REPUBLIC OF KENYA

HARAMBEE

MINISTRY OF AGRICULTURE, LIVESTOCK, FISHERIES AND COOPERATIVES

STATE DEPARTMENT FOR LIVESTOCK

Inventory of GHG emissions from dairy cattle in Kenya
1995-2017

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GLOBAL RESEARCH ALLIANCE ON AGRICULTURAL GREENHOUSE GASES

CLIMATE & CLEAN AIR COALITION TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

UNIQUE forestry and land use

Government of Kenya

Inventory of GHG Emissions from Dairy Cattle in Kenya

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Foreword

The objective of Kenya's livestock sub-sector is to contribute to food and nutrition security within the context of the national goal and ambition for a low carbon emission and climate resilient development pathway. Nationally, the livestock sub-sector contributes about 36 % and over 95 % of the total agricultural sector greenhouse gas (GHG) emissions. These emissions arise from enteric fermentation and manure, which contribute about 54.8 % and 40.7 % respectively, of agricultural sector emissions. Considering the negative effects of GHGs on the climate system and in recognition of Kenya's commitment and ambitions to mitigate climate change, it is incumbent upon the livestock sub-sector to reduce and remove these emissions. The periodic GHG inventory (emissions and their removals) in the sub-sector using recommended international guidelines is a unique opportunity to assess the effectiveness of policies and measures in addressing climate change. Additionally, such inventories provide crucial evidence that should inform future planning for enhanced emission reductions from the livestock sub-sector. A case in point on the use of GHG inventory to inform development of livestock emissions mitigation is the Nationally Appropriate Mitigation Actions (NAMA) for the dairy industry that was developed in 2017 by the State Department for Livestock (SDL).

Contained in this report is the GHG inventory of Kenya's dairy industry. The report details the process involved in data collection and basis for calculations of the emissions in accordance to the Intergovernmental Panel for Climate Change (IPCC) Tier 2 methods. The application of the IPCC Tier 2 methods is an improvement to the basic Tier 1 methods that were applied during the first livestock sub-sector GHG inventory conducted in 2015. The use of Tier 2 methods in the dairy industry is deliberate and based on its importance to Kenya's economy. The industry contributes an estimated 4 % to the GDP but also contributes 26 % of the total agricultural sector GHG emissions. Therefore, the industry by virtue of this contribution offers an immense opportunity for substantial reductions of livestock based GHG emissions and subsequently the mitigation against climate change.

The Department has identified valuable learning points from the inventory process, and it is our intention that the same will inform future application of the Tier 2 methods in other livestock sub-sector industries. Noting that the process is resource demanding and requires comprehensive involvement of strategic stakeholders, the Department intends to coordinate regular GHG inventories in an iterative manner to actualize comprehensive documentation of GHG emissions and removals in the sub-sector. This strategic approach should progressively develop the required stakeholder capacity and necessary coordination mechanism to ensure the livestock sub-sector more effectively contributes to Kenya's ability in measurement, reporting and verification (MRV) of GHG emissions. Additionally, the benefit of evidence from the inventory, will enable SDL develop climate policies and measures that contribute to the Kenya's global commitments on emission mitigation set out in the Nationally Determined Contribution. I am quite confident that this is the pathway for the livestock sub-sector's contribution to Kenya's ambition of a low carbon emission and climate resilient economy.

Harry Kimtai, CBS
PRINCIPAL SECRETARY, STATE DEPARTMENT FOR LIVESTOCK
MINISTRY OF AGRICULTURE, LIVESTOCK, FISHERIES AND COOPERATIVES

Acknowledgement

This inventory report was prepared by the State Department for Livestock, Ministry of Agriculture, Livestock, Fisheries and Cooperatives (MoALFC). Technical support was provided by UNIQUE Forestry and Land Use GmbH, implemented as part of the Global Research Alliance (GRA) on Agricultural Greenhouse Gases with support from the Government of New Zealand.

The core team that was involved in this document was appointed by the Principal Secretary, State Department for Livestock, to spearhead discussions and contribution to the content, including provision of relevant information, data, and related materials. This inventory process was consultative and participatory and involved key agencies in Kenya that possess experience and are highly conversant with the climate change and the mitigation agenda in livestock production systems and especially dairy cattle industry.

Special thanks go to Mr.Harry Kimtai, Principal Secretary, State Department for Livestock in the Ministry of Agriculture, Livestock, Fisheries and Cooperatives for initiating the process. I also wish to thank the staff in the Directorate of Livestock Production who were key in provision of data, requisite information and for logistical support. In this regard, I wish to appreciate the roles played by Mr Robin Mbae (Head: Climate change) Mr David Olang (Manager, Dairy Inventory), Mr Benjamin Kibor (Animal Breeding and Livestock Statistics) and Mr Bernard Kimoro (Climate Change Unit, SDL/Directorate of Livestock Production).

The process received enormous support from the experts and collaborators who belong to different agencies, firms, and institutions. We would therefore wish to appreciate both the administration and individuals that were involved closely to actualize the objective of generating this report. Subsequently we wish to give special mention to: Dr Samuel Mbuku (Kenya Agricultural and Livestock Research Organisation); Dr James Ondiek Egerton University); Dr. Anne Omambia (National Environment Management Authority); Patrick Mwaniki (Kenya National Bureau of Statistics); Alfred Gichu (Kenya Forest Service); David Adegu (Climate Change Directorate, Ministry of Environment and Forestry); Joseph Opiyo (Tegemeo Institute of Agricultural Policy and Development); and Dr. Todd Crane (International Livestock Research Institute). We also wish to give our special gratitude to Global Research Alliance on Agricultural Greenhouse Gases from the New Zealand Government for the support, both technical and financial in carrying out this exercise. We also to acknowledge the financial support provided by the Reducing Enteric Methane for Improving Food Security and Livelihoods project supported by the Climate and Clean Air Coalition (CCAC).

Finally, we acknowledge and appreciate the tireless efforts and commitments demonstrated by the UNIQUE forestry and land use GmbH consulting team comprised of Dr. Andreas Wilkes, and Dr Charles Odhong. Their valuable input and dedication to the process was instrumental in ensuring that the document was developed within the agreed timelines and met the threshold set by international standards.

Julius Kiptarus, OGW
DIRECTOR FOR LIVESTOCK PRODUCTION
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Abbreviations and acronyms

CCAC	Climate and Clean Air Coalition
CCD	Climate Change Directorate
CP	Crude Protein
CRF	Common Reporting Format
DE	Digestible Energy
DLP	Directorate of Livestock Production
EF	Emission Factor
FAO	Food and Agriculture Organization
GE	Gross Energy
GHG	Greenhouse Gas
GPG	Good Practice Guideline
GRA	Global Research Alliance
IEF	Implied Emission Factor
ILRI	International Livestock Research Institute
IPCC	Intergovernmental Panel on Climate Change
KNBS	Kenya National Bureau of Statistics
MCF	Methane Correction factor
ME	Metabolizable Energy
MMS	Manure Management System
MoALFC	Ministry of Agriculture, Livestock, Fisheries and Cooperatives
MRV	Measurement, Verification and Reporting
NAMA	Nationally Appropriate Mitigation Actions
NDC	Nationally determined Contribution
NE	Net Energy
PS	Principal Secretary
QAQC	Quality Assurance and Quality Control
SDL	State Department for Livestock
SNC	Second National Communication
UNFCCC	United Nations Framework Convention on Climate Change

Technical Summary

The dairy industry is Kenya's single largest agricultural sub-sector. It contributes 14% of agricultural gross domestic product (GDP) and 3.5% of total GDP. Most dairy cattle are raised by smallholders, in zero-grazing (i.e. stall-fed) feeding systems, mixed stall-fed and grazing systems, or grazing only feeding systems. Because it is an important source of both nutrition and income for the rural population, the dairy cattle population has been increasing continuously in recent decades, from 3.25 million in 1995 to almost 4.6 million in 2017. However, Climate Change is real and livestock sub-sector, dairy production included, is highly vulnerable to Climate Change. On the other hand, livestock especially ruminants contribute to greenhouse gas emission through enteric fermentation and manure management. Climate Change is not only a threat to achievement of sustainable development but deprives our livelihoods and economic sustenance.

Kenya being a signatory to international treaties and agreements, UNFCCC included, has designed, and implemented climate smart policies and strategies in line with its obligation and commitment in various agreements under UNFCCC. These agreements include, The Bali Action Plan adopted at COP 13 in 2007 which introduced the principle of measurement, reporting and verification (MRV) for both developed and developing Parties in the context of enhancing action at the international and national level to mitigate climate change. The other being The Paris agreement (2015) where countries showed their commitments in signing the actions they would undertake under NDC which calls for accuracy and transparency in reporting reductions in emissions intensity that result from improvements to agricultural production systems (dairy production systems included) to the UNFCCC. Many countries use simple (Tier 1) methods for estimating livestock emissions in their GHG inventories. However, Tier 1 methods are not adequate and accurate to capture the reductions in emissions intensity that results from improvements in livestock production systems other than changes in total animal numbers. Tier 2 method is an advanced inventory method that is more accurate and requires more detailed data that capture country specific production systems. Tier 2 methods also reflect changes in emissions that result from improved production efficiency.

With the above information on GHG emission and inventory methods in livestock and the global obligations therein, the State Department for Livestock (SDL) has taken the initiative to compile Kenya's livestock inventory using a Tier 2 approach. Since 2015, SDL has been working with stakeholders to develop a Nationally Appropriate Mitigation Action for the dairy sector. It was decided to first implement the Tier 2 approach in the GHG inventory for dairy cattle. It was intended that this would strengthen Kenya's ability to measure, report and verify emissions and emission reductions from future initiatives to develop the dairy sector. The report therefore will inform compilation of the GHG inventory in Kenya's Third National Communication to the UNFCCC.

To ensure consistency with other sector reports for the Third National Communication, the inventory used methods set out in the IPCC 2006 Guidelines and estimates GHG emissions for dairy cattle from five GHG sources. These sources were; 1) Enteric fermentation (CH_4); 2) Manure management (CH_4, N_2O); 3) Direct N_2O emissions from managed soils (dung and urine deposit on pasture (N_2O); 4) Indirect N_2O emissions from managed soils (dung and urine deposit on pasture) (N_2O) and; 5) Indirect N_2O emissions from manure management (N_2O) from the base year for Kenya's GHG inventory (i.e. 1995) until 2017. The GHG emissions time series were calculated using IPCC Tier 2 model of the IPCC 2006 Guidelines for 5 sub-categories of dairy cattle (cows, heifers, adult males, growing males, and calves) in three production systems (intensive, semi-intensive and extensive) in Kenya using excel spread sheet. Uncertainties and time series consistency 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 spread sheet were correctly inputted; 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 spread sheet 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 spread sheet. Quality assurance was also provided by a thorough review by two international reviewers.

From the Tier 2 GHG inventory time series, the emissions were consistently lower than Tier 1 as previously reported in second national communication. This implies that accuracies were improved by using Kenya specific activity data. For further improvement, the following were suggested to be done:

- Cross-check and validate or adjust allocation of counties to production systems;
- Conduct representative sample surveys in extensive and semi-intensive production systems to collect more accurate estimates of activity data used in the Tier 2 enteric fermentation model; and
- Research to develop cost-effective methods for accurate representation of diet composition for different dairy cattle sub-categories and feeding systems.

The State Department for Livestock in the long term is prioritizing improvement and accuracy of dairy cattle population (and sub-categories) and milk yield estimates collected by local (county) governments. It also plans to work with development partners to improve the administrative data collection system to achieve this longer-term objective.

This inventory was prepared by the State Department for Livestock of the Ministry of Agriculture, Livestock, Fisheries, and Cooperatives (MoALFC). Technical support was provided by UNIQUE forestry and land use GmbH, implemented as part of the Global Research Alliance on Agricultural Greenhouse Gases, and carried out with support of the New Zealand Government. For details, please visit http://www.kilimo.go.ke and www.globalresearchalliance.org/livestock. The views expressed in this document cannot be taken to reflect the official opinion of these organisations.

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1. Introduction

Considering the importance of greenhouse gas (GHG) emissions from livestock in Kenya's agriculture GHG inventory, the State Department of Livestock (SDL) has taken the initiative to compile Kenya's livestock inventory using a Tier 2 approach. Since 2015, SDL has been working with stakeholders to develop a Nationally Appropriate Mitigation Action for the dairy sector. It was decided to first implement the Tier 2 approach in the GHG inventory for dairy cattle. It is intended that this will strengthen Kenya's ability to measure, report and verify emissions and emission reductions from future initiatives to develop the dairy sector. This report will inform compilation of the GHG inventory in Kenya's Third National Communication to the UNFCCC, being prepared in 2019.

The dairy industry is Kenya's single largest agricultural sub-sector. It contributes 14% of agricultural gross domestic product (GDP) and 3.5% of total GDP. Total milk production from dairy cows in 2017 was about 2 billion litres. Per capita milk consumption in 2010 was about 100 litres per year, but is projected to reach 220 litres by 2030, with total milk demand of 12 billion litres by 2030 (SDL 2013). Most dairy cattle are raised by smallholders, in zero-grazing (i.e. stall-fed) feeding systems, mixed stall-fed and grazing systems, or grazing only feeding systems. Because it is an important source of both nutrition and income for the rural population, the dairy cattle population has been increasing continuously in recent decades, from 3.25 million in 1995 to almost 4.6 million in 2017. However, average milk yield remains low.

In Kenya's national livestock population statistics, dairy cattle are defined as cattle with some percentage of genetics from exotic dairy breeds. Common dairy cattle breeds include Friesian, Ayrshire, Jersey and Guernsey. The national livestock population data for dairy cattle include dairy cattle of different age and sex. Therefore, this inventory includes several sub-categories of dairy cattle: cows, heifers, adult males, growing males and calves. In the future, it is intended to also apply the Tier 2 approach to other cattle. Because of differences in breed, feeding and management between dairy and non-dairy cattle, greater clarity will be obtained if the inventories for dairy cattle and other cattle both include sub-categories of different ages and sex.

To ensure consistency with other sector reports for the Third National Communication, this inventory uses the methods set out in the IPCC 2006 Guidelines, and estimates GHG emissions for dairy cattle from five GHG sources (see ***Table 1*** **GHG sources estimated in this report**) from the base year for Kenya's GHG inventory (i.e. 1995) until 2017.

Table 1 GHG sources estimated in this report

CRF	Description	Gases
3A1 3A1ai	Enteric fermentation - Dairy cattle	CH_4
3A2 3A2ai	Manure management - Dairy cattle	CH_4, N_2O
3C4	Direct N_2O emissions from managed soils - Dung and urine deposit on pasture by dairy cattle	N_2O
3C5	Indirect N_2O emissions from managed soils - Dung and urine deposit on pasture by dairy cattle	N_2O
3C6	Indirect N_2O emissions from manure management - Dairy cattle	N_2O

2. 3A1 Enteric fermentation, dairy cattle

2.1 Source category description

Emissions sources	Sources included	Method	Emission factors
	Dairy cattle enteric fermentation	T2	CS
Gases reported	CH_4		
Completeness	All dairy cattle accounted for. No known omissions		
Improvements since last submission	This is the first inventory for dairy cattle that uses a Tier 2 approach		

Methane is produced by ruminants in the digestive process of enteric fermentation. This is the first time Kenya has used a Tier 2 approach for dairy cattle enteric fermentation. Using the Tier 2 approach, it is estimated that in 1995 CH_4 emissions amounted to 128.63 Gg CH_4 and increased to 192.02 Gg CH_4 in 2017 (**Table 2**, **Figure 1**). This increase is due to both an increase in dairy cattle numbers and to changes in cattle management and animal performance. A comparison with the trend estimated using a Tier 1 approach is provided in Section 2.5.

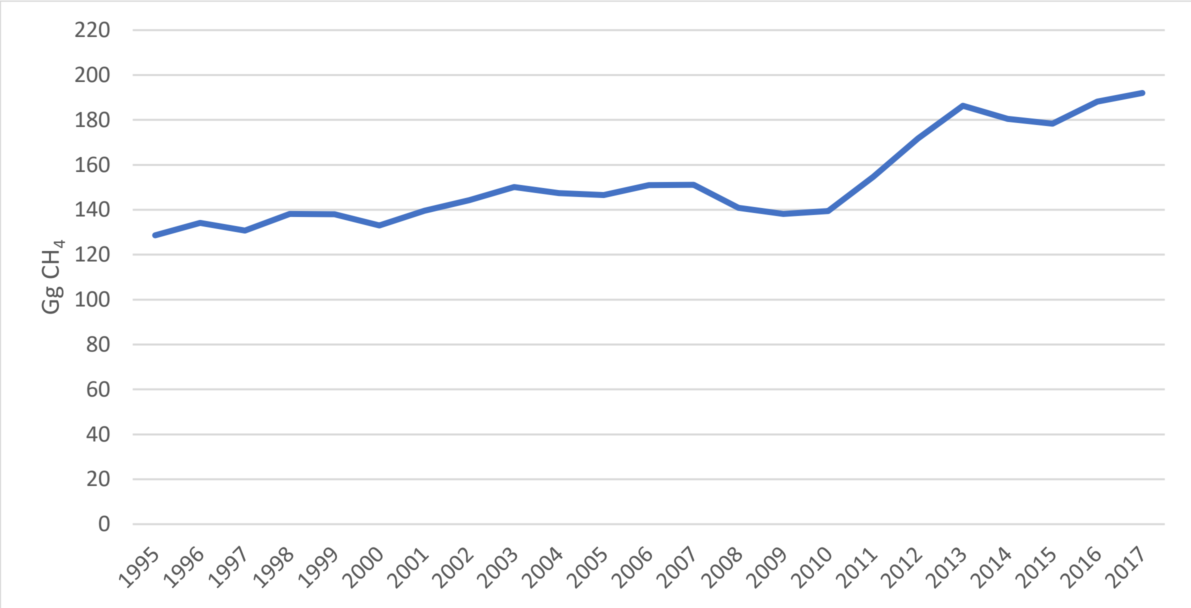

Figure 1: Trend in enteric fermentation emissions from dairy cattle, 1995-2017 (Gg CH_4)

Table 2: Enteric fermentation emissions from dairy cattle, Gg CH_4, 1995-2017

Year	Gg CH_4		Year	Gg CH_4		Year	Gg CH_4		Year	Gg CH_4		Year	Gg CH_4		Year	Gg CH_4
1995	128.63		**1999**	138.01		**2003**	150.18		**2007**	151.07		**2011**	154.62		**2015**	178.36
1996	134.18		**2000**	133.04		**2004**	147.39		**2008**	140.84		**2012**	171.77		**2016**	188.14
1997	130.68		**2001**	139.65		**2005**	146.52		**2009**	138.12		**2013**	186.4		**2017**	192.02
1998	138.11		**2002**	144.27		**2006**	150.95		**2010**	139.44		**2014**	180.53			

2.2. Methodological issues

This section summarizes the main methods and data used in the Tier 2 inventory for dairy cattle enteric fermentation. Specific description of data sources and methods used in data compilation, analysis and calculation of emissions 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 15 categories of dairy cattle.

In Kenya's national livestock population statistics, dairy cattle are distinguished from beef cattle. During census activities and administrative statistics reporting, dairy cattle in Kenya are defined as cattle with some percentage of genetics from exotic dairy breeds. Common dairy cattle breeds include Friesian, Ayrshire, Jersey and Guernsey. The national livestock population data for dairy cattle include all sub-categories of dairy cattle of these breeds. In this inventory, 5 sub-categories are identified:

- Dairy cows: Dairy cows that have calved at least once;
- Heifers: Female cattle > 1 year old that have not calved;
- Adult males: Bulls and oxen > 3 years old;
- Growing males: Males > 1 year old and <3 years old;
- Male and female calves: Calves <1 year old.

Separate calculations were made for each dairy cattle sub-category in each of three production systems: intensive, semi-intensive and extensive. These production systems are based on three common feeding systems for dairy cattle in Kenya: zero-grazing (i.e. stall feeding only), a mix of stall feeding and grazing (referred to as 'semi-zero grazing') and grazing only. The definition of each production system is as follows:

- **Intensive:** The population of dairy cattle in a county is defined as being in the intensive production system if zero-grazing is the most common feeding system used at household level
- **Semi-intensive:** Semi-intensive is indicated if semi-zero grazing is the most common feeding system; and
- **Extensive:** extensive is indicated if grazing only feeding systems are the most common feeding system in the county.

Each of Kenya's 47 counties was allocated to one of these production systems based on the estimated prevalence of different feeding systems implemented at the farm level. The allocation of each county to one of the three production systems is shown in ***Table 3***. This allocation was made based on a prior classification using expert judgement,[1] and additional expert judgement by county livestock officers and State Livestock Department staff collected as part of county livestock statistics validation exercises in 2019. Each production system has cattle raised in each of the three main feeding systems. For example, in 2017 it is estimated that in the intensive system, 63% of cattle were raised in zero-grazing systems, 26% in semi-zero grazing and 11% in grazing systems. Surveys conducted in counties mostly in the semi-intensive production system estimated 19% zero-grazing, 31% semi-zero grazing and 50% grazing in 1998, and 18%, 42% and 40% respectively in 2008 (EADD 2010), and 27.8%, 32.5% and 39.8% respectively in 2014 (Njarui et al. 2016). Thus, in total, the inventory is based on 15 dairy cattle categories (i.e., 5 cattle sub-categories and 3 production systems).

[1] FAO (2017) Options for low-emission development in the Kenya Dairy Sector. FAO, Rome.

Table 3: Counties allocated to the intensive, semi-intensive and extensive production systems

Production system	Counties
Intensive system	Garissa, Isiolo, Kiambu, Kirinyaga, Mandera, Masarbit, Meru, Murang'a, Nairobi, Nakuru, Nyeri, Samburu, Tana River, Turkana, Wajir
Semi-intensive system	Bomet, Bungoma, Busia, Embu, Homabay, Kakamega, Kericho, Kisumu, Kisii, Machakos, Makueni, Migori, Mombasa, Nandi, Nyamira, Nyandarua, Siaya, Tharaka Nithi,Trans Nzoia, Uasin Gishu, Vihiga
Extensive system	Baringo, Elgeyo Marakwet, Kajiado, Kilifi, Kitui, Kwale, Laikipia, Lamu, Narok, Taita Taveta, West Pokot

2.2.2 Dairy cattle population

Official data are available at the State Department of Livestock (SDL) on the total population of dairy cattle for each year from 1995 to 2017. Since 2012, the national total has been derived from the sum of dairy cattle populations reported by each county to the Ministry of Agriculture, Livestock, Fisheries and Irrigation, and is available by county. Prior to 2012, the data was collected through the administrative statistics system of the ministry and is available by province and county. The data sources and methods used to estimate dairy cattle populations for each production system are described in Annex 1. Allocating each county to a production system results in proportions of the total dairy cattle population in each system as shown in ***Figure 2***. The figure shows a decrease in livestock population in the semi-intensive system between the early 2000's and 2009, followed by an increase. The decrease may be due to successive and prolonged droughts during these years. In 2020 it will be possible to cross-check the 2019 reported population data against the results of the 2019 census, to verify the trend since 2010.

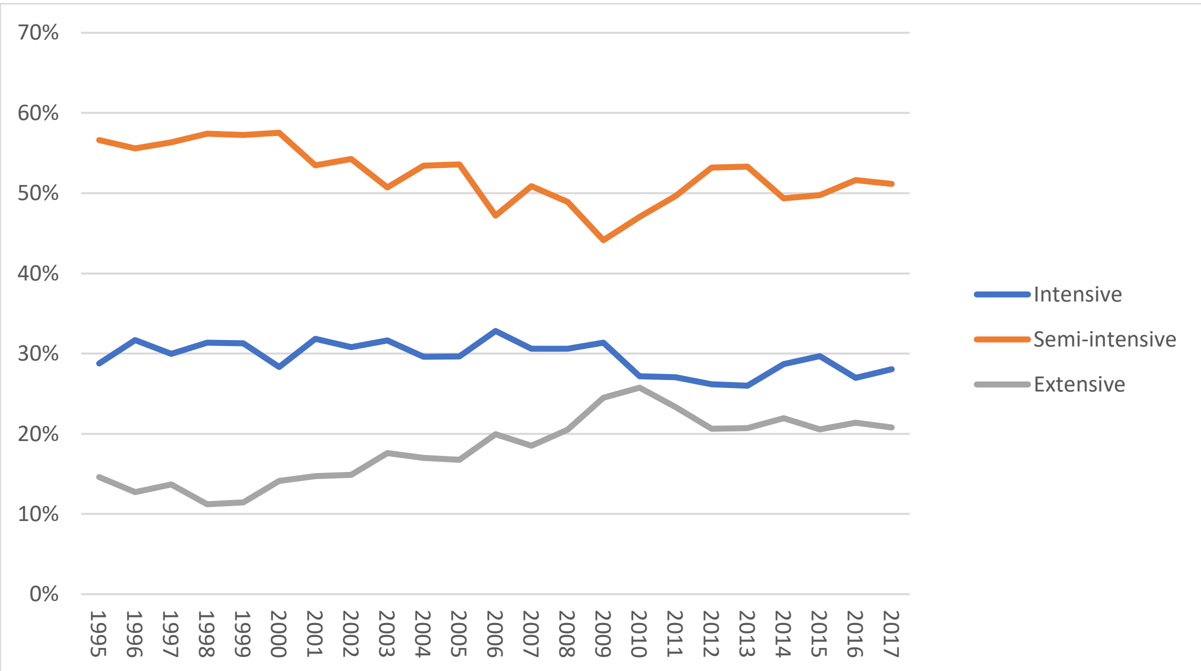

Figure 2: Proportions of dairy cattle in different production systems, 1995-2017

The official data do not distinguish different sub-categories of dairy cattle, and only give the total dairy cattle population. The structure of dairy herds (i.e., the proportion of each animal sub-category) in each production system was estimated using data from a large-scale repeat survey conducted by the Tegemeo Institute in 2000, 2004, 2007, 2010 and 2014, supplemented by literature reports, and shows slight variation from year to year (see Annex 1). Applying the estimated herd structure to the official dairy cattle population statistics gives a population of each sub-category of dairy cattle in each production system in each inventory year as shown in ***Table 4***.

Table 4: Time series for dairy cattle sub-category populations, 1995-2017 (head)

	Intensive					Semi-intensive					Extensive				
	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves
1995	402,698	180,101	34,282	98,666	220,423	630,009	394,025	155,611	193,088	471,115	133,435	83,454	72,454	54,105	132,011
1996	457,326	204,532	38,933	112,050	250,325	637,148	398,490	157,375	195,276	476,454	119,915	74,998	65,113	48,623	118,636
1997	422,974	189,169	36,008	103,633	231,522	631,645	395,049	155,513	193,693	472,591	126,213	78,937	68,533	51,177	124,866
1998	464,521	207,750	39,545	113,813	254,263	675,451	422,446	165,760	207,237	505,636	108,335	67,756	58,825	43,928	107,180
1999	462,094	206,665	39,339	113,218	252,935	672,275	420,460	164,445	206,372	503,527	110,521	69,123	60,012	44,814	109,342
2000	406,805	181,937	34,632	99,672	222,671	656,001	410,281	159,942	201,484	491,600	137,872	86,229	70,918	51,128	124,748
2001	471,047	210,669	50,464	112,504	251,339	629,124	393,472	152,889	193,332	471,710	154,357	96,539	75,332	52,320	127,657
2002	469,959	210,182	60,705	109,338	244,266	658,973	412,140	159,618	202,612	494,353	167,736	104,907	77,782	51,917	126,673
2003	497,672	222,577	75,273	112,703	251,783	635,789	397,640	153,497	195,588	477,215	212,562	132,942	93,780	59,995	146,384
2004	457,439	204,583	79,305	100,753	225,086	658,567	411,886	158,472	202,703	494,574	208,958	130,688	87,817	53,686	130,988
2005	456,282	204,066	68,218	102,861	229,797	657,903	411,471	160,984	199,852	487,619	210,093	131,398	69,363	55,104	134,449
2006	515,064	230,355	64,793	118,765	265,326	591,457	369,914	147,111	177,304	432,604	260,371	162,843	63,621	69,621	169,869
2007	485,779	217,257	49,660	114,498	255,793	644,271	402,945	162,829	190,579	464,995	249,269	155,900	40,517	67,866	165,588
2008	451,557	201,952	45,046	105,891	236,566	581,861	363,912	140,564	168,039	409,998	253,257	158,394	55,457	67,110	163,743
2009	451,732	202,031	43,954	105,395	235,458	517,165	323,450	119,304	145,817	355,778	290,815	181,884	80,475	74,898	182,745
2010	400,426	179,085	37,983	92,951	207,657	568,992	355,864	125,211	156,629	382,159	308,233	192,777	103,515	77,036	187,961
2011	434,417	194,287	46,821	103,726	231,729	676,584	423,154	131,506	181,603	443,094	314,412	196,642	90,159	78,920	192,556
2012	461,012	206,181	55,826	113,231	252,963	820,421	513,114	139,117	214,777	524,033	313,983	196,374	75,115	79,139	193,093
2013	488,216	218,348	65,822	123,357	275,585	906,399	566,887	131,985	231,486	564,801	346,839	216,923	67,006	87,772	214,156
2014	508,029	227,209	75,686	132,060	295,027	817,760	511,450	100,146	203,791	497,231	357,933	223,862	53,175	90,931	221,862
2015	516,842	231,150	76,999	134,350	300,145	810,386	506,838	99,243	201,954	492,747	329,123	205,843	48,895	83,611	204,004
2016	498,897	223,124	74,326	129,686	289,724	893,111	558,577	109,374	222,569	543,047	363,800	227,531	54,046	92,421	225,499
2017	526,508	235,473	78,439	136,863	305,758	898,336	561,845	110,014	223,872	546,224	358,982	224,517	53,331	91,197	222,512

2.2.3 Net energy for maintenance (NE_m)

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

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

Where:

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

Cf_j is coefficient for calculating NE_m for dairy cattle type *j*

$Weight_j$ is live weight of dairy cattle of type *j* (kg).

