill years with missing data. From 2003, variability is most likely due to the effects of drought on feed resources and reproduction (e.g. in 2008 and 2014-15).

Table A3.4a. Time series for proportion of does giving birth in mixed crop-livestock production system

Year	No. of kids born (< 6 month)	No. of dead kids (26.9%)	Total No. of kids	No. of does (2 year and above)	% of does giving birth
1994					65.6%
1995	1791288	381544.2	2172832	3275648	66.3%
1996					67.7%
1997	1823100	388320.3	2211420	3197910	69.2%
1998					71.3%
1999					73.5%
2000					75.6%
2001					77.8%
2002					80.0%
2003	3038047	647104	3685151	4486896	82.1%
2004	3044436	648464.9	3692901	5088315	72.6%
2005	3718549	792050.9	4510600	5521960	81.7%
2006	3810690	811677	4622367	6088692	75.9%
2007	4250772	905414.4	5156186	7144129	72.2%
2008	4408620	939036.2	5347657	7236522	73.9%
2009	3980605	847868.8	4828473	7305887	66.1%
2010	4219502	898753.9	5118256	7198767	71.1%
2011	4838102	1030516	5868618	6898126	85.1%
2012	4579531	975440	5554971	7187132	77.3%
2013	4794564	1021242	5815806	7873551	73.9%
2014	5276925	1123985	6400911	7993231	80.1%
2015	5377668	1145443	6523111	8346885	78.2%
2016	5494118	1170247	6664365	8554562	77.9%
2017	5872081	1250753	7122834	8946133	79.6%
2018	5458243	1162606	6620849	8702961	76.1%

Table A3.4b. Time series for proportion of does giving birth in pastoral/agro-pastoral production system

Year	No. of kids born (< 6 month)	No. of dead kids (26.9%)	Total No. of kids	No. of does (2 year and above)	% of does giving birth
1994					74.8%
1995	416540	160368	576908	757252	76.2%
1996					78.9%
1997	632920	243674	876594	1073620	81.6%
1998					80.6%
1999					79.5%
2000					78.5%
2001					77.4%
2002					76.4%
2003	607059	233718	840777	1116367	75.3%
2004	665382	256172	921554	1269326	72.6%
2005	617925	237901	855827	1107509	77.3%
2006	796221	306545	1102766	1672552	65.9%
2007	909965	350337	1260302	1804382	69.8%
2008	872094	335756	1207850	1863911	64.8%
2009	939479	361699	1301178	2089912	62.3%
2010	1179748	454203	1633951	2441684	66.9%
2011	1203382	463302	1666684	2583591	64.5%
2012	1273656	490358	1764014	3241847	54.4%
2013	1810073	696878	2506951	4330016	57.9%
2014	1793643	690553	2484196	4292882	57.9%
2015	1911613	735971	2647584	4734733	55.9%
2016	1810547	697061	2507608	4189427	59.9%
2017	2016457	776336	2792793	4824423	57.9%
2018	3421049.2	1317103.9	4738153.2	8532000.4	55.5%

Annex 4: Data sources and methods used to estimate diet composition and feed characteristics

Annex 4: Data sources and methods used to estimate diet composition and feed characteristics

Livestock feed resources in the CSA annual agricultural sample survey are grouped into six diet components: 1) natural pastures (grazing), 2) crop residues (straw and chaff of cereals), 3) improved feed crops (alfalfa), 4) hay (clover, cut and carry system), 5) agro-industrial by-products (oil cakes, grain bran) and 6) others such as non-conventional feeds (enset and banana leaves, local brewery by-products) (CSA 2009). The contribution of these feed resources depends mainly on agro-ecology and production system (Ahmed et al. 2010). Expert judgment was used to allocate common Ethiopian feedstuffs to these six feed components. The list of feedstuffs with their respective chemical composition and nutritive values including DE and ME was taken from the national feed database (EIAR 2007) presented in Appendix Table 9. EIAR (2007) collected more than 200 samples from six agro-ecological regions of the country. Dry and green forage samples were collected during the wet and dry season to represent the year-round feed resource availability. Protein and energy supplements were also sampled from feed processing and agro-industrial factories in the country. Dry matter and crude protein were determined by proximate analysis (AOAC, 1990), whereas ME was estimated using the equation of MAFF (1984):

ME (MJ/kg DM) = 0.15 * Digestible organic matter in dry matter *in-vitro*

The DE (%) of the six diet components were calculated as the average of the individual feedstuff's DE value, except for crop residue for which the DE value was calculated from the seven major cereal crops as follows. The seven major cereal crops in Ethiopia are teff, barley, wheat, sorghum, maize, millet, and oat, which are considered as available crop residues for livestock feed. First, the amount of grain yield per year was obtained from CSA from 2003-2018. Then the grain yield was converted to residue using fixed conversation factors (FAO 1987, see Appendix Table 9). The available residue was converted to dry matter yield using the respective dry matter value obtained from the national feed database (EIAR 2007). It was assumed that about 90% of the crop residues are used as livestock feed and 10% for other purposes and wastage (Tolera and Said 1991). The total crop residue available as livestock feed for a reference period was calculated as the sum of individual crop residue yield. Then the contribution of each crop residue (proportion) was calculated by dividing individual crop residue yield by total yield. The DE (%) value of each cereal crop residue was estimated using the ME content of the respective crop following the formulas described in Annex A4.1, which are based on CSIRO (2007). The final single DE (%) value for crop residue was calculated as the sum of each crop residue DE (%) multiplied by the proportion of the respective cereal crop in the crop residue category.

A4.1 Dairy cattle diet composition and feed characteristics

For commercial and smallholder intensive dairy production systems, the feed basket for dairy animals was constructed using expert judgment due to the fact that available small-scale studies are not representative of actual feeding practice.[1] Because of the scarcity of land, most dairy farmers keep their animals indoors and practice zero-grazing feeding systems. According to expert opinion, the feed basket composition for dairy cattle is as shown in Table A4.1a.

1 Expert judgement was elicited through discussions at a meeting held on 10th March 2020. The experts were Dr. Mesfin Dejene (Senior Researcher and Program Leader feeds and nutrition research, Holeta Research Center, EIAR), Dr. Getu Kitaw (Senior researcher, Holeta Research Center, EIAR), Dr. Aemiro Kehaliew (senior researcher, Holeta Research center, EIAR), Dr. Samuel Tufa (Animal feed resources and rangeland management researcher, Oromia Agricultural Research Institute), Mr. Philimon Teshome (Researcher, EIAR).

Table A4.1a. Feed basket for dairy cattle in commercial and smallholder intensive production system

Diet composition	Cow	Adult male	Heifers	Growing male	Calves <6 m	Calves 6 m - <1 year
Industrial by-product	0.47	0.47	0.47	0.47	0.47	0.47
Hay cut and carry	0.38	0.38	0.38	0.38	0.38	0.38
Crop residue	0.12	0.12	0.12	0.12	0.12	0.12
Improved forage crops	0.01	0.01	0.01	0.01	0.01	0.01
Other type of feeds	0.03	0.03	0.03	0.03	0.03	0.03

Feed energy digestibility values of each feedstuff was estimated using the following equations from CSIRO (2007):

Feed energy digestibility (DE, %) = Digestible energy (DE, MJ)/18.4 Equation 1

DE (MJ) = Metabolizable energy (ME MJ)/0.81 Equation 2

The DE (%) value of each feed component was calculated as the average of each individual feedstuff's DE value in the EIAR database. The DE value of crop residue was calculated as described above in section Annex A4.

The final DE (%) value for each animal sub-category was calculated as the weighted sum of DE values using diet composition from Table A4.1a for the weighting. Due to limited data availability, this value was used for each sub-category and is consistently used throughout the times series (Table A4.1b).

Table A4.1b Time series for feed digestibility (DE %) for dairy cattle sub-categories in the commercial and smallholder intensive dairy production systems, 1994-2018

	Cow	Adult male	Heifer	Growing male	Calves <6 m	Calves 6 m - <1 year
1994	61.8	61.8	61.8	61.8	61.8	61.8
1995	61.8	61.8	61.8	61.8	61.8	61.8
1996	61.8	61.8	61.8	61.8	61.8	61.8
1997	61.8	61.8	61.8	61.8	61.8	61.8
1998	61.8	61.8	61.8	61.8	61.8	61.8
1999	61.8	61.8	61.8	61.8	61.8	61.8
2000	61.8	61.8	61.8	61.8	61.8	61.8
2001	61.8	61.8	61.8	61.8	61.8	61.8
2002	61.8	61.8	61.8	61.8	61.8	61.8
2003	61.8	61.8	61.8	61.8	61.8	61.8
2004	61.8	61.8	61.8	61.8	61.8	61.8
2005	61.8	61.8	61.8	61.8	61.8	61.8
2006	61.8	61.8	61.8	61.8	61.8	61.8
2007	61.8	61.8	61.8	61.8	61.8	61.8
2008	61.8	61.8	61.8	61.8	61.8	61.8
2009	61.8	61.8	61.8	61.8	61.8	61.8
2010	61.8	61.8	61.8	61.8	61.8	61.8
2011	61.8	61.8	61.8	61.8	61.8	61.8
2012	61.8	61.8	61.8	61.8	61.8	61.8
2013	61.8	61.8	61.8	61.8	61.8	61.8
2014	61.8	61.8	61.8	61.8	61.8	61.8
2015	61.8	61.8	61.8	61.8	61.8	61.8
2016	61.8	61.8	61.8	61.8	61.8	61.8
2017	61.8	61.8	61.8	61.8	61.8	61.8
2018	61.8	61.8	61.8	61.8	61.8	61.8

A4.2 Other cattle diet composition and feed characteristics

Feed basket for the time series from 2003-2018 for other cattle in the mixed crop-livestock production system was provided by CSA. The CSA-reported data on livestock feed utilization was obtained by asking farmers to estimate the proportions of different feed types in the total feed utilized and not estimated specifically for different species or animal sub-categories. However, it is the only source of a consistent time series on diet composition. According to CSA, the feed basket for mixed crop-livestock production systems is composed of the six diet components: natural pasture, crop residue, improved feed, hay, agro-industrial by products, and others (Table A4.2a). However, compared to commercial dairy production system, natural pasture is the primary feed resource throughout the wet season while crop residues play a crucial role during the dry season in the mixed crop-livestock production system. The historical data (2003-2018) on actual feed utilization revealed a reduction (63.8 in 2003 to 54.8% in 2018) in the contribution of natural pasture as a livestock feed resource, which is partly paralleled by an increase (25.9% in 2003 to 31.55% in 2018) in use of crop residue as a livestock feed resource. For the missing years 1994 to 2002, the feed digestibility was calculated first and then DE% was linearly extrapolated for the missing years. Since the CSA data is not disaggregated by cattle sub-category, the same values are applied to all sub-categories in each year.

Table A4.2a. Time series (2003-2018) for feed basket for other cattle in the mixed crop-livestock production system

Year	Diet composition					
	Natural pasture	Crop residue*	Improved forage crops	Hay cut and carry	Industrial by-product	Other type of feeds
2003	0.638	0.259	0.001	0.059	0.010	0.033
2004	0.627	0.268	0.001	0.063	0.008	0.034
2005	0.614	0.278	0.001	0.064	0.008	0.035
2006	0.618	0.272	0.001	0.060	0.011	0.038
2007	0.619	0.270	0.002	0.066	0.008	0.036
2008	0.611	0.271	0.002	0.071	0.007	0.039
2009	0.595	0.283	0.002	0.074	0.008	0.039
2010	0.587	0.292	0.003	0.074	0.008	0.037
2011	0.586	0.294	0.003	0.065	0.010	0.042
2012	0.575	0.296	0.002	0.071	0.009	0.047
2013	0.571	0.293	0.002	0.072	0.012	0.049
2014	0.562	0.301	0.003	0.074	0.012	0.048
2015	0.552	0.314	0.003	0.071	0.014	0.047
2016	0.546	0.316	0.003	0.069	0.015	0.051
2017	0.560	0.301	0.003	0.066	0.016	0.054
2018	0.548	0.315	0.004	0.067	0.016	0.051

The crop residue value was derived from weighted proportion of the major cereal crops. #

The ME content of natural resources in the mixed crop-livestock production system was estimated based on expert judgment.[1] Accordingly, the ME content for natural pasture during the dry season (3 months) and wet season (9 months) was estimated as 6.9 and 8.8 MJ/kg DM, respectively, and the weighted average was calculated to be 8.3 MJ/kg DM. The ME value of the other feed components was obtained from feed nutrient databases (Appendix Table 9). The DE (%) value of each diet composition and final DE (%) value of the feed basket for the other cattle in mixed crop-livestock production systems was calculated as described in Annex A4.1. A linear extrapolation procedure was employed to fill in the missing years from 1994-2002. The resulting time series for feed energy digestibility is shown in Table A4.2b.

1 See previous footnote for details of experts consulted.

Table A4.2b. Time series (1994-2018) for feed digestibility (DE %) for other cattle sub-categories in the mixed crop-livestock production system

	Cow	Adult male used for drought	Adult male used for breeding	Heifer	Growing male	Calves <6 m	Calves 6 m - <1 year
1994	53.94	53.94	53.94	53.94	53.94	53.94	53.94
1995	53.94	53.94	53.94	53.94	53.94	53.94	53.94
1996	53.94	53.94	53.94	53.94	53.94	53.94	53.94
1997	53.94	53.94	53.94	53.94	53.94	53.94	53.94
1998	53.93	53.93	53.93	53.93	53.93	53.93	53.93
1999	53.93	53.93	53.93	53.93	53.93	53.93	53.93
2000	53.92	53.92	53.92	53.92	53.92	53.92	53.92
2001	53.90	53.90	53.90	53.90	53.90	53.90	53.90
2002	53.87	53.87	53.87	53.87	53.87	53.87	53.87
2003	53.80	53.80	53.80	53.80	53.80	53.80	53.80
2004	53.66	53.66	53.66	53.66	53.66	53.66	53.66
2005	53.52	53.52	53.52	53.52	53.52	53.52	53.52
2006	53.68	53.68	53.68	53.68	53.68	53.68	53.68
2007	53.68	53.68	53.68	53.68	53.68	53.68	53.68
2008	53.58	53.58	53.58	53.58	53.58	53.58	53.58
2009	53.52	53.52	53.52	53.52	53.52	53.52	53.52
2010	53.44	53.44	53.44	53.44	53.44	53.44	53.44
2011	53.42	53.42	53.42	53.42	53.42	53.42	53.42
2012	53.45	53.45	53.45	53.45	53.45	53.45	53.45
2013	53.55	53.55	53.55	53.55	53.55	53.55	53.55
2014	53.49	53.49	53.49	53.49	53.49	53.49	53.49
2015	53.48	53.48	53.48	53.48	53.48	53.48	53.48
2016	53.51	53.51	53.51	53.51	53.51	53.51	53.51
2017	53.64	53.64	53.64	53.64	53.64	53.64	53.64
2018	53.51	53.51	53.51	53.51	53.51	53.51	53.51

For the pastoral and agro-pastoral production system, expert judgment was used to construct the feed basket and ME content of feed, which was then used to estimate feed energy digestibility. Expert judgment suggested that the feed basket for pastoral/agro-pastoral systems is composed of natural pasture (97.7%) and crop residue (2.3%). Furthermore, unlike in the mixed crop-livestock production system, the major cereal crops grown in the pastoral/agro-pastoral production system are maize and sorghum. Therefore, crop residue from these two cereal crops were considered as available for livestock feed in the pastoral/agro-pastoral production system. Expert judgment suggested the dry season in the pastoral/agro-pastoral production system is longer, whereas the wet season is shorter than in mixed crop-livestock production systems. Accordingly, the ME content for natural pasture during the dry season (7 months) and wet season (5 months) were estimated as 7.3 and 9.5 MJ/kg DM, respectively, and the weighted average was calculated to be 8.2MJ/kg DM. The DE (%) value of natural pasture and crop reside for the pastoral and agro-pastoral production system was then estimated following the formulas described in Annex A4.1.
The resulting DE was consistently used for each sub-category throughout the time series (Table A4.2c).

Table A4.2c. Time series for feed digestibility (DE %) for other cattle sub-categories in the pastoral/agro-pastoral production system

Year	1994	1995	1996	1997	1998	1999	2000	2001
DE (%)	54.89	54.89	54.89	54.89	54.89	54.89	54.89	54.89
Year	2002	2003	2004	2005	2006	2007	2008	2009
DE (%)	54.89	54.89	54.89	54.89	54.89	54.89	54.89	54.89
Year	2010	2011	2012	2013	2014	2015	2016	2017
DE (%)	54.89	54.89	54.89	54.89	54.89	54.89	54.89	54.89
Year	2018							
DE (%)	54.89							

Smallholder fattening operations

Cattle to be fattened in the smallholder fattening system are adult male animals sourced from the mixed crop-livestock production system. It was assumed that animals to be fattened spent 3.5 months in the feedlot and 8.5 months in the mixed crop-livestock production system. Therefore, the DE value is the weighted average from these different feeding systems.

Expert judgment was employed to estimate the feed basket for smallholder fattening operations. It was suggested that smallholder fattening operations use natural pasture (20%), crop residues (20%), industrial by-products (30%) and other feed types (30%). The DE (%) value for smallholder fattening operations was estimated as the average of DE values for individual diet components presented in Appendix Table 9, resulting in an estimated value of 60.05%. However, this value is only applied for 3.5 months of a year and the rest of the year (8.5 months) used the DE values for adult male cattle from the mixed crop-livestock production system. The weighted average DE value for smallholder fattening operations was calculated using the following formula:

DE (%) = [(8.5 months*DE (%) value from mixed crop-livestock) + (3.5 months*60.02%)]/12

Accordingly, the weighted average of DE value for smallholder fattening operations in mixed crop-livestock production systems is 55.46%, and this value was used consistently throughout the time series.

Commercial feedlot

Cattle to be fattened in commercial feedlots are growing male animals sourced from the pastoral/agro-pastoral production system. It was assumed that animals to be fattened spent only 3 months in the feedlot and 9 months in the pastoral/agro-pastoral production system.

Feed basket reports for commercial feedlot systems were obtained from published literature (Tsegay and Mengistu 2013, Dadi et al. 2017, Gebremicheal et al. 2017). Commercial feedlots are primarily dependent on agro-industrial by-products (71%) and roughage feeds such as hay (14%) and crop residue (14%) as they do not have land for feed production. The DE (%) value was estimated using ME content of each feedstuffs under each diet composition presented in Appendix Table 9, a value of 68.86% was taken. The weighted average DE value for commercial feedlot cattle was estimated following the same procedure as described for smallholder fattening operations except that the growing male animals spent 9 months in the pastoral/agro-pastoral production system. Thus DE value for pastoral and agro-pastoral production system is used:

DE (%) = [(9 months*DE (%) value from pastoral and agro-pastoral) + (3 months*68.86%)]/12

The resulting DE value of 58.38 % is consistently used throughout the time series.

To calculate the crude protein content (CP%) of the diet, the same diet composition was used, and CP% taken from EAIR (2007). For calves <6 months, CP% was calculated assuming 3 months consuming milk with 3.5% protein content and 3 months consuming the same CP% as for other cattle sub-categories in each system. For feedlot cattle, CP% was calculated as the weighted average of time spent on feedlot and in the respective production system. The values for CP% used are shown in Tables A4.2d-f.

Table A4.2d Time series for crude protein content of the diet (CP%) for dairy cattle sub-categories

Year	Adult pure exotic dairy cows (3-10 years)	Adult pure exotic males 3-10 years	Pure exotic calves (<6 months) male & female	Pure exotic calves (6 m - < 1 yr) male & female	Pure exotic growing males (1 - < 3 years)	Pure exotic growing females (1 -< 3 years)
1994	14.54	14.54	9.02	14.54	14.54	14.54
1995	14.54	14.54	9.02	14.54	14.54	14.54
1996	14.54	14.54	9.02	14.54	14.54	14.54
1997	14.54	14.54	9.02	14.54	14.54	14.54
1998	14.54	14.54	9.02	14.54	14.54	14.54
1999	14.54	14.54	9.02	14.54	14.54	14.54
2000	14.54	14.54	9.02	14.54	14.54	14.54
2001	14.54	14.54	9.02	14.54	14.54	14.54
2002	14.54	14.54	9.02	14.54	14.54	14.54
2003	14.55	14.55	9.02	14.55	14.55	14.55
2004	14.55	14.55	9.02	14.55	14.55	14.55
2005	14.54	14.54	9.02	14.54	14.54	14.54
2006	14.54	14.54	9.02	14.54	14.54	14.54
2007	14.54	14.54	9.02	14.54	14.54	14.54
2008	14.54	14.54	9.02	14.54	14.54	14.54
2009	14.54	14.54	9.02	14.54	14.54	14.54
2010	14.53	14.53	9.02	14.53	14.53	14.53
2011	14.53	14.53	9.02	14.53	14.53	14.53
2012	14.53	14.53	9.02	14.53	14.53	14.53
2013	14.54	14.54	9.02	14.54	14.54	14.54
2014	14.53	14.53	9.02	14.53	14.53	14.53
2015	14.53	14.53	9.02	14.53	14.53	14.53
2016	14.53	14.53	9.02	14.53	14.53	14.53
2017	14.53	14.53	9.02	14.53	14.53	14.53
2018	14.53	14.53	9.02	14.53	14.53	14.53

Table A4.2e Time series for crude protein content of the diet (CP%) for mixed crop—livestock system cattle sub-categories

Year	Adult multipurpose cows >3 years	Adult males used for draught (3-10 years)	Adult males used for breeding & other purpose (>3-10 years)	Calves < 6 months (male & female)	Calves (6 m-1 yr) male & female	Growing males 1-3 years	Growing females 1-3 years	Adult males (>3 years) smallholder fattening	Adult males (>3 years) commercial feedlot
1994	6.93	6.93	6.93	5.22	6.93	6.93	6.93	8.79	11.10
1995	6.93	6.93	6.93	5.22	6.93	6.93	6.93	8.79	11.10
1996	6.93	6.93	6.93	5.22	6.93	6.93	6.93	8.79	11.10
1997	6.93	6.93	6.93	5.22	6.93	6.93	6.93	8.79	11.10
1998	6.93	6.93	6.93	5.22	6.93	6.93	6.93	8.79	11.10
1999	6.93	6.93	6.93	5.22	6.93	6.93	6.93	8.79	11.10
2000	6.93	6.93	6.93	5.22	6.93	6.93	6.93	8.79	11.10
2001	6.93	6.93	6.93	5.22	6.93	6.93	6.93	8.79	11.10
2002	6.93	6.93	6.93	5.22	6.93	6.93	6.93	8.79	11.10
2003	7.01	7.01	7.01	5.22	7.01	7.01	7.01	8.79	11.10
2004	6.93	6.93	6.93	5.22	6.93	6.93	6.93	8.79	11.10
2005	6.88	6.88	6.88	5.22	6.88	6.88	6.88	8.79	11.10
2006	6.98	6.98	6.98	5.22	6.98	6.98	6.98	8.79	11.10
2007	6.92	6.92	6.92	5.22	6.92	6.92	6.92	8.79	11.10
2008	6.89	6.89	6.89	5.22	6.89	6.89	6.89	8.79	11.10
2009	6.88	6.88	6.88	5.22	6.88	6.88	6.88	8.79	11.10
2010	6.84	6.84	6.84	5.22	6.84	6.84	6.84	8.79	11.10
2011	6.89	6.89	6.89	5.22	6.89	6.89	6.89	8.79	11.10
2012	6.89	6.89	6.89	5.22	6.89	6.89	6.89	8.79	11.10
2013	6.96	6.96	6.96	5.22	6.96	6.96	6.96	8.79	11.10
2014	6.93	6.93	6.93	5.22	6.93	6.93	6.93	8.79	11.10
2015	6.92	6.92	6.92	5.22	6.92	6.92	6.92	8.79	11.10
2016	6.97	6.97	6.97	5.22	6.97	6.97	6.97	8.79	11.10
2017	7.06	7.06	7.06	5.22	7.06	7.06	7.06	8.79	11.10
2018	6.97	6.97	6.97	5.22	6.97	6.97	6.97	8.79	11.10

Table A4.2f Time series for crude protein content of the diet (CP%) for pastoral crop—livestock system cattle sub-categories

Year	Adult multipurpose cows >3 years	Adult males used for draught (3-10 years)	Adult males used for breeding & other purpose (>3-10 years)	Calves < 6 months (male & female)	Calves (6 m-1 yr) male & female	Growing males 1-3 years	Growing females 1-3 years
1994	7.62	7.62	7.62	5.56	7.62	7.62	7.62
1995	7.62	7.62	7.62	5.56	7.62	7.62	7.62
1996	7.62	7.62	7.62	5.56	7.62	7.62	7.62
1997	7.62	7.62	7.62	5.56	7.62	7.62	7.62
1998	7.62	7.62	7.62	5.56	7.62	7.62	7.62
1999	7.62	7.62	7.62	5.56	7.62	7.62	7.62
2000	7.62	7.62	7.62	5.56	7.62	7.62	7.62
2001	7.62	7.62	7.62	5.56	7.62	7.62	7.62
2002	7.62	7.62	7.62	5.56	7.62	7.62	7.62
2003	7.63	7.63	7.63	5.56	7.63	7.63	7.63
2004	7.63	7.63	7.63	5.56	7.63	7.63	7.63
2005	7.62	7.62	7.62	5.56	7.62	7.62	7.62
2006	7.62	7.62	7.62	5.56	7.62	7.62	7.62
2007	7.62	7.62	7.62	5.56	7.62	7.62	7.62
2008	7.62	7.62	7.62	5.56	7.62	7.62	7.62
2009	7.62	7.62	7.62	5.56	7.62	7.62	7.62
2010	7.62	7.62	7.62	5.56	7.62	7.62	7.62
2011	7.62	7.62	7.62	5.56	7.62	7.62	7.62
2012	7.62	7.62	7.62	5.56	7.62	7.62	7.62
2013	7.62	7.62	7.62	5.56	7.62	7.62	7.62
2014	7.62	7.62	7.62	5.56	7.62	7.62	7.62
2015	7.62	7.62	7.62	5.56	7.62	7.62	7.62
2016	7.62	7.62	7.62	5.56	7.62	7.62	7.62
2017	7.62	7.62	7.62	5.56	7.62	7.62	7.62
2018	7.62	7.62	7.62	5.56	7.62	7.62	7.62

A4.3 Sheep diet composition and feed characteristics

Literature was reviewed to assess the feed basket for sheep and goat production systems in Ethiopia. Reports of feed baskets were obtained from Teshome (2006), Ketema (2007), Tesfaye (2008). Based on this literature, the feed basket for sheep in the mixed crop-livestock production system was defined as natural pasture (75.1%) followed by crop residues (16.9%) and indigenous browse (8%), since feeding concentrates to sheep and goats is not common in Ethiopia. For sheep in the pastoral/agro-pastoral system, expert judgment on the feed basket for other cattle was adopted, whereby natural pasture and crop residue comprise 97.7% and 2.3%, respectively.

The DE (%) value of the diet was estimated using the ME content of each diet component following the same procedure described in Annex A4.1, and DE values of 54.39% and 54.89% for sheep in the mixed crop-livestock and pastoral/agro-pastoral production systems were taken and used consistently throughout the time series. To calculate the CP% of the diet, the same diet composition was used, and CP content was taken from EIAR (2007). CP values of 8.06% and 7.62% for sheep in the mixed crop-livestock and pastoral/agro-pastoral production systems, respectively, were used consistently throughout the time series.

A4.4 Goats diet composition and feed characteristics

The assumptions used to estimate feed basket, and diet composition for sheep in both the mixed crop-livestock and pastoral/agro-pastoral production systems were also applied to goats in both production systems. Therefore, DE values of 54.39% and 54.89% for goats in the mixed crop-livestock and pastoral /agro-pastoral production systems were taken and used consistently throughout the time series. To calculate the crude CP% of the diet, the same diet composition was used, and CP content was taken from EIAR (2007). CP values of 8.20% and 7.62% for goats in the mixed crop-livestock and pastoral/agro-pastoral production systems, respectively, were used consistently throughout the time series.

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Annex 5: Data sources and methods used to estimate manure management activity data

Annex 5: Data sources and methods used to estimate manure management activity data

A5.1 Cattle manure management

Data on the proportion of manure managed in different manure management systems (MMS%) in Ethiopia is very limited. Using the available data, estimates of MMS% were made for each production system.

A5.1.1 Commercial and smallholder dairy production systems

Three studies were identified reporting on manure management practices in urban and peri-urban farms. Ndambi et al. (2019) reported the proportion of households using different manure management systems, but not the proportion of manure in each management system. The manure management systems reported included bedding, biogas, discharge of digestate from the farm, dung and urine separation, solid storage, and use as fuel after storage. Tezera (2018) reported the proportions of manure managed in different MMS in 80 urban and peri-urban farms. Table A5.1a shows the weighted average for urban and peri-urban farms calculated from Tezera (2018). A survey of peri-urban dairy farms was also done by Holeta Agricultural Research Centre (Holeta Agriculture Research Centre 2019). The summary results of their survey are shown in Table A5.1b.

Table A5.1a Proportions of manure managed in different manure management systems in 80 urban and peri-urban farms in the Zeway-Hawassa milkshed

Manure management system	Weighted average proportion
biogas	0.1104
daily spread	0.0285
burned	0.2710
compost	0.0084
solid storage	0.5817

Table A5.1b Proportions of manure managed in different manure management systems in urban and peri-urban farms, Holeta

Manure management system	proportion
liquid system	0.056
solid storage	0.189
Dry lot	0.545
pasture, range	0.142
daily spread	0.037
Compost	0.031

Table A5.1c Biogas units installed and operational

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Cumulative units installed	98	128	859	2500	5011	8161	10624	12884	15437	18028	20619
% functioning	40%	44.33%	48.67%	53.00%	57.33%	61.67%	66.00%	70.33%	74.67%	79.00%	79.00%
Estimated units in use	39	57	418	1325	2873	5033	7012	9062	11526	14242	16289

Data sources: 2008-2015 units installed from https://www.africabiogas.org/countries/ethiopia/ 2016-2017 World Bank (2019). 2008 proportion functioning from Mengistu et al. (2015); 2018 proportion functioning from Miklol Consulting and Research (2019).

Tezera (2018) did not mention liquid management systems, although other studies conducted in the same area have mentioned their presence in commercial dairy farms (Mudombi 2019). Following the Holeta data, we assume 5.6% of manure is in liquid management. Data on biogas use is taken from various sources (Table A5.1c) describing units installed and functional in the National Biogas Program and it is assumed that biogas units are only installed in the dairy system (i.e. urban-peri-urban farms), not in the mixed crop-livestock system. We discount non-functioning biogas systems from the number of biogas systems, using data from user surveys in 2009 and 2019. Assuming an average of 4.5 cattle per household, this suggests that in 2017, 3.13% of dairy manure was managed in biogas systems. After accounting for biogas and an assumed 5.6% liquid management, the proportion of manure managed in each manure management system in Table A5.1a was adjusted accordingly. Because of an increase in the number of biogas units each year, the proportions vary per year. In the Holeta survey, 14% of manure is deposited on pasture in commercial systems, but the diet data assumed in this initial inventory did not include pasture in the commercial dairy system, so for consistency we do not consider that dung and urine is deposited in pasture in the commercial dairy system. Further, the Holeta data reports 54.5% of manure managed in dry lot systems, which following the IPCC definitions means that it is left on a paved or unpaved open area. Since with limited space on urban and peri-urban dairy farms it is unlikely that dung is not removed periodically for storage using other methods, this inventory assumes that the length of time manure spends in solid storage is much greater than the length of time on drylot. The resulting estimated values for MMS% are shown in Table A5.1d.

Table A5.1d Proportions of manure managed in different manure management systems in the commercial dairy production system, 1994-2018

Year	Pasture	Compost	Solid storage	Liquid	Daily spread	Burned	Biogas digesters
1994	0.00%	0.89%	61.73%	5.60%	3.02%	28.76%	0.00%
1995	0.00%	0.89%	61.73%	5.60%	3.02%	28.76%	0.00%
1996	0.00%	0.89%	61.73%	5.60%	3.02%	28.76%	0.00%
1997	0.00%	0.89%	61.73%	5.60%	3.02%	28.76%	0.00%
1998	0.00%	0.89%	61.73%	5.60%	3.02%	28.76%	0.00%
1999	0.00%	0.89%	61.73%	5.60%	3.02%	28.76%	0.00%
2000	0.00%	0.89%	61.73%	5.60%	3.02%	28.76%	0.00%
2001	0.00%	0.89%	61.73%	5.60%	3.02%	28.76%	0.00%
2002	0.00%	0.89%	61.73%	5.60%	3.02%	28.76%	0.00%
2003	0.00%	0.89%	61.73%	5.60%	3.02%	28.76%	0.00%
2004	0.00%	0.89%	61.73%	5.60%	3.02%	28.76%	0.00%
2005	0.00%	0.89%	61.73%	5.60%	3.02%	28.76%	0.00%
2006	0.00%	0.89%	61.73%	5.60%	3.02%	28.76%	0.00%
2007	0.00%	0.89%	61.73%	5.60%	3.02%	28.76%	0.00%
2008	0.00%	0.89%	61.73%	5.60%	3.02%	28.76%	0.01%
2009	0.00%	0.89%	61.50%	5.60%	3.01%	28.65%	0.36%
2010	0.00%	0.88%	61.27%	5.60%	3.00%	28.55%	0.70%
2011	0.00%	0.88%	61.04%	5.60%	2.99%	28.44%	1.05%
2012	0.00%	0.88%	60.82%	5.60%	2.97%	28.34%	1.40%
2013	0.00%	0.87%	60.59%	5.60%	2.96%	28.23%	1.74%
2014	0.00%	0.87%	60.36%	5.60%	2.95%	28.12%	2.09%
2015	0.00%	0.87%	60.14%	5.60%	2.94%	28.02%	2.44%
2016	0.00%	0.86%	59.91%	5.60%	2.93%	27.91%	2.79%
2017	0.00%	0.86%	59.68%	5.60%	2.92%	27.81%	3.13%
2018	0.00%	0.86%	59.46%	5.60%	2.91%	27.70%	3.48%

A5.1.2 Pastoral/agro-pastoral production system

Dung is not widely used as a fuel energy source in the pastoral areas. The diet composition data assumed that 97.7% of DMI is obtained from natural pasture. Jagisso et al. (2019) refer to 10-11 hours grazing time per day, with the remainder in the kraal. Other studies refer to large amounts of dung collected in the kraal, which is cleaned every 1-5 days and stored in heaps. Based on the proportion of time spent grazing (10.5 hours per day) and in the corral (13.5 hours), we assume that 43.75% (i.e. 10.5/24) is deposited on pasture and 56.25% (i.e. 13.5/24) is stored in solid storage. Dung left in the kraal is closer to drylot management in the IPCC terminology, but since it is periodically removed and stored for long periods (many years) in heaps, more than 98% of the year it is managed in solid storage.