IPCC 2006 Table 10.4 gives default values for Cf_j for lactating cows (0.386), non-lactating cows (0.322) and bulls (0.37). IPCC 2006 Table 10.4 does not give specific guidance on choice of the coefficient for castrated males, so a Cf of 0.322 was used for oxen (i.e. adult castrated males) and heifers. For cows, the value of Cf was weighted by the proportion of lactating cows in the herd. Here, and elsewhere in the inventory, it was assumed that lactating cows lactate for 365 days (see Annex 5). For adult males, the value of Cf was weighted by the proportion of oxen and intact males in the population, and for calves the value of Cf was weighted by the proportion of female and male calves (Annex 1). ***Table 5*** shows the values of Cf used for different sub-categories.

Table 5: Coefficient for maintenance values for different cattle sub-categories

	Cf	Notes
Cows	0.360 – 0.370	IPCC default (0.386 lactating, 0.322 dry), average weighted by proportion of lactating cows
Heifers	0.322	IPCC default value
Adult male - intensive system - semi-intensive and extensive	 0.368 0.346	IPCC default (0.37 bulls 0.322 oxen), average weighted by proportion of intact and castrated adult males (see Annex 1)
Growing male	0.370	IPCC default value
Calves - intensive system - semi-intensive and extensive	 0.340 0.344	IPCC default (0.37 intact males, 0.322 non-lactating females), average weighted by proportion of male and female calves (see Annex 1)

The live weight of each sub-category of dairy cattle was estimated using published and unpublished data, and is shown in ***Table 6***. The specific data sources and methods used to estimate the time series for live weight are explained in Annex 2. It should be noted that the average weights of cows in the intensive production system are significantly higher than the IPCC default weight for Africa (i.e. 275 kg), so we can expect that the resulting emission factors are higher than the Tier 1 IPCC default value for Africa. Also, the estimated live weights in the semi-intensive and extensive production systems are lower than those used in the IPCC default factor (see IPCC 2006 Table 10A.1), and therefore we can expect the resulting emission factors are lower than the Tier 1 IPCC default value for Africa.

Table 6: Live weight (kg) of dairy cattle sub-categories

	Intensive system					Semi-intensive system					Extensive system				
	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves
1995	354.10	254.95	357.64	241.00	84.98	253.12	205.79	235.40	179.04	60.75	253.12	205.79	235.40	179.04	60.75
1996	354.95	255.56	357.64	241.00	85.19	253.39	206.01	235.65	179.22	60.81	253.39	206.01	235.65	179.22	60.81
1997	355.79	256.17	357.64	241.00	85.39	253.66	206.22	235.90	179.41	60.88	253.66	206.22	235.90	179.41	60.88
1998	356.63	256.78	357.64	241.00	85.59	253.92	206.44	236.15	179.60	60.94	253.92	206.44	236.15	179.60	60.94
1999	357.48	257.38	357.64	241.00	85.79	254.19	206.66	236.40	179.79	61.01	254.19	206.66	236.40	179.79	61.01
2000	358.32	257.99	357.64	241.00	86.00	254.46	206.88	236.65	179.98	61.07	254.46	206.88	236.65	179.98	61.07
2001	359.16	258.60	357.64	241.00	86.20	254.73	207.09	236.90	180.17	61.13	254.73	207.09	236.90	180.17	61.13
2002	360.01	259.21	357.64	241.00	86.40	255.00	207.31	237.15	180.36	61.20	255.00	207.31	237.15	180.36	61.20
2003	360.85	259.81	357.64	241.00	86.60	255.26	207.53	237.39	180.55	61.26	255.26	207.53	237.39	180.55	61.26
2004	361.70	260.42	357.64	241.00	86.81	255.53	207.75	237.64	180.74	61.33	255.53	207.75	237.64	180.74	61.33
2005	362.54	261.03	357.64	241.00	87.01	255.80	207.96	237.89	180.93	61.39	255.80	207.96	237.89	180.93	61.39
2006	363.38	261.64	357.64	241.00	87.21	256.07	208.18	238.14	181.12	61.46	256.07	208.18	238.14	181.12	61.46
2007	364.23	262.24	357.64	241.00	87.41	256.33	208.40	238.39	181.31	61.52	256.33	208.40	238.39	181.31	61.52
2008	365.07	262.85	357.64	241.00	87.62	256.60	208.62	238.64	181.50	61.58	256.60	208.62	238.64	181.50	61.58
2009	365.18	262.93	357.64	241.00	87.64	256.87	208.83	238.89	181.69	61.65	256.87	208.83	238.89	181.69	61.65
2010	365.28	263.00	357.64	241.00	87.67	257.14	209.05	239.14	181.88	61.71	257.14	209.05	239.14	181.88	61.71
2011	365.39	263.08	357.64	241.00	87.69	257.40	209.27	239.39	182.06	61.78	257.40	209.27	239.39	182.06	61.78
2012	365.49	263.15	357.64	241.00	87.72	257.67	209.49	239.63	182.25	61.84	257.67	209.49	239.63	182.25	61.84
2013	365.60	263.23	357.64	241.00	87.74	257.94	209.70	239.88	182.44	61.91	257.94	209.70	239.88	182.44	61.91
2014	365.70	263.31	357.64	241.00	87.77	258.21	209.92	240.13	182.63	61.97	258.21	209.92	240.13	182.63	61.97
2015	365.81	263.38	357.64	241.00	87.79	258.48	210.14	240.38	182.82	62.03	258.48	210.14	240.38	182.82	62.03
2016	365.91	263.46	357.64	241.00	87.82	258.74	210.36	240.63	183.01	62.10	258.74	210.36	240.63	183.01	62.10
2017	366.02	263.53	357.64	241.00	87.84	259.01	210.58	240.88	183.20	62.16	259.01	210.58	240.88	183.20	62.16

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). Dairy cattle in semi-zero and grazing only feeding systems in Kenya often do not travel long distances for grazing, as tethering in paddocks and by roadsides is common. To estimate appropriate values of C_a, the methods presented in NRC (2001) to estimate net energy for activity were used together with available data on grazing distances in Kenya (see Annex 4 for detailed explanation and data used). The values for C_a used in this inventory are shown in ***Table 7***.

Table 7: Estimated coefficients for activity (C_a) based on live weight and grazing distance in the Kenya

	Intensive			Semi-intensive and extensive		
	Distance grazed per day (km)	% of cattle grazing	Average C_a for each sub-category*	Distance grazed per day (km)	% of cattle grazing	Average C_a for each sub-category*
Cows	0.73	0.37	0.03	5.2	0.71	0.11
Heifers	0.71	0.42	0.03	5.2	0.71	0.12
Adult males	0.63	0.40	0.03	5.2	0.71	0.12
Growing males	0.86	0.43	0.03	5.2	0.71	0.10
Calves	0.76	0.36	0.02	0	0.00	0.00

* average in time series 1995-2017 for each animal type, with annual values varying by live weight.

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;

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 live weight values shown in Table 6 above. The data available to estimate mature weight and daily weight gain were different for the intensive and semi-intensive and extensive systems and are explained in Annex 2. Due to limited data and uncertainty about the reported values available, the same weight gain values were used for each sub-category throughout the inventory time series. For further discussion, see Annex 2. The weight gain values used are shown in ***Table 8***.

Table 8: Average daily weight gain (kg) values used for different dairy cattle sub-categories

	Intensive	Semi-intensive and extensive
Cows	0.017	0.03
Heifers	0.25	0.22
Adult males	0.14	0.03
Growing males	0.20	0.17
Calves	0.42	0.22

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 model, milk yield is expressed in kg head^{-1} day^{-1} over 365 days. Official milk output data is based on fixed technical coefficients that do not change over time. However, surveys show that pure exotic breeds, especially Holstein-Friesian and their crosses, have higher milk yields than other dairy breeds. Adoption of higher yielding breeds has been increasing over time. To reflect the effects of changes in the dairy sector, milk yield and its trend was estimated by using literature reports on the average milk yields of Friesian, Ayrshire and other breeds and genotypes, and their proportions in the herd, as described in Annex 5. The resulting trends in average milk yields for lactating cows in each production system are shown in ***Table 9***. To calculate net energy for lactation, the daily milk yields for lactating cows were multiplied by the proportion of cows lactating. For milk fat content, a default value of 4% was used (IPCC 2006).

Table 9: Average milk yields for lactating cows in, 1995-2017 (kg head^{-1} day^{-1})

	Intensive	Semi-intensive	Extensive	Weighted average
1995	6.17	4.75	4.75	5.16
1996	6.21	4.76	4.76	5.22
1997	6.25	4.77	4.77	5.21
1998	6.29	4.78	4.78	5.25
1999	6.33	4.79	4.79	5.27
2000	6.37	4.80	4.80	5.25
2001	6.41	4.81	4.81	5.32
2002	6.45	4.82	4.82	5.32
2003	6.49	4.84	4.84	5.36
2004	6.53	4.85	4.85	5.34

	Intensive	Semi-intensive	Extensive	Weighted average
2005	6.57	4.86	4.86	5.36
2006	6.60	4.87	4.87	5.44
2007	6.64	4.88	4.88	5.42
2008	6.68	4.89	4.89	5.44
2009	6.69	4.90	4.90	5.46
2010	6.69	4.91	4.91	5.40
2011	6.70	4.92	4.92	5.40
2012	6.70	4.94	4.94	5.40
2013	6.71	4.95	4.95	5.41
2014	6.71	4.96	4.96	5.46
2015	6.72	4.97	4.97	5.49
2016	6.72	4.98	4.98	5.45
2017	6.73	4.99	4.99	5.48

2.2.7 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 0.1.

$C_{pregnancy}$ was applied to the proportion of cows giving birth in the year (see Annex 1.3), and to the proportion of heifers pregnant in the year, the values of which are shown in ***Table 10***. For the semi-intensive and extensive systems, the estimated proportion of cows giving birth is lower than the IPCC default value of 67% for dairy cows in Africa (IPCC 2006, Table A10.1), but in the intensive system the estimated value is higher from 2003 onwards. For all other animal types, the coefficient was given a value of zero.

Table 10: Proportions of cows giving birth and heifers pregnant, 1995-2017

	Intensive system		Semi-intensive system		Extensive system	
	cows	Heifers	cows	heifers	Cows	Heifers
1995	0.63	0.2	0.60	0.2	0.60	0.2
1996	0.64	0.2	0.60	0.2	0.60	0.2
1997	0.64	0.2	0.60	0.2	0.60	0.2
1998	0.65	0.2	0.60	0.2	0.60	0.2
1999	0.65	0.2	0.60	0.2	0.60	0.2
2000	0.66	0.2	0.60	0.2	0.60	0.2
2001	0.66	0.2	0.60	0.2	0.60	0.2
2002	0.67	0.2	0.60	0.2	0.60	0.2
2003	0.68	0.2	0.60	0.2	0.60	0.2
2004	0.68	0.2	0.61	0.2	0.61	0.2
2005	0.69	0.2	0.61	0.2	0.61	0.2
2006	0.69	0.2	0.61	0.2	0.61	0.2
2007	0.70	0.2	0.61	0.2	0.61	0.2
2008	0.70	0.2	0.61	0.2	0.61	0.2
2009	0.71	0.2	0.61	0.2	0.61	0.2
2010	0.71	0.2	0.61	0.2	0.61	0.2
2011	0.72	0.2	0.61	0.2	0.61	0.2

	Intensive system		Semi-intensive system		Extensive system	
	cows	Heifers	cows	heifers	Cows	Heifers
2012	0.73	0.2	0.61	0.2	0.61	0.2
2013	0.73	0.2	0.62	0.2	0.62	0.2
2014	0.74	0.2	0.62	0.2	0.62	0.2
2015	0.74	0.2	0.62	0.2	0.62	0.2
2016	0.75	0.2	0.62	0.2	0.62	0.2
2017	0.75	0.2	0.62	0.2	0.62	0.2

2.2.8 Net energy for work (NE_{work})

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

$NE_{work} = 0.10 \times NE_m \times Hours$

Where:

NE_{work} is net energy for work, MJ day^{-1} and Hours is the average number of hours of work per calendar day.

The source of data on hours are described in Annex 6. It is assumed that only oxen do work, and the value of hours applied to adult males has been weighted by the proportion of oxen in adult males. In the intensive system, a value of 0.003 hours is used and in the semi-intensive and extensive systems a value of 0.3 hours is used. This is lower than the IPCC default value for work hours for other cattle in Africa (IPCC 2006, Table 10A.2), reflecting that most work is done by non-dairy breeds in Kenya.

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 obtained from published literature, unpublished survey data and feed nutrient databases (see Annex 3). The values for DE% used in the inventory are shown in ***Table 11***. The estimated feed digestibility values for different dairy cattle sub-categories in different years range between 54.1% and 61.5%, whereas the IPCC default value for dairy cattle in Africa is 60% (IPCC 2006, Table 10A.1). The trend in estimated feed digestibility is mainly due to assumptions about the change in proportions of dairy cattle raised in different feeding systems (i.e. zero-grazing, semi-zero grazing and grazing only systems), whereby an increase in zero- or semi-zero grazing is associated with a decrease in average digestibility of the diet, which is partially offset by the increasing use of commercial concentrate over time. Details of the data, assumptions and methods used are given in Annex 3.

Table 11: Time series for feed digestibility (%) for dairy cattle sub-categories in each production system (1995-2017)

	Intensive system					Semi-intensive system					Extensive system				
	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves
1995	59.52	57.48	57.96	54.12	57.88	60.85	60.21	60.21	60.21	60.21	60.85	60.21	60.21	60.21	60.21
1996	59.51	57.50	58.00	54.19	57.87	60.90	60.20	60.20	60.20	60.20	60.90	60.20	60.20	60.20	60.20
1997	59.51	57.52	58.03	54.26	57.86	60.95	60.20	60.20	60.20	60.20	60.95	60.20	60.20	60.20	60.20
1998	59.50	57.54	58.07	54.33	57.86	61.00	60.19	60.19	60.19	60.19	61.00	60.19	60.19	60.19	60.19
1999	59.50	57.56	58.11	54.40	57.85	61.06	60.18	60.18	60.18	60.18	61.06	60.18	60.18	60.18	60.18
2000	59.49	57.58	58.14	54.47	57.85	61.11	60.18	60.18	60.18	60.18	61.11	60.18	60.18	60.18	60.18
2001	59.49	57.60	58.18	54.54	57.84	61.16	60.17	60.17	60.17	60.17	61.16	60.17	60.17	60.17	60.17
2002	59.48	57.62	58.21	54.61	57.83	61.21	60.16	60.16	60.16	60.16	61.21	60.16	60.16	60.16	60.16
2003	59.47	57.64	58.25	54.67	57.83	61.27	60.15	60.15	60.15	60.15	61.27	60.15	60.15	60.15	60.15
2004	59.47	57.66	58.29	54.74	57.82	61.32	60.15	60.15	60.15	60.15	61.32	60.15	60.15	60.15	60.15
2005	59.46	57.69	58.32	54.81	57.82	61.37	60.14	60.14	60.14	60.14	61.37	60.14	60.14	60.14	60.14
2006	59.46	57.71	58.36	54.88	57.81	61.43	60.13	60.13	60.13	60.13	61.43	60.13	60.13	60.13	60.13
2007	59.45	57.73	58.39	54.95	57.81	61.48	60.13	60.13	60.13	60.13	61.48	60.13	60.13	60.13	60.13
2008	59.44	57.75	58.43	55.02	57.80	61.53	60.12	60.12	60.12	60.12	61.53	60.12	60.12	60.12	60.12
2009	59.44	57.77	58.46	55.09	57.79	61.53	60.07	60.07	60.07	60.07	61.53	60.07	60.07	60.07	60.07
2010	59.43	57.79	58.50	55.16	57.79	61.53	60.03	60.03	60.03	60.03	61.53	60.03	60.03	60.03	60.03
2011	59.43	57.81	58.54	55.23	57.78	61.52	59.98	59.98	59.98	59.98	61.52	59.98	59.98	59.98	59.98
2012	59.42	57.83	58.57	55.30	57.78	61.52	59.93	59.93	59.93	59.93	61.52	59.93	59.93	59.93	59.93
2013	59.42	57.85	58.61	55.37	57.77	61.52	59.89	59.89	59.89	59.89	61.52	59.89	59.89	59.89	59.89
2014	59.41	57.87	58.64	55.43	57.76	61.52	59.84	59.84	59.84	59.84	61.52	59.84	59.84	59.84	59.84
2015	59.40	57.90	58.68	55.50	57.76	61.51	59.79	59.79	59.79	59.79	61.51	59.79	59.79	59.79	59.79
2016	59.40	57.92	58.71	55.57	57.75	61.51	59.75	59.75	59.75	59.75	61.51	59.75	59.75	59.75	59.75
2017	59.39	57.94	58.75	55.64	57.75	61.51	59.70	59.70	59.70	59.70	61.51	59.70	59.70	59.70	59.70

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 12***. The estimated gross energy was cross-checked against the implied dry matter intake (DMI) using IPCC equations 10.17 and 10.18. The estimated DMI was in the range of 2.3%-2.8% of body weight for most animal types and 3.1%-3.5% for calves. Except for calves, this is within the range of 2-3% of body weight recommended by the IPCC (2006). The higher ratio of estimated DMI to body weight for calves and other growing animals has been widely reported in the literature.

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%. The resulting emission factors and implied emission factors (i.e. population-weighted emission factors) for each year are shown in ***Table 13***. The implied emission factor increases over time but is lower than the IPCC Tier 1 default value for dairy cattle in Africa (IPCC 2006, Table 10.11). This is because the Tier 1 default for dairy only includes the emission factor for lactating cows, while the implied emission factor includes all dairy cattle sub-categories. The emission factors range from 13.45 to 52.26 kg CH_4 head^{-1} year^{-1} dependant on sub-category, production system and year. The Tier 1 default for Other Cattle is 31 kg CH_4 head^{-1} year^{-1}, which is between the emission factors determined for the dairy cattle categories other than cows.

The IPCC Tier 1 default emission factor for cows (i.e. 46 kg CH_4 head^{-1} year^{-1}) was derived on the basis of assumed characteristics of a lactating dairy cow in Africa and the Middle East (annual milk yield 475 kg head^{-1} year^{-1}, see IPCC 2006, Table A10.1). The emission factors for dairy cows estimated in this inventory range between 51 and 74 kg CH_4 head^{-1} year^{-1}, which are all higher than the IPCC Tier 1 default emission factor. We have assumed an annual milk yield of between 1732 kg and 2458 kg head^{-1} year^{-1} dependant on the production system and year (Annex 5) in the inventory. Further discussion on the differences between the defaults and calculated emission factors can be found in section 2.4.

Total emissions from dairy cattle from enteric fermentation in each year between 1995-2017 are given in **Table 2**.

Table 12: Time series for gross energy (MJ head^{-1} day^{-1}) for dairy cattle sub-categories in each production system (1995-2017)

	Intensive system					Semi-intensive system					Extensive system				
	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves
1995	152.70	107.03	122.58	107.94	52.88	120.01	91.62	87.62	77.26	33.15	120.01	91.62	87.62	77.26	33.15
1996	153.72	107.09	122.46	107.68	52.97	120.06	91.69	87.70	77.32	33.18	120.06	91.69	87.70	77.32	33.18
1997	154.75	107.16	122.33	107.43	53.05	120.12	91.76	87.79	77.39	33.21	120.12	91.76	87.79	77.39	33.21
1998	155.78	107.22	122.20	107.17	53.14	120.17	91.83	87.87	77.46	33.23	120.22	91.83	87.87	77.46	33.23
1999	156.81	107.29	122.08	106.92	53.22	120.23	91.91	87.96	77.53	33.26	120.23	91.91	87.96	77.53	33.26
2000	157.86	107.35	121.95	106.67	53.31	120.28	91.98	88.04	77.60	33.29	120.28	91.98	88.04	77.60	33.29
2001	158.90	107.41	121.83	106.41	53.39	120.34	92.05	88.12	77.66	33.31	120.34	92.05	88.12	77.66	33.31
2002	159.96	107.48	121.70	106.16	53.48	120.39	92.12	88.21	77.73	33.34	120.39	92.12	88.21	77.73	33.34
2003	161.02	107.54	121.58	105.92	53.57	120.45	92.19	88.29	77.80	33.37	120.45	92.19	88.29	77.80	33.37
2004	162.08	107.61	121.46	105.67	53.65	120.50	92.27	88.37	77.87	33.39	120.50	92.27	88.37	77.87	33.39
2005	163.15	107.67	121.33	105.42	53.74	120.56	92.34	88.46	77.93	33.42	120.56	92.34	88.46	77.93	33.42
2006	164.23	107.73	121.21	105.18	53.82	120.61	92.41	88.54	78.00	33.45	120.61	92.41	88.54	78.00	33.45
2007	165.31	107.80	121.09	104.94	53.91	120.67	92.48	88.62	78.07	33.47	120.67	92.48	88.62	78.07	33.47
2008	166.40	107.86	120.96	104.69	53.99	120.72	92.55	88.71	78.14	33.50	120.72	92.55	88.71	78.14	33.50
2009	167.05	107.81	120.84	104.45	54.01	120.94	92.73	88.88	78.29	33.56	120.94	92.73	88.88	78.29	33.56
2010	167.71	107.75	120.72	104.21	54.03	121.16	92.92	89.06	78.44	33.63	121.16	92.92	89.06	78.44	33.63
2011	168.37	107.69	120.60	103.98	54.05	121.38	93.10	89.23	78.60	33.70	121.38	93.10	89.23	78.60	33.70
2012	169.03	107.64	120.48	103.74	54.07	121.60	93.28	89.41	78.75	33.76	121.60	93.28	89.41	78.75	33.76
2013	169.69	107.58	120.36	103.50	54.09	121.82	93.46	89.58	78.91	33.83	121.82	93.46	89.58	78.91	33.83
2014	170.35	107.53	120.23	103.27	54.11	122.04	93.65	89.76	79.06	33.89	122.04	93.65	89.76	79.06	33.89
2015	171.01	107.47	120.11	103.04	54.13	122.27	93.83	89.94	79.22	33.96	122.27	93.83	89.94	79.22	33.96
2016	171.68	107.41	119.99	102.80	54.15	122.49	94.01	90.11	79.37	34.03	122.49	94.01	90.11	79.37	34.03
2017	172.34	107.36	119.87	102.57	54.17	122.71	94.20	90.29	79.53	34.09	122.71	94.20	90.29	79.53	34.09

Table 13: Time series for emission factors (kg CH_4 head^{-1} year^{-1}) for dairy cattle sub-categories in each production system (1995-2017)

	Intensive system					Semi-intensive system					Extensive system					Implied emission factor
	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves	
1995	65.10	45.63	52.26	46.02	22.54	51.16	39.06	37.35	32.94	14.13	51.16	39.06	37.35	32.94	14.13	39.51
1996	65.54	45.66	52.21	45.91	22.58	51.19	39.09	37.39	32.97	14.15	51.19	39.09	37.39	32.97	14.15	39.99
1997	65.97	45.68	52.15	45.80	22.62	51.21	39.12	37.43	32.99	14.16	51.21	39.12	37.43	32.99	14.16	39.82
1998	66.41	45.71	52.10	45.69	22.65	51.23	39.15	37.46	33.02	14.17	51.25	39.15	37.46	33.02	14.17	40.12
1999	66.85	45.74	52.05	45.58	22.69	51.26	39.18	37.50	33.05	14.18	51.26	39.18	37.50	33.05	14.18	40.18
2000	67.30	45.77	51.99	45.47	22.73	51.28	39.21	37.53	33.08	14.19	51.28	39.21	37.53	33.08	14.19	39.88
2001	67.74	45.79	51.94	45.37	22.76	51.30	39.24	37.57	33.11	14.20	51.30	39.24	37.57	33.11	14.20	40.56
2002	68.19	45.82	51.89	45.26	22.80	51.33	39.27	37.60	33.14	14.21	51.33	39.27	37.60	33.14	14.21	40.63
2003	68.65	45.85	51.83	45.15	22.84	51.35	39.30	37.64	33.17	14.22	51.35	39.30	37.64	33.17	14.22	40.97
2004	69.10	45.88	51.78	45.05	22.87	51.37	39.34	37.68	33.20	14.24	51.37	39.34	37.68	33.20	14.24	40.88
2005	69.56	45.90	51.73	44.94	22.91	51.40	39.37	37.71	33.23	14.25	51.40	39.37	37.71	33.23	14.25	40.93
2006	70.01	45.93	51.67	44.84	22.95	51.42	39.40	37.75	33.25	14.26	51.42	39.40	37.75	33.25	14.26	41.48
2007	70.48	45.96	51.62	44.74	22.98	51.44	39.43	37.78	33.28	14.27	51.44	39.43	37.78	33.28	14.27	41.19
2008	70.94	45.98	51.57	44.63	23.02	51.47	39.46	37.82	33.31	14.28	51.47	39.46	37.82	33.31	14.28	41.38
2009	71.22	45.96	51.52	44.53	23.03	51.56	39.54	37.89	33.38	14.31	51.56	39.54	37.89	33.38	14.31	41.72
2010	71.50	45.94	51.47	44.43	23.04	51.65	39.61	37.97	33.44	14.34	51.65	39.61	37.97	33.44	14.34	41.30
2011	71.78	45.91	51.41	44.33	23.04	51.75	39.69	38.04	33.51	14.37	51.75	39.69	38.04	33.51	14.37	41.35
2012	72.06	45.89	51.36	44.23	23.05	51.84	39.77	38.12	33.57	14.39	51.84	39.77	38.12	33.57	14.39	41.31
2013	72.34	45.86	51.31	44.13	23.06	51.94	39.85	38.19	33.64	14.42	51.94	39.85	38.19	33.64	14.42	41.37
2014	72.62	45.84	51.26	44.03	23.07	52.03	39.92	38.27	33.71	14.45	52.03	39.92	38.27	33.71	14.45	41.83
2015	72.91	45.82	51.21	43.93	23.08	52.13	40.00	38.34	33.77	14.48	52.13	40.00	38.34	33.77	14.48	42.05
2016	73.19	45.79	51.16	43.83	23.09	52.22	40.08	38.42	33.84	14.51	52.22	40.08	38.42	33.84	14.51	41.75
2017	73.47	45.77	51.10	43.73	23.10	52.31	40.16	38.49	33.91	14.54	52.31	40.16	38.49	33.91	14.54	41.98

2.3 Uncertainties and time-series consistency

Annex 9 gives the main results of uncertainty analysis conducted using Monte Carlo simulation. Uncertainty of 2017 total enteric fermentation emissions was (+14.68%,-12.92%). Uncertainty is most strongly correlated with the proportion of the total herd in the semi-intensive system and the proportion of cows in the herd in the semi-intensive system, because the semi-intensive system accounts for just over 50% of the national herd. Among input variables to the emissions per head, feed digestibility (DE%), the methane conversion factor (Ym), live weight and weight gain are key variables, especially for cows, heifers and calves, which together account for >80% of the herd in each production system.

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

2.4 Source-specific QA/QC 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.

Quality assurance was also provided by a thorough review by an international reviewer.[2]

For verification, the estimated emission factors were compared with IPCC default values and emission factors used in other countries' national GHG inventories, and with publications for Sub-Saharan Africa. The IPCC default emission factor for dairy cows in Africa and the Middle East is 46 kg CH_4 head^{-1} year^{-1}, assuming a live weight of 275 kg, 60% feed digestibility and a milk yield of 1.3 kg head^{-1} day^{-1}. In the intensive system, live weights of adult cows are estimated to be 28.7% - 33% higher than the IPCC default value and milk yields are 200% - 287% higher. The emission factors are 41.5% - 59.7% higher than the IPCC default value. The average of the emission factor time series for cows in the intensive system (i.e. 69.69 kg CH_4 head^{-1} year^{-1}) is most similar to the IPCC default emission factor for Asia (i.e. 68 kg) which assumes live weight of 350 kg, digestibility of 60% and milk yield of 4.5 kg per day. In the inventory, the emission factor for cows in the intensive system does become higher than the Asia default from about 2003. With similar digestibility values throughout the time series, the increase in emission factor is to be expected as the milk yield for cows in the intensive system is higher than those in Asia.

For cows in the semi-intensive system, the average emission factor (i.e. 51.56 kg CH_4 head^{-1} year^{-1}) is slightly higher than the IPCC default for Africa and the Middle East (i.e. 46 kg CH_4 head^{-1} year^{-1}). The default emission factor assumes a live weight of 275 kg (i.e. slightly higher than in this inventory) and

[2] Andrea Pickering (Ministry for Primary Industries, New Zealand).

daily milk yield of 1.3 kg (i.e. much lower than the average of 4.87 kg in this inventory). Although milk yield is similar to that assumed in the default value for Asia, live weight in the semi-intensive system is much lower, hence the average emission factor is lower than the default for Asia (i.e. 68 kg).

A database containing 155 emission factors for cattle from the IPCC GPG and countries' submissions to the UNFCCC was used to cross-check the emission factors estimated in this inventory.[3] The relationships between live weight and milk yield and the emission factors in that database are shown in Figures 3 and 4. The estimated emission factors in this inventory compare well with the predicted emission factors given the live weight estimates used. For milk yield, the Kenyan Tier 2 emission factors are slightly lower than would be predicted on average, which probably reflects the low productivity in Kenya in comparison to the animals' potential. Apart from the IPCC default factors, no other entry in the database reflected conditions in Sub-Saharan Africa. Du Toit et al. (2013) estimated emission factors for dairy cattle in South Africa using a model based on Australian research. With much larger (ca. 580 kg) and more productive (ca. 10.5 kg milk per day) animals, the emission factors for cows in South Africa were higher (132 kg CH_4 head^{-1} year^{-1}) than in this inventory. Estimated emission factors for South African dairy heifers (i.e. 52-61 kg CH_4 head^{-1} year^{-1}) were more similar to emission factors for cows in this inventory, which can be explained by the similar live weights between heifers in South Africa and cows in Kenya.