A5.1.3 Mixed crop-livestock system

A survey by Holeta Agricultural Research Center (2019) estimated the proportions in the mixed crop-livestock system shown in Table A5.1e. This estimate is used with the following adjustments. First, following the National Energy Balance Assessment (ESMAP 1996), it is assumed that 18.56% of dung is burned for fuel. Although the diet composition data for mixed crop livestock systems in this inventory assumed 55-64% of diet is from natural pasture, in practice some is collected daily, so we assume that 40% is left on the pasture (Rimhanen and Kahiluoto 2014). Solid storage (i.e. dung cakes) is common, but several studies in the highlands also refer to compost. No data on the relative mass of these is available, so we assume the remainder is divided between compost (15%) and solid storage (85%). Because dung deposited in kraals is collected and heaped, for most of the year it is stored in heaps and not as drylot and therefore the inventory uses the solid storage category, not drylot manure management category. Daily spread is assumed to account for 7% as in the Holeta data. The resulting proportions are shown in Table A5.1f.

Table A5.1e Proportions of manure managed in different manure management systems in the mixed crop-livestock production system in Holeta

Manure management system	Proportion
Liquid	0.05
Solid	0.10
dry lot	0.13
Pasture	0.40
daily spread	0.07
Burn	0.24
Other	0.01

Table A5.1f Proportions of manure managed in different manure management systems in the mixed crop-livestock production system

Pasture	0.40
Compost	0.0578
Solid storage	03276
Liquid	0.00
Daily spread	0.0290
Burn	0.1856
Biogas digesters	0.00

A5.2 Sheep and goat manure management

No literature was identified on sheep and goat manure management. The diet composition for sheep and goats assumed in this inventory is based on 75% intake from natural pastures in the mixed crop-livestock system and 97% in the pastoral/agro-pastoral system. Due to a lack of other data, we adopt the default percentages in IPCC (2019) Table 10A.8, i.e. 17% solid storage, 3% drylot and 80% pasture, paddock and range.

CIAT/Georgina Smith

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Annex 6: Uncertainty analysis

Annex 6: Uncertainty analysis

Uncertainty analysis was accomplished using Monte Carlo (MC) simulation implemented in Palisade @Risk software. The key inputs to the uncertainty analysis were:

(1) Mean values: The mean values of all activity data, coefficients and emission factors were exactly as implemented in the draft inventory;

(2) Margins of error: Margins of error around the mean values were estimated for each input parameter.

(3) Probability Density Functions (PDFs): For each parameter, PDFs were chosen either by reference to IPCC guidelines or other literature.

Because animal sub-category populations were estimated using the same data sources, correlations between the time series for populations of each animal sub-category were included in the model. For activity data inputs into emission factors, it was assumed that there are no correlations. Uncertainty was estimated as the margin of error (e.g. ±18%) with a confidence interval of 95%. Calculation of margins of error used a z-score of 1.96 corresponding to an α value of 0.05. Sample sizes and standard errors for population estimates were taken directly from the CSA livestock sample survey reports for each year, except 1994 for which no standard errors are given. The method used to estimate MOE for 1994 is described below. Uncertainty analysis was conducted for the base year (1994), the latest year in the inventory (2018), and the CRGE base year (2010), and for the uncertainty in the trends 1994-2018 and 2010-2018.

A6.1 Uncertainty in livestock population activity data

For livestock population activity data, CSA annual livestock survey reports were the main data source for cattle in the smallholder dairy, mixed crop-livestock and pastoral/agro-pastoral production systems (except for parts of Afar and Somali regions).

Cattle: The CSA annual livestock survey reports estimate a standard error for the whole cattle population and for each animal sub-category enumerated. In the 2017/18 report, the standard error for the total cattle population converts to a margin of error (MOE) of ±3.2%, with sub-categories MOE ranging between ±3.05% and ±15.81%. In this inventory, the CSA male and female calf sub-categories and CSA data for cows and adult males 3-10 years and >10 years were combined. The MOEs for these combined sub-categories were calculated as the square root of the sum of MOEs squared:

$$MOE_{comb} = \pm\sqrt{\sum_m MOE_m^2}$$

where *m* is an index of each sub-category combined. For cattle sub-categories in the mixed crop-livestock system, the MoE for populations of each sub-category was taken as the MOE estimated from the standard errors reported in CSA annual livestock survey reports. Smallholder fattening cattle populations were derived from the CSA data for '≥3 to < 10 years males used for meat purpose'. The MOE for this sub-category uses the combined MoE calculated for adult males ≥3 years using the standard errors reported in the CSA livestock survey reports. Commercial feedlot cattle populations were estimated using export data. No reliable estimates of total commercial feedlot cattle population were identified, so an MOE of ±50% was assumed.

For cattle in the pastoral/agro-pastoral system, the total sub-category populations in the inventory are the sum of populations enumerated by CSA and populations estimated for zones in Afar and Somali regions that are not covered in CSA sample surveys. The combined MOE for each sub-category in the pastoral/agro-pastoral system was calculated using the CSA-reported standard errors for CSA enumerated populations and an assumed MOE of ±50% for each sub-category in the estimated populations of zones not covered by CSA in Afar and Somali regions. It should be noted that in compiling sub-populations, proportions of cattle in mixed crop-livestock and pastoral/agropastoral systems were estimated using zone level data from each region. Some districts or kebele in a zone dominated by mixed crop-livestock production may have a pastoral/agro-pastoral production system. However, data below the zone level was not consistently available with which to improve the allocation to production systems. This introduces additional uncertainty that has not been considered in this uncertainty analysis about the proportions of cattle with different animal performance parameters, but this omission does not impact on the estimate of the total cattle population.

For the smallholder dairy cattle sub-categories, the MOE values calculated from standard errors in the CSA livestock survey reports were combined with an assumed value for MOE of the herd structure estimates in Table A1.2 of ±5% for each sub-category. For the commercial dairy production system, cattle populations were estimated using data in Minten et al. (2018), which enabled an estimate of the total dairy population, but did not describe standard errors of the estimate. The uncertainty analysis here assumes that each sub-category population estimate has an MoE of ±50%.

The 1994 and 1995 CSA livestock survey reports do not provide the standard error of population and sub-population estimates. Standard errors are only reported in the reports from 1997 and 2003 onwards. The survey sample size in 1995 was 14,923 households, which is much smaller than the average of 58,398 households surveyed from 2003-2018. At the same time, there has been a general increasing trend in the MOE of the cattle population estimate in CSA data. Linear regressions were run with MOE of the total cattle population estimate as the dependent variable and year and sample size as independent variables. For the MOE of cattle population estimates, sample size was not significant, but a regression with year as the dependent variable was significant (R^2=0.32, $F<0.05$). This may be because household production systems have been changing over time and becoming more diverse. The resulting coefficients indicate a predicted MOE about half the size of the MOE in 2018. To account for the use of some extrapolated values in the inventory base year cattle population estimates, we use the same values for MOE in 1994 as are used for the 2018 dataset, i.e. double the predicted value of the MOE. The MOE assumed for each cattle sub-category population is shown in Table A6.1. A normal distribution was used to characterize all sub-category populations.

Table A6.1 Margins of error for cattle sub-category population estimates used in uncertainty analysis (%)

System	Sub-category	MOE 1994	MOE 2010	MOE 2018
Mixed crop live-stock system	Adult multipurpose cows >3 years	3.75	2.77	3.75
	Adult males used for draught (3-10 years)	3.05	2.16	3.05
	Adult males used for breeding & other purpose (>3-10 years)	3.05	2.16	3.05
	Calves < 6 months (male & female)	2.64	1.87	2.64
	Calves 6 m-<1 year (male & female)	3.99	2.93	3.99
	Growing males 1-<3 years	4.14	3.46	4.14
	Growing females 1-<3 years	3.65	3.69	3.65
	Smallholder fattening cattle (male 3-10 years)	3.05	2.16	3.05
	Commercial feedlot-fed cattle (male 3-10 years)	50.00	50.00	50.00
Pastoral and agropastoral system	Adult multipurpose cows >3 years	18.04	18.54	18.04
	Adult males used for draught (3-10 years)	9.32	8.41	9.32
	Adult males used for breeding & other purpose (>3-10 years)	10.04	12.30	10.04
	Calves < 6 months (male & female)	20.19	17.38	20.19
	Calves 6 m-<1 year (male & female)	16.42	15.95	16.42
	Growing males 1-<3 years	13.98	11.55	13.98
	Growing females 1-<3 years	15.80	17.80	15.80
Commercial dairy system	Adult crossbred & pure exotic dairy cows (3-10 years)	50.00	50.00	50.00
	Adult crossbred & pure exotic males 3 years & above	50.00	50.00	50.00
	Pure exotic calves (<6 months) male & female	50.00	50.00	50.00
	Crossbred & Pure exotic calves (6 m - < 1 yr) male & female	50.00	50.00	50.00
	Crossbred & Pure exotic growing males (1 - < 3 years)	50.00	50.00	50.00
	Crossbred & Pure exotic growing females (1 -< 3 years)	50.00	50.00	50.00
Smallholder dairy system	Adult crossbred & pure exotic dairy cows (3-10 & above years)	6.25	5.72	6.25
	Adult crossbred & pure exotic males (3 & above years)	5.86	5.45	5.86
	Crossbred & Pure exotic calves (<6 months) male & female	5.65	5.34	5.65
	Crossbred & Pure exotic calves (6 m - < 1 yr) male & female	6.40	5.79	6.40
	Crossbred & Pure exotic growing males (1 - < 3 years)	6.49	6.08	6.49
	Crossbred & Pure exotic growing females (1 -< 3 years)	6.19	6.22	6.19

For sheep and goat sub-categories, similar analysis of the MOE based on sample size and standard errors reported in the CSA survey reports was conducted. MOE was estimated for each sheep and goat sub-category in the 2017/18 CSA livestock survey report. For pastoral populations, a combined MOE was calculated using the CSA reported MOE and an assumed value of ±50% for estimated populations in Afar and Somali regions. Regressions of year and sample size against the MOE of the total sheep population were not significant, so for sheep, the same MOE values are used for 1994 and 2018. For goats, similar to cattle, sample size was not significant, but a regression with year as the dependent variable was significant (R^2=0.28, F<0.05), which predicted an MOE for 1994 about 67% of the value for 2018. To account for the use of some extrapolated values in the inventory base year goat population estimates, we use the same values for MOE in 1994 as are used for the 2018 dataset, i.e. double the predicted value of MOE.

Table A6.2 Margins of error for sheep and goat sub-category population estimates used in uncertainty analysis (%)

Species	Production system	Animal sub-category	MOE 1994	MOE 2010	MOE 2018
Sheep	Mixed crop livestock system	Breeding ewes (>2 yrs)	6.41	5.73	6.41
		Mature male (>2 years)	11.87	9.70	11.87
		female (1-2 yrs)	9.63	7.85	9.63
		Male (1-2 years)	10.75	9.84	10.75
		Intact male lambs (< 1 yr)	5.27	4.66	5.27
		Castrated male lambs (< 1 yr)	5.27	4.66	5.27
		Female lambs (< 1 yr)	5.41	4.72	5.41
	Pastoral and agropastoral system	Breeding ewes (>2 yrs)	12.67	19.58	12.67
		Mature male (>2 years)	9.59	19.11	9.59
		female (1-2 yrs)	13.03	21.68	13.03
		Male (1-2 years)	9.63	19.63	9.63
		Intact male lambs (< 1 yr)	12.17	18.99	12.17
		Castrated male lambs (< 1 yr)	12.17	18.99	12.17
		Female lambs (< 1 yr)	12.52	19.61	12.52
Goats	Mixed crop livestock system	Adult does (2+ years)	8.68	5.93	8.68
		Bucks (2+ years)	11.70	6.45	11.70
		Yearlings (1-2 yrs)	9.37	10.02	9.37
		Kids (male & female, <1 yr)	4.32	3.26	4.32
	Pastoral and agropastoral system	Adult does (2+ years)	7.33	18.21	7.33
		Bucks (2+ years)	6.05	18.84	6.05
		Yearlings (1-2 yrs)	6.70	16.32	6.70
		Kids (male & female, <1 yr)	6.94	17.18	6.94

A6.2 Uncertainty in animal performance data

The Tier 2 emission factors used in the inventory are calculated following the IPCC guidelines using activity data on animal performance and management. To target limited resources for inventory compilation, in-depth analysis of uncertainty in animal performance data was only applied to cattle. For parameters in the model to calculate enteric fermentation emission factors, the MOE (with a 95% CI) and PDFs and their justifications are given in the sub-sections that follow.

Live weight and weight gain: The MOE for LW of different cattle sub-categories was calculated from the variability in the datasets shown in the data tables in the appendix. In addition, most of the literature reports cited therein used heart-girth measurements and allometric equations to estimate LW. Goopy et al. (2018) estimate root mean square error of prediction when using allometric equations to estimate LW of about ±14.5% of the mean. The MOE for LW and WG were calculated as the combined MOE from the variability in the dataset and from the measurement methods used. The MOE values used in uncertainty analysis are shown in Table A6.3. For growing animal types in the commercial dairy production system, the MOE calculated from the dataset was used with no adjustment for measurement uncertainty because most studies used weighing scales, so uncertainty associated with conversion of linear measurements was not included. For smallholder dairy, because the LW values derived from studies on commercial farms, it was assumed that the MOE for LW was twice that for commercial farms. A normal distribution was used.

Table A6.3 Margins of error for cattle sub-category LW and WG estimates used in uncertainty analysis (%)

System	Sub-category	MOE 1994, 2010 & 2018
Mixed crop livestock system	Adult multipurpose cows >3 years	17.88
	Adult males used for draught (3-10 years)	16.73
	Adult males used for breeding & other purpose (>3-10 years)	16.73
	Calves < 6 months (male & female)	36.91
	Calves 6 m-<1 year (male & female)	21.66
	Growing males 1-<3 years	19.50
	Growing females 1-<3 years	18.86
	Smallholder fattening cattle (male 3-10 years)	18.64
	Commercial feedlot-fed cattle (male 3-10 years)	14.72
Pastoral and agropastoral system	Adult multipurpose cows >3 years	16.16
	Adult males used for draught (3-10 years)	16.98
	Adult males used for breeding & other purpose (>3-10 years)	16.98
	Calves < 6 months (male & female)	15.54
	Calves 6 m-<1 year (male & female)	21.25
	Growing males 1-<3 years	20.18
	Growing females 1-<3 years	14.75
Commercial dairy system	Adult crossbred & pure exotic dairy cows (3-10 years)	14.56
	Adult crossbred & pure exotic males 3 years & above	14.56
	Pure exotic calves (<6 months) male & female	1.29
	Crossbred & Pure exotic calves (6 m - < 1 yr) male & female	1.26
	Crossbred & Pure exotic growing males (1 - < 3 years)	0.88
	Crossbred & Pure exotic growing females (1 -< 3 years)	0.88
Smallholder dairy system	Adult crossbred & pure exotic dairy cows (3-10 & above years)	29.12
	Adult crossbred & pure exotic males (3 & above years)	29.12
	Crossbred & Pure exotic calves (<6 months) male & female	2.58
	Crossbred & Pure exotic calves (6 m - < 1 yr) male & female	2.52
	Crossbred & Pure exotic growing males (1 - < 3 years)	1.76
	Crossbred & Pure exotic growing females (1 -< 3 years)	1.76

Proportion of cows giving birth: The MOE of the proportion of cows giving birth was estimated by calculating the number of cows giving birth in each production system, to which the MOE of sub-category population estimates (Table A6.1) was applied. The resulting half-widths of the difference between upper and lower 95% confidence intervals were then expressed as a percentage of the number of cows giving birth in each production system. The MOE for the proportion of cows in each production system giving birth in 1994 and 2018 is shown in Table A6.3. A beta distribution was used, because the proportion can only take positive values.

Table A6.3 Margins of error for proportion of cows giving birth in each production system used in uncertainty analysis (%)

System	1994 & 2018	2010
Mixed crop-livestock	3.75	2.77
Pastoral/agro-pastoral	18.04	18.54
Commercial dairy	50.00	50.00
Smallholder dairy	6.25	5.72

Milk yield: The CSA livestock survey reports were the main source of data for milk off-take. The survey collects farmer-reported milk yields and lactation lengths. Migose et al. (2020) estimated a mean absolute error of 27.5% for farmer recall data. Calf milk suckling was estimated using methods described in NRC (2001) which do not give an estimate of error. Assuming a 10% error for predicted calf milk suckling, the combined MOE is estimated at ±29.26% and applied to all production systems. A normal distribution was used.

Milk fat content: The IPCC default value of 4% was used and uncertainty analysis assumed a MOE of ±10%. A normal distribution was used.

Work hours: Work hours were estimated on the basis of two single studies (1994 and 2018). Neither study reported standard errors. The inventory assumes an MOE of ±30% in all years. A normal distribution was used.

Feed digestibility: CSA feed composition data is from a survey questionnaire with unknown measurement error. There is also considerable variability in available ME and DE estimates for each feed type. IPCC (2006) guidance suggests an expected range of 45%-55%, and considering that IPCC (2019) default values for Africa are 58%-60% for other cattle, uncertainty was expressed as a triangular distribution with the inventory estimate as the most likely value, 45% as the minimum likely value and 60% as the maximum likely value. For dairy cattle, the IPCC (2019) default DE% values for Africa are 50%-51%. However, expert consultation elicited estimates for Ethiopia ranging from 56% to 63%. A triangular distribution was used with the inventory estimate as the most likely value, 50% as the minimum likely value and 65% as the maximum likely value.

Other coefficients: Table A6.4 shows the MOEs used for other coefficients in the IPCC enteric fermentation model.

Table A6.4 Margins of error and PDFs used for Y_m and other coefficients used in uncertainty analysis (%)

Parameter	Margin of error 1994, 2010 & 2018	PDF	Explanation
Y_m (%) (all sub-categories)	±20%	Normal	Normal, s.e. small. Margin of error from IPCC (2019).
Cf_i (all sub-categories)	±15%	Beta	Beta, proportion, cannot have negative values. 15% from Monni et al. (2007).
C_a (all sub-categories)	±15%	Beta	Beta, proportion, cannot have negative values. 15% from Monni et al. (2007).
C_p (all sub-categories)	±15%	Beta	Beta, proportion, cannot have negative values. 15% from Monni et al. (2007).
C (all sub-categories)	±15%	Beta	Beta, proportion, cannot have negative values. 15% from Monni et al. (2007).

Manure management: The parameters used for uncertainty analysis of methane and nitrous oxide emissions from manure management and deposit of dung and urine on pasture are shown in Table A6.5.

Table A6.5 Margin of error and PDFs used in the uncertainty analysis for manure management and managed soils

Parameter	Margin of error 1994, 2010 & 2018	PDF	Explanation
Ash content	±10%	Normal	s.e. small compared to mean
B_o	±15%	Normal	s.e. small compared to mean. Uncertainty range from IPCC (2019) Table 10.16
MMS%, various manure management systems	±50%	Normal	Uncertainty range ±50% from IPCC (2006) Ch. 10, p. 10.50.
MCF, various manure management systems	±50%	Normal	Uncertainty range ±50% chosen, slightly higher than MCF uncertainty range used in Karimi-Zindashty *et al*. (2012) of ±45%
MCF, pasture, cattle	±27%	Normal	Calculated from supplementary data in IPCC (2019) Annex 10B.6
Crude protein content of diet, various animal sub-categories	±35%	Normal	Uncertainty range ±35% based on s.d. of Wilkes *et al*. (2019) dataset
Milk protein content (%)	±10%	Normal	Uncertainty range ±55% based on s.e. reported in Desyibelew et al. (2019)
EF_3, pasture deposit, cattle	See explanation	PERT	Uncertainty range from IPCC (2019) Table 11.1 of 0.007 - 0.06, which were taken as min and max of PERT distribution, with 0.02 as most likely
EF_3, dry lot	±100%	beta	Uncertainty range from IPCC (2019) Table 10.21
EF_3, solid storage	±100%	beta	Uncertainty range from IPCC (2019) Table 10.21
EF_3, composting	±100%	beta	Uncertainty range from IPCC (2019) Table 10.21
EF_3, liquid slurry	±100%	beta	Uncertainty range from IPCC (2019) Table 10.21
$Frac_{gasm}$, pasture deposit	See explanation	PERT	IPCC (2019) Ch. 11 Table 11.3 gives uncertainty range of 0.05 – 0.5, which were taken as min and max of PERT distribution, with 0.2 as most likely.
$Frac_{gas}$, daily spread	See explanation	PERT	Uncertainty ranges taken from IPCC (2019) Ch. 10 Table 10.22 taken as min and max of PERT distribution, with default value as most likely.
$Frac_{gas}$, dry lot	See explanation	PERT	
$Frac_{gas}$, solid storage	See explanation	PERT	
$Frac_{gas}$, compost	See explanation	PERT	
$Frac_{gas}$, liquid slurry	See explanation	PERT	
EF_4	See explanation	PERT	IPCC (2019) Ch. 11 Table 11.3 for dairy and mixed crop-livestock gives uncertainty range of 0.011 – 0.017, which were taken as min and max of PERT distribution, with 0.014 as most likely. In pastoral/agro-pastoral system, Table 11.3 gives uncertainty range of 0.000 – 0.011, with 0.005 as most likely
$Frac_{leach}$, solid storage, composting	See explanation	PERT	IPCC (2019) Annex 10B.7 suggests a range of 0 to 38% for solid storage and composting, which are taken as the min and max of the PERT distribution
$Frac_{leach}$, drylot	See explanation	PERT	IPCC (2019) Annex 10B.7 suggests a range of 0 to 7% for drylot, which are taken as the min and max of the PERT distribution
EF_5	See explanation	PERT	IPCC (2006) Ch. 11 Table 11.3 $Frac_{GASM}$ uncertainty range of 0.0005 – 0.025, which were taken as min and max of PERT distribution, with 0.0075 as most likely.
$Frac_{LEACH}$, pasture	See explanation	PERT	IPCC (2006) Ch. 11 Table 11.3 $Frac_{LEACH}$ uncertainty range of 0.1 – 0.8, which were taken as min and max of PERT distribution, with 0.3 as most likely.

A6.3 Results

6.3.1 Uncertainty in activity data

The results for cattle population activity data suggest that the uncertainty of the 1994 total cattle population is ±2.85% and of the 2018 total population it is ±3.23%. In both years, uncertainty of the total cattle population is mainly due to uncertainty in the populations of cows in the mixed crop-livestock and pastoral/agro-pastoral production systems, and oxen in the mixed crop-livestock production system.

Table A6.6 Regression coefficients indicating cattle sub-category population contributions to uncertainty of total cattle population (1994, 2018)

Sub-category	1994	2018
PAPcow	0.33	0.42
MCLcow	0.41	0.32
MCLoxen	0.25	0.20
PAPcalf0-6	0.1	0.14
MCLcalf6-12	0.09	0.09
MCLGrF	0.11	0.09
MCLGrM	0.1	0.08
PAPcalf6-12	0.08	0.08
C_Dcow	0.01	0.07
MCLcalf0-6	0.06	0.06
PAPGrF	0.08	0.06
PAPbulls	0.03	0.04
PAPGrM	0.06	0.04
C_DGrF		0.04
PAPoxen	0.06	0.03
S_Dcow	0.01	0.02

Note: A regression coefficient of 0 indicates no relationship between the input variable and total cattle population, while a value of 1 indicates that a 1 standard deviation change in the input variable will lead to a 1 standard deviation change in the total cattle population.

6.3.2 Uncertainty in enteric methane emissions

Table A6.7 shows the uncertainty for total cattle enteric methane emissions for 1994, 2010 and 2018. Uncertainty for total emissions in 1994 was in the range of ±19.2 and in 2018 was in the range of ±18.2. Error propagation therefore suggests that the average uncertainty of emission factors was about ±18.7% in 1994 and ±18.0% in 2018. This compares well with the IPCC (2006) default uncertainty range for Tier 2 emission factors of ±20%.

The main factors associated with uncertainty in total enteric fermentation emissions are shown in Table A6.8. There is significant overlap between the input variables with high correlation to total emissions in 1994 and 2018, but the rank order of input variables is slightly different. In 2018, the top input variables that can be estimated using improved data from surveys were:

- Feed digestibility for cows, mixed crop-livestock system
- Feed digestibility for oxen, mixed crop-livestock system
- Live weight of cows, mixed crop-livestock system
- Live weight of oxen, mixed crop-livestock system
- Population of cows in the mixed crop-livestock and pastoral/agro-pastoral systems.

The reason that mixed crop-livestock system cows and oxen are so influential is that together these two sub-categories account for 49.5% of all cattle in the inventory in 2018. Cow populations in the pastoral/agro-pastoral system also had some influence on 1994 and 2018 emissions.

Table A6.7: Estimated enteric fermentation emissions and their uncertainties 1994, 2010 and 2018

	1994	2010	2018
Total enteric fermentation emissions (Gg CH_4)	1,454.14	2,718.26	3,145.58
Uncertainty (%)	+18.9, -16.1%	+19.0, -16.3%	+18.2, -15.7%

Table A6.8: Contribution of each variable to enteric fermentation emissions and rank order

	1994		2018	
	Correlation coefficient	Rank order	Correlation coefficient	Rank order
DE%_MCLcow	-0.40	1	-0.40	1
Ym_MCLcow	0.39	2	0.40	1
%DE_MCLoxen	-0.33	3	-0.31	3
Ym_MCLoxen	0.33	4	0.30	4
Cfi_MCLcow	0.31	5	0.31	2
Cfi_MCLoxen	0.28	6	0.25	5
LW_MCLcow	0.25	7	0.25	5
LW_MCLoxen	0.20	8	0.19	6
MCL cow	0.12	9	0.12	8
PAP cow	0.11	10	0.17	7
%DE MCL GrM	-0.10	11	-0.09	13
%DE_PAPcow	-0.08	12	-0.08	15
%DE_MCLGrF	-0.08	12	0.08	15
Ym_MCLGrF	0.08	12	-	-
MCL GrM	0.07	13	0.12	9
%DE_PAPcow	-	-	-0.12	9
YmPAPcow	-	-	0.12	9
MCLoxen	-	-	0.11	10
PAPcow_pop	-	-	0.10	11
Cfi_PAPcow	-	-	0.10	11
C dairy cow	-	-	0.09	12

Note: Parameters that can be estimated using survey data are highlighted in orange

Proportion of cows giving birth: The MOE of the proportion of cows giving birth was estimated by calculating the number of cows giving birth in each production system, to which the MOE of sub-cat Uncertainty of the trend was calculated as:

Trend = $(TotalCH4_{2018} – TotalCH4_{1994})/TotalCH4_{1994}$

Uncertainty of the trend for 1994-2018 was (+49.8%, -41.8%). For the period 2010-2018, uncertainty of the trend was (+200.0%, -168.0%), and the probability distribution overlapped zero.

The main variables contributing to uncertainty of the trend are shown in Figure A6.1. The key parameters influencing the trend are similar to those influencing the level of emissions: feed digestibility, methane conversion factor and coefficient for maintenance of cows and oxen in the mixed crop-livestock system.

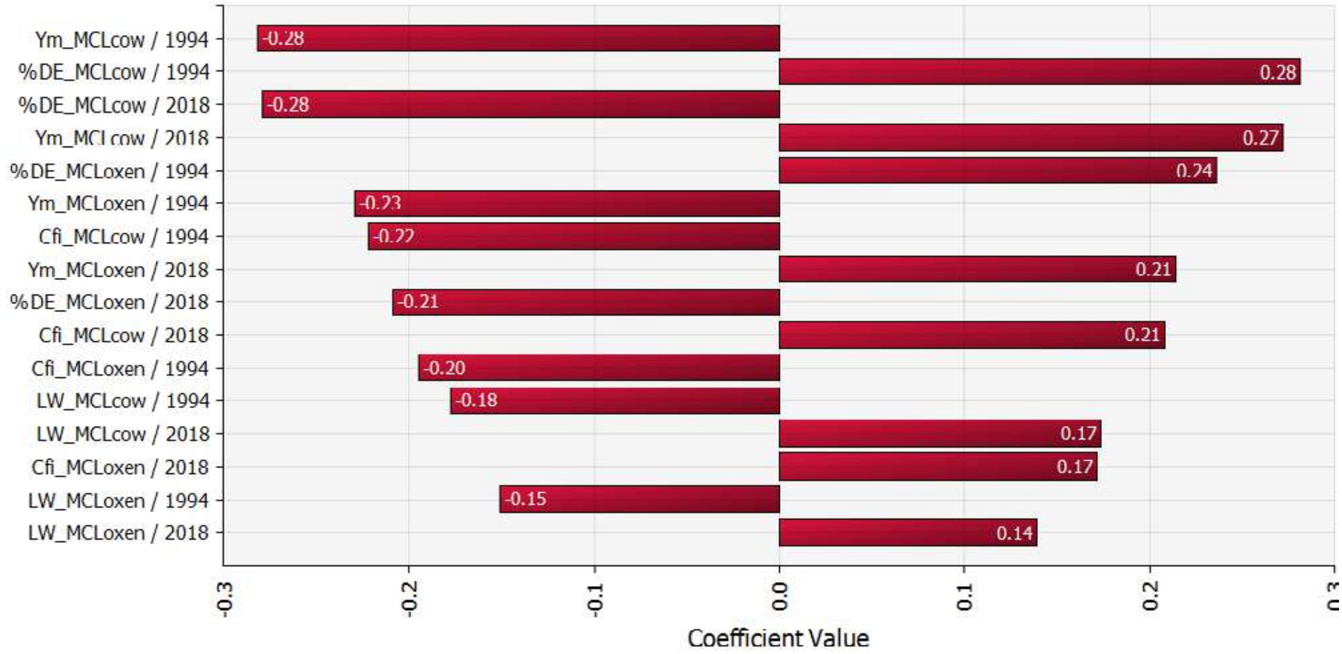

Figure A6.1 Contribution of each variable to the trend in enteric fermentation emissions, 1994-2018

6.3.3 Uncertainty in manure management direct emissions

Table A6.9 shows the uncertainty for total cattle manure management methane emissions for 1994, 2010 and 2018. Uncertainty for total manure management methane emissions in 1994 was in the range of ±52.5 and in 2018 was in the range of ±47.7. Error propagation therefore suggests that the average uncertainty of emission factors was about ±52.4% in 1994 and ±47.6% in 2018. Uncertainty for total manure management direct N_2O emissions was within ±67.3% in 1994 and ±61.1% in 2018.

The main factors associated with uncertainty in total manure management methane emissions are shown in Table A6.10. There is significant overlap between the input variables with high correlation to total emissions in 1994 and 2018, but some variables are influential in 2018 that were not in 1994. In 2018, the top input variables that can be estimated using improved data from surveys were:

- Proportion of manure managed by burning, mixed crop-livestock system
- Proportion of manure managed in solid storage, mixed crop-livestock system
- Feed digestibility for cows, mixed crop-livestock system
- Feed digestibility for oxen, mixed crop-livestock system

Note that apart from manure management activity data, feed digestibility and live weight data that contribute to uncertainty in enteric fermentation emissions also contribute to uncertainty in manure management methane emissions.

Table A6.10 also indicates with an asterisk some parameters that have a strong influence on direct N_2O emissions from manure management. In addition to the variables marked, EF_3 for solid storage and composting are also influential variables, but can only be measured with specialized scientific research.

Table A6.9: Estimated manure management emissions and their uncertainties 1994, 2010 and 2018

	1994	2010	2018
Total manure mgt. CH4 emissions (Gg CH_4)	104.82	200.80	241.85
Uncertainty (%)	+52.5, -40.5%	+51.5, -39.4%	+47.7, -36.7%
Total manure mgt. direct N2O emissions (kg N_2O)	4,812,750	8,863,967	10,833,035
Uncertainty (%)	+67.3%, -49.9%	+66.4%, -49.0%	+61.1%, -46.9%

Table A6.10: Contribution of each variable to manure management methane emissions and rank order

	1994		2018	
	Correlation coefficient	Rank order	Correlation coefficient	Rank order
MCF burned, MCL	0.43	1	0.41	1
MMS% burned, MCL	0.41	1	0.41	1
MCF solid storage, MCL	0.38	3	0.37	3
MMS% solid storage, MCL*	0.37	3	0.36	3
Bo, other cattle	0.30	5	0.30	5
%DE_MCLcow*	-0.23	6	-0.23	6
%DE_MCLoxen*	-0.20	7	-0.17	7
Cfi MCL cow*	0.11	8	0.11	10
MCF solid storage C_D oxen	0.11	8	0.14	8
MMS%solid storage, PAP*	0.11	11	0.13	9
Cfi_MCLoxen*	0.10	12	0.10	11
LW_MCLcow*	0.10	12	0.09	12
LW_MCLoxen*	0.08	13	0.07	13
%DE_MCLGrM	-0.05	14	-	-
%DE_MCLGrF	-0.05	14	-	-
MMS% pasture, MCL	0.05	14	-	-
C_D cow			0.07	14
MCL cow			0.06	15
MCF liquid, C-dairy	-	-	0.06	15

Note: Parameters that can be estimated using survey data are highlighted in orange. *Indicates that the parameter is also a sensitive parameter for direct N_2O emissions.

For manure management methane emissions, uncertainty of the trend for 1994-2018 was (+94.9%, -66.6%). For the period 2010-2018, uncertainty of the trend was (+266.4%, -189.7%) and the distribution overlapped zero. For manure management direct N_2O emissions, uncertainty of the trend for 1994-2018 was (+111.7%, -76.4%). For the period 2010-2018, uncertainty of the trend was (+308.9%, -209.8%).

The main variables contributing to uncertainty of the trend in manure management methane emissions are shown in Figure A6.2. The key parameters influencing the trend are similar to those influencing the level of emissions: MMS% for burning and solid storage, feed digestibility, live weight and the coefficient for maintenance for cows and oxen in the mixed crop-livestock system. Figure A6.3 shows that the same parameters are also influential on direct N_2O emissions from manure management.