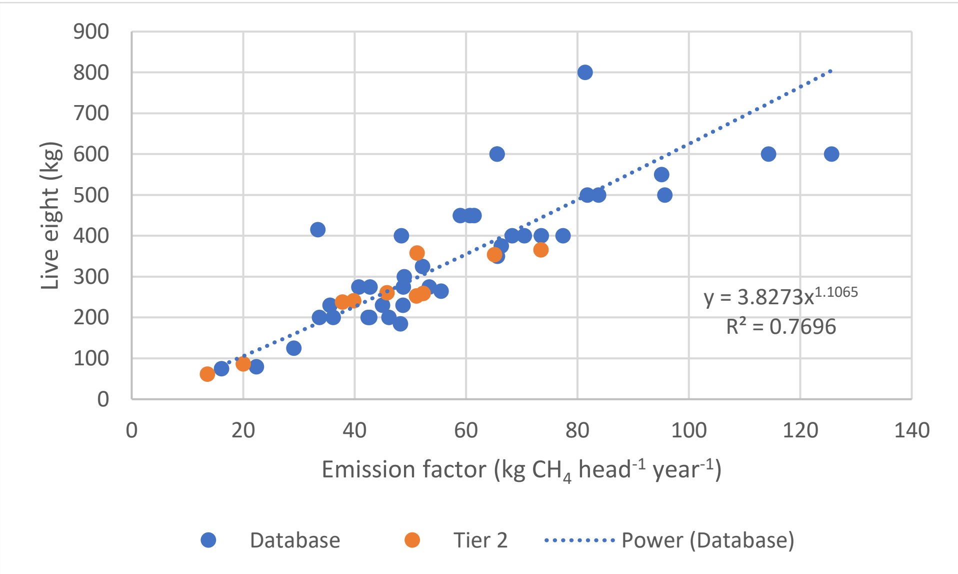

Figure 3: Relationship between live weight and average emission factors from this inventory (Tier 2) compared to emission factors in the IPCC GPG and other countries' submissions to the UNFCCC (Database)

[3] Thorley et al. (2019), in which all emission factors come from IPCC guidelines or national communications, national inventory reports or BUR submissions to the UNFCCC and use the IPCC model in their estimations.

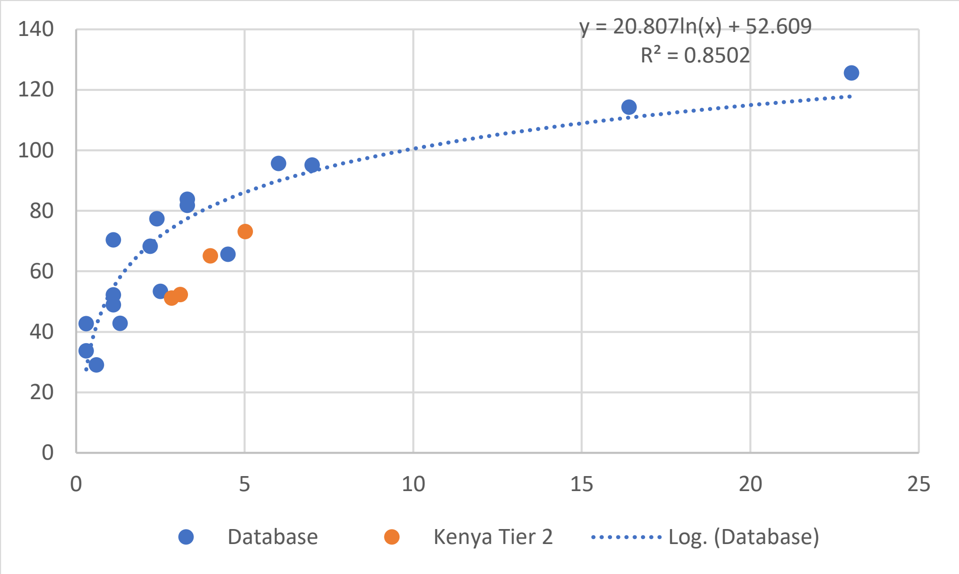

Figure 4: Relationship between milk yield and average emission factors from this inventory (Kenya Tier 2) compared to emission factors in the IPCC GPG and other countries' submissions to the UNFCCC (Database)

Two recent publications (Goopy et al. 2018b, Ndung'u et al. 2018) report estimated emission factors from sites in Kenya. Those studies used an emissions model based on equations developed in Australia, rather than the IPCC model which was used here. Figure 5 illustrates a broadly similar relationship between live weight and the emission factors from those publications and this inventory. The published values are over a smaller range of live weight and the best-fit relationship is not linear, whereas those produced with the IPCC model for the inventory are best described by a linear equation across the range of live weights used in the inventory.

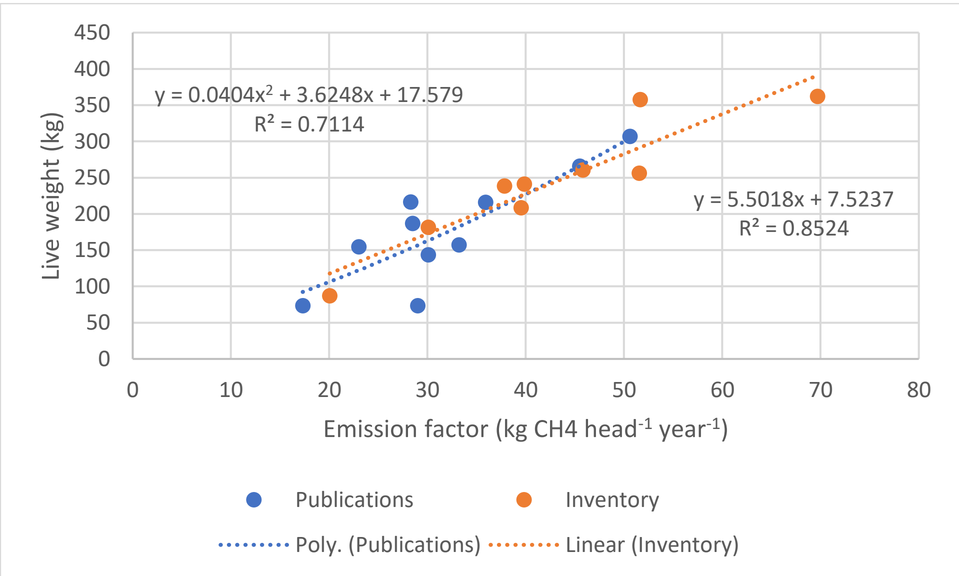

Figure 5: Relationship between live weight and emission factors in literature reports from Kenya and this inventory

2.5 Source-specific recalculations

Both the activity data and emission factors used in this inventory differ from those used in Kenya's Second National Communication (2012). The reason is that the official dairy cattle population time series has been revised through numerous efforts of the State Department of Livestock, particularly in light of the data from the 2009 agricultural census. ***Table 14*** compares the activity data, implied emission factors and total enteric fermentation emissions calculated using the Tier 2 approach with the previous time series that was calculated using the Tier 1 approach. The revised activity data shows an increase in 10 of the 16 years (1995-2010) compared to the earlier population time series. However, with a lower implied emission factor than the IPCC Tier 1 default value for the entire time series, total emissions are lower than those estimated using the Tier 1 approach for all years. Figure 6 provides a visual comparison of estimates in the Second National Communication, using a Tier 1 approach and the revised activity data, and using a Tier 2 approach with the revised activity data.

Table 14: Comparison of Second National Communication time series with Tier 2 inventory time series (1995-2010)

	Second National Communication			**Tier 2 inventory**		
	population	EF (kg CH_4 hd^{-1} yr^{-1})	Gg CH_4	population	IEF (kg CH_4 hd^{-1} yr^{-1})	Gg CH_4
1995	3,449,951	46	158.70	3,255,468	39.51	128.63
1996	3,391,302	46	156.00	3,355,181	39.99	134.17
1997	3,054,985	46	140.53	3,281,542	39.82	130.68
1998	3,027,597	46	139.27	3,442,423	40.12	138.11
1999	3,101,506	46	142.67	3,435,120	40.18	138.01
2000	3,369,417	46	154.99	3,335,902	39.88	133.04
2001	3,288,327	46	151.26	3,442,732	40.56	139.65
2002	3,505,678	46	161.26	3,551,137	40.63	144.27
2003	3,473,421	46	159.78	3,665,375	40.97	150.18
2004	3,448,270	46	158.62	3,605,486	40.88	147.39
2005	3,497,563	46	160.89	3,579,440	40.93	146.52
2006	3,298,347	46	151.72	3,638,996	41.48	150.95
2007	3,579,437	46	164.65	3,667,724	41.19	151.07
2008	3,403,346	46	156.55	3,403,321	41.38	140.84
2009	3,310,898	46	152.30	3,310,877	41.72	138.12
2010	3,673,212	46	168.97	3,386,594	41.30	139.86
2011	-	-	-	3,739,604	41.35	154.62
2012	-	-	-	4,158,353	41.31	171.77
2013	-	-	-	4,505,582	41.37	186.40
2014	-	-	-	4,316,152	41.83	180.53
2015	-	-	-	4,242,108	42.05	178.36
2016	-	-	-	4,505,731	41.75	188.14
2017	-	-	-	4,573,848	41.98	192.02

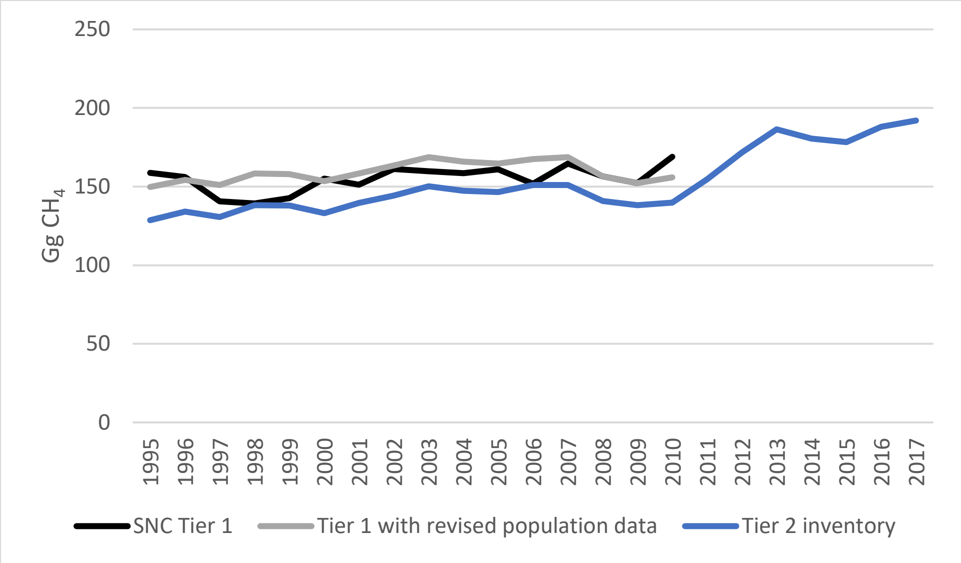

Figure 6: Time series for dairy cattle enteric fermentation emissions using the Tier 1 and Tier 2 approaches (1995-2017)

2.6 Source-specific improvements

Annex 10 discusses priorities for improvements to this inventory. For enteric fermentation emissions, these improvements include:

- Cross-check and validate or adjust allocation of counties to production systems;
- Conduct representative sample surveys in extensive and semi-intensive production systems to collect more accurate estimates of activity data used in the Tier 2 enteric fermentation model; and
- Research to develop cost-effective methods for accurate representation of diet composition for different dairy cattle sub-categories and feeding systems.

In the longer-term, improving the accuracy of dairy cattle population and milk yield estimates collected by local governments is a priority. The State Department of Livestock plans to work with development partners to improve the administrative data collection system to achieve this longer-term objective.

3. 3A2 Manure management, dairy cattle

3.1 Source category description

Emissions sources	Sources included	Method	Emission factors
	Dairy cattle manure management	T2	CS
Gases reported	CH_4, N_2O		
Completeness	All dairy cattle 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 emissions of CH_4 and direct N_2O emissions from management of manure from dairy cattle. The literature for Kenya identifies & main types of manure management system (not including deposit of dung and urine on pasture, which is reported under managed soils):

- Daily spread: Manure is removed daily from where animals are kept and applied to fodder or food crops. This system is common for households with zero-grazing units.
- Dry lot: Dung is deposited on the hard surface where animals are kept and removed periodically.
- Solid storage: Manure is stored in heaps in the farm yard.
- Deep bedding: Manure is mixed with other organic material and left as bedding. The bedding is mostly removed only after several months. This is common in households with open boma (kraals)
- Compost: Manure and other organic material in bedding is composted.
- Liquid slurry: Some zero-grazing units have drainage systems feeding into slurry pits. In some households, manure is stored in pits, which often gets inundated with rainwater.

These manure management systems may be associated with different housing types (e.g. traditional or improved bomas and zero-grazing units), but this association is currently not well documented. Specific manure management practices have also not been documented in detail.

3.2 Methodological issues

3.2.1 Methane emissions from manure management

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 cattle sub-category, T, kg CH_4 head^{-1} year^{-1}
VS_T is daily volatile solids excreted by cattle 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 were identified for B_o or MCF, so the IPCC default values for Africa (IPCC 2006, Table 10A-4) were used.[4] Country specific manure management system activity data ($MS_{T,S,k}$) were estimated using data and methods described in Annex 7. The methane emission factors thus derived are shown in ***Table 15***. These were multiplied by population numbers of the relevant category in each year and the resulting time series for methane emissions from manure management is shown in ***Table 16***.

[4] Note, however, that the IPCC default values are based on Safley (1992), which used limited data to estimate Bo values for developing countries. Further examination should consider whether the Bo values for Africa are the most applicable to Kenyan dairy production systems.

Table 15: Manure management methane emission factors (kg CH_4 head^{-1} year^{-1}) and Methane Emissions (Gg CH_4) for dairy cattle sub-categories in each production system (1995-2017)

	Intensive system					Semi-intensive system					Extensive system					Implied emission factor	Methane Emissions Gg CH_4
	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves		
1995	6.76	5.02	5.35	4.85	2.45	3.31	2.45	2.35	2.07	0.89	3.88	2.87	2.74	2.42	1.04	3.16	10.29
1996	6.84	5.04	5.37	4.86	2.47	3.33	2.47	2.36	2.08	0.89	3.91	2.89	2.76	2.44	1.05	3.26	10.95
1997	6.91	5.06	5.38	4.87	2.48	3.35	2.49	2.38	2.10	0.90	3.94	2.91	2.79	2.46	1.05	3.24	10.63
1998	6.98	5.08	5.40	4.88	2.49	3.37	2.51	2.40	2.11	0.91	3.96	2.93	2.81	2.47	1.06	3.30	11.35
1999	7.06	5.10	5.42	4.88	2.51	3.39	2.53	2.42	2.13	0.91	3.99	2.96	2.83	2.49	1.07	4.12	11.40
2000	7.13	5.11	5.43	4.89	2.52	3.41	2.54	2.43	2.15	0.92	4.01	2.98	2.85	2.51	1.08	4.06	10.90
2001	7.20	5.13	5.45	4.90	2.53	3.44	2.56	2.45	2.16	0.93	4.04	3.00	2.87	2.53	1.09	4.22	11.74
2002	7.28	5.15	5.46	4.91	2.55	3.46	2.58	2.47	2.18	0.93	4.07	3.02	2.89	2.55	1.09	4.22	12.13
2003	7.36	5.17	5.48	4.92	2.56	3.48	2.60	2.49	2.19	0.94	4.09	3.04	2.91	2.57	1.10	4.29	12.79
2004	7.43	5.19	5.50	4.93	2.57	3.50	2.61	2.50	2.21	0.95	4.12	3.07	2.94	2.59	1.11	4.25	12.47
2005	7.51	5.21	5.51	4.94	2.59	3.52	2.63	2.52	2.22	0.95	4.14	3.09	2.96	2.61	1.12	4.28	12.46
2006	7.59	5.23	5.53	4.94	2.60	3.54	2.65	2.54	2.24	0.96	4.17	3.11	2.98	2.63	1.13	4.45	13.16
2007	7.67	5.25	5.54	4.95	2.61	3.56	2.67	2.56	2.25	0.97	4.20	3.13	3.00	2.64	1.13	4.39	13.06
2008	7.75	5.26	5.56	4.96	2.63	3.58	2.69	2.58	2.27	0.97	4.22	3.15	3.02	2.66	1.14	4.43	12.26
2009	7.79	5.26	5.56	4.95	2.63	3.61	2.72	2.61	2.29	0.98	4.26	3.19	3.06	2.70	1.16	4.50	12.19
2010	7.83	5.26	5.56	4.95	2.64	3.65	2.75	2.63	2.32	1.00	4.31	3.24	3.10	2.73	1.17	4.38	12.12
2011	7.87	5.26	5.56	4.94	2.64	3.68	2.78	2.66	2.35	1.01	4.35	3.28	3.14	2.77	1.19	4.39	13.45
2012	7.91	5.26	5.56	4.94	2.64	3.71	2.81	2.69	2.37	1.02	4.39	3.32	3.18	2.80	1.20	4.38	14.89
2013	7.95	5.26	5.56	4.94	2.65	3.74	2.84	2.73	2.40	1.03	4.43	3.36	3.22	2.83	1.22	4.40	16.22
2014	7.99	5.26	5.57	4.93	2.65	3.78	2.87	2.76	2.43	1.04	4.48	3.40	3.26	2.87	1.23	4.54	16.02
2015	8.03	5.26	5.57	4.93	2.65	3.81	2.91	2.79	2.45	1.05	4.52	3.44	3.30	2.90	1.25	4.60	15.96
2016	8.07	5.26	5.57	4.92	2.66	3.84	2.94	2.82	2.48	1.06	4.56	3.48	3.34	2.94	1.26	4.54	16.72
2017	8.11	5.26	5.57	4.92	2.66	3.88	2.97	2.85	2.51	1.08	4.61	3.52	3.38	2.98	1.28	4.60	17.22

3.2.2 Direct N_2O emissions from 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 Section 5. Emission factors for direct N_2O emissions were calculated using the IPCC Tier 2 approach by applying IPCC (2006) Equation 10.25:

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

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 (2006) Equations 10.31-10.33. The data sources and values used for crude protein content of the diet (CP%) are shown in Annex 8. 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, NEg) 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 7). The emission factors, EF_3, used were the IPCC default emission factors from 10.21 (***Table 16***). The resulting time series for direct N_2O emissions is shown in ***Table 17***.

Table 16: 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 2006 Table 10.21
Solid storage (e.g. heap)	0.005	IPCC 2006 Table 10.21
Dry lot (e.g. periodic removal from confinement area)	0.02	IPCC 2006 Table 10.21
Composted (static pile)	0.006	IPCC 2006 Table 10.21
Liquid (e.g. pit)	0.005	IPCC 2006 Table 10.21
Biogas	0	IPCC 2006 Table 10.21
Deep bedding	0.01	IPCC 2006 Table 10.21

Table 17: Direct N_2O emissions from manure management from dairy cattle, Kg N_2O, 1995-2017

Year	Kg N_2O		Year	Kg N_2O		Year	Kg N_2O		Year	Kg N_2O		Year	Kg N_2O		Year	Kg N_2O
1995	433,650		**1999**	474,906		**2003**	529,104		**2007**	535,231		**2011**	545,269		**2015**	639,888
1996	459,620		**2000**	453,227		**2004**	514,864		**2008**	500,382		**2012**	600,478		**2016**	670,221
1997	445,349		**2001**	487,105		**2005**	512,988		**2009**	497,341		**2013**	650,990		**2017**	634,589
1998	474,038		**2002**	502,444		**2006**	541,118		**2010**	493,473		**2014**	641,736			

3.3 Uncertainties and time-series consistency

Annex 9 gives the main results of uncertainty analysis conducted using Monte Carlo simulation. Uncertainty of 2017 total methane emissions from manure management was (+24.39%,-20.65%), and for direct nitrous oxide emissions it was (+27.78%,-23.48%). For methane emissions, uncertainty is most strongly correlated with MCFs, MMS, DE% and proportion of different animal sub-categories in the herd, especially for the semi-intensive system, which accounts for just over 50% of the national herd. For direct nitrous oxide emissions from manure management uncertainty is most strongly correlated with crude protein content of the diet and DE% for cows, and EF_3 for solid storage. A consistent method was used to estimate emissions in each year of the time series.

3.4 Source-specific QA/QC 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.

For verification, the estimated emission factors were compared with IPCC default values and emission factors used in other countries' national GHG inventories.

3.5 Source-specific recalculations

Tier 1 emissions using activity data reported in the Second National Communication were reconstructed for methane and direct nitrous oxide emissions from manure management (

Table 18). The reconstructed SNC time series used the IPCC (2006) default values for MMS and emission factors. Methane emissions are about 3.5 times higher in the Tier 2 time series. This is because (a) the Tier 2 implied emission factor was about 4 kg CH_4 head^{-1} year^{-1} between 1995 and 2010, and (b) the Tier 2 time series uses revised livestock population data. Nitrous oxide emissions are similar when estimated using Tier 1 and Tier 2 methods. The Tier 1 default value for Nex was 60 kg N head^{-1} year^{-1}, whereas the Tier 2 weighted average value for Nex was about 31.19 kg N head^{-1} year^{-1}, but the IPCC default MMS values for Africa assume 83% manure deposited on pasture, which is much higher than in the Tier 2 inventory.

Table 18 Recalculated estimates of methane and direct nitrous oxide emissions from manure management 1995-2010

	Methane (Gg CH_4)		Nitrous Oxide (kg N_2O)	
	SNC 2 Tier 1	Tier 2	SNC 2 Tier 1	Tier 2
1995	3.45	10.29	460,010	433,650
1996	3.39	10.95	452,190	459,620
1997	3.05	10.63	407,346	445,349
1998	3.03	11.35	403,694	474,038
1999	3.10	11.40	413,549	474,906
2000	3.37	10.90	449,272	453,227
2001	3.29	11.74	438,459	487,105
2002	3.51	12.13	467,441	502,444
2003	3.47	12.79	463,140	529,104
2004	3.45	12.47	459,786	514,864
2005	3.50	12.46	466,359	512,988
2006	3.30	13.16	439,795	541,118
2007	3.58	13.06	477,276	535,231
2008	3.40	12.26	453,796	500,382
2009	3.31	12.19	441,469	497,341
2010	3.67	12.12	489,779	493,473

3.6 Source-specific improvements

Annex 10 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.

4 3C6 Indirect emissions of nitrous oxide from manure management

4.1 Source category description

Emissions sources	Sources included	Method	Emission factors
	Dairy cattle manure management	T2	CS
Gases reported	N_2O		
Completeness	All dairy cattle 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 management of manure from dairy cattle.

4.2 Methodological issues

Following IPCC (2006, page 10.56), this source category only includes N losses from volatilization. N losses from leaching, while they have been reported in relation to manure management Kenya, are not included because of the lack of country-specific information on the fraction of N loss due to leaching and runoff.

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

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

Where:

$N_{volatilization\text{ - }MMS}$ 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:

$N_2O_{G(mm)}$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)$^{-1}$.

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)$^{-1}$.

The data sources and values used for crude protein content of the diet (CP%) are shown in Annex 8. Milk protein content (milk PR%) used a default value of 3.5% (IPCC 2006, page 10.60). Other values used in these calculations (GE, milk, WG, NEg) 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 7). The emission factor, EF_4, used the IPCC default emission factor from IPCC (2006) Table 11.3. Fracgas was taken from IPCC (2006) Table 10.22 (see ***Table 19***). The value of Fracgas used for compost and deep bedding used the value for deep bedding for 'other cattle' in the absence of specific guidance for dairy cattle. The resulting time series for direct N_2O emissions is shown in ***Table 19***.

Table 19: Fraction of nitrogen lost due to volatilization (Fracgas) used in estimating indirect N_2O emissions from manure management

Manure management system	Fracgas	Source
Daily spread	7%	IPCC 2006 Table 10.22
Solid storage (e.g. heap)	30%	IPCC 2006 Table 10.22
Dry lot (e.g. periodic removal from confinement area)	20%	IPCC 2006 Table 10.22
Composted (static pile)	30%	Value for deep bedding for 'other cattle' in IPCC 2006 Table 10.22
Liquid (e.g. pit)	40%	IPCC 2006 Table 10.22
Biogas	0%	-
Deep bedding	30%	Value for 'other cattle' in IPCC 2006 Table 10.22

Table 20: Indirect N_2O emissions from manure management from dairy cattle, Kg N_2O, 1995-2017

Year	Kg N_2O		Year	Kg N_2O		Year	Kg N_2O		Year	Kg N_2O		Year	Kg N_2O		Year	Kg N_2O
1995	246,088		**1999**	270,976		**2003**	302,200		**2007**	308,127		**2011**	318,836		**2015**	378,956
1996	260,462		**2000**	259,869		**2004**	295,464		**2008**	288,781		**2012**	354,655		**2016**	399,291
1997	253,391		**2001**	277,993		**2005**	294,956		**2009**	286,275		**2013**	386,977		**2017**	411,032
1998	269,947		**2002**	287,484		**2006**	309,528		**2010**	286,421		**2014**	380,529			

4.3 Uncertainties and time-series consistency

Annex 9 gives the main results of uncertainty analysis conducted using Monte Carlo simulation. Uncertainty of 2017 for total indirect nitrous oxide emissions was (+80.52%,-48.97%). For indirect nitrous oxide emissions from manure management the most sensitive factors affecting emissions were EF_4, crude protein content of diet (CP%) and feed digestibility (DE%).

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

4.4 Source-specific QA/QC 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 several the calculations to cross-check the intermediate calculations and results in the inventory spreadsheet.

4.5 Source-specific recalculations

Tier 1 emissions using activity data reported in the Second National Communication were reconstructed for indirect direct nitrous oxide emissions from manure management (Table 20). The reconstructed SNC time series used the IPCC (2006) default values for MMS and emission factors. The Tier 2 estimates are about half the Tier 1 estimates. The Tier 1 default value for Nex was 60 kg N head^{-1} year^{-1}, whereas the Tier 2 weighted average value for Nex was about 31.19 kg N head^{-1} year^{-1}, but the IPCC default MMS values for Africa assume 83% manure deposited on pasture, which is much higher than in the Tier 2 inventory.

Table 21 Recalculated estimates of indirect nitrous oxide emissions from manure management 1995-2010

	Nitrous oxide (Kg N_2O)	
	SNC 2 Tier 1	**Tier 2**
1995	563,214	246,088
1996	553,639	260,462
1997	498,735	253,391
1998	494,264	269,947
1999	506,329	270,976
2000	550,067	259,869
2001	536,828	277,993
2002	572,312	287,484
2003	567,046	302,200
2004	562,940	295,464
2005	570,987	294,956
2006	538,464	309,528
2007	584,353	308,127
2008	555,606	288,781
2009	540,513	286,275
2010	599,662	286,421

4.6 Source-specific planned improvements

Annex 10 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.

5. 3C4 Direct nitrous oxide emissions from managed soils due to dairy cattle

5.1 Source category description

Emissions sources	**Sources included**	**Method**	**Emission factors**
	Dairy cattle deposit of dung and urine on pasture	T2	CS
Gases reported	N_2O		
Completeness	All dairy cattle accounted for. No known omissions		
Improvements since last submission	This is the first inventory for dairy cattle 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 Sections 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:

$$N_2O - N_{PRP} = F_{PRP} \times EF_{3PRP}$$

Where:

$N_2O - N_{PRP}$ 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 on pasture and paddock, kg N_2O-N (kg N input)$^{-1}$.

and

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

Where:

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

$Nex_{(T)}$ isannual 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.

$N_2O - N_{PRP}$ 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. A value of 0.00115 was used for the emission factor, $EF_{3,PRP}$, taken from Tully et al. (2017). They measured N_2O emissions from dung and urine deposited by dairy cattle on pastures in the dry and wet seasons in Kenya. This value is below the uncertainty range estimated by IPCC (2006) for the default $EF_{3,PRP}$ value, but reflects the low protein content of cattle diets in Kenya. Several recent publications on N_2O emissions from dung and urine in Kenya all suggest that emissions are lower than the IPCC default value. The resulting time series for direct N_2O emissions from pasture deposit of dung and urine is shown in **Table *22***.

Table 22: Direct N_2O emissions from dung and urine deposited on pasture by dairy cattle, Kg N_2O, 1995-2017

Year	Kg N_2O		Year	Kg N_2O		Year	Kg N_2O		Year	Kg N_2O		Year	Kg N_2O		Year	Kg N_2O
1995	73,693		**1999**	76,651		**2003**	77,791		**2007**	75,739		**2011**	73,898		**2015**	77,220
1996	75,111		**2000**	74,426		**2004**	77,530		**2008**	69,493		**2012**	82,471		**2016**	81,683
1997	73,546		**2001**	74,675		**2005**	76,443		**2009**	64,799		**2013**	87,698		**2017**	80,919
1998	77,181		**2002**	77,173		**2006**	73,936		**2010**	66,974		**2014**	79,956			

5.3 Uncertainties and time-series consistency

Annex 9 gives the main results of uncertainty analysis conducted using Monte Carlo simulation. Uncertainty of 2017 for total direct nitrous oxide emissions from managed soils was (+33.75%,-27.23%). For direct nitrous oxide emissions from managed soils the most sensitive factors affecting emissions were the proportion of dung and urine deposited on pasture for cows and heifers in the semi-intensive system, EF_3, crude protein content of diet (CP%) and feed digestibility (DE%). A consistent method was used to estimate emissions in each year of the time series.

5.4 Source-specific QA/QC 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.

5.5 Source-specific recalculations

Tier 1 emissions using activity data reported in the Second National Communication were reconstructed for direct nitrous oxide emissions from dung and urine deposited on pasture (**Table 22**). There is a significant discrepancy between the Tier 1 and Tier 2 estimates. The main reason is that the IPCC default MMS values for Africa assume that 83% of dung and urine is deposited on pasture, which is much higher than in the Tier 2 inventory.

Table 23 Recalculated estimates of direct N_2O emissions from dung and urine deposited on pasture by dairy cattle, 1995-2010

	Nitrous oxide (Kg N_2O)	
	SNC 2 Tier 1	**Tier 2**
1995	5,419,915	73,693
1996	5,327,777	75,111
1997	4,799,419	73,546
1998	4,756,392	77,181
1999	4,872,504	76,651
2000	5,293,395	74,426
2001	5,166,002	74,675
2002	5,507,463	77,173
2003	5,456,787	77,791
2004	5,417,274	77,530
2005	5,494,714	76,443
2006	5,181,743	73,936
2007	5,623,339	75,739
2008	5,346,698	69,493
2009	5,201,461	64,799
2010	5,770,661	66,974

5.6 Source-specific planned improvements

Annex 10 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.

6 3C5 Indirect emissions of nitrous oxide from managed soils due to dairy cattle

6.1 Source category description

Emissions sources	Sources included	Method	Emission factors
	Dairy cattle dung and urine deposit on pasture	T1	CS
Gases reported	N_2O		
Completeness	All dairy cattle 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 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 farmyards is assumed to be included in manure management emissions in Sections 3 and 4.

6.2 Methodological issues

Indirect N_2O emissions from deposit of dung and urine on pasture by dairy cattle was 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:

$N_2O_{ATD} - N$ 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:

$N_2O_{(L)} - N$ 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 (0.010) and EF_5 (0.0075) and default fractions for $Frac_{GASM}$ (0.20) and $Frac_{Leach}$ (0.30) 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 24*** presents the resulting estimated indirect N_2O emissions from deposit of dung and urine on pasture by dairy cattle.

Table 24: Indirect N_2O emissions from dung and urine deposited on pasture by dairy cattle, Kg N_2O, 1995-2017

Year	Kg N_2O		Year	Kg N_2O		Year	Kg N_2O		Year	Kg N_2O		Year	Kg N_2O		Year	Kg N_2O
1995	272,342		**1999**	283,275		**2003**	287,487		**2007**	279,905		**2011**	273,101		**2015**	285,377
1996	277,584		**2000**	275,053		**2004**	286,525		**2008**	256,823		**2012**	304,783		**2016**	301,874
1997	271,799		**2001**	275,974		**2005**	282,505		**2009**	239,474		**2013**	324,101		**2017**	299,048
1998	285,236		**2002**	285,204		**2006**	273,242		**2010**	247,513		**2014**	295,489			

6.3 Uncertainties and time-series consistency

Annex 9 gives the main results of uncertainty analysis conducted using Monte Carlo simulation. Uncertainty of 2017 for total indirect nitrous oxide emissions from managed soils due to dairy cattle was (+56.60%,-38.92%). For indirect nitrous oxide emissions from managed soils the most sensitive factors affecting emissions were the proportion of dung and urine deposited on pasture, $Frac_{LEACH}$, EF_4 and EF_5 and crude protein content of diet (CP%) for cows in the semi-intensive system.

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 FPRP 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 QA/QC 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.

6.5 Source-specific recalculations

Tier 1 emissions using activity data reported in the Second National Communication (2012) were reconstructed for direct nitrous oxide emissions from dung and urine deposited on pasture (**Table 24**).

There is a significant discrepancy between the Tier 1 and Tier 2 estimates. The main reason is that the IPCC default MMS values for Africa assume that 83% of dung and urine is deposited on pasture, which is much higher than in the Tier 2 inventory. In addition, the Tier 2 value for Nex is about half that of the Tier 1 default value.

Table 25 Indirect N_2O emissions from dung and urine deposited on pasture by dairy cattle, 1995-2010

	Nitrous oxide (Kg N_2O)	
	SNC 2 Tier 1	**Tier 2**
1995	1,151,732	272,342
1996	1,132,153	277,584
1997	1,019,876	271,799
1998	1,010,733	285,236
1999	1,035,407	283,275
2000	1,124,846	275,053
2001	1,097,775	275,974
2002	1,170,336	285,204
2003	1,159,567	287,487
2004	1,151,171	286,525
2005	1,167,627	282,505
2006	1,101,120	273,242
2007	1,194,960	279,905
2008	1,136,173	256,823
2009	1,105,310	239,474
2010	1,226,265	247,513

6.6 Source-specific planned improvements

Annex 10 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: Derivation of dairy cattle population and herd structure

This annex explains how the total population of dairy cattle, dairy cattle sub-categories and the proportion of cows giving birth were derived.

A1.1 Total population

A time series from 1995-2017 for total national dairy cattle population was provided by the State Department of Livestock (SDL).[5] Other data sources used included:

- District and Provincial Annual reports from SDL (1998-2010);
- Validated data from the counties from SDL Livestock Statistics (2012-2017)
- Data compendium for 'Kenya's Agricultural Sector' KIPPRA Special Report (Gitu & Nzuma 2003)
- Livestock Recording Centre Naivasha.

The national dairy population time series has been prepared through several years of work and was taken as the official national total. For the period 1998-2010, the provincial data was close to the national data, varying on average by 4.56%, while the county data for that period varied from the national total by 10.34%. After cleaning the dataset for obvious errors, the approach used was as follows.

(1) The national total population was taken as the official total dairy cattle population.
(2) The provincial data (1998-2010) was adjusted by applying the same adjustment factor to all provinces in each year such that the provincial totals equalled the national total.
(3) The county data (1998-2010) was adjusted by applying the same fixed factor to all counties in each province in each year such that the county totals equalled the province totals.
(4) The county data (2012-2017) was, for years where it was necessary, adjusted by a fixed factor applied to all counties such that the county totals equalled the national total.
(5) For 2011, the county data were interpolated linearly.
(6) For 1995-1998, the county totals were adjusted by a fixed factor applied to all counties such that the county totals equalled the national total in each year.
(7) Due to rounding, errors between the inventory and official time series varied by an average of 15 cattle per year. These errors were allocated to counties in each production system in proportion to the distribution of the total herd in each production system. A final error due to rounding of <1 head of cattle remained in 7 of the 2 years in the time series.

Table A1.1 Total national dairy cattle population, 1995-2017

1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
3,255,479	3,355,192	3,281,522	3,442,446	3,435,141	3,335,920	3,442,754	3,551,160	3,665,398	3,605,506
2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
3,579,461	3,639,018	3,667,746	3,403,346	3,310,898	3,376,479	3,739,610	4,158,378	4,505,582	4,316,153
2015	**2016**	**2017**							
4,242,132	4,505,733	4,573,871							

[5] B. Kibor, pers. comm.

Further examination of data held by the State Department may enable improvement in the historical dataset, but the adjustments are expected to be minor. The national total dairy cattle population time series is shown in Table A1.1.

A1.2 Herd structure

Panel surveys implemented by the Tegemeo Institute from 2000 to 2014 provide a consistent dataset on herd structure (see Table A1.2(B)). Data on dairy cows were extracted from that dataset and herd structure analysed in line with the allocation of counties to production systems used in this inventory.[6] The survey tool used in the Tegemeo surveys classifies both adult cows and heifers as 'cows', and growing males as 'calves'. Therefore, for the inventory it was necessary to use additional information disaggregate these categories in the Tegemeo dataset.

To estimate the relative proportions of cows and heifers, growing males and calves, and the proportions of male and female calves, a review of published herd structure data was conducted (Table A1.2(A)).[7] Average proportions of each sub-category in the herd were calculated, weighted by the number of households in each sample. (Weighting by numbers of individual animals in each sample would have been more accurate, but this was not possible given the way each data source reported their data.) Analysis was undertaken separately for the intensive region and together for semi-intensive and extensive regions. The relative proportions are shown in Table A1.2(C). Although herd structure may change over the longer term (e.g. as feeding systems change or households' herds become established) and the shorter term (e.g. in response to extreme weather events or market prices), due to lack of further evidence on these changes,[8] the proportions shown in Table A1.2(C) were applied in each year of the Tegemeo dataset to disaggregate the sub-categories in the years that the Tegemeo dataset was carried out. As the Tegemeo dataset does not cover all years from 1995, years from 2001-2014 with no data were filled by linear interpolation; years before 2000 used the 2000 proportions; and years after 2014 used the 2014 proportions. The resulting proportions for the time series for herd structure is shown in Table A1.2.(D). These proportions were combined with the livestock population data for each production system to estimate the population of each animal sub-category in each production system in each year of the inventory time series (see Table 4 in the main text).

Proportions of bulls and oxen in adult males: Numbers of bulls and oxen are reported on in the literature as detailed in A.1.2(A). In the intensive system, the average percentages of bulls and oxen in adult males weighted by sample size are 5% oxen and 95% bulls. This reflects that in the intensive region with small land plots, most adult males are kept for breeding purposes. In the semi-intensive system, the weighted average percentages of bulls and oxen in adult males is 56% bulls and 44% oxen. This reflects greater use of oxen for draft power in areas with larger average farm sizes and larger herds (de Groot et al. 2018).

Proportions of male and female calves: This version of the inventory combines male and female calves into one category. However, the IPCC default value for the coefficient for growth is different for male and female animals, so an estimate of the percentages of male to female calves is needed. The relative proportions of male and female calves in total calves was reported in several reports

[6] J. Opiyo, pers. comm. 26 February 2019.

[7] Literature reports were excluded where sub-category definitions were not in line with those used in this inventory (e.g. where adult animals were defined as >2 years).

[8] De Groote et al. (2018) provide some evidence that the proportion of households owning oxen increased between 2000 and 2012, but there are large differences between the proportions reported there and in herd structure studies, and it is not clear that the same definition of 'oxen' was used.

(Table A1.2(A)). The weighted average for the intensive region is 38% male and 62% female. For semi-intensive and extensive regions, the weighted average is 46% male calves and 54% female calves. These proportions were used to calculate weighted average values for the coefficient for growth for calves.

Proportions of cows and heifers: Data presented in Table A1.2(A) was used to estimate that the percentage of cows and heifers in the intensive system are 69% and 31%, respectively, and in the semi-intensive system are 62% and 38%. These percentages were applied to disaggregate the category 'cows' in the Tegemeo dataset. The estimated percentage of cows in the total herd (28% – 41%) varies from the rule of thumb applied by most county livestock officers whereby cows make up 55% of the herd. The total milk output estimate in this inventory is therefore different from the official milk output statistics.

Table A1.2 Data on herd structure

(A) Data from literature review

source	UNIQUE (2018)	Staal et al 1997	Kilungu 1999	Waithaka et al. 2002	Ongadi 2014	Mungunbe et al. 2014	Lukuyu et al. 2011	Wanjala & Njehia 2014	Yegon et al 2016	Kithale 2007
year	2018	1996	1992	2000	2006	2012	ca. 2010	2013	ca. 2015	2007
location	intensive	Kiambu	Kiambu	western	Vihiga	Coastal	western	Busia, Kakamega	Kericho, Bomet	Kitui
Sample size	429	253	380	1575	236	75	341	400	151	116
Bulls	2.73%	4.33%	9.74%	6%	-	13.20%	5.77%	1.80%	7.40%	-
oxen	0.30%	0.67%		6%	-	-	5.86%	-	-	-
growing males	3.15%	12.00%	-	12%	17.72%	5.60%	-	5.70%	-	14%
cows	44.00%	48.67%	43.16%	26%	24.00%	46.40%	37.79%	48.40%	53.79%	51%
heifers	16.97%	23.33%	21.32%	22%	22.42%	16.40%	21.69%	17%	12.45%	17%
calves	16.36%	11.00%	25.79%	28.00%	35.85%	18.40%	28.88%	27.10%	26.35%	18.00%
Male calves	5.27%	5.67%	-	13%	17.10%	5.60%	-	12.10%	-	9%
Female calves	11.21%	5.33%	-	15%	18.75%	12.80%	-	15%	-	9%

(B) Data from Tegemeo repeat surveys

	2000	2004	2007	2010	2014
Intensive					
Cows*	62.25%	62.04%	62.60%	63.12%	59.39%
Bulls**	3.66%	7.43%	4.42%	4.14%	6.11%
Calves***	34.08%	30.53%	32.97%	32.74%	34.50%
Semi-intensive					
Cows*	55.56%	55.57%	56.13%	58.21%	62.39%
Bulls**	8.33%	8.23%	8.73%	7.88%	4.70%
Calves***	36.11%	36.20%	35.14%	33.91%	32.91%

Extensive					
Cows*	47.59%	55.49%	59.66%	57.62%	61.39%
Bulls**	15.06%	14.35%	5.97%	11.90%	5.61%
Calves***	37.35%	30.17%	34.38%	30.48%	33.00%

* includes heifers. ** includes bulls and oxen. *** includes growing males and male and female calves.

Data source: J. Opiyo pers. comm.

(C): Relative proportions of different dairy cattle sub-categories

	Intensive	Semi-intensive and extensive
% of oxen in 'bulls+oxen'	5%	44%
% of heifers in 'cows+heifers'	31%	38%
% of male calves in 'male+female calves'	38%	46%
% of growing males in 'growing males+calves'	31%	29%

Table A.1.2.(D) Time series for dairy cattle herd structure (% of total population)

	Intensive					Semi-intensive					Extensive				
	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves	Cows	Heifers	Adult males	Growing males	Calves
1995	0.43	0.19	0.03	0.11	0.24	0.34	0.21	0.08	0.10	0.26	0.28	0.18	0.15	0.11	0.28
1996	0.43	0.19	0.03	0.11	0.24	0.34	0.21	0.08	0.10	0.26	0.28	0.18	0.15	0.11	0.28
1997	0.43	0.19	0.03	0.11	0.24	0.34	0.21	0.08	0.10	0.26	0.28	0.18	0.15	0.11	0.28
1998	0.43	0.19	0.03	0.11	0.24	0.34	0.21	0.08	0.10	0.26	0.28	0.18	0.15	0.11	0.28
1999	0.43	0.19	0.03	0.11	0.24	0.34	0.21	0.08	0.10	0.26	0.28	0.18	0.15	0.11	0.28
2000	0.43	0.19	0.04	0.11	0.24	0.34	0.21	0.08	0.10	0.26	0.29	0.18	0.15	0.11	0.26
2001	0.43	0.19	0.05	0.10	0.23	0.34	0.21	0.08	0.11	0.26	0.30	0.19	0.15	0.10	0.25
2002	0.43	0.19	0.06	0.10	0.22	0.34	0.21	0.08	0.11	0.26	0.32	0.20	0.15	0.10	0.24
2003	0.43	0.19	0.06	0.10	0.22	0.34	0.21	0.08	0.11	0.26	0.33	0.21	0.15	0.09	0.23
2004	0.43	0.19	0.07	0.09	0.21	0.34	0.21	0.08	0.11	0.26	0.34	0.21	0.14	0.09	0.21
2005	0.43	0.19	0.06	0.10	0.22	0.34	0.21	0.08	0.10	0.25	0.35	0.22	0.12	0.09	0.22
2006	0.43	0.19	0.05	0.10	0.22	0.34	0.22	0.09	0.10	0.25	0.36	0.22	0.09	0.10	0.23
2007	0.43	0.19	0.04	0.10	0.23	0.35	0.22	0.09	0.10	0.25	0.37	0.23	0.06	0.10	0.24
2008	0.43	0.19	0.04	0.10	0.23	0.35	0.22	0.08	0.10	0.25	0.36	0.23	0.08	0.10	0.23
2009	0.43	0.19	0.04	0.10	0.23	0.35	0.22	0.08	0.10	0.24	0.36	0.22	0.10	0.09	0.23
2010	0.44	0.20	0.04	0.10	0.23	0.36	0.22	0.08	0.10	0.24	0.35	0.22	0.12	0.09	0.22
2011	0.43	0.19	0.05	0.10	0.23	0.36	0.23	0.07	0.10	0.24	0.36	0.23	0.10	0.09	0.22
2012	0.42	0.19	0.05	0.10	0.23	0.37	0.23	0.06	0.10	0.24	0.37	0.23	0.09	0.09	0.23
2013	0.42	0.19	0.06	0.11	0.24	0.38	0.24	0.05	0.10	0.24	0.37	0.23	0.07	0.09	0.23
2014	0.41	0.18	0.06	0.11	0.24	0.38	0.24	0.05	0.10	0.23	0.38	0.24	0.06	0.10	0.23
2015	0.41	0.18	0.06	0.11	0.24	0.38	0.24	0.05	0.10	0.23	0.38	0.24	0.06	0.10	0.23
2016	0.41	0.18	0.06	0.11	0.24	0.38	0.24	0.05	0.10	0.23	0.38	0.24	0.06	0.10	0.23
2017	0.41	0.18	0.06	0.11	0.24	0.38	0.24	0.05	0.10	0.23	0.38	0.24	0.06	0.10	0.23

Years that are highlighted grey are years where the Tegemeo survey was not carried out and assumptions were used to fill in the gaps.

A1.3 Proportion of cows giving birth

The proportion of cows giving birth can be estimated from calving intervals:

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

For the intensive production system, reports of calving intervals were obtained from the published literature for the mid-late 1990s (Kilungu 1992, Omore et al. 1998, Staal et al. 1997, Romney et al. 1996, Owango et al. 1998) and unpublished data from 2018 (UNIQUE 2018).[9] The calving rates in the mid- to late-1990s averaged 63%. For 2018, the UNIQUE (2018) data had an average calving rate of 76%. There was no significant difference in calving interval between feeding systems in that dataset, although some other studies have reported longer calving intervals in grazing compared to other feeding systems (Mbugua et al. 1999). Therefore, the inventory uses a value of 63% for 1995 and 76% for 2018, with linear interpolation for intervening years. Romney et al. (1996) found that improved feeding significantly reduced calving intervals, which supports the assumption of an increasing trend in calving rates.

For the semi-intensive production system, Ongadi (2014), Waithaka et al. (2002) and Owango et al. (1998) provide estimates of calving interval ranging from 513-677 days, which equates to calving rates of about 65.5%. Ongadi (2014) gives calving interval for zero-grazing, semi-zero grazing and grazing systems in the studied site. Using the ratio of households in each feeding system for 1995 (see Annex 3 below), the weighted average calving rate is 59.6% for 1995, while using the ratio for 2018 the weighted average calving rate is 62.1%. These values were used, with linear interpolation of the intervening years (see Table 9 in the main text).

Extended lactations (often much longer than 365 days) and long calving intervals are commonly reported in Kenya (e.g. Omore et al. 1998, Staal et al. 1997, Reynolds et al. 1996, Richards et al. 2016). This may lead to a higher proportion of cows lactating than cows giving birth in the year. The reason for extended lactation is probably management by smallholders who seek to maintain a constant stream of milk income by delaying reproduction. A small number of available surveys directly report the proportion of cows that are in milk, ranging between 34% and 88% (Kilungu 1992, Weiler 2014, Kithale 2007, Wanjala & Njehia 2014, Tegemeo various years). The standard technical coefficient used by the Ministry of Agriculture in compiling national milk output data is 45% of the adult female herd is lactating, which is lower than all but one data point in the literature report reviewed. Given the limited data, for this initial inventory, the proportion of cows lactating is assumed to be the same as the proportion of cows giving birth. This should be one area for future inventory improvements.

For the extensive production system, due to lack of other information sources, the calving rates for the semi-intensive production system were also applied to the extensive production system. For the proportion of heifers pregnant, the only available data source was the UNIQUE (2018) dataset. In that dataset, 20% of heifers were pregnant. This percentage was applied to heifers in all three production systems due to lack of alternative data.

[9] Subsequently published at https://ccafs.cgiar.org/publications/methods-and-guidance-support-mrv-livestock-emissions-methods-data-collection-analysis#.XmYB5aj7Q2w

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

1. Intensive system

For the intensive system, the main data source used was the Dairy NAMA Baseline Survey conducted by UNIQUE in 2018 (UNIQUE forestry and land use 2018).[10] The survey measured heart girth of 734 animals. Heart girth measurements were converted to estimates of kg live weight using the Box-Cox model ($LW^{0.3595} = 0.01543 + 0.04920 * HG$) validated for an East African dataset in Goopy et al. (2018a). The live weight estimates from that dataset are shown in Table A2.1. These live weight estimates were used as the live weight values for 2018 in the intensive system.

Table A2.1: Live weight (kg) of dairy cattle sub-categories in the intensive system (2018)

	Sample size	Age (months)		Mean live weight (kg)	s.e.
		Mean ($\bar{x}$)	median ($\tilde{x}$)		
Cows	372	56.67	53.54	365.35	0.20
Heifers	166	21.71	23.27	262.92	7.63
Adult males	20	52.42	48.00	357.64	30.49
Growing males	27	18.24	17.72	241.07	20.70
Female calves	110	4.51	4.00	88.19	0.86
Male calves	39	4.47	5.00	89.66	1.46

Source: UNIQUE forestry and land use (2018)

To estimate the time series for live weight, the following data sources and methods were used. Analysis of the UNIQUE dataset indicated that there is a significant difference between live weights of different breeds. Regression analysis showed that live weight of cows is significantly affected by breed ($p<0.05$) and production system ($p<0.06$). However, the effect size (indicated by the standardized coefficient) of breed is much larger than that of production system. The unstandardized coefficients suggest that compared to Friesian and Ayrshire, other breeds (e.g. Jersey, Guernsey, Zebu, Sahiwal, Boran, unspecified exotic cross) are on average 58 kg lighter than Friesian or Ayrshire when controlling for differences in animal age within the dataset (Table A1.2). The average live weight for Friesian-Ayrshire cows was 372.25 kg and for other breeds 317.20 kg.

Table A2.2 Regression results for age, breed, and production system on live weight of cows

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	432.725	17.952		24.104	.000
	Age	.335	.185	.092	1.814	.071
	Breed dummy	-58.125	11.722	-.252	-4.959	.000
	System	-12.658	6.570	-.097	-1.927	.055
Dependent Variable: Liveweight (kg). Independent variables: age (months, continuous variable); breed dummy (0=Friesian or Ayrshire, 1 = other breed); system (1 = zero grazing, 2 = semi-zero grazing, 3= grazing)						

[10] Subsequently published at https://ccafs.cgiar.org/publications/methods-and-guidance-support-mrv-livestock-emissions-methods-data-collection-analysis#.XmYB5aj7Q2w

The literature was reviewed to identify survey results indicating the breed composition of dairy cattle in the intensive system (Owango et al. 1998; MOLD 2008 data cited in Kariuki 2011). Together with the UNIQUE 2018 data, this gave estimates of breed structure in the intensive region for 1998, 2008 and 2018. Assuming that the mean live weight of cows by breed has not changed in the past 30 years,[11] the weighted average live weight for cows was calculated to reflect the effect of changing breed composition on average live weight of cows (Table A2.3). Values for other years were linearly interpolated. As a result, the estimated mean live weight in 1995 was 354.1 kg, which is close to the average of 358.1 kg reported by Nyaata et al. (2000) for cows on 10 farms in Embu in 1995. The estimate for 2018 is close to a median weight of 362 kg reported by Muraya et al. (2018) from a study in Meru.

Table A2.3: Estimated mean live weight and mature weight of dairy cows, 1998-2018

	1998	2008	2018
% Friesian or Ayrshire	0.72	0.87	0.89
% other breeds	0.28	0.13	0.11
Weighted average live weight (kg)	356.63	365.07	366.12
Weighted average mature weight (kg)	363.68	372.28	373.35

To estimate mature weight, 146 dairy cows of fourth parity or greater not in poor body condition were selected from the UNIQUE dataset (UNIQUE forestry and land use 2018). The mean live weight was 373.35 kg (s.e. 0.32 kg). Analysis showed a significant difference between Friesian-Ayrshire (mean: 379.58 kg) and other breeds (mean: 323.52 kg). The weighted average mature weight was calculated using data on the proportion of different breeds from Owango et al. (1998), MOLD 2008 data cited in Kariuki (2011) and UNIQUE (2018). The resulting estimates for 1998, 2008 and 2018 are shown in Table A2.3. Values for other years were filled using linear interpolation.

Daily weight gain of cows was calculated as

$WG_{day} = (MW – LW)/days_{growing}$

Where:

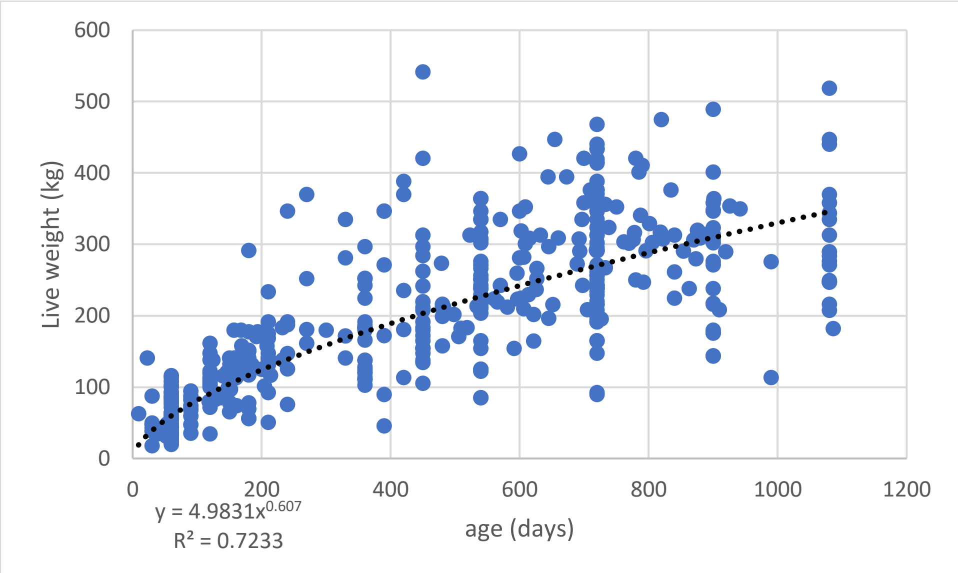
$days_{growing}$ is the number of days between the average age of mature cows in the dataset and the average age of all cows in the dataset. For mature cows, the average age of the 146 animals used to estimate mature weight was 5.88 years and the average age of all cows used to estimate live weight was 4.72 years. The difference between the two is about 424 days. The estimated daily weight gain for the average cow is 0.017 kg per day. No reports of weight gain in cows below the age of full skeletal maturity were identified from Kenya or neighbouring countries with which to verify this estimate. Due to lack of other data, this value was applied throughout the whole time series.

For heifers and calves, the following methods were used. The UNIQUE (2018) dataset suggests that mean heifer live weight is 72.0% of the mean cow live weight (Table A2.1). Weighting by the sample sizes for male and female calves in the UNIQUE dataset, the weighted mean calf live weight is 24.2% of the mean cow live weight (Table A2.1). These percentages were applied to the average live weight

[11] There are few studies on the effects of concentrate feeding levels on body weight of dairy cows in Kenya. Biwott et al. (n.d.) show significantly higher body weight when fed 8 kg per day, but little difference when fed between 2 and 4 kg. Given the moderate amounts of concentrate fed (see Section 2.2.9), we assume no effect of concentrate feeding on live weight of dairy cows. The effects of other management practices, such as those leading to improved health, are not considered.

of cows in each year of the time series to estimate a time series for average heifer and average calf live weights.

For heifer weight gain, the UNIQUE dataset was used to estimate the relationship between age and weight (Figure 1). The average age at first calving for cows in the dataset was 27.56 months (i.e. 827 days). For heifers, the average daily weight gain was calculated from the relationship in Figure A2.1 between 366 days and 827 days of age. The estimated average daily weight gain for heifers is 0.25 kg. There are few literature reports to verify this estimate. The estimate is lower than a value of 0.36 reported in a study of 99 heifers in Meru reported by Makau et al. (2018), but that study sampled heifers from active members in a dairy cooperative in Meru, which is among the more intensive counties of the intensive region. The value of 0.25 kg daily weight gain was applied throughout the time series for lack of any alternative data sources.



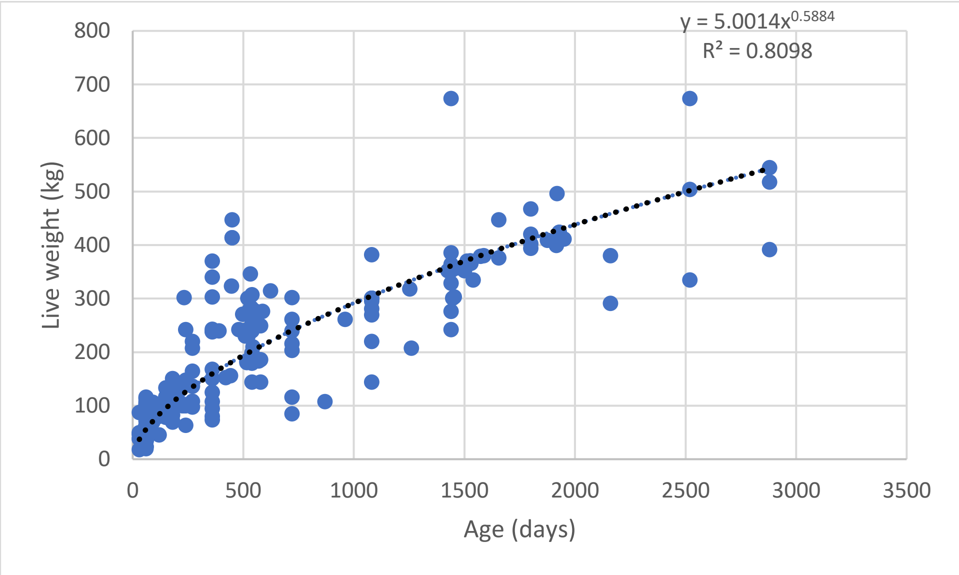
Source: UNIQUE (2018) unpublished dataset.

Figure A2.1: Live weight development of female dairy cattle in the intensive system

For calf weight gain The UNIQUE 2018 survey indicated a daily weight gain for male and female calves (0-12 months of age) of 0.41 kg. The proportions of male and female calves in that dataset are different from the proportions assumed in the inventory. When the proportions assumed in the inventory (see Table A1.2(D)) are applied to the weight gain estimates from the UNIQUE dataset, the average daily weight gain is 0.42 kg. This is slightly lower than the mean of 0.482 reported by Makau et al. (2018) from a study in Meru. Lanyasunya et al. (2006) reported average daily weight gain of 0.307 kg on control farms using smallholder management practices, and 0.37 kg on test farms using improved feeding practices. Gitau et al. (1994) reported a mean of 0.207 kg for farms in Kiambu in 1991-1992. These three data points suggest a trend of increasing average daily weight gain over time. However, the trend in live weight for heifers and growing males estimated above is only very gradual. Therefore, so that average weight gain estimates for calves is in line with the trend in live weights for heifers and growing males, a value of 0.42 kg/day is consistently used throughout the time series.

For adult males and growing males, the mean values in the UNIQUE dataset (Table A2.1) were used throughout the time series. Whereas there is data from different years on breed composition for cows, there is no such data for adult or growing males with which to estimate a trend in live weight over time. No other reports were identified with which to verify the assumption of no change in live weight over time for these sub-categories. However, given that the proportions of adult and growing males in the herd are small (Table A.1.2.(D)), the effect on inventory estimates of this assumption is expected to be limited.