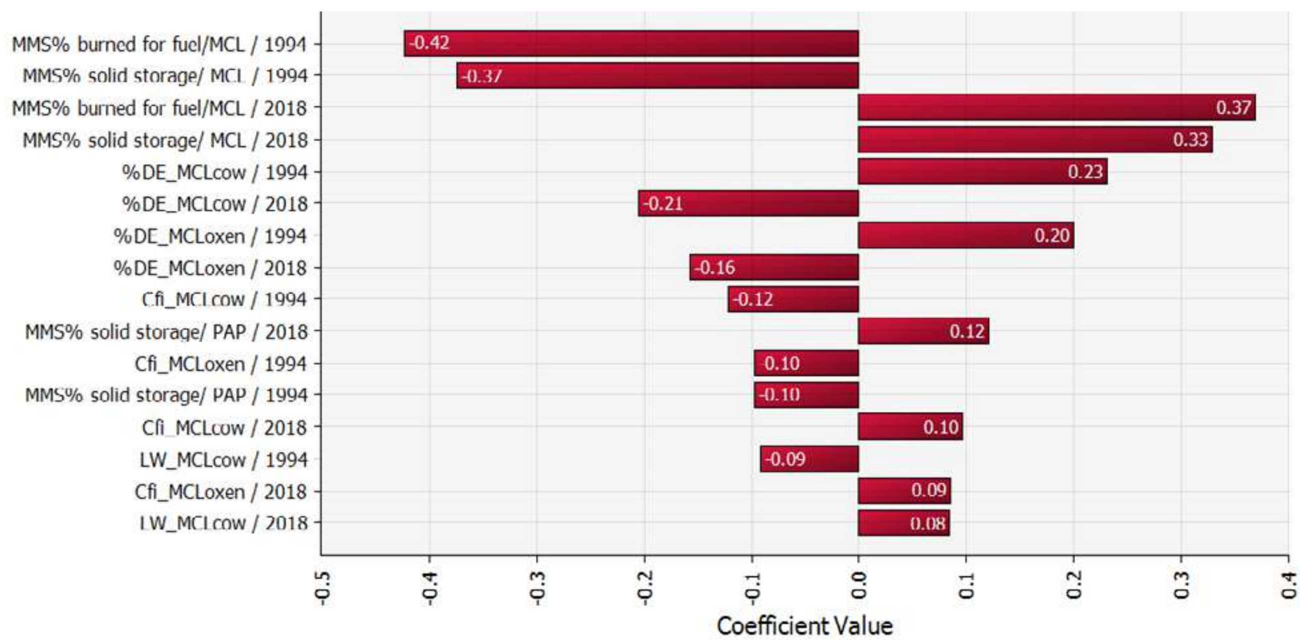

Figure A6.2 Contribution of each variable to the trend in manure management methane emissions, 1994-2018

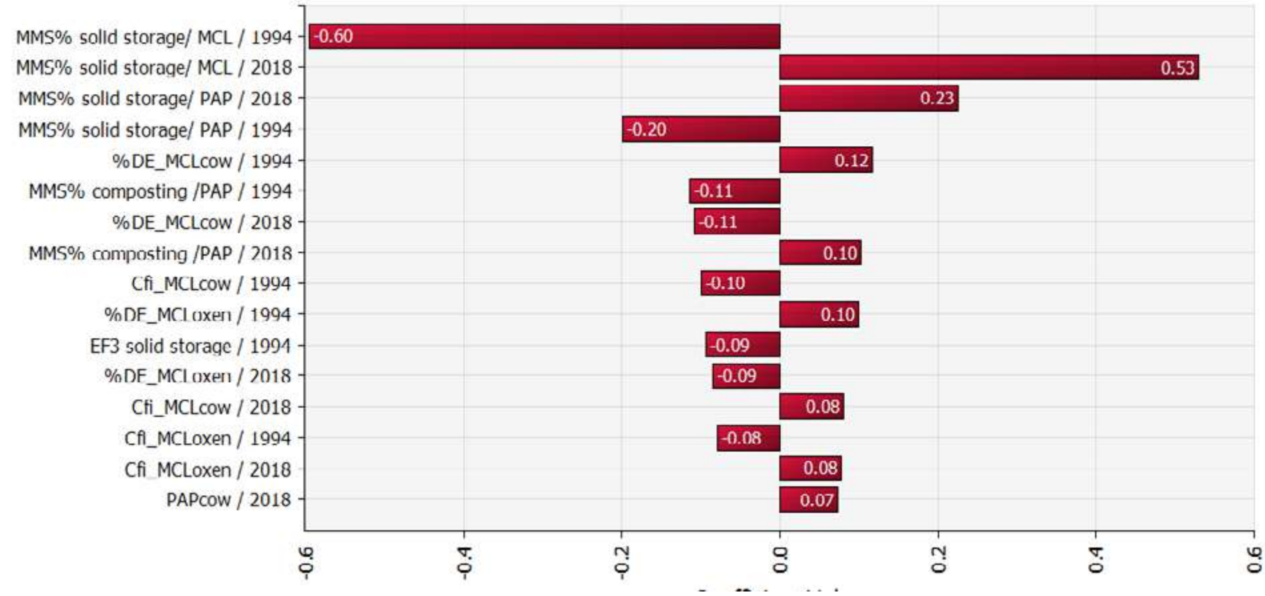

Figure A6.3 Contribution of each variable to the trend in manure management direct N_2O emissions, 1994-2018

6.3.4 Uncertainty in manure management indirect N_2O emissions

Table A6.11 shows the uncertainty for total cattle indirect N_2O manure management emissions for 1994, 2010 and 2018. Uncertainty for total manure management indirect N_2O emissions in 1994 was in the range of ±61.4 and in 2018 was in the range of ±56.2.

The main factors associated with uncertainty in total manure management indirect N_2O emissions included proportions of manure managed in solid storage and composting, and feed digestibility and live weights for cows and oxen in the mixed crop-livestock system. These factors were also influential on the trend in emissions from 1994 to 2018 (Figure A6.4). The level of indirect N_2O emissions in each year was also influenced by $Frac_{gasm}$, $Frac_{leach}$, EF_4 and EF_5 but because these factors do not change in the time series, they have no impact on the trend. For manure management indirect N_2O emissions, uncertainty of the trend for 1994-2018 was (+116.9%, -78.2%). For the period 2010-2018, uncertainty of the trend was (+346.5%, -130.6%).

Table A6.11: Estimated manure management indirect N_2O emissions and their uncertainties 1994, 2010 and 2018

	1994	2010	2018
Total manure mgt. indirect N2O emissions (kg CH_4)	1,195,457	4,408,811	5,385,891
Uncertainty (%)	+61.4%, -46.3%	+59.7%, -45.3%	+56.2%, -42.8%

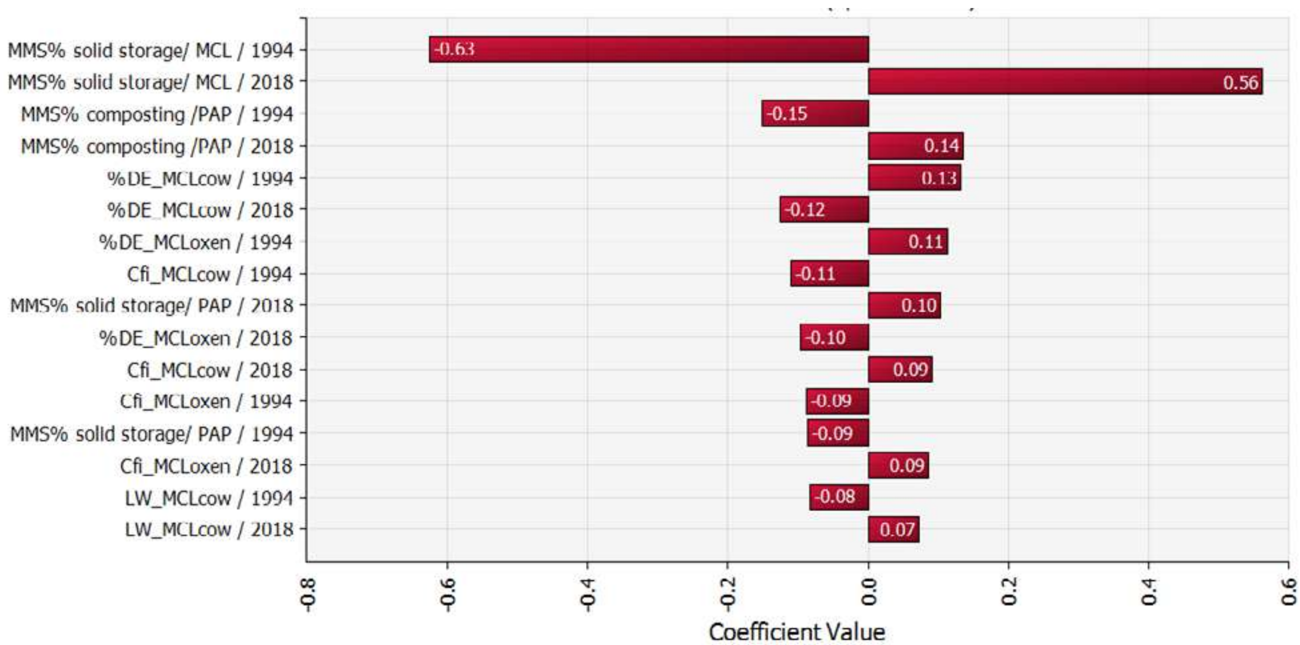

Figure A6.4 Contribution of each variable to the trend in manure management indirect N_2O emissions, 1994-2018

6.3.5 Uncertainty in direct N_2O emissions from deposit of dung and urine on pasture

The uncertainty of direct N_2O emissions from deposit of dung and urine on pasture by cattle is shown in Table A6.12 and was within ±164.8. The uncertainty of the trend in emissions from 1994 to 2018 was +155.3, - 95.3. For 2010-2018, it was +441.3%, -273.5%. The main influential factors on the level and trend were $EF_{3,PRP}$, which was taken from IPCC (2019), and activity data related to the proportion of manure deposited on pasture in the mixed crop-livestock and pastoral/agro-pastoral systems, and cow and oxen feed digestibility, coefficient for maintenance and live weight in the mixed crop-livestock system (Figure A6.5).

Table A6.12: Estimated manure management direct N_2O emissions from dung and urine deposit on pasture and their uncertainties 1994, 2010 and 2018

	1994	2010	2018
Total manure mgt. direct N_2O emissions PRP (kg N_2O)	2,474,130	4,495,911	5,080,995
Uncertainty (%)	+161.4%, -82.2%	+164.8%, -82.4%	+156.2%, -81.0%

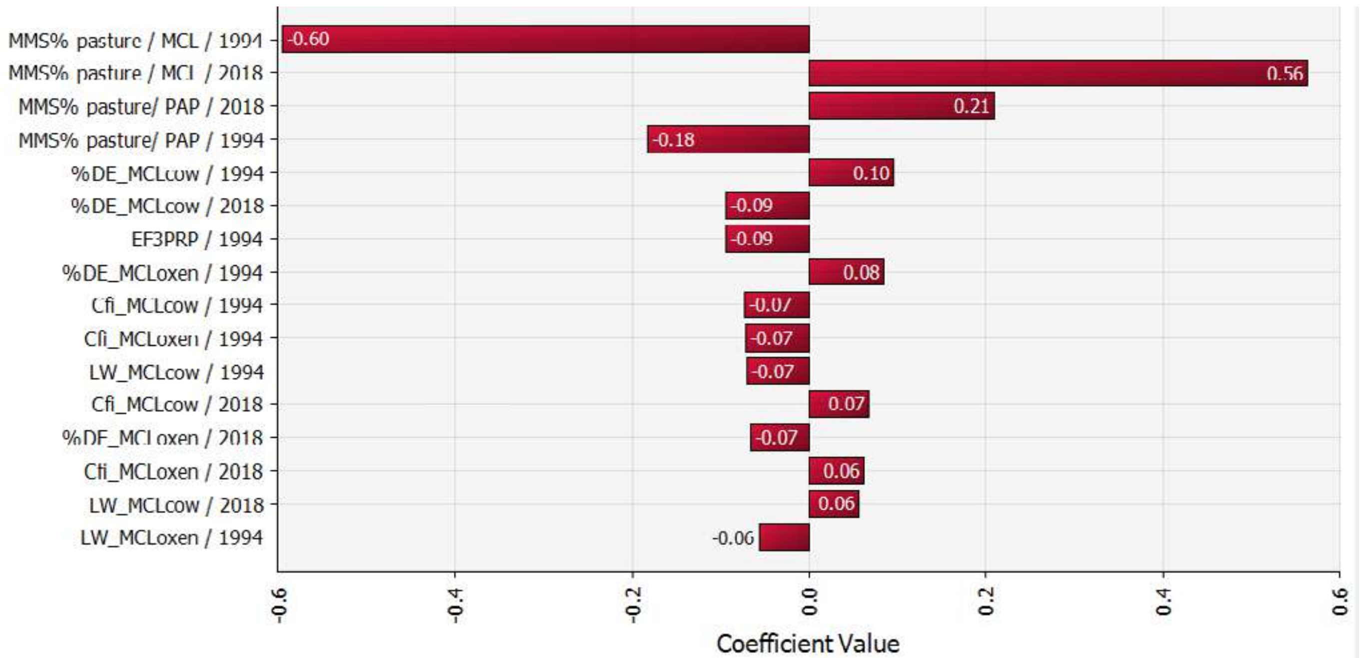

Figure A6.5 Contribution of each variable to the trend in direct N_2O emissions from dung and urine deposit on pasture by cattle, 1994-2018

6.3.6 Uncertainty in indirect N_2O emissions from deposit of dung and urine on pasture

The uncertainty of direct N_2O emissions from deposit of dung and urine on pasture by cattle is shown in Table A6.13 and was within ±106.0%. The uncertainty of the trend in emissions from 1994 to 2018 was (+189.3%, -191.7%). For 2010-2018, it was (+631.0%, -353.8%). The main influential factors on the level and trend were EF_4 and EF_5, which was taken from IPCC (2019), and activity data related to the proportion of manure deposited on pasture in the mixed crop-livestock and pastoral/agro-pastoral systems, and cow and oxen live weight and feed digestibility in the mixed crop-livestock system (Figure A6.6).

Table A6.13: Estimated manure management direct N_2O emissions from dung and urine deposit on pasture and their uncertainties 1994, 2010 and 2018

	1994	2010	2018
Total manure mgt. indirect N_2O emissions PRP (kg CH_4)	2,238,902	4,072,038	4,568,766
Uncertainty (%)	+105.9%, -65.1%	+104.9%, -64.3%	+105.0%, -64.1%

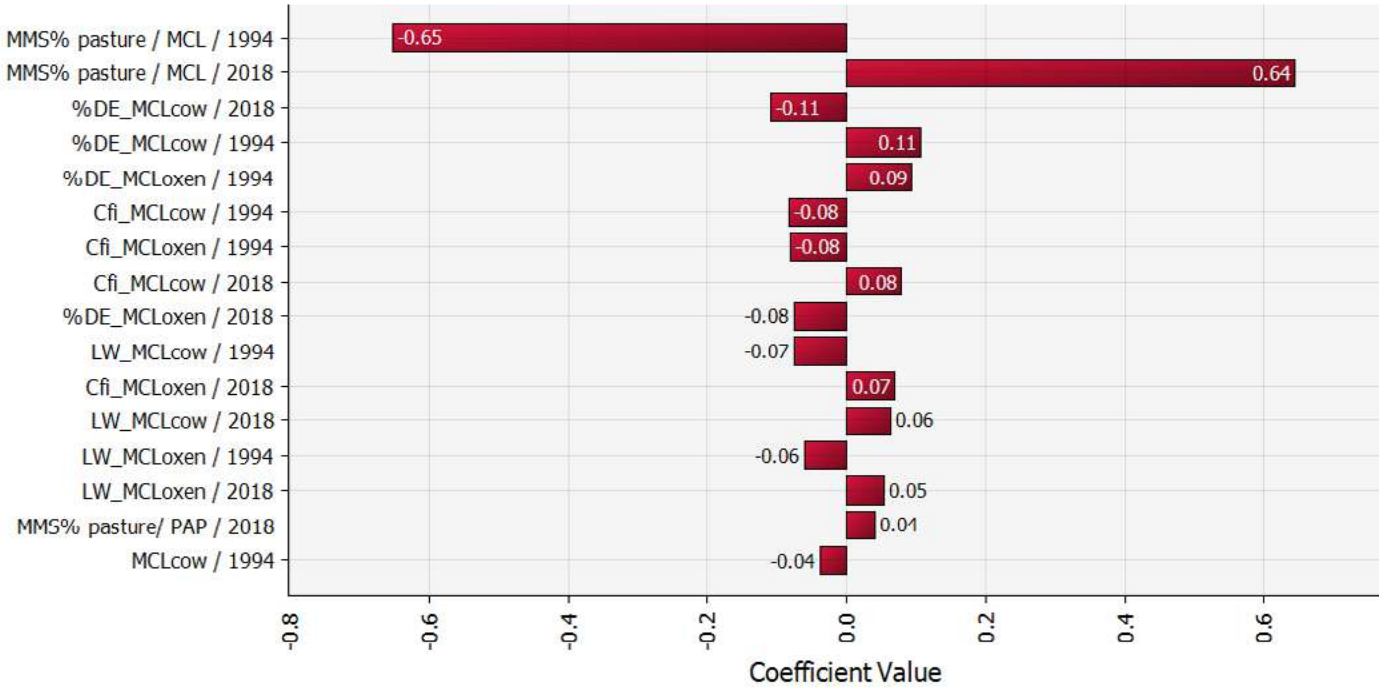

Figure A6.6 Contribution of each variable to the trend in indirect N_2O emissions from dung and urine deposit on pasture by cattle, 1994-2018

Annex 7: Inventory improvement

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Annex 7: Inventory improvement

The IPCC guidelines (IPCC 2006) and the Modalities, Procedures and Guidelines for transparency under the Paris Agreement (FCCC/PA/CMA/2018/3/Add.2) both confirm that GHG inventories should conform to the IPCC methodological principles for good practice in inventory compilation: transparency, accuracy, completeness, consistency and comparability.

This inventory report on cattle, sheep and goat emissions transparently presents the data, assumptions and methodologies used to calculate GHG emissions. The inventory is complete in that GHG emissions are included from all GHG emission sources from all cattle, sheep and goats in Ethiopia. To ensure comparability, the IPCC 2006 Guidelines were followed, with additional reference to the 2019 Refinement to the 2006 IPCC Guidelines to ensure that calculation methods and default values used followed that latest available science. All time series for activity data and emission factors within each production system have been produced using consistent methods, although data sources may differ within a time series due to the lack of a single data source covering the whole of the 1994-2018 period. Where time series data was missing, the gap-filling methods recommended in IPCC (2006) have been applied.

The estimates in this inventory have used the best available data. However, accuracy can be improved for some parameters, particularly where data is either missing or of poor quality. Uncertainty analysis was used to identify the parameters with the greatest influence on inventory uncertainty. The priorities for improving accuracy and reducing uncertainty are set out in Sections A7.1-A7.3. Section A7.4 gives recommendations for institutional arrangements and procedures for regular updating of the inventory on a biennial basis.

A7.1 Livestock population data

The inventory mostly uses CSA annual livestock survey reports as the source of livestock population data. The coverage of CSA surveys is not complete. Therefore, alternative data sources and assumptions were used to estimate livestock populations in some production systems. Table A7.1 indicates the animal sub-categories for which improved data is required. Uncertainty analysis (Table A6.6) indicated that among the population data needs in Table A7.1, accurate estimation of the population of cows in the pastoral/agro-pastoral system would have the greatest impact on reducing inventory uncertainty. Better estimation of calves (0-6 and 6-12 months), growing females, growing males and oxen in the pastoral/agro-pastoral system, and cows and growing females in the commercial dairy system would also reduce inventory uncertainty. The animal sub-categories in the mixed crop-livestock system that have a strong impact on inventory uncertainty (Table A6.6) are estimated using CSA data, which are considered the best currently available estimates.

Table A7.1: Animal sub-categories for which improved population data is required

System	Current shortcomings	Improvements required
Commercial dairy	• No available complete survey • Total population and herd structure estimated using various data sources and methods	Survey or census-based estimates of total populations and herd structure or populations of each sub-category
Smallholder dairy	• Total population from CSA, but no CSA herd structure data for cross-bred/exotic • Herd structure from other data sources	Whether CSA can also provide annual data herd structure for crossbred/exotic cattle
Pastoral/agro-pastoral*	• CSA data does not cover all zones of Afar and Somali regions	CSA survey in these zones being conducted in 2020, ideally should be conducted annually
Commercial feedlot	• No representative survey or census data • Population estimated using exports as a proxy	Survey or census-based estimates of total feedlot populations

*Applies to cattle as well as sheep and goats.

To improve data on pastoral/agro-pastoral populations, in 2020 CSA was collecting data on livestock populations in zones that are not included in previous annual sample surveys. Ideally this data should be collected annually if conditions permit. To improve data on commercial dairy populations, CSA should conduct surveys of both commercial farms and small-scale urban/peri-urban farms. In 2019 CSA piloted a survey of commercial farms, and is currently working to improve the methods used. Ideally, commercial dairy populations would be surveyed each year. Since the inventory is structured on the basis of existing CSA livestock categories, there are no recommendations to change existing livestock categories in the CSA survey tools or reports.

A7.2 Animal performance data

Enteric methane emissions are the largest emission source in the inventory. Gross energy used in estimating enteric methane emissions is also used to estimate methane emissions from manure management (the second largest emission source). There are numerous input variables into estimating these emission sources. Table A7.2 indicates the parameters for which improved animal performance data is required. Table A6.8 also suggested that improved feed digestibility data for growing males and growing females in the mixed crop livestock system would reduce inventory uncertainty. Existing LW estimates were taken from the literature, which mostly consists of reports on small-scale surveys. LW estimates can be improved if data come from representative sample surveys. Large-scale surveys typically use heart-girth measurements together with allometric equations to estimate LW. Although this method is highly practical, there is significant inherent uncertainty in this estimation method. Significant reductions in the margin of error may only be achievable if calibrated weighing scales are used, but this method is difficult to implement at large scale in rural areas. Further research is needed to produce more accurate allometric equations and to validate them so that the uncertainty associated with use of heart girth measurements can be better estimated.

For feed digestibility, CSA data on farmer-reported diet composition is used. The CSA survey asks farmers to estimate the percentage of each main type of feed used, but the survey does not enumerate specific feeds used or collect data on feeding practices for specific cattle sub-categories. To estimate the specific diet composition based on the broad feed categories in CSA, other data sources and assumptions, validated on the basis of expert judgement, were used. CSA is currently participating in research to test the feasibility of collecting data on feed types by season and by animal sub-category for potential inclusion in the annual livestock sample survey tool.[1] Further studies are also required to provide more reliable estimates of the metabolizable energy (ME) of natural pasture in different seasons. These innovations may enable replacement of expert judgement as an input into the estimate of feed digestibility.

Because of the small population of cattle in commercial and smallholder dairy production systems and the relatively low contribution of net energy for lactation to total energy requirements at low milk yields, uncertainty of inventory estimates are not sensitive to milk yield. However, because the GHG inventory may also contribute to MRV of the Climate Resilient Green Economy strategy and the NDC, it would be highly beneficial if the inventory could provide an accurate estimate of dairy milk yields and describe a precise trend over time. Currently there is no established data management system (whether surveys, administrative data or other) that can provide a representative annual time series of data on milk yield from dairy cattle. Data collection methods are being tested by the Ministry of Agriculture for potential inclusion in an annual survey in commercial farms.[2] For the smallholder dairy production system, which is covered by CSA annual livestock sample surveys, it would be useful for the GHG inventory if CSA livestock sample survey annual reports could report separately the average milk yield of exotic/crossbred and indigenous cows, or if this data can be extracted from the sample survey data and reported to the inventory agency.

1 CSA collaboration with UNIQUE forestry and land use GmbH, EIAR and CCAFS supported by ACIAR small research and development activity (ACIAR contract number 3603517).

2 Ministry of Agriculture collaboration with UNIQUE forestry and land use GmbH, EIAR and CCAFS supported by ACIAR small research and development activity (ACIAR contract number 3603517).

Table A7.2: Parameters for which improved animal performance data is required

Parameter	Current shortcomings	Improvements required
DE%, mixed crop-livestock system, cows	• DE% estimated using CSA diet composition data plus additional assumptions	Survey of diet composition for cows
DE%, mixed crop-livestock system, oxen	• DE% estimated using CSA diet composition data plus additional assumptions	Survey of diet composition for oxen
LW, mixed crop-livestock system, cows	• LW estimated using literature, no fully representative dataset available	Survey of cow LW
LW, mixed crop-livestock system, oxen	• LW estimated using literature, no fully representative dataset available	Survey of oxen LW
Milk yield, commercial dairy system	• Milk yield estimated using one 2018 survey and interpolation of trend	Annual data on commercial milk yields
Milk yield, smallholder dairy system	• CSA does not report milk yield specific for crossbred/exotic cows • Milk yield estimated using one 2018 survey and interpolation of trend	Annual data on smallholder milk yields Disaggregate CSA annual livestock survey milk yield data for cross-bred/exotic cows

The uncertainty of manure management emission estimates is greater than the uncertainty of enteric fermentation emissions. Analysis of uncertainty suggests that improved data on feed digestibility for cows and oxen in the mixed crop-livestock system can also reduce the uncertainty of manure management methane and direct N_2O emission estimates. In addition, better data is required on the proportion of manure managed in different manure management systems, particularly in the mixed crop-livestock system. The values for MMS% used in the commercial and smallholder dairy systems were also based on very limited literature values, and could be improved with representative sample surveys. Manure management systems most likely do not change very rapidly, so it could be sufficient to undertake representative surveys every few years. Alternatively, if a relationship can be established through survey data between MMS% and other farm attributes, such as animal housing or grazing practices, it may be possible to include simple proxies for MMS% in the annual CSA livestock surveys. CSA and Ministry of Agriculture are participating in research to test the feasibility of collecting data on manure management systems and farm attributes for potential inclusion in future sample surveys.[1]

1 CSA and Ministry of Agriculture collaboration with UNIQUE forestry and land use GmbH, EIAR and CCAFS supported by ACIAR small research and development activity (ACIAR contract number 3603517).

Table A7.3: Animal sub-categories for which improved manure management data is required

System	Current shortcomings	Improvements required
Mixed crop-livestock	• Estimates based on very limited available data	Representative sample surveys of manure management practices
Commercial dairy	• Estimates based on very limited available data	Representative sample surveys of manure management practices
Smallholder dairy	• Estimates based on very limited available data	Representative sample surveys of manure management practices
Smallholder fattening operations and commercial feedlots	• Estimates based on very limited available data	Representative sample surveys of manure management practices

A7.3 Manure managment

In the current inventory,manure management CH_4 and N_2O emissions account for 17.69% of the total livestock emissions thus, manure management emissions are the key inventory source in Ethiopia. The main types of manure management system identified in the current inventory were:

- Daily spread: Manure is removed daily from where animals are kept and applied to fodder or food crops.
- Solid storage (i.e. manure is stored in heaps in or near the farm yard).
- Compost: Manure and other organic material in bedding is composted.
- Liquid slurry: Manure is stored in pits which may also be inundated with water
- Burned for fuel.
- Biogas.
- Deposited on pasture.

The main factors affecting CH_4 and N_2O emissions are the amount of manure produced and the portion of the manure that managed in the specific manure management system. Annex 5 indicated that very limited data is available on manure management systems in Ethiopia. Due to a lack of country-specific activity data on manure management systems and manure characteristics, default values had to be used for some of the inputs and also the same manure management system had to be applied to all animal sub-categories. Thus, there is a high uncertainty associated with the emissions estimated. To reduce this uncertainty, the percentage of animal populations and manure management systems in different production systems needs to be determined so that more specific data such as VS and MCF values can be used. In addition, the future research should be in the direction of methodological improvements to monitor changes in manure management practices that affect CH_4 and N_2O emissions. One option could be to include manure management activity data in the CSA annual livestock survey. However, it is likely that manure management practices change slowly (with changes in housing type and/or production system), in which case surveys at longer intervals would be sufficient.

A7.4 Regular updating of the inventory

This inventory provides a basis for ongoing updating of the inventory in the future. Inventories should be reported every two years, but can be compiled on an annual basis. To enable annual (or biennial) updating, preparation of user-friendly software and manuals, and capacity building for inventory compilation agencies would be useful to build inventory compilation agencies capacities for:

- Processing data from CSA annual livestock sample survey reports and other data (e.g. ERCA export data) in line with inventory data needs and assumptions;

- Other data analysis and processing required to update input values used in the calculation of emission factors.

With this basis, using available activity data and the other methods and assumptions in this inventory, the inventory can be updated for future years at regular intervals.

In order to ensure continuous improvement of the inventory, it is recommended for the Ministry of Agriculture to delegate EIAR to conduct an annual review of newly published materials, survey reports and other relevant data sources. Every two years, inventory compilation agencies should undertake a systematic review of newly available data and decide whether to revise the historical time series in light of improved activity data, or to revise input values used in estimating emission factors. Decisions should be made and justified in consideration of the TCCCA principles. Whenever a historical time series is recalculated due to change in input data or assumptions, the inventory report should describe the changes made, their justification and the comparison between the new time series and the previously reported time series.

In addition, the following short-term (1-6 months), medium-term (6-18 months) and longer-term actions were identified in order to ensure continuous improvement of the livestock GHG inventory in Ethiopia.

Table A7.4 Short-, medium and longer-term options to improve livestock GHG inventory

Time frame	Options to improve livestock GHG inventory
Short-term (1-6 months)	**1.1 Improve the availability and quality of data** a) Design, test and evaluate methods for filling data gaps and collecting better quality data, including sampling design, data collection protocols, data management and data analysis procedures. b) Collect data to fill data gaps and improve data quality focusing on inventory improvement priorities c) Analyze data to identify cost-effective sampling strategies d) Validate accuracy of data collection methods for key parameters e) Produce standardized manuals for data collection and management and inventory compilation
Medium term (6-18 months)	**1.2 Review institutional arrangements** a) Based on Tier 2 inventory data sources and ongoing data management initiatives, review and revise institutional arrangements for inventory data management b) Ensure that livestock inventory improvement needs are considered in the plans and budgets of relevant government agwencies 1.3 **Capacity building** a) Assess institutional and staff capacities in relevant institutions involved in GHG inventory data provision, compilation and management b) Train staff of relevant institutions to collect, analyze and manage the data required using standardized manuals
Longer term	**1.5 Institutionalize improved data management** a) Incorporate data collection and management activities, including coordination, in the mandates and working procedures of relevant institutions b) Develop and implement automated data management systems c) Ensure links between inventory data improvement initiatives and national livestock statistics improvement initiatives.

The inventory software has been structured so that activity data is input per region, and emission factors may either use the national average or a region-specific value. If better data becomes available for specific regions, this may be used to produce region-specific values in the national inventory. The basis for deciding whether to use a national average or region-specific value should consider the TACCC principles, including trade-offs between them. One principle that could be applied is that region-specific emission factors should be adopted if they reduce the uncertainty of the total inventory. It remains to be tested whether and under what conditions this is possible.

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Annex 8: Tier 1 inventory reconstructions

Annex 8: Tier 1 inventory reconstructions

The IPCC Guidelines (IPCC 2006, Volume 1, Chapter 5) recommend that whenever there is a change in activity data, emission factor or methodology affecting the estimates in a time series, the recalculations should be transparently represented. To increase the transparency of the recalculations in Sections 2.4, 3.6, 4.6, 5.5 and 6.5, this annex presents the data sources and assumptions used in making the recalculations. The sections referred to present reconstructions of the emissions reported in Ethiopia's SNC. The original worksheets for that inventory could not be obtained. After following IPCC Guidelines to reconstruct the SNC inventory estimates, there was some difference with the estimates reported in the SNC. In some cases, the reasons for these differences could not be identified.

A8.1 Enteric fermentation

According to the SNC, the Tier 1 methodology from the 1996 Revised Guidelines was used. The emission factors used were reported in SNC Table 3-10. Dairy cattle were not estimated separately from other cattle, so an emission factor of 31 kg CH_4 $head^{-1}$ $year^{-1}$ was used for all cattle. The default emission factor of 5 kg CH_4 $head^{-1}$ $year^{-1}$ was used for sheep and goats. The activity data used was not reported in the SNC. Livestock population data were obtained from EFCCC[1] (Table A8.1). A GWP of 25 was used to convert CH_4 to CO_2e (SNC, page xi). SNC Table 3-24 gives total enteric fermentation emissions of 30,694 Gg CO_2e in 2000, and 52,088 Gg CO_2e in 2013. The total of cattle, sheep and goat emissions recalculated using the activity data in Table A8.1 and the emission factors mentioned above is 28,077 Gg CO_2e in 2000, and 48,288 Gg CO_2e in 2013. The differences with the SNC reported totals for enteric fermentation are most likely due to emissions from donkeys, camels and pigs. If FAOSTAT data for donkeys, camels and pigs are used for activity data together with the emission factors in SNC Table 3-10, the total emissions are 29,303 Gg CO_2e in 2000 and 51,290 Gg CO_2e in 2013, which are 4% and 6% greater than the estimates reported in the SNC. This is most likely due to differences in activity data.

1 Asaye Ketema (EFCCC), email 11 May 2020.

Table A8.1 Cattle, sheep and goat populations assumed for Tier 1 calculation (1994-2013)

Year	Cattle	Sheep	Goats
1994	29,450,000	10,870,000	8,350,000
1995	29,825,000	10,900,000	8,300,000
1996	31,207,000	11,950,000	8,400,000
1997	35,371,768	13,428,500	10,460,400
1998	35,371,768	13,428,500	10,460,400
1999	35,095,232	12,235,000	9,544,320
2000	33,075,330	10,950,700	8,597,770
2001	35,383,312	11,438,200	9,620,890
2002	40,638,800	14,321,800	11,000,000
2003	39,000,000	16,000,000	12,000,000
2004	38,749,300	18,074,700	14,850,600
2005	40,390,100	20,733,900	16,364,000
2006	43,124,600	23,633,000	18,559,700
2007	49,000,000	26,117,300	21,709,400
2008	49,000,000	26,117,300	21,798,500
2009	50,884,005	25,979,919	21,960,706
2010	53,382,200	25,509,000	22,786,900
2011	52,129,000	24,221,400	22,613,100
2012	53,990,100	25,489,200	24,060,800
2013	54,000,000	26,500,000	25,000,000

A8.2 Manure management methane emissions

The SNC estimated methane emissions from manure management using default emission factors of 1 kg CH_4 $head^{-1}$ $year^{-1}$ for cattle, 0.189 kg CH_4 $head^{-1}$ $year^{-1}$ for sheep and 0.204 kg CH_4 $head^{-1}$ $year^{-1}$ for goats (SNC Table 3-11). Using the population data in Table A8.1, this gives a total of 922 Gg CO_2e for 2000 and 1603 Gg CO_2e for 2013. SNC Table 3-24 gives total manure management methane emissions of 1139 Gg CO_2e in 2000, and 2035 Gg CO_2e in 2013. The difference with the estimates here may be due to to emissions from donkeys, camels, pigs and chickens. If FAO data for donkeys, camels, pigs and chickens are used together with the emission factors in SNC Table 3-11, total manure management emissions are 1048 Gg CO_2e in 2000, and 1892 Gg CO_2e in 2013, which are 92% and 93%, respectively, of the emissions reported in the SNC. The difference is likely due to differences in activity data.