For adult males, average live weight in 2018 was calculated from the 20 adult males in the UNIQUE 2018 dataset (i.e. 357.64 kg, see Table A2.1). Because of the limited sample size, the mature weight was estimated as the average weight of the oldest 20% in that dataset, i.e. 542 kg. Weight gain rate was estimated using the relationship between age and weight in the UNIQUE dataset (Figure A2.2). Given an average age of 4.37 years for adult males, the estimated daily weight gain is 0.14 kg. No literature could be identified to verify this estimate. For growing males 1-3 years old, the same relationship in the UNIQUE dataset was used to estimate average daily weight gain of 0.2 kg.



Source: UNIQUE (2018) unpublished dataset.

Figure A2.2: Live weight development of male dairy cattle in the intensive system

2. Semi-intensive system

For the semi-intensive system, live weights for cows and heifers are taken from M. Lukuyu et al. (2016). That publication reports live weight of 352 cows and 100 heifers measured in 2014 at three locations in Bomet, Nandi and Kakamega counties, which are categorized as semi-intensive in this inventory. Weights were given for 3 genotypes (40–60%, 61–80% and 81–100 % exotic). Sample size for each genotype, not reported in that publication, was obtained from the lead author.[12] The weighted average live weight of cows was 258.21 kg and of heifers was 209.97 kg, i.e. 81.3% of average cow weight. Age structure of cows and heifers was not given in that publication.

Waithaka et al. (2002) reported results of a large-scale survey in counties with semi-intensive production systems, which found that 9.1% of dairy cattle were 'high grade' and 90.9% were crosses. Assuming that 'high grade' equates to Lukuyu et al.'s '80-100%' genotype, and assuming that the average live weight of each genotype did not change between 2000 and 2014, the weighted average live weight of cows in 2000 was estimated at 254.46 kg. Live weights for years between 2000 and 2014 were linearly interpolated and for years before 2000 and after 2014 were linearly extrapolated.

[12] M. Lukuyu (pers. comm. 9 March 2019)

To estimate live weight of other animal sub-categories, the following rules of thumb were applied to each year in the time series:

- Heifers: assumed to be 81.3% of cow weight (M. Lukuyu et al. 2016);
- Adult male: Based on live weight data presented in Goopy et al. (2018b) and Ndung'u et al. (2018), adult male live weight is assumed to be 93% of cow live weight;[13]
- Growing male: Based on live weight data presented in Goopy et al. (2018b) and Ndung'u et al. (2018), growing male live weight is assumed to be 87% of heifer mean live weight;
- Calves: Based on data in Table A2.3 for the intensive production system, calf live weight is assumed to be 24% of cow mean live weight.[14]

There was no detailed data on the age structure of cows or adult males, and the genetic composition of cattle in the region makes it inappropriate to use standard breed mature weights. Mature weights were estimated using the ratio of mature to average live weights in the intensive system (Table A2.3). The mature weight of cows (e.g. 263.37 kg in 2014) was estimated at 2% higher than average live weight. The mature weight of males (e.g. 363.80 kg in 2014) was estimated at 51.5% higher than average live weight. The reason for this is that the average age structure of male cattle is young due to culling and sales and few males are kept to a high age. For calves, the mature weight was the average of mature weights for adult males and cows weighted by the proportion of female (54%) to male (46%) calves.

Table A2.3: Estimated mean live weight and mature weight of cows and adult males, 2000 and 2014, semi-intensive system

	2000	2014
Cows		
Live weight	254.46	258.21
Mature weight	259.28	263.37
Adult males		
Live weight	236.65	240.13
Mature weight	358.52	363.80

[13] Adult males are assumed to be lighter than females because of a younger age structure in the male population, whereas females are often kept to an older age.

[14] This is slightly lower than the average ratio of calf to cow live weights in Goopy et al. (2018b) and Ndung'u et al. (2018), but cows in that publication were represented by the category "female >2 years", while age at first calving in the semi-intensive region is commonly greater than 24 months (Waithaka et al. 2002).

Table A2.4 Assumed live weight and age used to estimate daily weight gain in semi-intensive region (2014)

	Average live weight (kg)	Median age (months)	Median age (days)	Average daily weight gain (kg)
Females				
Calf	61.97	6	180	0.23*
Heifer	209.92	22.5	675	0.22
Cow	258.21	57	1710	0.03
Males				
Calf	61.97	7	210	0.20*
Growing male	182.63	24	720	0.17
Adult male	240.13	60	1800	0.03

*weighted average 0.22.

Daily weight gain was estimated using the data shown in Table A2.4 and the following assumptions:

- Calf birth weight is assumed to be 8% of cow mean live weight, i.e. 20.66 kg;
- 54% of calves are female and 46% are male (Table A1.2(A));
- Average age at first calving is 33 months (Waithaka et al. 2002), so the median age of heifers is 22.5 months;
- Maturity is reached after 4th parity, so average age of a mature cow is 33 + (12 * 4) = 81 months, and the median of 33 and 81 is 57 months;
- The adult male category begins at 36 months, so the median age of growing males is 24 months;
- Male mature weight is achieved at 84 months, so the median age of adult males is 60 months.

These assumptions were applied to estimate daily weight gain for each animal sub-category in each year. Estimated calf weight gain (i.e. 0.20-0.23 kg, weighted average 0.22 kg) is slightly lower than 0.24-0.26 kg measured in open grazing systems at sites in the intensive region (Gitau et al. 2001), and lower than 0.322 kg reported from a study that used a questionnaire survey method in Nyandarua (Muia et al. 2011). For heifers, the estimate was similar to measurements on heifers grazing cultivated fodder in dry conditions (Abate et al. 1981).

3. Extensive system

Very few studies have been conducted on dairy cattle in extensive regions. Most studies in these regions focus on other cattle breeds, which are not counted in the official statistics as dairy cattle. For this reason, in this version of the inventory, the assumptions used to estimate live weights and live weight change in the semi-intensive system are also applied in the extensive system.

Annex 3: Data sources and methods used to estimate diet composition and feed characteristics

Diet composition and digestibility of the diet are most strongly affected by differences in feeding system. The production systems used in the inventory are defined in Section 2.2.1, and comprise of zero-grazing, semi-zero grazing and grazing only feeding systems. Literature was used to characterize dairy cattle diets in each feeding system in each production system and to estimate the proportion of dairy cattle in each production system. Change in average diet digestibility over time is in part affected by change in feeding system as represented by the proportion of cattle in different production systems. Another significant change is the increase in proportion of households feeding dairy meal and concentrates and an increase in the average amount of concentrate fed per cow. Given the average basal diet, for a cow with an average roughage digestibility of 60%-61%, a 1 kg increase in concentrate (digestibility 75%) would imply an increase of about 2% in digestibility of the diet. Hence, it was decided to incorporate change in concentrate feeding in the estimation of the time series for digestibility.

For each production system, a typical diet for animals in zero-grazing, semi-zero grazing and grazing systems was constructed using literature values for the mid-late 1990s and for the mid-late 2010's. Nutritive values of each feed were obtained from the literature (Table A3.1). Literature values for proportions of dairy cattle in each production system were also obtained. The weighted average feed digestibility was calculated for the mid-1990s and late 2010's. Values between 1995 and 2018 were interpolated using linear interpolation.

Table A3.1 Nutritive values for feed types assumed in dairy cattle diets

	DE%	CP%	Sources
Basal feed			
Natural pasture	61.76*	11.1	Goopy et al. 2018b; Ndung'u et al. 2018; Onyango et al. 2018
Napier grass	56.30	10.2	Gwayumba et al. 2002; Njoka-Njiru et al. 2006; Laswami et al. (2013)
Maize stover	60.67*	10.1	Murdoch et al. 2003; Laswami et al. (2013)
Forage supplement			
Rhodes grass (fresh)	59.89	8.83	ILRI Sub-Saharan Africa Feed Composition Database https://www.ilri.org/feedsdatabase/
Rhodes grass hay	55.60	10.1	https://www.feedipedia.org/node/12519
Sweet potato vines	54.89	12.2	Laswai et al. 2013
Lucerne hay	58.40	18.2	https://www.feedipedia.org/node/11743
Desmodium hay	49.60	12.8	https://www.feedipedia.org/node/19048
Fodder legume trees	56.13	21.99	ILRI Sub-Saharan Africa Feed Composition Database https://www.ilri.org/feedsdatabase/
Wheat or oat straw	56.75	3.71	ILRI Sub-Saharan Africa Feed Composition Database https://www.ilri.org/feedsdatabase/
Weeds	63.56*	19.2	Murdoch et al. 2003
Feed concentrates and supplements			
Maize germ	0.808	14.3	https://www.feedipedia.org/node/20334
Mineral salts	0	8.69	ILRI Sub-Saharan Africa Feed Composition Database https://www.ilri.org/feedsdatabase/
Concentrate	0.75*	15	Katiku et al. 2016; Nyaata et al. 2000

DE% is digestible energy as a percentage of gross energy. CP% is crude protein content (%). * Dry matter digestibility (DMD) converted to DE% using M/D=0.172*DMD-1.707 and ME=0.81DE and GE=18.4 (CSIRO 2007), where ME is metabolizable energy; M/D is metabolizable energy concentration in dry matter; GE is gross energy.

1. Intensive system

Despite the great attention to dairy nutrition in intensive areas of Kenya, there are few published reports of direct measurements of feed intake or feed offered in the intensive system. For the intensive system, the main data source on feed composition was UNIQUE forestry and land use (2018). The data results from a questionnaire asking about how much forage and feed is offered to each type of animal on 429 farms in the intensive region. Source of uncertainty include errors associated with farmer self-reported volumes. For grazed pasture intake, that study assumed that pasture intake was equal to dry matter intake (DMI) requirements minus cultivated fodder and feed available. Refusals is a known issue, e.g. for maize stover (Methu et al. 2001), but was not considered in the data source used. Cattle are often fed as a group, so diets specific to different animal sub-categories are difficult to quantify or verify (Staal et al. 1997).

Feed composition: The UNIQUE (2018) dataset provides estimates of feed composition for different types of dairy cattle as shown in Table A3.2. Basal fodders, including grazed natural pasture, Napier grass and maize account for 62%-90% of DMI for different cattle sub-categories. The main supplementary forages were hay (most commonly Rhodes grass), Lucerne and Desmodium, accounting for 3%-14% of DMI. In addition to commercial or home-made feeds, feeds including maize germ and minerals were commonly fed, with total feeds accounting for 14%-26% of DMI for cows and 7%-24% of DMI for other cattle sub-categories. The resulting feed digestibility estimates ranged between 54% and 60%.

In 2018, estimated average daily consumption by cows of feed concentrate was 1.6 kg DM under zero-grazing, 1.10 kg DM under semi-zero grazing and 1.4 kg DM in grazing systems. Assuming dry matter content of 85% (Katiku et al. 2016) and proportions of dairy cows in each feeding system fed concentrates ranging between 65% and 73% (UNIQUE 2018), the UNIQUE dataset suggests that each cow that is fed concentrates is given an average of 2.3 kg (fresh matter) in zero-grazing systems, 1.74 kg in semi-zero grazing and 1.83 kg in grazing systems, or a weighted average of 2.1 kg (fresh matter) of concentrate per day. These concentrate feeding rates are similar to those reported in some other recent surveys in the intensive region (Kimenchu et al. 2014, Richards et al. 2015).

Surveys from the 1990s and 2000s conducted in Kiambu and other parts of the intensive region suggest that feed structure was broadly similar to that indicated in Table A3.2 (e.g. Utiger et al. 2000). These surveys also indicated that about 70% of zero-grazing households fed concentrates and that feeding rates were also about 2 kg per cow per day (Staal et al. 1997, Lekasi et al. 2001, Kilungo 1999, Mburu et al. 2007). Studies in the mid-late 1990s suggested that intensification (i.e. increases in zero- and semi-zero grazing) was accompanied by increases in imported feed, including concentrate (Staal et al. 1997, Bebe et al. 2003). Therefore, to develop a time series for digestibility, we make the following assumptions for diet composition in 1995:

- For cows, the average diet composition (%) in each feeding system is the same as that presented in Table A3.2 (but because live weight was slightly lower in 1995 and the proportion of cows in different feeding systems differed, this equates to average concentrate fresh matter fed of 1.5 kg per day):

- For other cattle sub-categories, no concentrate was fed, with the equivalent proportion of total DMI of the 2018 concentrate being replaced with maize in the zero-grazing system and with grazed natural pasture in semi-zero and grazing systems.

The time series for digestibility is thus a function of (a) change on proportion of dairy cattle in different feeding systems and (b) a gradual increase in concentrate consumption over time. For 1995, the proportion of cattle in each feeding system is estimated from Staal et al. (2001), and for 2018 the proportions in the UNIQUE (2018) dataset, with linear interpolation of intervening years. The UNIQUE dataset gives proportions of households with zero-grazing, semi-zero and grazing systems as 62.9%, 25.9% and 11.2%, respectively, for 2018. For the mid-1990s, Staal et al. (2001) reports 40.5%, 39.5% and 20.0%, respectively.[15] Concentrate fed is also linearly interpolated between the estimate for 1995 (i.e. 0 for sub-categories other than cows) and the estimates for 2018 presented in Table A3.2.

Time series for digestibility: The resulting time series for feed digestibility is shown in Table A3.3. The results show a 1% decrease in feed digestibility for cows, which is due to a decrease in the proportion of cows raised in fully grazing systems, where average diet digestibility is estimated to be 60%, compared to 59% in the other feeding systems (Table A3.1). For heifers, adult males and growing males, there is estimated to be a 1-2% increase in average diet digestibility between 1995 and 2018, which may be attributed to the gradual addition of concentrate to the diet.

[15] This is estimated from the data given in Figure 8 of Staal et al. (2001) on proportion of households with different feeding systems and Table 10 on average dairy cattle herd size, considering only those survey locations that are in the intensive production system. The Tegemeo repeat surveys 2000-2014 also have an indicator for households with zero-grazing, but the questionnaire did not specify whether zero-grazing was applied to dairy cattle. The trends in that dataset are inconsistent with both Staal et al. (2001) and UNIQUE (2018), with a reported decrease in proportion of households with zero-grazing, from 49% in 2000 to 26% in 2014 for the intensive production system. The Tegemeo dataset was not used.

Table A3.2 Diet composition (proportion of kg DMI) for dairy cattle in the intensive production system

	Zero-Grazing					Semi-zero					Grazing system				
	Cow	Heifer	Adult male	Growing male	Calf	Cow	Heifer	Adult male	Growing male	Calf	Cow	Heifer	Adult male	Growing male	Calf
Total Basal	**0.62**	**0.68**	**0.77**	**0.68**	**0.76**	**0.76**	**0.75**	**0.90**	**0.75**	**0.85**	**0.73**	**0.79**	**0.72**	**0.72**	**0.77**
Napier	0.26	0.27	0.35	0.25	0.36	0.13	0.12	0.25	0.04	0.16	0.09	0.08	0.05	0.18	0.11
Maize	0.34	0.42	0.42	0.44	0.40	0.25	0.35	0.29	0.13	0.39	0.19	0.34	0.06	0.20	0.26
Grazed pasture	0.00	0.00	0.00	0.00	0.00	0.37	0.27	0.36	0.58	0.30	0.45	0.37	0.60	0.35	0.40
Total Supplement	**0.11**	**0.12**	**0.09**	**0.14**	**0.13**	**0.05**	**0.09**	**0.03**	**0.04**	**0.08**	**0.08**	**0.07**	**0.13**	**0.04**	**0.11**
Other grass	0.10	0.11	0.05	0.13	0.11	0.04	0.05	0.03	0.04	0.07	0.07	0.06	0.13	0.03	0.10
Legume	0.01	0.01	0.03	0.01	0.02	0.00	0.04	0.00	0.00	0.01	0.01	0.02	0.00	0.01	0.01
Total Feed	**0.26**	**0.20**	**0.15**	**0.18**	**0.12**	**0.20**	**0.16**	**0.07**	**0.21**	**0.07**	**0.19**	**0.14**	**0.15**	**0.24**	**0.13**
Concentrate	0.16	0.08	0.06	0.03	0.04	0.11	0.06	0.02	0.02	0.03	0.14	0.10	0.05	0.14	0.09
Maize germ	0.05	0.04	0.06	0.04	0.03	0.03	0.06	0.03	0.07	0.01	0.01	0.01	0.00	0.01	0.00
Minerals	0.05	0.07	0.03	0.11	0.05	0.05	0.05	0.01	0.13	0.03	0.04	0.03	0.10	0.09	0.04
% of total DMI	*84.00*	*83.70*	*82.80*	*79.10*	*80.20*	*87.10*	*86.80*	*84.10*	*89.30*	*87.40*	*86.80*	*77.70*	*75.40*	*85.10*	*92.10*
Average digestibility	**59%**	**57%**	**59%**	**54%**	**57%**	**59%**	**59%**	**60%**	**55%**	**60%**	**60%**	**60%**	**55%**	**57%**	**59%**

Table A3.3: Time series for feed digestibility (DE%) for dairy cattle sub-categories in the intensive system

	Cow	Heifer	Adult male	Growing male	Calf
1995	60	57	58	54	58
1996	60	57	58	54	58
1997	60	58	58	54	58
1998	60	58	58	54	58
1999	59	58	58	54	58
2000	59	58	58	54	58
2001	59	58	58	55	58
2002	59	58	58	55	58
2003	59	58	58	55	58
2004	59	58	58	55	58
2005	59	58	58	55	58
2006	59	58	58	55	58
2007	59	58	58	55	58
2008	59	58	58	55	58
2009	59	58	58	55	58
2010	59	58	58	55	58
2011	59	58	59	55	58
2012	59	58	59	55	58
2013	59	58	59	55	58
2014	59	58	59	55	58
2015	59	58	59	56	58
2016	59	58	59	56	58
2017	59	58	59	56	58
2018	59	58	59	56	58

2. Semi-intensive system

Feed composition: There are several scientific and 'grey literature' (i.e. reports from donor projects, NGOs and research institutes) on cattle diet composition from sites in the semi-intensive system, particularly from locations in western Kenya. The methods used to estimate diet composition in the identified reports varied, and included focus group discussions, household interviews and surveys of available fodder biomass. A study by Ongadi et al. (2006) presents diets for cows, while the other studies did not specify different diets for dairy cattle sub-categories. The diet composition described in each study is summarized in Table A3.4.

Table A3.4 Diet composition (proportion of kg DM) for dairy cattle reported in the literature for the semi-intensive region

Location	Busia[16]	Vihiga[6]	Kisii[6]	Kisumu[6]	Nandi[17]	Nandi[18]	Nandi[19]	Uasin Gishu[20]	Uasin Gishu[21]	Nyando[22]	Nandi[23]	Vihiga[24]	Nandi[25]
Method	FGD & FEAST	FGD & FEAST	FGD & FEAST	FGD & FEAST	FGD & FEAST	FGD & FEAST	FGD & FEAST	FGD & FEAST	FGD & FEAST	Measure available feed	Measure available feed	Questio-nnaire survey	Questio-nnaire survey
Pasture	0.54	0.23	0.22	0.43	0.52	0.33	0.49	0.52	0.53	0.90	0.70	0.30	n.r.
cultivated fodder	0.26	0.41	0.30	0.22	0.29	0.51	0.17	0.09	0.08	0.03	0.16	0.23	0.53
crop residue	0	0.01	0.23	0.02	0	0.1	0.03	0.30	0.21	0.01	0.09	0.32	0.33
purchased feed	0.06	0.03	0.01	0.06	0	0.02	0.04	0.0	0	-	-	0.11	0.11
Weeds	0.14	0.33	0.23	0.28	0.19	0.04	0.27	0.09	0.18	-	-	0.04[a]	-
Av. DE%	64.7	64.0	62.7	63.6	61.9	62.4	62.6	61.2	61.4	57	63	-	-
Av. CP%	12.0	11.9	11.0	12.2	11.9	11.0	12.2	9.8	10.5	-	-	-	-

FGD means focus group discussion. FEAST refers to FEAST tool (https://www.ilri.org/feast). n.r. means not reported but indicated as present in the study. '–' means not reported as present in the study. [a]protein rich fodder

[16] Muyekho et al. 2014
[17] Wafula et al. 2015a
[18] Wafula et al. 2015b
[19] Wafula et al. 2015c
[20] Wafula et al. 2015d
[21] Wafula et al. 2015e
[22] Goopy et al. 2018b. Diet composition estimated here used reported diet composition by location weighted by animal population by location reported in that paper. DMD reported in that publication were converted to %DE using equations from CSIRO (2007).
[23] Ndung'u et al. 2018. Diet composition estimated here used reported diet composition by location weighted by animal population by location reported in that paper. DMD reported in that publication were converted to %DE using equations from CSIRO (2007).
[24] Ongadi et al. 2006. Data presented here are the weighted average of 3 different feeding systems in that study.
[25] Weiler et al. 2014

To determine feed composition, the approach taken was to construct three typical diets for cattle in zero-grazing, semi-zero grazing and grazing systems based on the average diet reported in the studies summarized in Table A3.4. For the zero-grazing household, the assumed diet is based on Ongadi et al. (2006). For the semi-zero grazing household, the assumed diet is the simple average of diet composition in the studies reported in Table A3.4. For the grazing household, the assumed diet is that for semi-zero grazing but replacing cultivated fodder with pasture consumption. These assumed diets are summarized in Table A3.5.

Table A3.5: Assumed diet composition (proportion of DMI) for dairy cattle in the semi-intensive production system (2008)

	Zero-grazing		Semi-zero grazing		Grazing	
	Cow	Other sub-categories	Cow	Other sub-categories	Cow	Other sub-categories
pasture	0.00	0.00	0.50	0.59	0.69	0.77
cultivated fodder	0.52	0.65	0.18	0.18	0.00	0.00
crop residue	0.30	0.28	0.11	0.11	0.11	0.11
purchased feed	0.13	0.00	0.08	0.00	0.08	0.00
weeds/protein rich fodders	0.06	0.06	0.12	0.11	0.11	0.11
minerals	0.01	0.01	0.01	0.01	0.01	0.01
DE%	60	57	61	60	62	61
CP%	11.1	10.7	12.0	11.7	12.0	11.86

EADD (2010) baseline survey in western Kenya suggests that in 2008, about 33% of households fed concentrate feed, and that in 1998 the proportion was 17.5%. Assuming that the feeding practice was to feed 2 kg (fresh matter) concentrate per cow per day, in 1998 the average cow would have received about 0.3 kg DM of concentrate (assuming 85% dry matter content), and in 2008 the average cow would have received about 0.55 kg DM of concentrate. Extrapolating this trend linearly implies about 0.7 kg DM concentrate per cow in 2014. Based on this average trend, and the proportions of households with different feeding systems (see below), the trend in concentrate feed in different feeding systems was extrapolated, such that the weighted average closely matched the linear trend in concentrate feeding (Table A3.6). Intervening years were linearly interpolated. The time series for digestibility for cows is thus a function of (a) change on proportion of dairy cattle in different feeding systems and (b) a gradual increase in concentrate consumption over time.

Table A3.6 Estimated average concentrate fed per cow in the semi-intensive production system (kg DM)

	Zero-grazing	Semi-zero	Grazing	Weighted average
1998	0.50	0.35	0.21	0.31
2008	0.75	0.58	0.45	0.56
2014	0.98	0.73	0.60	0.74

It was assumed that no dairy cattle sub-types other than cows are fed commercial dairy concentrate in any year in the time series.

Production systems: Two data points for the proportion of households with different feeding systems in 1998 and 2008 were obtained from EADD (2010) and one data point from 2014 from Njarui et al.

(2016).[26] Neither of these surveys covered the whole of the semi-intensive region, but they are the best large-scale survey data available that include semi-intensive counties. Njarui et al. (2016) also includes some extensive counties, and since no data are available for extensive counties, the data are applied to both production systems. EADD (2010) estimated in 2008 18% zero-grazing, 42% semi-zero grazing and 40% grazing, with 19%, 31% and 50% respectively in 1998. Njarui et al. (2016) estimated 27.8%, 32.5% and 39.8% respectively in 2014. Intervening years were linearly interpolated.

Time series for digestibility: The resulting time series for feed digestibility is shown in Table A3.7. The results show a 1% increase for dairy cows between 1995 and 2018 and no change in feed digestibility for any other sub-category.

Table A3.7 Time series for feed digestibility (DE%) for dairy cattle sub-categories in the semi-intensive system

	Cow	Heifer	Adult male	Growing male	Calf
1995	61	60	60	60	60
1996	61	60	60	60	60
1997	61	60	60	60	60
1998	61	60	60	60	60
1999	61	60	60	60	60
2000	61	60	60	60	60
2001	61	60	60	60	60
2002	61	60	60	60	60
2003	61	60	60	60	60
2004	61	60	60	60	60
2005	61	60	60	60	60
2006	61	60	60	60	60
2007	61	60	60	60	60
2008	62	60	60	60	60
2009	62	60	60	60	60
2010	62	60	60	60	60
2011	62	60	60	60	60
2012	62	60	60	60	60
2013	62	60	60	60	60
2014	62	60	60	60	60
2015	62	60	60	60	60
2016	62	60	60	60	60
2017	62	60	60	60	60
2018	62	60	60	60	60

3. Extensive region

Due to lack of data to typify diets in the extensive region, it is assumed that diets in the extensive region are the same as in the semi-intensive region.

[26] Waithaka et al. (2002) estimate for 2000 of 5% zero grazing, 73% semi-zero and 22% grazing appears inconsistent with these other data sources.

Annex 4: Data sources and methods used to estimate the coefficient for activity

Some data on hours spent grazing are given in Staal et al (2001). However, grazing is often tethered in a paddock or by a roadside, so grazing hours may contribute little to energy expenditure. IPCC (2006) provides default factors for energy expenditure for grazing activity (0.17 for grazing flat pastures, 0.36 for extensive grazing), but no specific guidance on when to use which default value is given. NRC (2001) estimates energy expenditure for activity as deriving from two components:

Energy for locomotion (Mcal) = 0.00045 * LW * km
Where 0.00045 is Mcal/kg live weight, LW is live weight and km is kilometres, and
Energy for eating (Mcal) = 0.0012 * LW

Where: 0.0012 is Mcal/kg live weight. So:

Energy for activity = (0.00045 * LW * km) + (0.0012 * LW).

Mcal is then converted to MJ by multiplying by 4.1868.

The coefficient for activity (C_a) is expressed as a proportion of net energy for maintenance (NEm= Cf_i*$LW^{0.75}$), so net energy for activity is divided by NEm. Thus:

$$C_a = \left(\frac{((0.00045*LW*km)+(0.0012*LW)*4.1868)}{(Cfi*LW^{0.75})}\right)$$

For example, this would imply that for a 365 kg cow, a C_a value of 0.17 corresponds to a daily average grazing distance of 5.3 km, while a value of 0.36 corresponds to a distance of 14.2 km.

Data on grazing distances and live weight were available from three studies. The data is summarized in Tables A4.1 and A4.2.

Table A4.1 Data on daily grazing distances and animal live weights from two studies in semi-intensive region

Animal type	Goopy et al. (2018b)		Ndung'u et al. (2018)		*Calculated*
	Annual average distance travelled (km)	Annual average live weight (kg)	Annual average distance travelled (km)	Annual average live weight (kg)	***Average distance travelled (km)***
females > 2 years old	2.4 ± 0.72	216.4 ± 46.17	8.0±3.06	305.8±1.88	***5.2***
females 1-2 years old	2.4 ± 0.72	160.7 ± 55.58	8.0±3.06	186.8±6.56	***5.2***
males > 2 years old	2.4 ± 0.72	214.5 ± 45.33	8.0±3.06	265.9±5.47	***5.2***
males 1-2 years old	2.4 ± 0.72	143.4 ± 42.86	8.0±3.06	156.9±5.33	***5.2***
Calves*	0	73.1 ± 41.93	0	73.2±2.25	***0***

L. Merbold, ILRI, pers. comm. DATE. Notes:

Data shown are arithmetic mean ± one standard deviation. Data on distance travelled were measured using GPS. *according to L. Merbold, pers. comm. "calves were mostly tethered at and around the homestead hence the distance travelled was assumed to be negligible".

Table A4.2 Data on daily grazing distances and animal live weights from one study in intensive region

Animal type	Number of animals	Proportion of animals in zero-grazing	Annual average grazing distance (km)	Estimated live weight (kg)
Cows	726	0.635	0.73 ± 1.15	341.54 ± 82.78
Heifers	280	0.579	0.71 ± 1.17	260.62 ± 92.15
Adult males	51	0.60	0.63 ± 0.67	372.81 ± 106.19
Growing males	52	0.57	0.86 ± 1.00	211.12 ± 85.29
Calves	270	0.637	0.76 ± 1.19	108.96 ± 85.55

UNIQUE (2018). Note: Distances were farmer self-reported estimates of distance to and from grazing locations. Cattle were often tethered at the grazing location.

The equation for calculating C_a presented above was applied to the average daily distances travelled from each data source and the average live weight in the time series for each animal sub-category in the inventory (i.e. not the live weight data presented in Tables A4.1 and A4.2). The value of C_a was then weighted by the proportion of each sub-category of animal that grazes for some part of the year. For the semi-intensive and extensive region, the estimated proportion grazing was 0.71, which is based on the estimate of 71% of households in semi-zero and grazing systems from Njarui et al. (2016), which is also the value used in the estimation of the feed digestibility time series. The resulting estimated coefficients for activity are shown in Table A4.3.

Table A4.3 Estimated coefficients for activity based on live weight and grazing distance in the Kenya

	Distance travelled (km)	Live weight (kg)*	Cf_i	NE_m	NE_a (Mcal)	NE_a (MJ)	C_a for those grazing	%grazing	average C_a
Intensive									
Cow	0.73	362	0.386	32.03	0.55	2.32	0.07	0.37	0.03
Heifer	0.71	260.71	0.322	20.89	0.40	1.66	0.08	0.42	0.03
Adult male	0.63	357.64	0.368	30.26	0.53	2.22	0.07	0.40	0.03
Growing male	0.86	241	0.370	22.63	0.38	1.60	0.07	0.43	0.03
Calves	0.76	86.9	0.340	9.68	0.13	0.56	0.06	0.36	0.02
semi-intensive and extensive									
Cow	5.2	256.2	0.386	24.72	0.91	3.80	0.15	0.71	0.11
Heifer	5.2	208.29	0.322	17.65	0.74	3.09	0.17	0.71	0.12
Adult male	5.2	238.27	0.346	20.98	0.84	3.53	0.17	0.71	0.12
Growing male	5.2	181.21	0.370	18.27	0.64	2.69	0.15	0.71	0.10
Calves	0	61.49	0.344	7.55	0.07	0.31	0.04	0.00	0.00

* average live weight in time series 1995-2018 for each animal sub-category. Cf_i = coefficient for maintenance; NE_m = net energy for maintenance; NE_a = net energy for activity; C_a = coefficient for activity.

Annex 5: Milk yield and milk fat content

5.1 Milk yield

Milk output reported at county level is produced by local officials estimating numbers of dairy cattle, proportion of cows in the herd, proportion of cows lactating and annual milk yield per cow. The figures are estimated in various different ways and are not consistent. At national level, when estimating national milk output, it is assumed that annual milk yield per cow is about 1800 liters in all years.

The method used in this inventory to estimate a time series for milk yield is similar to the method and data sources used to estimate the trend in live weight (see Annex 2). Several studies show that Friesian and Ayrshire and other pure breeds have higher milk yields than crosses and other local breeds (Table A5.1). In the intensive system, the trend in live weight was estimated using the proportion of Friesians and Ayrshire in the herd as reported for 1996-7 by Owango et al. (1998), 2008 by Kariuki (2011) and 2018 by UNIQUE (2018) to calculate the weighted average live weight across breeds. In the semi-intensive system, the estimated live weight was calculated using data on live weight by genotype and proportions of genotypes in the population from Waithaka et al. (2002) and Lukuyu et al. (2016). For milk yields:

(a) In the intensive system, milk yield (kg per day) used data from UNIQUE (2018) (Table A5.1) together with proportions of breeds from Owango et al. (1998), Kariuki (2011) UNIQUE (2018) to calculate weighted average milk yields for 1996-7, 2008 and 2018. Intervening years were interpolated linearly.

(b) In the semi-intensive region, the weighted average milk yield (kg per day) from Wanjala et al (2014), Waithaka et al. (2002) and Tegemeo (2004) for pure breeds (7.73 kg) and crosses (4.51 kg) were applied to the proportions of 'high grade' and cross cows reported by Waithaka et al. (2002) and Lukuyu et al. (2016) to calculate the weighted average milk yields for 2000 and 2014. Intervening years were linearly interpolated.

In both systems it was assumed that cows lactate for 365 days. This assumption was made because extended lactation duration longer than one year is commonly reported in the literature from Kenya (e.g. Omore et al. 1998, Staal et al. 1997, Reynolds et al. 1996, Richards et al. 2016). It is generally thought that this is due to smallholder management purposively delaying reproduction in order to maintain a stream of income from milk. This assumption may require further verification.

Table A5.1 Milk yield associations with breed in various surveys

Source	Location	Sample size (head)	Breeds	Mean milk yield per day (kg)
Mbugu et al. 1999	**Kiambu, Nyandarua**	**162**	**Friesian, Ayrshire, Guernsey**	**8.39**
			Crosses	4.53
Muraya et al. 2018	Meru	314	Friesian	7.50
			Guernsey	6.24
			Ayrshire, Jersey	5.38
Wanjala et al. 2014	Busia, Kakamega	362	Friesian, Ayrshire	7.54
			Jersey and crosses	4.29
Waithaka et al. 2002	Various sites, western Kenya	200	Pure grades	5.26
			Crosses	3.09
Tegemeo 2004	national	890	Pure exotic	8.37
			Crosses	4.93
UNIQUE 2018	Intensive prodn system	702	Friesian, Ayrshire	7.02
			Other crosses and breeds	4.44

Applying these data sources and this method, in the intensive system, 1995 average milk yield is estimated to be 2252 kg, rising to 2456 kg in 2017. In the semi-intensive system, 1995 average milk yield is estimated to be 1732 kg, rising to 1826 kg in 2017. Expressed in liters per head, the population weighted average milk yield across all production systems is about 1825 L in 1995, and about 1932 L in 2017, which are higher than the 1800 L 'rule of thumb' used in Kenya. Considering these different assumptions regarding milk yield and the different assumptions about proportion of cows and lactating cows in the herd (Annex 1), the total milk output implied by this inventory will differ from official national estimates. The average milk yield per head in each production system and the weighted average across all production systems are shown in Table 9 in the main text.

5.2 Milk fat content

Dairy processors test milk fat content, but this data was not available for the inventory. The Livestock Recording Centre in Naivasha has data on milk fat and protein, but it is not possible to calculate averages from the dataset that are representative of smallholder-dominated farming.[27] There are various literature reports of milk fat content (Table A5.2). Overall, the available data is limited. Therefore, IPCC default values of 4% milk fat and 3.5% milk protein were used in the inventory (IPCC 2006 page 10.60). The default values are within range of those reported in the sources in Table A5.2, so are likely to be appropriate for Kenya.

Table A5.2 Milk fat and protein content reports from the literature

Source	Year	Location	Sample size	Milk fat content (%)	Milk protein content (%)
Yator et al. 2017	ca. 2016	KARI, Kitale	n.r.	4.53[a,b]	3.37[a,b]
Kabui 2012	ca. 2010	Limuru	202	3.8[b]	3.1[b]
		Eldoret	105	4.3[b]	3.64[b]
Kashongwe et al. 2017	ca. 2015	Nakuru	97	3.9 ± 1.2	2.8 ± 0.2
Muinga 1992	1990	KARI, Mtwapa	36	3.8[b]	2.7[b]

[a]Mean of 5 supplementation treatments. Standard errors not reported. n.r. indicates not reported.

[27] Fred Oruru, LRC, pers. comm.

Annex 6: Estimation of oxen work hours

There is little reported data on oxen work hours. De Groote et al. (2018) found that about 33% of households in rural Kenya owned an ox in 2012. However, draft animals are often Zebu, which are not classified as dairy cattle (Guthiga et al. 2007). Muchuri (2012) estimated that land preparation using oxen for maize requires about 13 hours of work per hectare. This is similar to the work rate estimated by a study conducted in Uganda near the border with Kenya (Okello et al. 2015). That study, conducted in an area with average farm size of 1.46 hectares, estimated annual hours worked of 221 hours, of which 31% were spent on the owner's own farm. Average land size in Kenya is about 2.35 hectares (Kibaara et al. 2008), but specific data on how many farmers use manual tools or tractors for field operations is unavailable. Due to lack of other data, the inventory uses the data from Okello et al. (2015), which equates to an annualized average of 0.6 hours per calendar day. Oxen are estimated to be 5% of adult males in the intensive region and 51% of adult males in the semi-intensive and extensive regions. Work hours per adult male per day were calculated as:

$$Hours = Hours_{rep} \times Ox_{prop}$$

Where:

Hours is average amount of work performed per day (hours day^{-1});

$Hours_{rep}$ is the average amount of work performed per day reported in the literature (hours day^{-1});

Ox_{prop} is the proportion of oxen in adult males.

The work hours applied to adult males in these regions are shown in Table A6.1.

Table A6.1 Estimated average work hours per day for adult males

	Intensive	Semi-intensive and extensive
Oxen work hours	0.03	0.3

Annex 7: Sources of data on manure management

There is limited data on dairy cattle manure management practices in Kenya, and each available source presents challenges for use of the data in the inventory. Surveys reporting data on manure management systems are summarized in Table A7.1.

Sources 1-5 in Table A7.1 focused only on management of manure on-farm and did not report % of households with grazing cattle or the % of manure deposited on pasture. Source 6 estimated the percentage of manure deposited on pasture based on farmer self-reported proportions of time cattle spent grazing. Sources 3-5, which focused specifically on manure management characterized significant proportions of manure as being managed in deep bedding systems, sometimes before transfer to solid storage systems, while sources 1, 2 and 6 appear not to have considered deep bedding as an option in their survey tools. More generally, matching IPCC manure management categories to farmers' practices is a challenge with all the data sources. Source 3 found that farmers stored manure in either heaps or pits, and classified pits as 'liquid slurry', which IPCC (2006) indicates should have <20% dry matter content, while heaps are classified as 'solid storage'. Source 6 classified both heaps and pits as 'solid storage', unless the farmer reported that the manure was stored as slurry or liquid. The various data sources therefore use different classifications of farmer practices. High proportions of daily spread reported in Source 1 and high proportions of liquid slurry reported in Source 2 appear to be inconsistent with other available data.

For this inventory, we applied the following assumptions to the available data.

Proportion of manure deposited on pasture: Estimates of time spent grazing are available from the UNIQUE (2018) dataset for the intensive region, but not for the other production systems. For consistency between these production systems, rather than use time spent grazing, we assume that the proportion of manure deposited on pasture is the same as the proportion of DMI from pasture (Tables A3.1 and A3.4).[28]

For the intensive system, proportions of manure managed in systems other than pasture deposit are estimated based on the relative proportions in UNIQUE (2018) with two adjustments:

(a) an adjustment is made based on Source 3 such that 28% of manure reported by UNIQUE (2018) as solid storage is assumed to be stored in pits rather than heaps and are reclassified from solid storage to liquid slurry systems.
(b) For biogas, it is assumed that widespread uptake among small holder dairy farmers began only with the national biogas programme (KENDBIP) in 2009.[29] The trend in adoption between 2009 and 2018 is assumed to be linear, and the increase in the proportion of manure applied to biogas systems is reflected in a decrease in the proportion of manure in solid storage systems.

Since the proportion of DMI from pasture was estimated by cattle sub-category and feeding system (A.3.1) the proportion of manure managed in different manure management systems is estimated separately for each cattle sub-category, with proportions of manure deposited on pasture weighted by the proportion of cattle in each feeding system. Table A7.2 shows the weighted average MMS fractions for the intensive system.

[2828] Time spent grazing may be a poor indicator of proportion of manure deposited on pasture, as tethered grazing in paddocks and by roadsides is common. Where the paddock is close to the homestead, the dung is often collected. On the other hand, proportion of DMI from pasture has its limitations, as cattle may spend a considerable amount of time grazing even though they obtain most DMI from cut-and-carry fodder provided at the homestead.

[29] https://www.build-a-biogas-plant.com/PDF/biogas_programme_implementation_kenya.pdf

Table A7.1 Summary of data on manure management systems in Kenya

					% with different manure management systems									
source	**Location**	**Feeding system**	**N**	**Indicator**	**uncovered lagoon**	**liquid slurry**	**solid storage**	**drylot**	**pasture/ paddock**	**daily spread**	**burned**	**compost**	**biogas**	**deep bedding**
1	Intensive & semi-intensive	n.r.	120	% of hh	1.65%	2.48%	5.79%	29.75%	0%	44.63%	0%	15.70%		
2	Mostly intensive		52	% of hh		39.30%	11.80%	22.10%		11.40%				
3	Maragua	8% grazing, mostly tethered in compound	125	% of hh				39%					4%	57%
				% of hh		28%	72%							
4	Maragua	Mostly semi-zero grazing	299	% of hh			67%							33%
5	Kiambu	Zero-grazing	30	% of hh			83%					33%		33%
	Mbeere	Grazing and semi-zero	30	% of hh			40%					7%		81%
6	Intensive region	Zero grazing	262	% of manure		2.22%	62.63%	3.53%	0.70%	11.81%		12.38%	6.70%	
		Semi-zero	105	% of manure		4.10%	56.30%	2.93%	10.90%	7.36%	0.20%	15.10%	3.10%	
		Grazing	47	% of manure		1%	26.30%	5.40%	51.00%	10.70%		4.80%	0.50%	

Sources:

1) Climate Focus (2017) Carbon Monitoring and User Survey VPA-1, Africa Biogas Carbon Programme (ABC)
2) SIMGAS IP BV (2016) SIMGAS Biogas Programme of Activities First Monitoring Report (https://cdm.unfccc.int/filestorage/Y/W/D/YWD6O47NPCVGRKJ18A9XZIFEQHM0S2/7734%20CDM%20Monitoring%20Report%205July2016.pdf?t=SmV8cG9lbjBmfDASjZ9rfedcpUgnXThpWqZm)
3) Ortiz-Gonzalo, D., Vaast, P., Oelofse, M., de Neergaard, A., Albrecht, A., & Rosenstock, T. S. (2017). Farm-scale greenhouse gas balances, hotspots and uncertainties in smallholder crop-livestock systems in Central Kenya. *Agriculture, Ecosystems & Environment*, *248*, 58-70.
4) Lekasi, J. K., Tanner, J. C., Kimani, S. K., & Harris, P. J. C. (2003). Cattle manure quality in Maragua District, Central Kenya: effect of management practices and development of simple methods of assessment. *Agriculture, ecosystems & environment*, *94*(3), 289-298.
5) Onduru, D.D., Snijders, P., Muchena, F.N., Wouters, B., De Jager, A., Gachimbi, L., Gachini, G.N. (2008) Manure and Soil Fertility Management in sub-Humid and Semi-arid Farming Systems of sub-Saharan Africa: Experiences from Kenya. International Journal of Agricultural Research 3 (3), 166-187
6) UNIQUE (2018)

Table A7.2 Weighted average MMS fractions in the intensive production system

Year	Pasture	daily spread	drylot	solid storage	composted	liquid slurry	biogas	Deep bedding
1995	24.46%	10.98%	4.27%	37.19%	9.04%	14.55%	0.00%	0.00%
1996	24.05%	11.04%	4.29%	37.37%	9.09%	14.63%	0.00%	0.00%
1997	23.65%	11.10%	4.32%	37.54%	9.13%	14.70%	0.00%	0.00%
1998	23.24%	11.16%	4.34%	37.72%	9.18%	14.78%	0.00%	0.00%
1999	22.83%	11.22%	4.36%	37.90%	9.23%	14.86%	0.00%	0.00%
2000	22.43%	11.28%	4.38%	38.07%	9.28%	14.94%	0.00%	0.00%
2001	22.04%	11.33%	4.41%	38.24%	9.33%	15.01%	0.00%	0.00%
2002	21.66%	11.39%	4.43%	38.41%	9.37%	15.09%	0.00%	0.00%
2003	21.27%	11.44%	4.45%	38.57%	9.42%	15.16%	0.00%	0.00%
2004	20.89%	11.50%	4.47%	38.74%	9.46%	15.24%	0.00%	0.00%
2005	20.45%	11.56%	4.50%	38.93%	9.52%	15.32%	0.00%	0.00%
2006	20.02%	11.63%	4.52%	39.12%	9.57%	15.40%	0.00%	0.00%
2007	19.59%	11.69%	4.54%	39.31%	9.62%	15.48%	0.00%	0.00%
2008	19.18%	11.75%	4.57%	39.49%	9.67%	15.56%	0.00%	0.00%
2009	18.77%	11.81%	4.59%	39.24%	9.72%	15.64%	0.42%	0.00%
2010	18.36%	11.87%	4.61%	39.00%	9.77%	15.72%	0.85%	0.00%
2011	17.98%	11.92%	4.64%	38.74%	9.81%	15.80%	1.27%	0.00%
2012	17.60%	11.98%	4.66%	38.48%	9.86%	15.87%	1.69%	0.00%
2013	17.22%	12.03%	4.68%	38.22%	9.90%	15.94%	2.11%	0.00%
2014	16.84%	12.09%	4.70%	37.96%	9.95%	16.02%	2.54%	0.00%
2015	16.43%	12.15%	4.72%	37.72%	10.00%	16.09%	2.96%	0.00%
2016	16.02%	12.21%	4.75%	37.47%	10.05%	16.17%	3.38%	0.00%
2017	15.61%	12.27%	4.77%	37.22%	10.10%	16.25%	3.80%	0.00%
2018	15.20%	12.33%	4.79%	36.98%	10.14%	16.33%	4.23%	0.00%

For the semi-intensive and extensive systems, a similar approach is used, but owing to lack of data for extensive systems, it is assumed that manure management practices in extensive and semi-intensive systems are the same. The proportion of pasture in DMI (Table A3.4) is assumed to be the same as the proportion of manure deposited on pasture. For manure deposited on the farm, the following assumptions are made:

(1) For households with zero-grazing feeding systems, manure is managed in the same proportions as in the intensive system;
(2) The study by Source 4 in Maragua suggested that 67% of manure is in solid storage and 33% in deep bedding for periods of >1 month. Source 3, which studied in the same area as Source 4, suggests that 28% of the storage is in pits and not heaps, and should be classified as liquid slurry systems. Source 5 noted that 7% of households in a less intensive site use composting. For households with semi-zero grazing feeding systems, we assume that 7% of manure not deposited on pasture is composted, and the remainder is managed in heaps (67%) or pits (26%).
(3) For all households with grazing only systems, following Source 5, we assume 40% of manure not deposited on pasture is managed in heaps (29%) or pits (11%), and 60% in deep bedding systems.

Weighting the proportions of manure in different management systems by the proportion of cattle in each feeding system, Table A7.3 shows the weighted average MMS fractions for the semi-intensive and extensive systems. Note that while the proportion managed in biogas systems increases after 2009, and it is assumed that the manure input to biogas systems would otherwise have been managed in solid storage, the total proportion of manure managed in solid storage increases because of a gradual increase in the proportion of cattle raised in zero-grazing systems.

Overall, there is extremely limited data on manure management systems in Kenya, and the available data does not use consistent categorizations. Estimates of emissions from manure management can be improved with better quality manure management system activity data.

Table A7.3 Weighted average MMS fractions in the semi-intensive and extensive production systems

Year	Pasture	daily spread	drylot	solid storage	composted	liquid slurry	biogas	Deep bedding
1995	56.04%	2.30%	0.69%	21.75%	3.24%	8.34%	0.00%	7.64%
1996	55.91%	2.28%	0.68%	21.95%	3.26%	8.42%	0.00%	7.50%
1997	55.78%	2.27%	0.68%	22.14%	3.28%	8.50%	0.00%	7.35%
1998	55.64%	2.26%	0.68%	22.34%	3.30%	8.57%	0.00%	7.21%
1999	55.51%	2.25%	0.67%	22.53%	3.32%	8.65%	0.00%	7.06%
2000	55.37%	2.24%	0.67%	22.73%	3.35%	8.73%	0.00%	6.92%
2001	55.24%	2.22%	0.66%	22.92%	3.37%	8.80%	0.00%	6.78%
2002	55.11%	2.21%	0.66%	23.12%	3.39%	8.88%	0.00%	6.63%
2003	54.97%	2.20%	0.66%	23.32%	3.41%	8.96%	0.00%	6.49%
2004	54.84%	2.19%	0.65%	23.51%	3.43%	9.03%	0.00%	6.34%
2005	54.70%	2.18%	0.65%	23.71%	3.45%	9.11%	0.00%	6.20%
2006	54.57%	2.17%	0.65%	23.91%	3.47%	9.19%	0.00%	6.06%
2007	54.43%	2.15%	0.64%	24.10%	3.49%	9.27%	0.00%	5.91%
2008	54.28%	2.14%	0.64%	24.31%	3.51%	9.35%	0.00%	5.77%
2009	53.33%	2.34%	0.70%	24.51%	3.67%	9.49%	0.20%	5.77%
2010	52.38%	2.53%	0.76%	24.71%	3.82%	9.64%	0.39%	5.77%
2011	51.43%	2.72%	0.81%	24.92%	3.98%	9.79%	0.58%	5.77%
2012	50.47%	2.92%	0.87%	25.12%	4.14%	9.94%	0.78%	5.76%
2013	49.52%	3.11%	0.93%	25.33%	4.29%	10.09%	0.97%	5.76%
2014	48.57%	3.30%	0.99%	25.54%	4.45%	10.24%	1.16%	5.76%
2015	47.64%	3.50%	1.05%	25.73%	4.60%	10.38%	1.35%	5.76%
2016	46.71%	3.69%	1.10%	25.93%	4.76%	10.53%	1.54%	5.75%
2017	45.77%	3.88%	1.16%	26.12%	4.91%	10.67%	1.73%	5.74%
2018	44.84%	4.08%	1.22%	26.31%	5.07%	10.82%	1.93%	5.74%

The values for MCF used in calculation of methane emissions from manure management are shown in Table A7.4. Each production system was characterized by long-term mean annual temperature (MAT) obtained from https://climateknowledgeportal.worldbank.org/country/kenya/climate-data-historical source for the period 1991-2016.[30] MCF values for liquid slurry and deep bedding (>1 month) were selected based on average MAT for each production system in each year.

Table A7.4 Values of MCF used in calculation of manure management methane

Manure management system	MCF value
Pasture/range/paddock	1.5%
Daily spread	0.5%
Dry lot	1.5%
Solid storage	4%
Composted	0.5%
Liquid slurry (with crust cover)	26%-34% depending on temperature
Biogas	0%*
Deep bedding (>1 month)	42%-55% depending on temperature

* IPCC default values are 0-100%; Climate Focus (2017) applies a value of 0%.

Sources: All other MCF values from IPCC (2006) Table 10-17.

[30] Kenya Meteorology Department was only able to provide data for annual long term mean minimum and maximum temperature at each weather station, so this data source was not used.

Annex 8: Sources of data on N_2O from manure management

Table A3.1 reports the estimated crude protein content (CP%) of the main diet components. CP% of the diet was estimated using the same assumed diets and sources as reported in Annex 3. Tables A8.1 and A8.2 show the estimated trend in CP% for diets of each sub-category of dairy cattle for the three production systems. The resulting time series suggests that CP% has not increased for cows in the intensive system. This may reflect constraints of farmers in zero-grazing feeding systems in producing and obtaining fodder sources with higher protein content. It may also be a short-coming of the methodology used to construct typical diets (see Annex 3), if for example high protein feeds have increased but have not been captured in the feed categories used to construct these assumed diets.

Table A8.1 Time series for feed crude protein content for dairy cattle sub-categories in the intensive system

	Cow	Heifer	Adult male	Growing male	Calf
1995	11.16	10.51	10.57	10.51	10.48
1996	11.15	10.52	10.58	10.51	10.49
1997	11.15	10.53	10.59	10.51	10.49
1998	11.15	10.53	10.60	10.51	10.50
1999	11.15	10.54	10.61	10.52	10.50
2000	11.15	10.55	10.62	10.52	10.51
2001	11.15	10.56	10.63	10.52	10.51
2002	11.15	10.57	10.64	10.52	10.51
2003	11.15	10.58	10.65	10.52	10.52
2004	11.15	10.59	10.65	10.52	10.52
2005	11.15	10.60	10.66	10.52	10.53
2006	11.15	10.61	10.67	10.52	10.53
2007	11.15	10.61	10.68	10.52	10.54
2008	11.15	10.62	10.69	10.52	10.54
2009	11.15	10.63	10.70	10.52	10.55
2010	11.15	10.64	10.71	10.52	10.55
2011	11.15	10.65	10.72	10.52	10.56
2012	11.15	10.66	10.73	10.53	10.56
2013	11.15	10.67	10.73	10.53	10.57
2014	11.15	10.68	10.74	10.53	10.57
2015	11.15	10.69	10.75	10.53	10.58
2016	11.15	10.69	10.76	10.53	10.58
2017	11.15	10.70	10.77	10.53	10.59
2018	11.15	10.71	10.78	10.53	10.59

Table A8.2 Time series for feed crude protein content for dairy cattle sub-categories in the semi-intensive and extensive systems

	Cow	Heifer	Adult male	Growing male	Calf
1995	11.75	11.59	11.59	11.59	11.59
1996	11.77	11.59	11.59	11.59	11.59
1997	11.79	11.59	11.59	11.59	11.59
1998	11.80	11.59	11.59	11.59	11.59
1999	11.82	11.59	11.59	11.59	11.59
2000	11.84	11.59	11.59	11.59	11.59
2001	11.86	11.58	11.58	11.58	11.58
2002	11.87	11.58	11.58	11.58	11.58
2003	11.89	11.58	11.58	11.58	11.58
2004	11.91	11.58	11.58	11.58	11.58
2005	11.92	11.58	11.58	11.58	11.58
2006	11.94	11.58	11.58	11.58	11.58
2007	11.96	11.58	11.58	11.58	11.58
2008	11.98	11.58	11.58	11.58	11.58
2009	11.97	11.56	11.56	11.56	11.56
2010	11.97	11.55	11.55	11.55	11.55
2011	11.96	11.53	11.53	11.53	11.53
2012	11.96	11.51	11.51	11.51	11.51
2013	11.96	11.50	11.50	11.50	11.50
2014	11.95	11.48	11.48	11.48	11.48
2015	11.95	11.47	11.47	11.47	11.47
2016	11.95	11.45	11.45	11.45	11.45
2017	11.94	11.43	11.43	11.43	11.43
2018	11.94	11.42	11.42	11.42	11.42

Annex 9: 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 inventory;
(2) Standard deviations: Standard deviations (where applicable) were taken from the data sources used to estimate mean values. Where multiple datasets were combined to estimate a parameter value, weighted average standard deviations were calculated using error propagation rules. Where mean values used in the inventory differed from the mean value reported in the original data sources, standard deviations were scaled to reflect the relative change in mean values;
(3) Probability Density Functions (PDFs): For each parameter, PDFs were chosen either by reference to the distribution of data in the UNIQUE (2018) dataset or other data sources, or by reference to the instructions in the IPCC Guidelines for selection of PDFs (Vol. 1 Ch. 3).

The mean values, margin of error, pdfs used, and their justifications are shown in Table A9.1. Because animal sub-category populations were estimated using the same data sources, correlations between the proportions of each animal sub-category in the total herd 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%. Uncertainty analysis was conducted for the base year (1995) and the latest year in the inventory (2017), and uncertainty in the trend (1995-2017).

9.1 Uncertainty in activity data

For activity data, uncertainty was estimated for the population of each sub-category by characterizing the pdfs for:

(1) **the total population:** A margin of error of ±1.5% was estimated assuming a normal distribution on the basis that the 2009 population estimate from administrative data was revised using 2009 census data by 1.34% (B. Kibor pers. comm);

(2) **the proportion of livestock populations in each production system:** Allocation of counties to production systems was done using expert judgement. Expert judgement suggested that reallocation of 2-3 counties per production system could lead to an increase or decrease in population of each production system by up to 20%. This was represented using a triangular distribution, with the most likely value set at the inventory population value, the minimum at 20% below and the maximum at 20% above the most likely value, giving 95% confidence bounds of ±15.5%.

(3) **proportion of each sub-category in the herd:** Inventory herd structure was estimated using literature reported values. The frequency-weighted average standard deviation of these values was used to estimate the margin of error, which was used to characterise a Beta distribution.

The datasets used to estimate proportions of total population in each production system and proportions of sub-categories in the herd were the same for each production system. Therefore, correlations between input variables were calculated and included in the model.

The results for activity data alone suggest that the uncertainty of the 1995 total population is ±8.97% and of the 2017 total population is ±7.99%. Uncertainty of total population is mainly due to uncertainty in the proportion of total population allocated to semi-intensive and intensive production systems, the proportions of calves and growing males in the intensive and extensive production systems, and the proportions of adult males and heifers in the intensive and semi-intensive systems. Uncertainty of sub-populations ranges from ±14% to ±80% (Table A9.4). (Results for 1995 and 2017 are remarkably similar). This uncertainty is due to the use of expert judgement to allocate the population in each county to different production systems and variation in the different data sources used to estimate herd structure.

Table A9.1 Mean, margin of error and pdfs used in the uncertainty analysis for livestock population data

Parameter	Mean value		Margin of error		PDF	Explanation
	1995	2017	1995	2017		
Total population	2,355,479	4,573,871	±1.5%	±1.5%	Normal	Normal selected because s.e. small compared to mean
Proportion in each production system:						
Intensive	0.29	0.28	±20%	±20%	Triangular	Triangular, expert judgement specified most likely, minimum and maximum
Semi-intensive	0.57	0.51	±20%	±20%	Triangular	Triangular, expert judgement specified most likely, minimum and maximum
Extensive	0.15	0.21	±20%	±20%	Triangular	Triangular, expert judgement specified most likely, minimum and maximum
Herd structure intensive system:						
% cows	0.43	0.41	±3.95%	±3.95%	Beta	Beta, proportion, cannot have negative values. Weighted s.d. of sources used.
% heifers	0.19	0.18	±10.66%	±10.66%	Beta	Beta, proportion, cannot have negative values. Weighted s.d. of sources used.
% adult males	0.04	0.06	±40.66%	±40.66%	Beta	Beta, proportion, cannot have negative values. Weighted s.d. of sources used.
% growing males	0.11	0.11	±95.33%	±95.33%	Beta	Beta, proportion, cannot have negative values. Weighted s.d. of sources used.
% calves	0.24	0.24	±25.21%	±25.21%	Beta	Beta, proportion, cannot have negative values. Weighted s.d. of sources used.
Herd structure semi-intensive system:						
% cows	0.34	0.38	±15.37%	±15.37%	Beta	Beta, proportion, cannot have negative values. Weighted s.d. of sources used.
% heifers	0.21	0.24	±6.86%	±6.86%	Beta	Beta, proportion, cannot have negative values. Weighted s.d. of sources used.
% adult males	0.08	0.05	±27.75%	±27.75%	Beta	Beta, proportion, cannot have negative values. Weighted s.d. of sources used.
% growing males	0.10	0.10	±20.17%	±20.17%	Beta	Beta, proportion, cannot have negative values. Weighted s.d. of sources used.
% calves	0.26	0.23	±6.04%	±6.04%	Beta	Beta, proportion, cannot have negative values. Weighted s.d. of sources used.
Herd structure extensive system:						
% cows	0.28	0.38	±15.37%	±15.37%	Beta	Beta, proportion, cannot have negative values. Weighted s.d. of sources used.
% heifers	0.18	0.24	±6.86%	±6.86%	Beta	Beta, proportion, cannot have negative values. Weighted s.d. of sources used.
% adult males	0.15	0.06	±27.75%	±27.75%	Beta	Beta, proportion, cannot have negative values. Weighted s.d. of sources used.
% growing males	0.11	0.10	±20.17%	±20.17%	Beta	Beta, proportion, cannot have negative values. Weighted s.d. of sources used.
% calves	0.28	0.23	±6.04%	±6.04%	Beta	Beta, proportion, cannot have negative values. Weighted s.d. of sources used.