A8.3 Manure management N_2O emissions

Calculation of N_2O emissions requires information on livestock populations, nitrogen excretion, fractions of manure managed in different manure management systems and emission factors. The SNC reports the assumed fractions of manure management systems in SNC Table 3-12 and emission factors in Table 3-13. Tier 1 emissions were reconstructed using that information and the ruminant livestock population data in Table A8.1. SNC (Table 3-24) reported total direct N_2O emissions from manure management of 6366 Gg CO_2e

in 2000 and 12,037 Gg CO_2e in 2013. The sum of Tier 1 estimated N_2O emissions from cattle, sheep and goats is 6035 Gg CO_2e in 2000 and 10,355 Gg CO_2e in 2013. The difference with the SNC total estimates is most likely due to emissions from other animal species, which were not calculated here.

A8.4 Manure management indirect N_2O emissions

The SNC is not explicit about how indirect N_2O emissions from manure management were calculated, even though it was a key source in the national inventory. SNC Table 3-24 gives emissions of 1062 Gg CO_2e in 2000 and 2013 Gg CO_2e in 2013. If indirect N_2O emissions included both volatilization and leaching, emissions from cattle alone calculated using the IPCC (1996) guidelines would be 3131 Gg CO_2e in 2000. However, if only volatilization is included, emissions from cattle would be 659 Gg CO_2e in 2000. Therefore, it is plausible that leaching was not considered for indirect N_2O emissions. In the Tier 2 inventory, leaching was not considered in the pastoral/agro-pastoral system, but was estimated in the other production systems. In the recalculations shown in Section 4.5, the Tier 1 estimate does not include leaching.

A8.5 Direct N_2O emissions from managed soils

The SNC is not explicit about how direct N_2O emissions from dung and urine deposited on pasture were calculated. SNC Table 3-24 gives total emissions for direct N_2O emissions from managed soils (i.e. reporting category 3C4) of 3340 Gg CO_2e in 2000 and 7553 Gg CO_2e in 2013. Using the population data in Table A8.1, the default emission factors in the IPCC (1996) Guidelines and equation 8 in the IPCC 1996 Guidelines (Chapter 4), direct emissions from cattle, sheep and goats from dung and urine deposited on pasture are estimated at 8243 Gg CO_2e in 2000 and 14,689 Gg CO_2e in 2013. Since reporting category 3C4 contains other emission sources, it is not clear why the Tier 1 estimated emissions are much higher than the possible level implied by the total emissions from reporting category 3C4 in Table 3-24 of the SNC.

A8.6 Indirect N_2O emissions from managed soils

The SNC is not explicit about how indirect N_2O emissions from dung and urine deposited on pasture were calculated. SNC Table 3-24 gives emissions of 2544 Gg CO_2e in 2000 and 5212 Gg CO_2e in 2013 for reporting category 3C5. If indirect N_2O emissions included both volatilization and leaching, emissions from cattle alone calculated using the IPCC (1996) guidelines would be 2048 Gg CO_2e in 2000. However, if only volatilization is included, emissions from cattle would be 431 Gg CO_2e in 2000. Therefore, it is plausible that leaching was not considered for indirect N_2O emissions. In the Tier 2 inventory, leaching was not considered in the pastoral/agro-pastoral system, but was estimated in the other production systems. In the recalculations shown in Section 6.5, the Tier 1 estimate does not include leaching.

Data appendixes

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Data appendixes

Appendix Table 1. Summary of literature review on mean live weight, weight gain and mature weight at different ages in cattle commercial dairy production system

Year	BREED	Sex	Production system	Birth wt (kg)	Weaning Wt (kg)	6 m wt (kg)	12 m wt (kg)	18 m wt (kg)	24 m wt (kg)	Adult wt (kg)	ADG1 (g/d)	ADG2 (g/d)	ADG3 (g/d)	Source
1986	Crossbred	Male	Commercial							372.0				Astatke et al. 1986
1986	Crossbred	Male	Commercial							465.0				Astatke et al. 1987
2016	Crossbred	Female	Commercial							436.5				Fekade and Mekasha 2016
2017	Crossbred	Female	Commercial							332.0				Gelane Kumsa 2017
2016	Crossbred	Female	Commercial							503.0				Kassu Tsegaye 2016
2009	Crossbred	Female	Commercial							443.0				Kurtu and Waal 2009
1990-2004	50%	Both	Commercial	26.0	56.8	92.1	146.9	203.0	257.7		511.7	302.7		Aynalem Haile et al. 2011
1990-2004	62.50%	Both	Commercial	29.2	54.2	89.2	143.9	197.5	263.0		495.4	342.7		Aynalem Haile et al. 2011
1990-2004	75%	Both	Commercial	31.1	55.2	90.4	142.5	201.4	261.0		502.4	323.0		Aynalem Haile et al. 2011
1990-2004	87.50%	Both	Commercial	31.4	56.6	90.8	145.0	201.4	262.3		504.4	310.0		Aynalem Haile et al. 2011

ADG1: average daily weight gain from six months to two years, ADG2: average daily weight gain from six months to 12 months, ADG3: average daily weight gain from 12 months to 24 months

Appendix Table 2. Summary of literature review on mean live weight, weight gain and mature weight at different ages in cattle mixed crop-livestock production

system

Year	BREED	Sex	Production system	Birth wt (kg)	Wean-ing wt (kg)	6 m wt (kg)	12 m wt (kg)	18 m wt (kg)	24 m wt(kg)	36 m wt (kg)	Adult wt (kg)	ADG1 (g/d)	ADG2 (g/d)	ADG3 (g/d)	Source
1990	Arsi	Male	Mixed								355.0				FAO 2002
1992-1996	Fogera	Male	Mixed	24.1		123.0	150.2		205.4						Bitew and Hedge 2003
1991-2004	Ogaden	Male	Mixed	22.0	61.4	95.4	145.0	171.9	214.8	306.5	316.3	405.5	350.0	226.9	Mekuriaw et al. 2009
1994	Barca	Male	Past/Agro				182.0		257.0		320.0				FAO 2002
1994	Boran	Male	Past/Agro				192.0		269.0		338.0				Mekonnen 1994
1994	barca	Male	Past/Agro								335.0				DAGRIS 2006
1999	Horro	male	Mixed								400.0				Rege 1999
1999	Barca	Male	Mixed								412.5				Rege 1999
1999	Boran	Male	Mixed								342.5				Rege 1999
1999	Danakil	Male	Past/Agro								315.0				Rege 1999
1999	Arsi	Male	Mixed								280.0				DADIS 2004
1999	Begait	Male	Past/Agro								380.0				DADIS 2004
1999	Boran	Male	Mixed	23.0											DADIS 2004
2002	Barca	Male	Past/Agro								490.0				DAGRIS 2004
2002	Kereyu	Male	Past/Agro								329.0				FAO 2002
2002	Horro	Male	Mixed				112.0		267.0		384.4				Habtamu Abera et al. 2012
2002	Boran	Male	Mixed								300.0				DAGRIS 2006
2002	Boran	Male	Mixed						189.6		385.0				DARGIS 2006
2002	Local	Male	Mixed								274.0				DARGIS 2006
2007	Ogaden	Male	Mixed								321.0				Ermias 2007
2008-09	Local	Male	Mixed			92.0	126.9	203.0	257.7			511.7	302.7		Abera et al. 2011
1992-2013	Fogera	Male	Mixed	21.8	98.9										Tesfa et al. 2016
1994	Barca	Female	Past/Agro				134.0		188.8		239.0				FAO 2002
1994	Boran	Female	Past/Agro						350.0						Nicolson et al. 1988
1995	Boran	Female	Past/Agro								285.0				Osuji et al. 1995
2002	Barca	Female	Past/Agro								295.0				DARGIS 2006

2001	Barca	Female	Past/Agro								415.0				DARGIS 2006
2002	Kereyu	Female	Past/Agro								259.0				FAO 2002
2002	Horro	Female	Mixed								247.0				Workneh et al. 2002
2002	Horro	Female	Mixed				115.0		160.0		256.0				FAO, expert opinion
1990	Arsi	Female	Mixed								245.0				Million et al. 2003
2002	Fogera	Female	Mixed								256.0				DARGIS 2006
2002	Local	Female	Mixed								250.0				DARGIS 2006
2007	Ogaden	Female	Mixed								280.0				Ermias 2007
1991-2004	Ogaden	Female	Mixed	21.0	69.0	87.9	127.7	154.7	186.6	228.7	274.0	413.5	307.5	199.8	Mekuriaw et al. 2010
1999	Horro	Female	Mixed								305.0				Rege 1999
1999	Barca	Female	Mixed								355.0				Rege 1999
1999	Boran	Female	Mixed								325.0				Rege 1999
1999	Danakil	Female	Past/Agro								252.5				Rege 1999
1999	Arsi	Female	Mixed	21.0							230.0				DADIS 2004
1999	Begait	Female	Past/Agro								280.0				DADIS 2004
1999	Boran	Female	Mixed	17.8											DADIS 2004
1992-1996	Fogera	Female	Mixed	23.0	120.0		149.9		197.6						Bitew and Hedge 2003
2013	Horro	Female	Mixed	20.4	45.5		92.2				406.0	314.0	130.8		Abera et al. 2012
1992-2013	Fogera	Female	Mixed	20.9	105.4										Tesfa et al. 2016
2010	Boran	Both	Mixed		79.0										Aynalem Haile et al. 2011
1987	Boran	Both	Mixed		157.2										Mekonnen 1987
2001	Boran	Both	Mixed		79.4										Gojjam et al. 2001
2003	Boran	Both	Mixed		94.2										Amsalu Sisay 2003
1999	Fogera	Both	Mixed		49.8	68.2	113.0					591.0	374.0		Desalegn 2015
2011	Horro	Both	Mixed	19.9											Cited in Aynalem et al. 2011
2011	Fogera	Both	Mixed	21.9											Cited in Aynalem et al. 2011
1999	Boran	Both	Mixed	25.0											DADIS 2004
1992-1994	Fogera	Both	Mixed	22.7	98.0										Tesfa et al. 2016
1995-1997	Fogera	Both	Mixed	22.0	96.7										Tesfa et al. 2016
1998-2000	Fogera	Both	Mixed	21.6	98.9										Tesfa et al. 2016

2001-2003	Fogera	Both	Mixed	21.8	99.0										Tesfa et al. 2016
2004-2006	Fogera	Both	Mixed	23.3	96.9										Tesfa et al. 2016
2007-2009	Fogera	Both	Mixed	19.2	94.6										Tesfa et al. 2016
2010-2013	Fogera	Both	Mixed	19.3	110.3										Tesfa et al. 2016
1990-2004	Boran	Both	Past/Agro	23.3	54.0	79.0	111.2	149.4	195.3			438.7	219.6		Aynalem Haile et al. 2011
2006	Barca	Both	Mixed		92.0										Aynalem Haile 2006
2013	Begait	Both	Past/Agro	22.6	96.7		120.2				360.0				Cited in Aynalem et al. 2011
2013	Boran	Both	Past/Agro	23.3	99.9		128.5				268.0				Amsalu 2004
1983-1999	Fogera	Both	Mixed	21.5	88.6		125.2								Bitew 1999
2011	Boran	Both	Past/Agro	22.9							304.0				Cited in Aynalem et al. 2011
2015	Sheko	Both	Mixed	16.1											Bayou et al. 2015

ADG1: average daily weight gain from birth months six months, ADG2: average daily weight gain from six months 12 months, ADG3: average daily weight gain from 12 months to 24 months

Appendix Table 3. Summary of literature review on mean live weight, weight gain and mature weight at different ages in cattle pastoral and agro-pastoral production system

Year	BREED	Sex	Production system	Birth wt (kg)	Weaning wt (kg)	6 m wt (kg)	9 m wt (kg)	12 m wt (kg)	18 m wt (kg)	24 m wt (kg)	36 m wt (kg)	Adult wt (kg)	ADG1 (g/d)	ADG2 (g/d)	ADG3 (g/d)	Source
2002	Kereyu	M	Past/Agro									329.0				FAO 2002
1999	Danakil	M	Past/Agro									315.0				Rege 1999
1994	Begait	M	Past/Agro					182.0		257.0		320.0				FOA 2002
1994	Begait	M	Past/Agro									335.0				DAGRIS 2006
2002	Begait	M	Past/Agro									490.0				DAGRIS 2006
1999	Begait	M	Past/Agro									380.0				DADIS 2004
1999	Begait	M	Past/Agro									333.9				DADIS 2004
2018	Begait	M	Past/Agro	22.8	63.2	101.0	139.0	164.0	182				429.0	204.0		Mezgebe et al. 2018
2007	Ogaden	M	Past/Agro									321.0				Ermias 2007
1991-2004	Ogaden	M	Past/Agro	22.0	61.4	95.4	116.6	144.96	171.92	214.8	306.53	316.3	405.5	350.0	226.9	Mekuriaw et al. 2009
1994	Boran	M	Past/Agro					192.0		269.0		338.00				Mekonnen 1994
2002	Boran	M	Past/Agro									300.00				DAGRIS 2006
2002	Boran	M	Past/Agro							189.6		385.00				DARGIS 2006
1999	Boran	M	Past/Agro	23.0												DADIS 2004
1999	Boran	M	Past/Agro									342.20				Rege 1999
2002	Kereyu	F	Past/Agro									259.0				FAO 2002
1999	Danakil	F	Past/Agro									252.5				Rege 1999
2018	Begait	F	Past/Agro	21.1	58.3	95.3	128.0	154.0	171				395.0	201		Mezgebe et al. 2018
1994	Begait	F	Past/Agro					134.0		188.8		239.0				FAO 2002
2002	Begait	F	Past/Agro									295.0				DAGRIS 2006
2001	Begait	F	Past/Agro									415.0				DAGRIS 2006
1999	Begait	F	Past/Agro									278.0				DADIS 2004
2007	Ogaden	F	Past/Agro									280.0				Ermias 2007
1991-2004	Ogaden	F	Past/Agro	20.9	68.9	87.9	105.5	127.65	154.7	186.6	228.7	273.9	413.5	308	199.8	Mekuriaw et al. 2009
1994	Boran	F	Past/Agro													Nicolson et al. 1987
1995	Boran	F	Past/Agro									285				Osuji et al. 1995

1999	Boran	F	Past/Agro									325.0				Rege 1999
1999	Boran	F	Past/Agro	17.8												DADIS 2004
2006	Begait	B	Past/Agro		92.0											Aynalem Haile 2006
2013	Begait	B	Past/Agro	22.6	96.7			120.2				360.0				Hailu 2003
1990-2004	Boran	B	Past/Agro	23.3	54.0			111.2	149.4	195.3			438.7	219.6		Aynalem et al. 2011
2010	Boran	B	Past/Agro		79.0											Aynalem et al. 2011
2001	Boran	B	Past/Agro		79.4											Gojjam et al. 2001
2003	Boran	B	Past/Agro		94.2											Sisay 2003
2013	Boran	B	Past/Agro	23.3	99.9			128.5				268.0				Amsalu 2004
2011	Boran	B	Past/Agro	22.9								304.0				Aynalem et al. 2011
1999	Boran	B	Past/Agro	25.0												DADIS 2004

ADG1: average daily weight gain from birth months six months, ADG2: average daily weight gain from six months 12 months, ADG3: average daily weight gain from 12 months to 24 months, M:male, F: female, B: both female and male

Appendix Table 4. Summary of literature review on mean live weight, weight gain and mature weight in smallholder and commercial feedlot production system

Sex	Production system	Initial live weight (kg)	Final live weight (kg)	Weight gain (g/d)	Source
Male	Smallholder fattening	415.40	333.90	0.690	Bezahegn Abebe 2014
Male	Smallholder fattening	497.30	404.50	0.780	Bezahegn Abebe 2014
Male	Smallholder fattening	258.50	277.80	0.390	Yoseph et al. 2011
Male	Smallholder fattening	258.50	288.00	0.470	Yoseph et al. 2011
Male	Smallholder fattening	258.50	304.50	0.650	Yoseph et al. 2011
Male	Smallholder fattening	221.50	257.60	0.400	Tesfaye 2016
Male	Smallholder fattening	249.80	297.60	0.530	Tesfaye 2016
Male	Smallholder fattening	275.00	341.24	0.602	Shitahun 2009
Male	Smallholder fattening	213.10	267.40	0.605	Nega et al. 2008
Male	Smallholder fattening	168.30	221.92	0.598	Nega et al. 2008
Male	Smallholder fattening	255.89	278.63	0.200	Guyo 2016
Male	Smallholder fattening	255.35	313.39	0.696	Guyo 2016
Male	Smallholder fattening	282.73	345.00	1.147	Guyo 2016
Male	Smallholder fattening	328.90	387.40	0.650	Kebede et al. 2013
Male	Smallholder fattening	329.00	411.00	0.913	Kebede et al. 2013
Male	Commercial feedlot	274.00	356.00	0.910	Tesfaye 2016
Male	Commercial feedlot	270.00	368.50	1.090	Dadi et al. 2017
Male	Commercial feedlot	275.00	372.60	1.090	Dadi et al. 2017
Male	Commercial feedlot	260.00	352.00	1.010	Dadi et al. 2017
Male	Commercial feedlot			0.650	Aberash 2000
Male	Commercial feedlot			0.740	Fikadu 1999
Male	Commercial feedlot			0.836	Nega et al. 2002
Male	Commercial feedlot			0.740	Nega et al. 2002
Male	Commercial feedlot			0.830	Tsigereda 2010
Male	Commercial feedlot			0.770	Yohannes 2011

Appendix Table 5. Summary of literature review on mean live weight, weight gain and mature weight in sheep mixed crop-livestock production system