Table A9.2 Mean, margin of error and pdfs used in the uncertainty analysis for enteric fermentation

Parameter	Mean value		Margin of error		PDF	Explanation
	1995	2017	1995	2017		
Live weight intensive system:						
cows	354.10	366.02	±18.07%	±18.07%	Normal	Normal selected because s.e. small compared to mean
heifers	254.95	263.53	±18.93%	±18.93%	Normal	Normal selected because s.e. small compared to mean
adult males	357.64	357.64	±24.54%	±24.54%	Normal	Normal selected because s.e. small compared to mean
growing males	241.00	241.00	±29.38%	±29.38%	Normal	Normal selected because s.e. small compared to mean
calves	84.98	87.84	±29.56%	±29.56%	Normal	Normal selected because s.e. small compared to mean
Live weight semi-intensive & extensive system:						
cows	253.12	259.01	±24.80%	±24.80%	Normal	Normal selected because s.e. small compared to mean
heifers	205.79	210.58	±6.91%	±6.91%	Normal	Normal selected because s.e. small compared to mean
adult males	235.40	240.88	±34.28%	±34.28%	Normal	Normal selected because s.e. small compared to mean
growing males	179.04	183.20	±6.91%	±6.91%	Normal	Normal selected because s.e. small compared to mean
calves	60.75	62.16	±24.8%	±24.8%	Normal	Normal selected because s.e. small compared to mean
Weight gain intensive system:						
cows	0.017	0.017	±16.68%	±16.68%	Lognormal	Lognormal, only positive values; s.d. scaled from Makau et al. (2018)
heifers	0.25	0.25	±18.02%	±18.02%	Lognormal	Lognormal, only positive values; s.d. scaled from Makau et al. (2018)
adult males	0.14	0.14	±8.17%	±8.17%	Lognormal	Lognormal, only positive values; s.d. scaled from Makau et al. (2018)
growing males	0.20	0.20	±18.02%	±18.02%	Lognormal	Lognormal, only positive values; s.d. scaled from Makau et al. (2018)
calves	0.42	0.42	±18.02%	±18.02%	Lognormal	Lognormal, only positive values; s.d. scaled from Makau et al. (2018)
Weight gain semi-intensive & extensive system:						
cows	0.03	0.03	±16.68%	±16.68%	Lognormal	Lognormal, only positive values; s.d. scaled from Makau et al. (2018)
heifers	0.22	0.22	±18.02	±18.02	Lognormal	Lognormal, only positive values; s.d. scaled from Makau et al. (2018)
adult males	0.03	0.03	±16.68	±16.68	Lognormal	Lognormal, only positive values; s.d. scaled from Makau et al. (2018)
growing males	0.17	0.17	±18.02	±18.02	Lognormal	Lognormal, only positive values; s.d. scaled from Makau et al. (2018)
calves	0.22	0.22	±18.02	±18.02	Lognormal	Lognormal, only positive values; s.d. scaled from Makau et al. (2018)

Milk yield						
Intensive	3.89	5.08	±23.9%	±23.9%	Normal	Normal, s.e. small compared to mean. s.d. from UNIQUE (2018)
Semi-intensive & extensive	2.85	3.09	±23.9%	±23.9%	Normal	Normal, s.e. small compared to mean. s.d. scaled from UNIQUE (2018)
Milk fat content (%)	4	4	±10.3%	±10.3%	Normal	Normal, s.e. small. Weighted average s.d. from studies in Table A5.2
Proportion giving birth						
Intensive	0.63	0.75	±5.72%	±3.10%	Normal	Normal, s.e. small. 1995 Weighted average s.d. from studies used. 2017 s.d. from UNIQUE (2018)
Semi-intensive & extensive	0.60	0.62	±5.63%	±5.82%	Normal	Normal, s.e. small. 1995 weighted average s.d. from studies used. 2017 s.d. scaled from weighted average of studies used.
DE% (all sub-categories)			±15%	±15%	Normal	Normal, s.e. small. UNIQUE (2018) and Goopy et al (2018) ME <3%. Inventory estimated 'typical' diets per sub-category. ME assumed to be ±15% (Monni et al. 2007).
Ym (%) (all sub-categories)	6.5	6.5	±15.4%	±15.4%	Normal	Normal, s.e. small. ME taken from IPCC (2006), i.e. 6.5± a range of 1%.
Cfi (all sub-categories)	0.322-0.368	0.322-0.37	±15%	±15%	Beta	Beta, proportion, cannot have negative values. 15% ME from Monni et al (2007)
Ca (all sub-categories)	0.03 - 0.12	0.03 - 0.12	±15%	±15%	Beta	Beta, proportion, cannot have negative values. 15% ME from Monni et al (2007)
Cp (all sub-categories)	0.1	0.1	±15%	±15%	Beta	Beta, proportion, cannot have negative values. 15% ME from Monni et al (2007)
C (all sub-categories)	0.8 – 1.086	0.8 – 1.086	±15%	±15%	Beta	Beta, proportion, cannot have negative values. 15% ME from Monni et al (2007)

Table A9.3 Mean, margin of error and pdfs used in the uncertainty analysis for manure management and managed soils

Parameter	Mean value		Margin of error		PDF	Explanation
	1995	2017	1995	2017		
Ash content	0.08	0.08	±10%	±10%	Normal	s.e. small compared to mean
Bo	0.13	0.13	±15%	±15%	Normal	s.e. small compared to mean. Uncertainty range from IPCC (2006) Ch. 10 Table 10A.4
MMS%, various manure management systems	various	various	±50%	±50%	Normal	Uncertainty range ±50% from IPCC (2006) Ch. 10, p. 10.50.
MCF, various manure management systems	various	various	±50%	±50%	Normal	Uncertainty range ±50% chosen, slightly higher than MCF uncertainty range used in Karimi-Zindashty et al. (2012) of ±45%
Crude protein content of diet, various animal sub-categories	various	various	±35%	±35%	Normal	Uncertainty range ±35% based on s.d. of UNIQUE (2018) dataset
Milk protein content (%)	3.5	3.5	±55%	±55%	Normal	Uncertainty range ±55% based on weighted average s.d. from studies in Table A5.2
EF3, pasture deposit	0.00115	0.00115	See expln	See expln	PERT	Uncertainty range taken from Tully et al (2018).
EF3, dry lot	0.02	0.02	+100%,-50%	+100%,-50%	beta	Uncertainty range from IPCC (2006) Table 10.21
EF3, solid storage	0.005	0.005	+100%,-50%	+100%,-50%	beta	Uncertainty range from IPCC (2006) Table 10.21
EF3, composting	0.006	0.006	+100%,-50%	+100%,-50%	beta	Uncertainty range from IPCC (2006) Table 10.21
EF3, liquid slurry	0.005	0.005	+100%,-50%	+100%,-50%	beta	Uncertainty range from IPCC (2006) Table 10.21
EF3, bedding	0.01	0.01	+100%,-50%	+100%,-50%	beta	Uncertainty range from IPCC (2006) Table 10.21
Fracgas, pasture deposit	20	20	See expln	See expln	PERT	IPCC (2006) Ch. 11 Table 11.3 gives uncertainty range of 5 – 50, which were taken as min and max of PERT distribution, with 20 as most likely.
Fracgas, daily spread	7	7	See expln	See expln	PERT	IPCC (2006) Ch. 10 Table 10.22 gives uncertainty range of 5 – 60, which were taken as min and max of PERT distribution, with 7 as most likely.
Fracgas, dry lot	20	20	See expln	See expln	PERT	IPCC (2006) Ch. 10 Table 10.22 gives uncertainty range of 10 – 35, which were taken as min and max of PERT distribution, with 20 as most likely.
Fracgas, solid storage	30	30	See expln	See expln	PERT	IPCC (2006) Ch. 10 Table 10.22 gives uncertainty range of 10 – 40, which were taken as min and max of PERT distribution, with 30 as most likely.

Parameter	Mean value		Margin of error		PDF	Explanation
	1995	2017	1995	2017		
Fracgas, compost	20	20	See expln	See expln	PERT	IPCC (2006) Ch. 11 Table 11.3 $Frac_{GASM}$ uncertainty range of 5 – 50, which were taken as min and max of PERT distribution, with 20 as most likely.
Fracgas, liquid slurry	40	40	See expln	See expln	PERT	IPCC (2006) Ch. 10 Table 10.22 gives uncertainty range of 15 – 45, which were taken as min and max of PERT distribution, with 40 as most likely.
Fracgas, bedding	20	20	See expln	See expln	PERT	IPCC (2006) Ch. 11 Table 11.3 $Frac_{GASM}$ uncertainty range of 5 – 50, which were taken as min and max of PERT distribution, with 20 as most likely.
EF4	0.01	0.01	See expln	See expln	Lognormal	IPCC (2006) Ch. 11 Table 11.3 gives uncertainty range of 0.002 – 0.05, which were taken as min and max of PERT distribution, with 20 as most likely.
$Frac_{GASM}$	0.2	0.2	See expln	See expln	PERT	IPCC (2006) Ch. 11 Table 11.3 $Frac_{GASM}$ uncertainty range of 0.05 – 0.5, which were taken as min and max of PERT distribution, with 0.2 as most likely.
EF5	0.0075	0.0075				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.
$Frac_{LEACH}$	0.3	0.3	See expln	See expln	PERT	IPCC (2006) Ch. 11 Table 11.3 $Frac_{GASM}$ uncertainty range of 0.1 – 0.8, which were taken as min and max of PERT distribution, with 0.3 as most likely.

Table A9.4 Margin of error for livestock sub-category populations (1995)

	Upper 95% CI as % of mean	Lower 95% CI as % of mean
Intensive system:		
Cow	14.31	-14.08
Heifer	17.38	-16.10
Adult males	40.78	-38.70
Growing male	80.09	-77.12
Calves	27.79	-25.60
Semi-intensive system:		
Cow	20.37	-19.01
Heifer	15.21	-14.63
Adult male	30.20	-27.56
Growing male	23.62	-21.25
Calves	14.82	-14.42
Extensive system:		
Cow	20.27	-18.64
Heifer	15.08	-14.54
Adult male	29.62	-27.31
Growing male	23.94	-21.81
Calves	14.86	-14.32

9.2 Uncertainty in enteric methane emissions

Table A9.5 shows the uncertainty for enteric methane emission factors and total methane emissions from each sub-category for 1995. (Results for 2017 were similar). Uncertainty for emission factors averaged (+51%,-33%) in the intensive system and (+41%,-30%) in the semi-intensive and extensive production systems. In comparison, IPCC (2006, page 10.33) suggests that the uncertainty range for Tier 1 emission factors are between ±30% and ±50%, while for Tier 2 emission factors it is likely to be in the order of ±20%.

For each sub-category, uncertainty for total sub-category methane emission averaged (+68%,-48%) in the intensive system and (+48%,-34%) in the semi-intensive and extensive systems. Total 1995 enteric fermentation emissions had an uncertainty of (+15.37%,-13.22%) and total 2017 enteric fermentation emissions had an uncertainty of (+14.68%,-12.92%). Uncertainty of the trend was calculated as:

Trend = (Total$CH_4$2017 – Total$CH_4$1995)/Total$CH_4$1995

Uncertainty of the trend was (+53.99%, -48.91%).

The main factors associated with uncertainty in total enteric fermentation emissions are shown in Figure A9.1 and A9.2. There is significant overlap between the input variables with high correlation to total emissions in 1995 and 2017, but the rank order of input variables is slightly different. In 1995, the top 5 input variables were:

1. Proportion of total herd in semi-intensive system
2. DE% for cows in the semi-intensive system
3. Proportion of total herd in the intensive system
4. DE% for cows in the intensive system
5. Weight gain for heifers in the intensive system.

In 2017, the top 5 variables were:

1. Proportion of total herd in semi-intensive system
2. Proportion of cows in the herd in the semi-intensive system
3. DE% for cows in the semi-intensive system
4. Proportion of total herd in the intensive system
5. DE% for cows in the intensive system

In general, because the semi-intensive system accounts for just over 50% of the national herd, the proportion of total dairy cattle in that system and the proportion of cows in the herd in that system are important variables. Similarly, for the intensive system. Among input variables to the emissions per head, digestibility, the methane conversion factor, live weight and weight gain are key variables, especially for cows, heifers and calves, which together account for >80% of the herd in each production system.

For the trend in enteric fermentation emissions (Figure A9.3), important factors include the proportion of the total herd in the extensive system; DE% for cows and heifers in semi-intensive and intensive systems; and Ym for cows in the semi-intensive system. This inventory used a constant value for Ym throughout the time series, and the values of DE% varied by only 0.1% and 0.7% between 1995 and 2017 for cows in the intensive and semi-intensive systems, respectively. Weight gain for heifers in the intensive system (for which a constant value was used throughout the time series) and cow live weight in the semi-intensive system are also important factors associated with the trend.

Table A9.5 Upper and lower confidence bounds for enteric fermentation emission factors and sub-category emissions (1995)

	Emission factor		Sub-category emissions	
	Upper	**Lower**	**Upper**	**Lower**
Intensive system:				
Cow	30.43	-24.40	34.33	-27.57
Heifer	64.84	-36.75	68.27	-39.76
Adult male	37.24	-29.55	58.30	-45.57
Growing male	41.21	-31.45	95.73	-78.77
Calves	81.06	-43.87	86.96	-48.49
Semi-intensive system:				
Cow	32.12	-25.36	38.59	-30.50
Heifer	33.16	-25.87	37.28	-28.58
Adult male	38.65	-32.02	50.99	-39.91
Growing male	42.90	-29.20	48.98	-35.22
Calves	59.34	-36.97	61.74	-38.85
Extensive system:				
Cow	31.78	-25.44	38.68	-30.64
Heifer	33.64	-25.69	37.14	-28.68
Adult male	38.40	-31.58	51.23	-39.32
Growing male	43.27	-29.41	49.83	-35.13
Calves	61.54	-37.19	64.74	-38.86

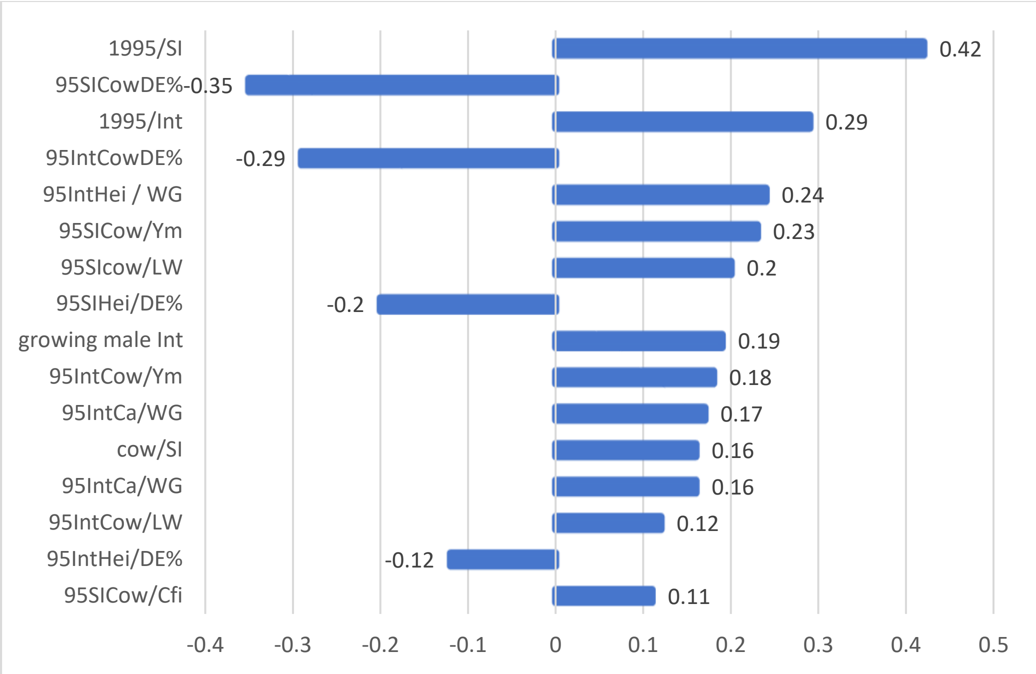


Figure A9.1 Correlation coefficients between total 1995 enteric fermentation emissions and input variables

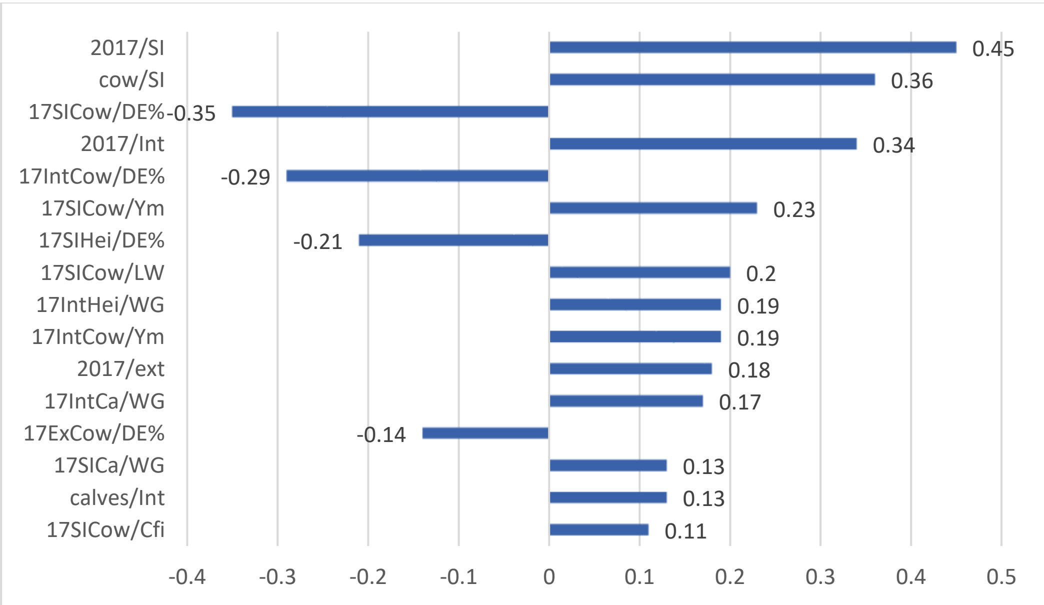


Figure A9.2 Correlation coefficients between total 2017 enteric fermentation emissions and input variables

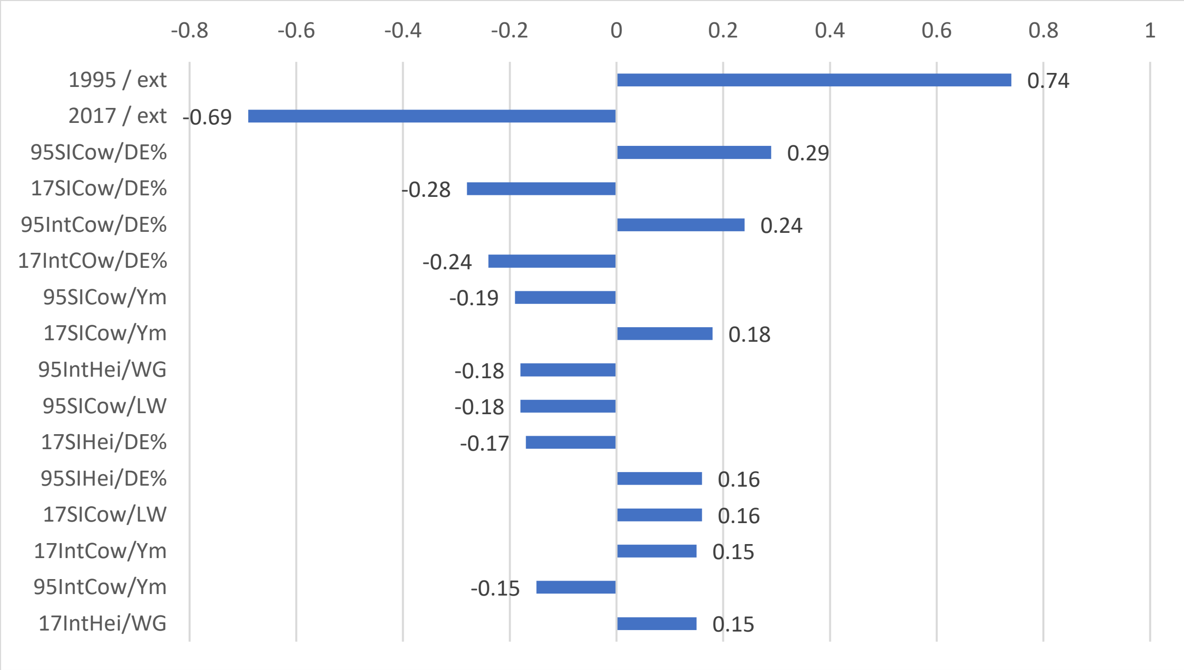


Figure A9.3 Correlation coefficients between 1995-2017 enteric fermentation trend and input variables

9.3 Uncertainty in manure management methane emissions

Table A9.6 shows the uncertainty for emission factors and total methane emissions from each sub-category for 1995. (Results for 2017 were similar). Uncertainty for emission factors averaged (+74%,-50%) in the intensive system and (+65%,-46%) in the semi-intensive and extensive production systems. In comparison, the IPCC estimates that Tier 1 emission factors have an uncertainty of ±30% and Tier 2 emission factors could reduce uncertainty to ±20%.

For each sub-category, average uncertainty for total sub-category methane emission averaged (+90%,-59%) in the intensive system and (+70%,-49%) in the semi-intensive and extensive systems. Total 1995 manure management emissions had an uncertainty of (+25.04%,-20.94%) and total 2017 manure management emissions had an uncertainty of (+24.39%,-20.65%). Uncertainty of the trend was calculated as:

Trend = (Total$CH_4$2017 – Total$CH_4$1995)/Total$CH_4$1995

Uncertainty of the trend was (+80.33%, -66.31%).

The main factors associated with uncertainty in total manure management emissions are shown in Figures A9.4 and A9.5. There is significant overlap between the input variables with high correlation to total emissions in 1995 and 2017, but the rank order of input variables is slightly different. In 1995, the top 5 input variables were:

1. MCF for liquid slurry in the intensive system
2. Proportion of manure handled in liquid slurry systems in the intensive system
3. Proportion of total herd in the extensive system
4. Proportion of total herd in the extensive system
5. DE% for cows in the intensive system.

In 2017, the top 5 variables were:

1. MCF for liquid slurry in the intensive system
2. Proportion of manure handled in liquid slurry systems in the intensive system
3. MCF for liquid slurry in the semi-intensive system
4. Proportion of manure handled in liquid slurry systems in the semi-intensive system
5. DE% for cows in the intensive system

In general, the most sensitive factors were MCFs, MMS, DE% and proportion of different animal sub-categories in the herd, especially for the semi-intensive system, which accounts for just over 50% of the national herd.

For the trend in manure management methane emissions (Figure A9.6), the most important factors were liquid slurry MCFs and the proportion of manure from cows managed as liquid slurry in 1995 and 2017, and the digestibility of feed for cows in the intensive and semi-intensive systems.

Table A9.6 Upper and lower confidence bounds for methane manure management methane emission factors and sub-category emissions (1995)

	Emission factor		**Sub-category emissions**	
	Upper	**Lower**	**Upper**	**Lower**
Intensive system:				
Cow	60.54	-46.47	63.49	-47.73
Heifer	83.35	-52.19	85.36	-53.65
Adult male	64.91	-47.50	81.93	-55.96
Growing male	66.28	-48.02	117.22	-80.30
Calves	96.48	-56.32	102.50	-59.00
Semi-intensive system:				
Cow	58.05	-43.86	62.46	-46.23
Heifer	57.99	-43.95	61.48	-45.37
Adult male	62.13	-46.36	72.55	-51.00
Growing male	64.25	-45.89	70.26	-48.63
Calves	77.87	-50.26	80.44	-51.45
Extensive system:				
Cow	60.14	-45.25	64.63	-47.30
Heifer	60.04	-44.79	62.87	-45.96
Adult male	63.71	-47.68	72.95	-51.74
Growing male	66.60	-47.08	72.24	-50.00
Calves	78.91	-51.10	81.26	-52.12

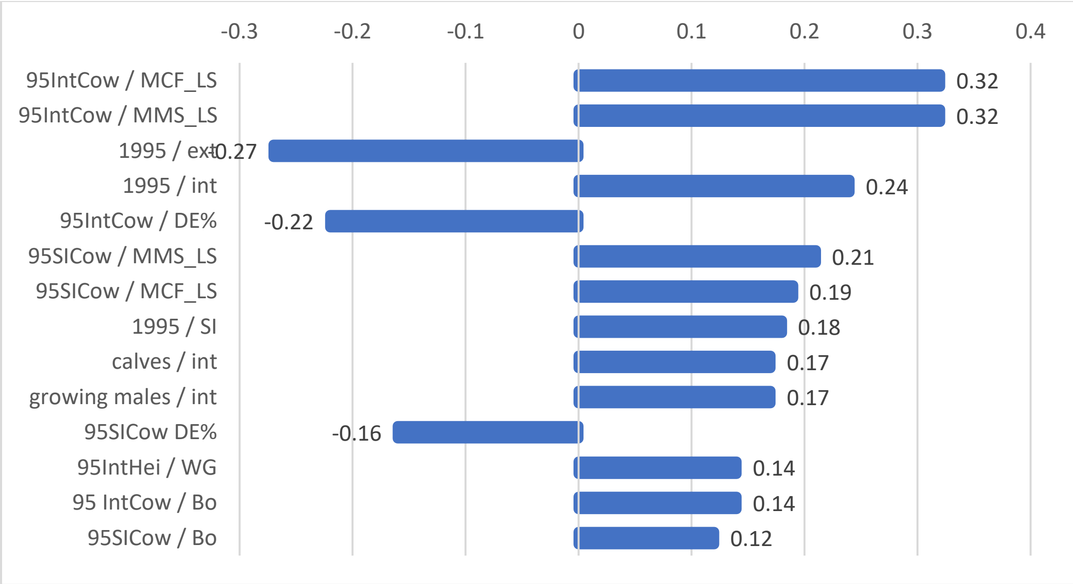


Figure A9.4 Correlation coefficients between total 1995 manure management methane emissions and input variables

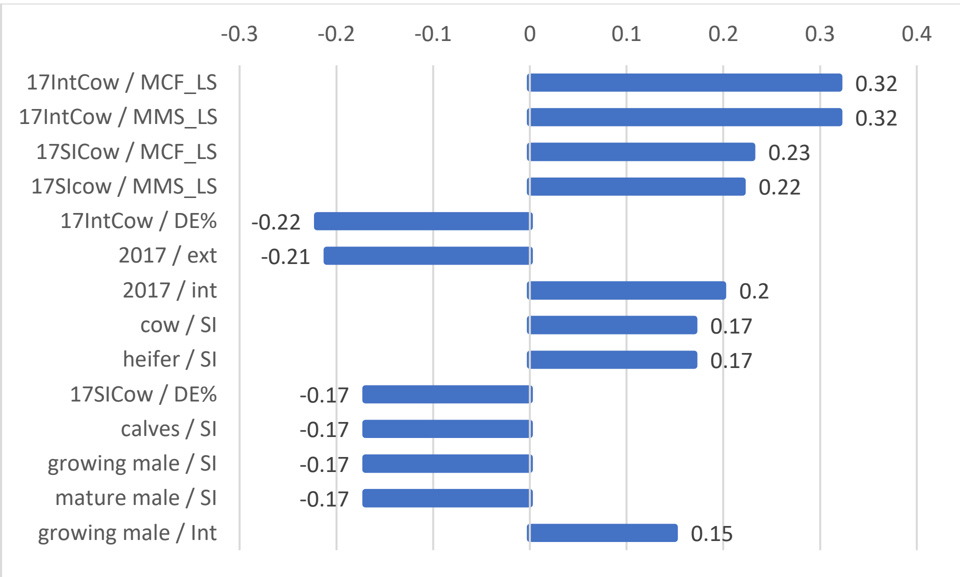


Figure A9.5 Correlation coefficients between total 2017 manure management methane emissions and input variables

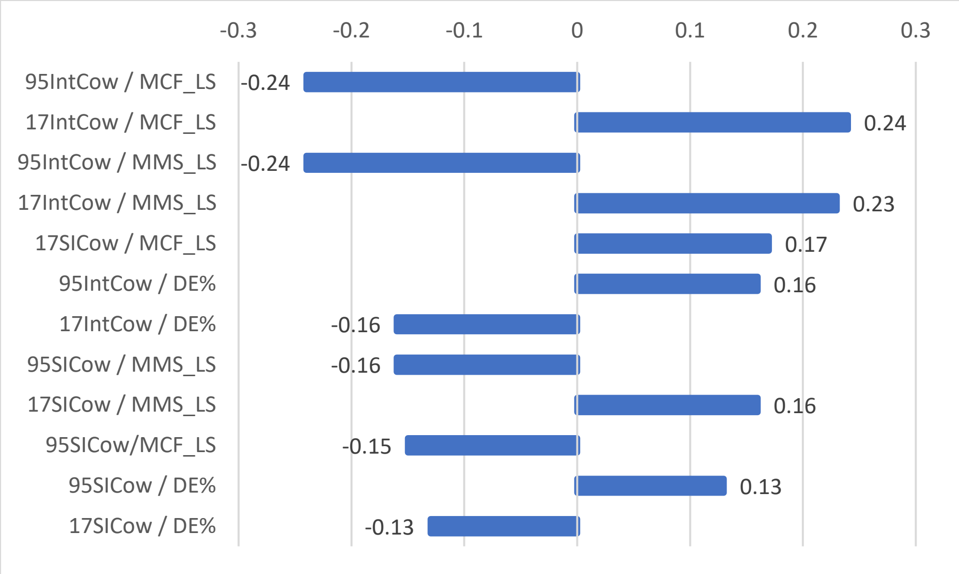


Figure A9.6 Correlation coefficients between 1995-2017 manure management methane emission trend and input variables

9.4 Uncertainty in manure management direct nitrous oxide emissions

Table A9.7 shows the uncertainty for total direct nitrous oxide manure management emissions from each sub-category for 1995. (Results for 2017 were similar). For each sub-category, average uncertainty for total sub-category direct nitrous oxide manure management emissions averaged (+110%,-75%) in the intensive system and (+84%,-60%) in the semi-intensive and extensive systems. Total 1995 direct nitrous oxide manure management emissions had an uncertainty of (+28.89%,-24.12%) and total 2017 direct nitrous oxide manure management emissions had an uncertainty of (+27.78%,-23.48%). Uncertainty of the trend was calculated as:

Trend = (TotalN_2O2017 – TotalN_2O1995)/TotalN_2O1995

Uncertainty of the trend was (+96.99%, -77.57%).