Year	Breed	Production system	Sex	Birth wt (kg)	weaning wt (kg)	6 m wt (kg)	12 m wt(kg)	Adult wt (kg)	ADG1 (g/d)	ADG2 (g/d)	Source
1980-2011	Horro	Mixed	Male		12.30	16.40	28.40	25.00	101	55	Alemayehu et al. 2017
1991	BHS	Past/Agro	Male					40.50			Abegaze 1991
1992-97	Menth	Mixed	Male	2.10	7.43		17.00	25.30			Tibbo et al. 2004
1992-97	Horro	Mixed	Male	2.35	8.93		16.80	28.50			Tibbo et al. 2004
2002	CHS	Mixed	Male					29.43			Sisay 2002
2002	Rift Valley	Mixed	Male					27.46			Sisay 2002
2007	Gumuze	Mixed	Male					34.63			Abegaz 2007
2008	Washera	Mixed	Male	2.70	11.90			32.30			Mengiste 2008
2010/11	Sekota	Mixed	Male	2.76	11.90						Yiheyis et al. 2012
2007-2010	Washera	Mixed	Male	2.60			23.09				Mekuriaw et al. 2013
2013-2015	Abera	Mixed	Male	2.80	12.70	19.00					Marufa et al. 2017
2015-16	Fentale	Mixed	Male	2.89	8.03	11.67	16.00				Worku et al. 2019
2014	Afar male		Male							44.33	
1978-2011	Horro	Mixed	Female		11.50	15.00	24.70	23.00	93	44	Alemayehu et al. 2017
1982	Afar	Past/Agro	Female				26.00	31.00			Gizaw et al. 2008a
1991	BHS	Past/Agro	Female					33.00			Sheep productivity improvement handbook of Ethiopia 2008
1992-97	Menth	Mixed	Female	2.06	7.01		15.40	23.02			Tibbo et al. 2004
1992-97	Horro	Mixed	Female	2.26	8.55		15.50	24.70			Tibbo et al. 2004
2002	Horro	Mixed	Female					38.20			Sheep productivity improvement handbook of Ethiopia 2008
2002	CHS	Mixed	Female					24.64			Sisay 2002
2002	Rift Valley	Mix-Pasto	Female					24.71			Sisay 2002
2007	Gumuze	Mix-Pasto	Female					31.40			Abegaz 2007
2007-2010	Washera	Mixed	Female	2.60			23.52				Mekuriaw et al. 2013
2008	Washera	Mixed	Female					28.30			Mengiste 2008
2010/11	Sekota	Mixed	Female								Yiheyis et al. 2012

2013-2015	Abera	Mixed	Female	2.70	11.60	18.00					Marufa et al. 2017
2015-16	Fentale		Female	2.79	7.89	11.92	15.74				Worku et al. 2019
1982	Afar	Pastoral	Both	2.50	13.00	25.80	28.20				Galal and Kassahun 1982
1987/08	Arsi-Bale	Mix-Pasto	Both	2.80	14.20			28.60	65.63	62.95	Gizaw et al. 2008a
1991	BHS	Past/Agro	Both	2.70			24.80	27.90			Gizaw et al. 2008
1991	BHS	Past/Agro	Both				25.00				Gizaw et al. 2009
1992	Afar	Past/Agro	Both		13.00	18.40	26.00				Small ruminant breeding strategy 2019
1992	BHS	Past/Agro	Both		14.20	17.70	24.80				Small ruminant breeding strategy 2019
1991	BHS	Past/Agro	Both				23.80				Institute of Biodiversity Conservation 2018
1990-2000	Menth	Mixed	Both	2.07			15.40	20.10			Gizaw et al. 2008a
1990-2000	menth	Mixed	Both	2.40			16.90				Markos 2006
1990-2000	Menth	Mixed	Both	2.09			19.10				Markos 2007
1990-2000	Menth	Mixed	Both		11.00		26-30	35.00			Sheep productivity improvement handbook of Ethiopia 2008
2000	Horro	Mixed	Both	2.70			23.70	35.40			Abegaz and Gemeda 2000b
2000	Horro	Mixed	Both	2.80			24.00				Abegaz 2002a
2002	Horro	Mixed	Both		13-15		25.33				Meat Road Map
2008-2011	Washera	Mixed	Both	2.70	13.80	22.70	23.60				Shigdaf 2011
2008-2011	Washera	Mixed	Both	2.61			24.70	32.80			Shigdaf 2011
2008	Adello	Mixed	Both				28.10				Gizaw et al. 2008a
2008	Bonga	Mixed	Both				27.80	34.20			Gizaw et al. 2008a
2008-2011	Farta	Mixed	Both	2.50			20.08				Shigdaf 2011
2008	Sekota	Mixed	Both				26.60				Gizaw et al. 2008a
2008	Simen	Mixed	Both	3.04			22.87	26.90			Surafel 2010
2007	Gumuz	Mix-Pasto	Both	2.79			31.00				Abegaz 2007
2008	Local	Mixed	Both					25.40			Gizaw et al. 2008a
2008	Wollo	Mixed	Both				21.70				Gizaw et al. 2008a
2011-2012	Menth	Mixed	Both	2.14	9.60				81		Lemma et al. 2011
2018	Horro	Mixed	Both		15.00	19.70	24.00				Small ruminant breeding strategy 2019
2018	menth	Mixed	Both		10.90						Small ruminant breeding strategy 2019

2018	Horro	Mixed	Both					19.70			Institute of Biodiversity Conservation 2018
2018	Horro	Mixed	Both				24.00				Institute of Biodiversity Conservation 2018
2018	Afar	Pastoral	Both				24.50				Institute of Biodiversity Conservation 2018
2018	Menth	Mixed	Both				17.40				Institute of Biodiversity Conservation 2018
1985	Local								100	50	Wilson 1985

ADG1: average daily weight gain from birth to 6 month, ADG2: average daily weight gain from six months to 12 months, BHS:Black head somali sheep, CHS: central highland shee

Appendix Table 6. Summary of literature review on mean live weight, weight gain and mature weight in sheep pastoral and agro-pastoral production system

Year	Breed	Production system	Sex	Birth wt(kg)	Weaning wt(kg)	6 m wt(kg)	12 m wt(kg)	Adult wt (kg)	ADG1 (g/d)	ADG2 (g/d)	Source
1991	BHS	Pastoral	Male					40.5			Institute of Biodiversity Conservation 2018
2002	Rift Valley		Male					27.5			Sisay 2002
1982	Afar	Pastoral	Female				26	31.0			Galal 1983, Gizaw et al. 2008a
2002	Rift Valley		Female					24.7			Sisay 2002
1991	BHS	Pastoral	Female					33.0			Sheep productivity improvement handbook of Ethiopia 2008
	Afar	Pastoral	Both				24.5				Institute of Biodiversity Conservation 2018
1991	BHS	Pastoral	Both	2.7			24.8	27.9			Galal 1983, Wilson 1991, Gizaw et al. 2008a
1991	BHS	Pastoral	Both				25				Galal 1983, Wilson 1991, Gizaw et al. 2008a
1992	Afar	Pastoral	Both		13	18.4	26				National small ruminant breeding strategy 2018
1992	BHS	Pastoral	Both		14.2	17.7	24.8				National small ruminant breeding strategy 2018
1991	BHS	Pastoral	Both				23.8				Institute of Biodiversity Conservation 2018

ADG1: average daily weight gain from birth to 6 month, ADG2: average daily weight gain from six months to 12 months, BHS: Black head somali sheep, CHS: central highland sheep

Appendix Table 7. Summary of literature review on mean live weight, weight gain and mature weight in goat mixed crop-livestock production system

Year	Breed	Production system	Sex	Birth wt (kg)	3 m wt (kg)	6 m wt (kg)	12 m wt (kg)	Adult wt (kg)	ADG1 (g/d)	ADG2 (g/d)	Source
1998	Local	Mixed	Male					29.4			Tolera 1998
2004	Arsi-Bale goat	Mixed	Male	2.34	8.48				74.5		Woldu et al. 2004
2009	Local	Mixed	male	2.36	13.18			33.99	120		Tsegaye 2009
1998	Local	Mixed	male					29.4			Tolera 1998
2007	Arsi-Bale	Mixed	male					26.5			Ketema 2007
2018	Abergelle	Past/Agro	male	2.28	7.42						Birhanie et al. 2018
2000	Mid Rift Valley	Mixed	male	2.00	7.46		13.93				Tesfaye et al. 2000
2000	Boran	Past/Agro	male	2.28	7.38		13.38				Tesfaye et al. 2000
2006	Arsi Bale	Mixed	male		7.80		15.5				Takele et al. 2006
2000	Arsi Bale	Mixed	male	2.32	8.48						Tatek et al. 2004
2008	Arsi-Bale	Mixed	male						65.63	62.93	Kebede et al. 2008
Average											
1998	Local	Mixed	Female					28.3			Tolera 1998
2004	Arsi-Bale goat	Mixed	Female	2.25	8.08				70.1		Woldu et al. 2004
2009	Local	Mixed	Female	2.20	12.27			31.92	111.35		Tsegaye 2009
2018	Abergelle	Past/Agro	Female	2.27	7.38						Birhanie et al. 2018
1998	Local	Mixed	Female					28.3			Tolera 1998
2007	Arsi-Bale	Mixed	Female					22.5			Ketema 2007
2000	Mid Rift Valley	Mixed	female		6.32		11.76				Tesfaye et al. 2000
2000	Arsi Bale	Mixed	female	2.25	8.08						Tatek et al. 2004
1990	Arsi Bale	Mixed	female		7.00		13.2				Takele et al. 2006
2000	Boran	Past/Agro	female	2.36	6.89		12.68				Tesfaye et al. 2000
Average											
2009	Local	Mixed	Both	2.78	9.00						Gemeda 2009
2014	Borena	Past/Agro	Both	2.36	10.34				89.88	32.96	Gatew et al. 2014
2014	Short-eared Somali	Past/Agro	Both	2.15	8.52				73.15	47.2	Gatew et al. 2015

2006	Abergelle	Mixed	Both	2.27	7.91				62.93		Muluken 2006
2014	Bati	Mixed	Both	2.71	10.44				86.22	56.46	Gatew et al. 2014
2007	Arsi-Bale	Mixed	Both	2.52	9.57						Assefa 2007
2014	Afar	Past/Agro	Both				14.3				Tekle 2014
2017	Local	Mixed	Both				16.13				Dejene 2017
2018	Woyto-Guji	Mixed	Both	2.15	9.32			24.67	62.32		Dea and Eramo 2018
2015	Abergelle	Past/Agro	Both	2.28	7.40	9.39	11.4				Birhanie et al. 2015
2019	Local	Mixed	Both								Gatew et al. 2019
2013	Abergele	Mixed	Both	1.91	6.84	9.13	14.15		53.4		Deriber and Taye 2013
2000	Arsi-Bale	Mixed	Both					21			Institute of Biodiversity Conservation 2018
2009	Western Low land	Mixed	Both	2.28	12.00						Tsegaye 2009
2006	Central high land	Mixed	Both	2.32	7.17	9.3	13.04				Getachew et al. 2006
2008	Central high land	Mixed	Both	2.01	9.02	13.82					Deribe 2008
2008	Arsi-Bale	Mixed	Both		6.95	9	14.31				Dadi et al. 2008
2013	Arsi-Bale	Mixed	Both	1.91	6.65	9	14.32				Bedhane et al. 2013
2004	Arsi-Bale	Mixed	Both	2.8	8.39						Weldu et al. 2004
2009	Keffa	Mixed	Both	2.78	9						Shenkute 2009
2007	Somali	Past/Agro	Both	3.19	11.67						Zeleke 2007
2007	Afar	Past/Agro	Both					31.0			Gizaw et al. 2007
2007	Somali	Past/Agro	Both					27.9			Gizaw et al. 2008
2007	Local	Mixed	Both					30.35			Assefa 2007

ADG1: average daily weight gain from birth to 6 month, ADG2: average daily weight gain from six months to 12 months,

Appendix Table 8. Summary of literature review on mean live weight, weight gain and mature weight in goat pastoral and agro-pastoral production system

Year	Breed	Production system	Sex	Birth wt (kg)	3 m wt (kg)	6 m wt (kg)	12 m wt (kg)	Adult wt (kg)	ADG1 (g/d)	ADG 2 (g/d)	Source
2018	Abergelle	Past/Agro	Male	2.28	7.42						Birhanie et al. 2018
2000	Boran	Past/Agro	Male	2.28	7.38		13.38				Tesfaye et al. 2000
2018	Abergelle	Past/Agro	Female	2.27	7.38						Birhanie et al. 2018
2000	Boran	Past/Agro	Female	2.36	6.89		12.68				Tesfaye et al. 2000
2014	Borena	Past/Agro	Both	2.36	10.34				89.88	32.96	Gatew et al. 2014
2014	Short-eared Somali	Past/Agro	Both	2.15	8.52				73.15	47.2	Gatew et al. 2014
2006	Sekota(Abergelle)	Past/Agro	Both	2.27	7.91				62.93		Muluken 2006
2013	Abergele	Past/Agro	Both	1.91	6.84				53.4		Deribe and Taye 2013
2014	Afar	Past/Agro	Both				14.3				Tekle 2014
2015	Abergelle	Past/Agro	Both	2.28	7.40	9.39	11.4				Birhanie et al. 2015
2013	Abergele	Past/Agro	Both	1.91	6.84	9.13	14.15		53.4		Deribe and Taye, 2013
2007	Somali	Past/Agro	Both	3.19	11.67						Zeleke 2007
2007	Afar	Past/Agro	Both					31.0			Gizaw et al. 2007
2007	Somali	Past/Agro	Both					27.9			Gizaw et al. 2008

ADG1: average daily weight gain from birth to 6 month, ADG2: average daily weight gain from six months to 12 months,

Appendix Table 9. Chemical composition and nutritive value of common feed resources available in different live-stock production systems

	DM(%)	CP(%, DM)	ME(MJ/kg DM)	OMD(%)	DE(MJ)	DE(%)
Natural pasture, Mixed*	91.3	7.7	8.3	47.1	10.2	55.7
Natural pasture, pastoral#			8.21		10.1	55.1
Improved feed (Alfalfa)	34.9	25.9	9.2	61.4	11.4	61.7
Hay						
Native grass, hay	92.3	6.6	7.40	49.2	9.1	49.7
Native grass, hay	93.3	3.7	6.40	42.4	7.9	42.9
Native grass, hay	91.9	2.3	6.20	41.5	7.7	41.6
Bermuda grass, hay	92.6	4.6	6.50	43.2	8.0	43.6
Purchased hay	92.4	6.1	7.30	48.7	9.0	48.9
Purchased hay-2	91.5	7.2	8.12	54.2	10.0	54.5
						46.9
Industrial by-Products						
Energy supplement	78.7	13.9	13.1	82.2	16.2	87.9
Protein supplment	78.9	30.3	10.2	65.3	12.6	68.4
Dairy ration	92.5	31.4	11.1	74.3	13.7	74.5
						78.2
Others						
Brewery by-products	15.7	20.1	9.8		12.0	65.5
Banan leaves	92.5	14.7	5.9	39.4	7.3	39.6
Enset leaves	94.7	4.8	7.2	48.5	8.9	48.3
Sugar cane leaves	91.0	4.9	9.0	60.0	11.1	60.4
Acacia sp. (fresh)	59.5	17.6	10.9	72.8	13.5	73.1
Coffee pulp	90.3	11.1	7.36	49.0	9.1	49.4
						56.0
Crop residue++						
Teff	92.7	5.2	8.0	53.1	9.9	53.7
Barley	93.0	6.0	6.8	48.0	8.3	45.3
Wheat	93.1	4.8	7.5	50.0	9.3	50.3
Maize	92.1	3.7	6.9	40.9	8.5	46.3
Sorghum	93.0	3.7	7.3	53.0	9.0	48.9
Finger millet	92.1	6.6	9.4	62.4	11.6	62.9
Oats/'Aja'	91.8	6.7	6.7	44.4	8.3	44.9
Browse spp						
Acacia spp.1	42.6	17.0	3.9	25.8	4.8	26.2
Acacia spp.2	47.9	25.4	8.9	59.3	11.0	59.7
Acacia spp.3	44.1	20.1	6.5	43.1	8.0	43.6
Acacia spp.4	59.5	17.6	10.9	72.8	13.5	73.1
Leucaena spp.1	35.1	21.0	7.5	50.1	9.3	50.3
Leucaena spp.2	46.8	20.8	6.6	44.2	8.1	44.3
Susbania spp.	29.5	21.0	9.7	64.5	12.0	65.1
Tree Lucern	40.0	18.0	10.7	71.0	13.2	71.8
Native legume	43.8	22.7	8.6	57.1	10.6	57.7
Khat	92.2	7.4	5.0	33.0	6.2	33.6

DE is digestible energy, CP:crude protein content, ME: metabolizable energy concentration

Chemical composition database for the feed type were obtained from Ethiopian Institute of Agricultural Research (EIAR, 2007).

*ME concentration of natural pasture in mixed crop-livestock production system (expert judgment), # ME concentration of natural pasture in pastoral and agro-pastoral production system (expert judgment)

++A residue to crop yield ratio of 1.5, 1.35, 1.28, 1.96, 2.44, 2.54, 1.42 was used to estimate the amount of residue from teff, barley, wheat, maize, sorghum, finger miller, oats/aja cereals, respectively (FAO 1987).

The DE (%) was estimated from ME and DE concentrations of feed using the following formula:

DE (%) = DE(MJ)/18.4, DE (MJ) = ME(MJ)/0.81 (CSIRO 2007).

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Inventory of greenhouse gas emissions from cattle, sheep and goats in Ethiopia (1994-2018) calculated using the IPCC Tier 2 approach