The main factors associated with uncertainty in total manure management direct nitrous oxide emissions are shown in Figures A9.7 and A9.8. There is significant overlap between the input variables with high correlation to total emissions in 1995 and 2017, but the rank order of input variables is slightly different. In 1995, the top 5 input variables were:

1. Crude protein content of diet for cows in intensive system
2. Crude protein content of diet for cows in semi-intensive system
3. EF_3 for solid storage, cows in intensive system
4. Proportion of total dairy herd in the extensive system
5. DE% for cows in intensive system

In 2017, the top 5 variables were:

1. Crude protein content of diet for cows in intensive system
2. Crude protein content of diet for cows in semi-intensive system
3. EF_3 for solid storage, cows in intensive system
4. EF_3 for solid storage, cows in semi-intensive system
5. DE% for cows in the intensive system

In general, the most sensitive factors affecting emissions per animal were crude protein content of diet, EF3 and MMS. Some factors affecting numbers of animals in each sub-category were also important.

For the trend in direct nitrous oxide emissions from manure management (Figure A9.9), the most important factors were crude protein content of the diet for cows, EF3 for solid storage for cows and DE% for cows.

Table A9.7 Upper and lower confidence bounds for direct nitrous oxide manure management emission factors and sub-category emissions (1995)

	Sub-category emissions	
	Upper	**Lower**
Intensive system:		
Cow	72.12	-53.44
Heifer	100.00	-61.76
Adult male	86.62	-58.84
Growing male	124.21	-81.41
Calves	166.59	-119.42
Semi-intensive system:		
Cow	72.61	-52.50
Heifer	67.92	-49.57
Adult male	76.81	-53.74
Growing male	82.41	-56.17
Calves	122.47	-89.20
Extensive system:		
Cow	72.08	-52.62
Heifer	68.46	-49.53
Adult male	76.99	-53.36
Growing male	83.13	-56.71
Calves	121.42	-88.36

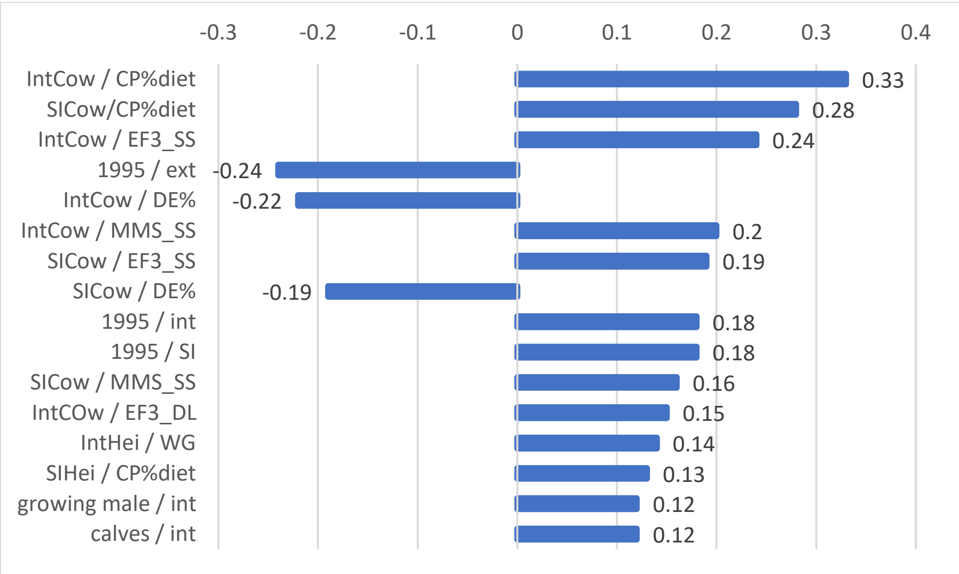


Figure A9.7 Correlation coefficients between total 1995 manure management direct nitrous oxide emissions and input variables

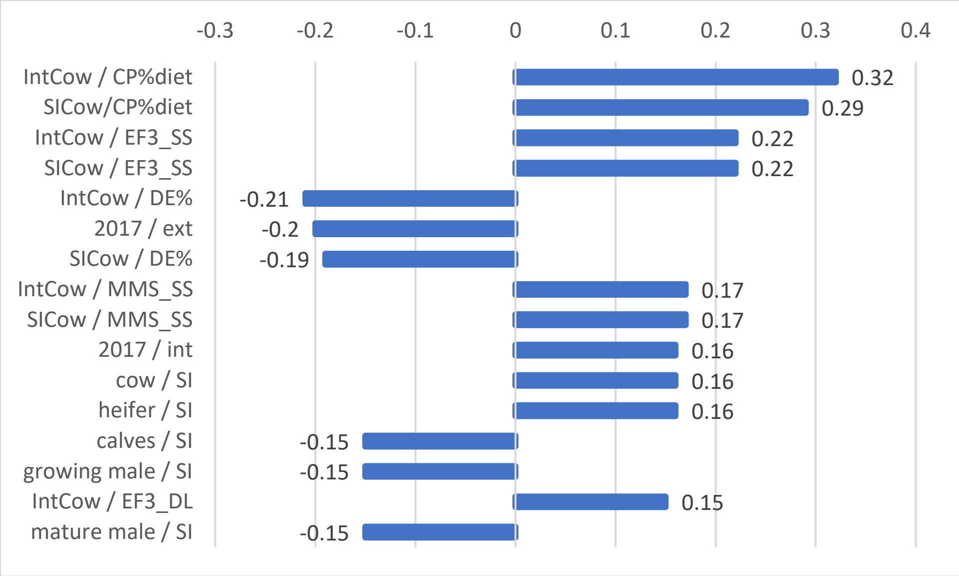


Figure A9.8 Correlation coefficients between total 2017 manure management direct nitrous oxide emissions and input variables

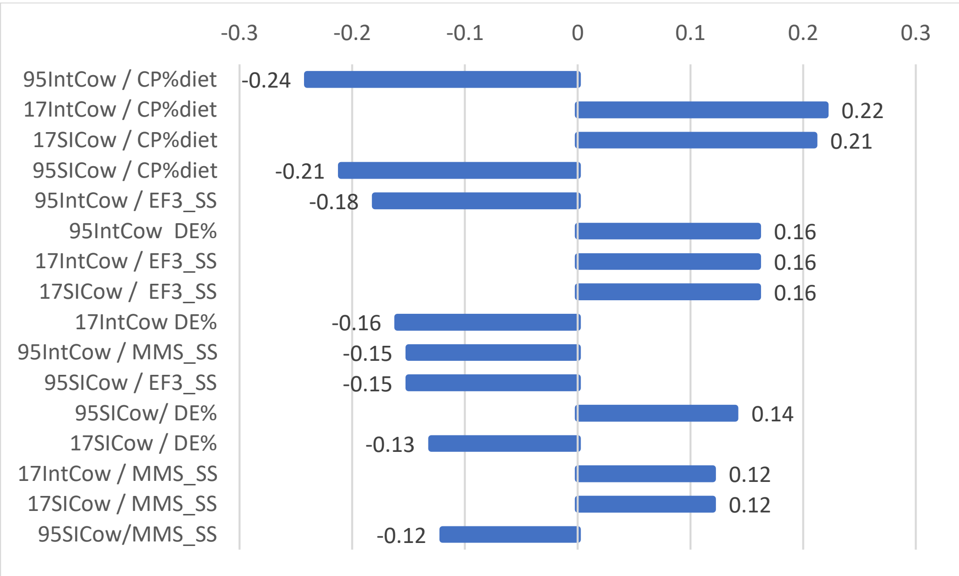


Figure A9.9 Correlation coefficients between 1995-2017 manure management direct nitrous oxide emission trend and input variables

9.5 Uncertainty in manure management indirect nitrous oxide emissions

Table A9.8 shows the uncertainty for total indirect nitrous oxide manure management emissions from each sub-category for 1995. (Results for 2017 were similar). For each sub-category, average uncertainty for total sub-category indirect nitrous oxide manure management emissions averaged (+217%,-93%) in the intensive system and (+201%,-87%) in the semi-intensive and extensive systems. Total 1995 direct nitrous oxide manure management emissions had an uncertainty of (+83.77%,-

50.29%) and total 2017 indirect nitrous oxide manure management emissions had an uncertainty of (+80.52%,-48.97%). Uncertainty of the trend was calculated as:

Trend = (TotalN_2O2017 – TotalN_2O1995)/TotalN_2O1995

Uncertainty of the trend was (+229.49%, -134.21%).

The main factors associated with uncertainty in total manure management direct nitrous oxide emissions are shown in Figures A9.10 and A9.11. There is significant overlap between the input variables with high correlation to total emissions in 1995 and 2017, but the rank order of input variables is slightly different. In 1995, the top 5 input variables were:

1. EF_4 for cows in intensive system
2. EF_4 for cows in semi-intensive system
3. EF_4 for heifers in semi-intensive system
4. EF_4 for heifers in intensive system
5. Crude protein content in diet for cows in intensive system

In 2017, the top 5 variables were:

1. EF_4 for cows in intensive system
2. EF_4 for cows in semi-intensive system
3. EF_4 for heifers in semi-intensive system
4. EF_4 for cows in extensive system
5. EF_4 for heifers in intensive system

In general, the most sensitive factors affecting emissions were EF_4, crude protein content of diet and feed digestibility. The same factors also had a strong correlation with the trend in indirect nitrous oxide emissions between 1995 and 2017 (Figure A9.12).

Table A9.8 Upper and lower confidence bounds for indirect nitrous oxide manure management emission factors and sub-category emissions (1995)

	Sub-category emissions	
	Upper	**Lower**
Intensive system:		
Cow	195.40	-85.23
Heifer	204.85	-87.40
Adult male	198.58	-86.36
Growing male	224.38	-91.98
Calves	261.34	-112.00
Semi-intensive system:		
Cow	194.04	-85.44
Heifer	192.33	-84.93
Adult male	194.80	-85.77
Growing male	198.90	-86.33
Calves	226.47	-95.49
Extensive system:		
Cow	194.30	-85.28
Heifer	192.66	-84.96
Adult male	195.71	-85.57
Growing male	198.20	-86.26
Calves	228.87	-95.29

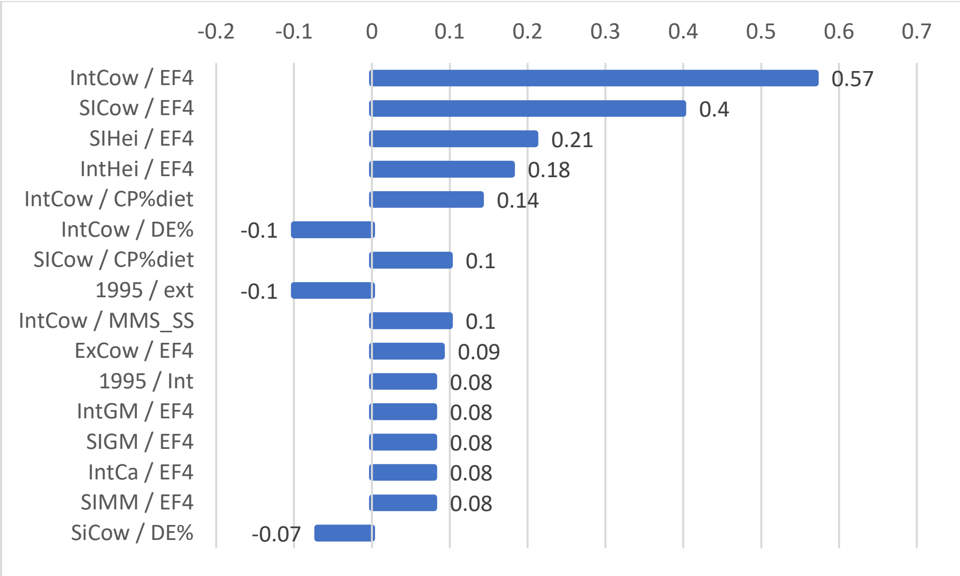


Figure A9.10 Correlation coefficients between total 1995 indirect nitrous oxide emissions and input variables

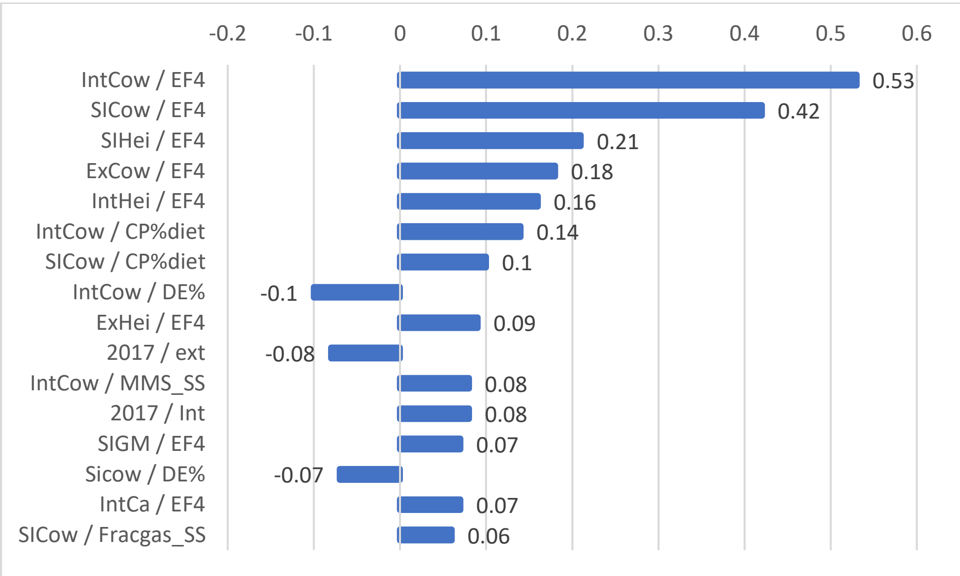


Figure A9.11 Correlation coefficients between total 2017 manure management indirect nitrous oxide emissions and input variables

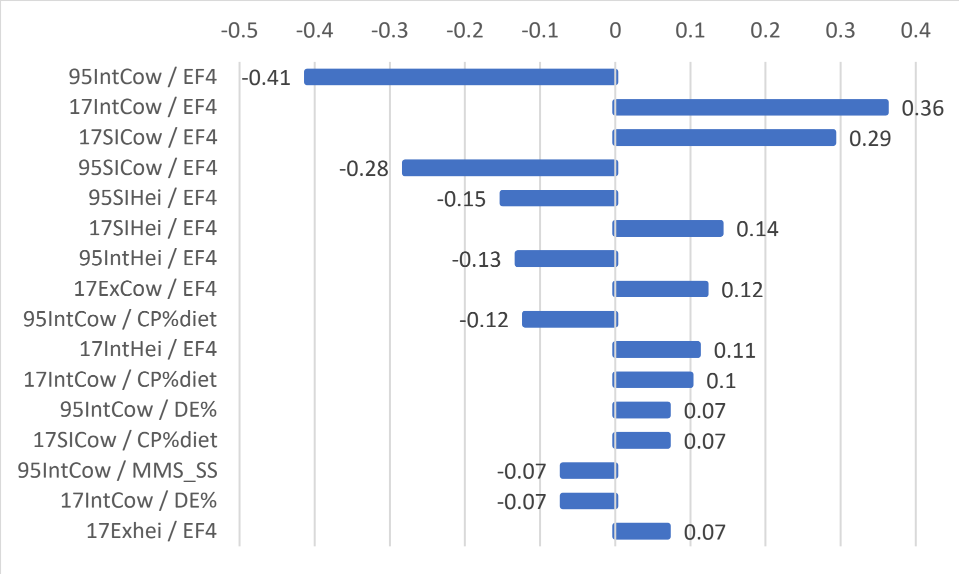


Figure A9.12 Correlation coefficients between 1995-2017 manure management indirect nitrous oxide emission trend and input variables

9.6 Uncertainty in direct nitrous oxide emissions from urine and dung deposited on pasture

Table A9.9 shows the uncertainty for total direct nitrous oxide emissions from pasture deposit of urine and dung for each sub-category for 1995. (Results for 2017 were similar). For each sub-category, average uncertainty for total sub-category direct nitrous oxide emissions averaged (+122%,-76%) in the intensive system and (+99%,-67%) in the semi-intensive and extensive systems. Total 1995 direct nitrous oxide emissions from managed soils had an uncertainty of (+33.39%,-26.92%) and total 2017 uncertainty was (+33.75%,-27.23%). Uncertainty of the trend was calculated as:

Trend = (TotalN_2O2017 – TotalN_2O1995)/TotalN_2O1995

Uncertainty of the trend was (+266.54%, -205.53%).

The main factors associated with uncertainty in total manure management direct nitrous oxide emissions are shown in Figures A9.13 and A9.14. There is significant overlap between the input variables with high correlation to total emissions in 1995 and 2017, but the rank order of input variables is slightly different. In 1995, the top 5 input variables were:

1. Proportion of dung and urine deposited on pasture for cows in semi-intensive system
2. EF_3 for cows in semi-intensive system
3. Crude protein content of diet for cows in semi-intensive system
4. Proportion of dung and urine deposited on pasture for heifers in semi-intensive system
5. DE% for cows in semi-intensive system

In 2017, the top 5 variables were the same.

In general, the most sensitive factors affecting emissions were the proportion of dung and urine deposited on pasture, EF_3 and crude protein content of diet and feed digestibility. The same factors also had a strong correlation with the trend in indirect nitrous oxide emissions between 1995 and 2017 (Figure A9.15).

Table A9.9 Upper and lower confidence bounds for direct nitrous oxide from dung and urine deposited on pasture for each sub-category (1995)

	Sub-category emissions	
	Upper	**Lower**
Intensive system:		
Cow	84.97	-59.59
Heifer	110.87	-67.03
Adult male	98.94	-64.21
Growing male	134.10	-82.87
Calves	178.89	-118.85
Semi-intensive system:		
Cow	86.70	-60.22
Heifer	83.57	-58.34
Adult male	92.30	-61.36
Growing male	97.69	-63.95
Calves	134.64	-90.32
Extensive system:		
Cow	86.22	-60.25
Heifer	83.31	-58.82
Adult male	91.03	-61.33
Growing male	96.82	-63.80
Calves	132.60	-89.93

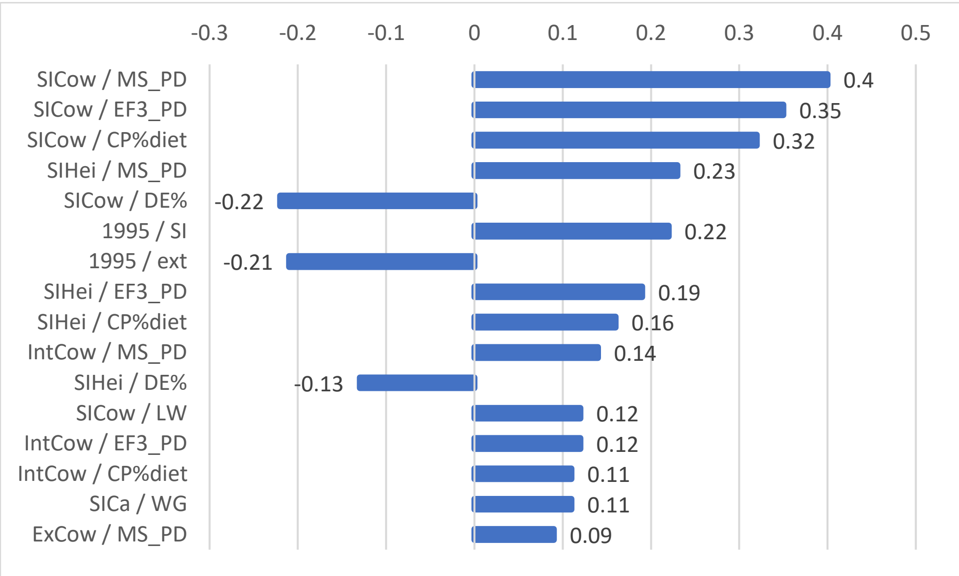


Figure A9.13 Correlation coefficients between total 1995 direct nitrous oxide emissions from pasture deposit and input variables

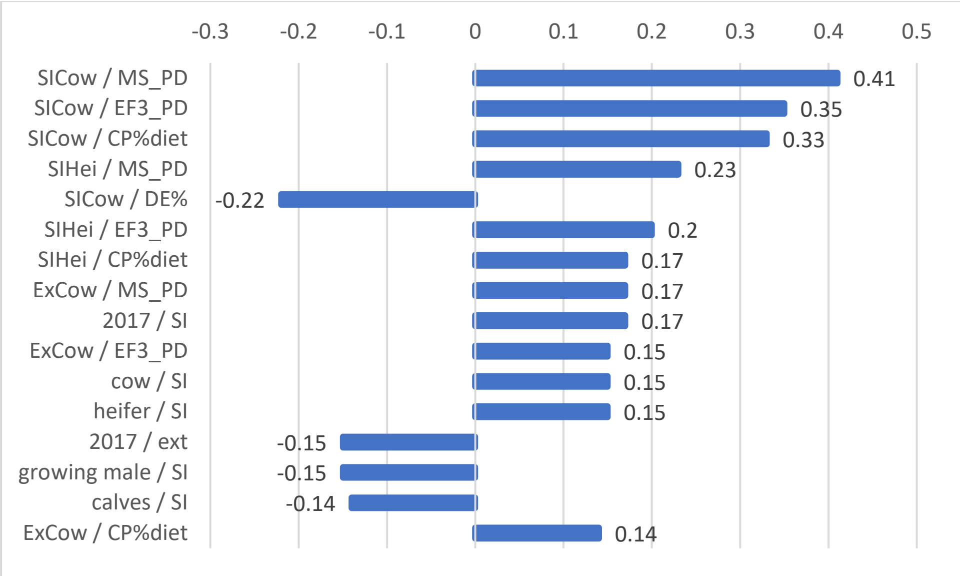


Figure A9.14 Correlation coefficients between total 2017 direct nitrous oxide emissions from pasture deposit and input variables

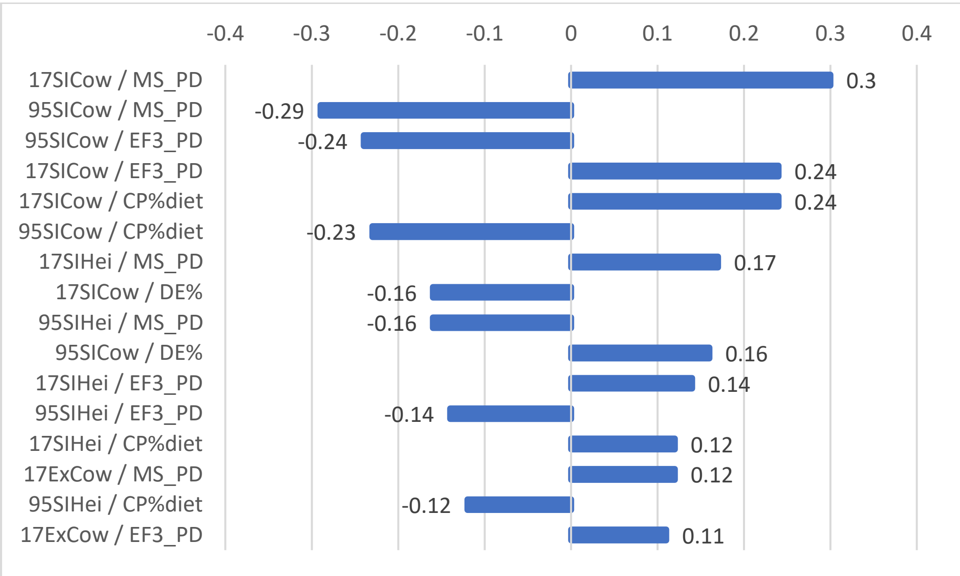


Figure A9.15 Correlation coefficients between 1995- 2017 trend in direct nitrous oxide emissions from pasture deposit and input variables

9.7 Uncertainty in indirect nitrous oxide emissions from urine and dung deposited on pasture

Table A9.10 shows the uncertainty for total indirect nitrous oxide emissions from pasture deposit of urine and dung for each sub-category for 1995. (Results for 2017 were similar). For each sub-category, average uncertainty for total sub-category indirect nitrous oxide manure management emissions averaged (+171%,-88%) in the intensive system and (+153%,-80%) in the semi-intensive and extensive systems. Total 1995 indirect nitrous oxide manure management emissions had an uncertainty of

(+54.20%,-38.37%) and total 2017 indirect nitrous oxide manure management emissions had an uncertainty of (+56.60%,-38.92%). Uncertainty of the trend was calculated as:

Trend = (TotalN_2O2017 – TotalN_2O1995)/TotalN_2O1995

Uncertainty of the trend was (+365.09%, -244.95%).

The main factors associated with uncertainty in total manure management direct nitrous oxide emissions are shown in Figures A9.16 and A9.17. There is significant overlap between the input variables with high correlation to total emissions in 1995 and 2017, but the rank order of input variables is slightly different. In 1995, the top 5 input variables were:

1. Fracleach for cows in semi-intensive system
2. EF_5 for cows in semi-intensive system
3. EF_4 for cows in semi-intensive system
4. Proportion of dung and urine deposited on pasture for cows in semi-intensive system
5. Crude protein content of diet for cows in semi-intensive system

In 2017, the top 5 variables were the same.

The same factors also had a strong correlation with the trend in indirect nitrous oxide emissions between 1995 and 2017 (Figure A9.18).

Table A9.10 Upper and lower confidence bounds for indirect nitrous oxide from dung and urine deposited on pasture for each sub-category (1995)

	Sub-category emissions	
	Upper	**Lower**
Intensive system:		
Cow	141.18	-76.08
Heifer	159.84	-79.97
Adult male	152.82	-78.12
Growing male	181.80	-87.84
Calves	218.69	-115.52
Semi-intensive system:		
Cow	142.95	-76.25
Heifer	138.89	-75.65
Adult male	146.55	-76.70
Growing male	151.97	-78.24
Calves	184.36	-93.43
Extensive system:		
Cow	142.12	-76.19
Heifer	141.90	-75.79
Adult male	145.23	-77.13
Growing male	150.12	-78.39
Calves	181.97	-92.92

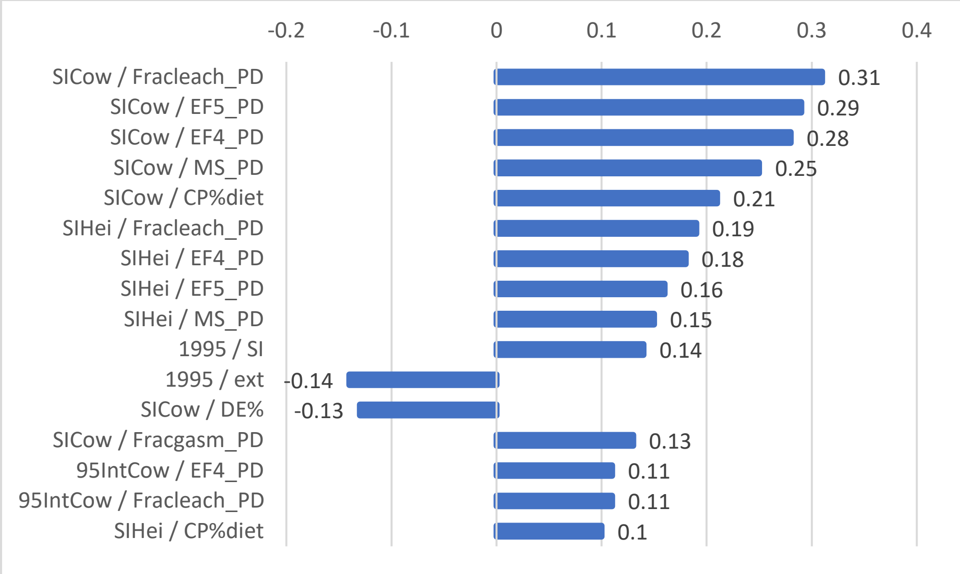


Figure A9.16 Correlation coefficients between total 1995 indirect nitrous oxide emissions from pasture deposit and input variables

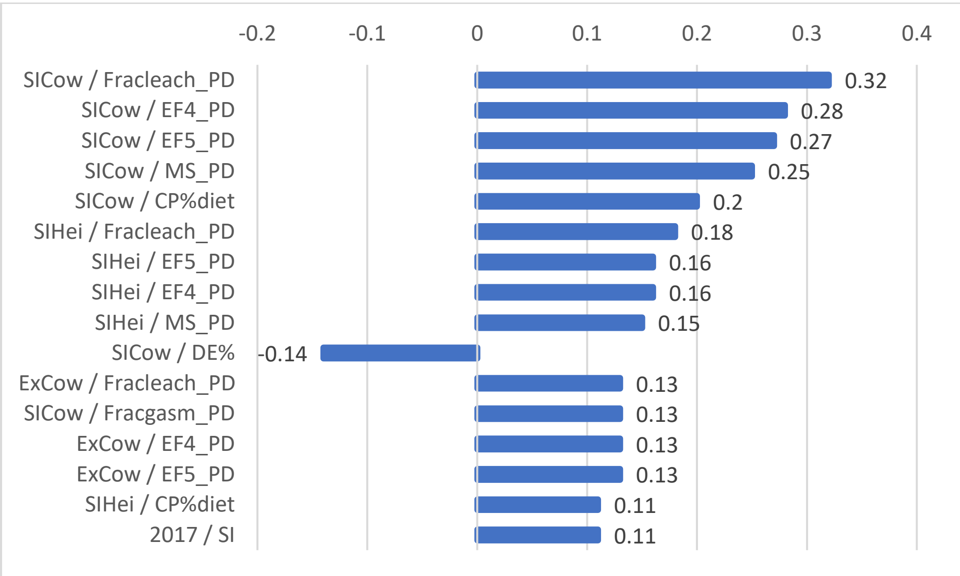


Figure A9.17 Correlation coefficients between total 2017 indirect nitrous oxide emissions from pasture deposit and input variables

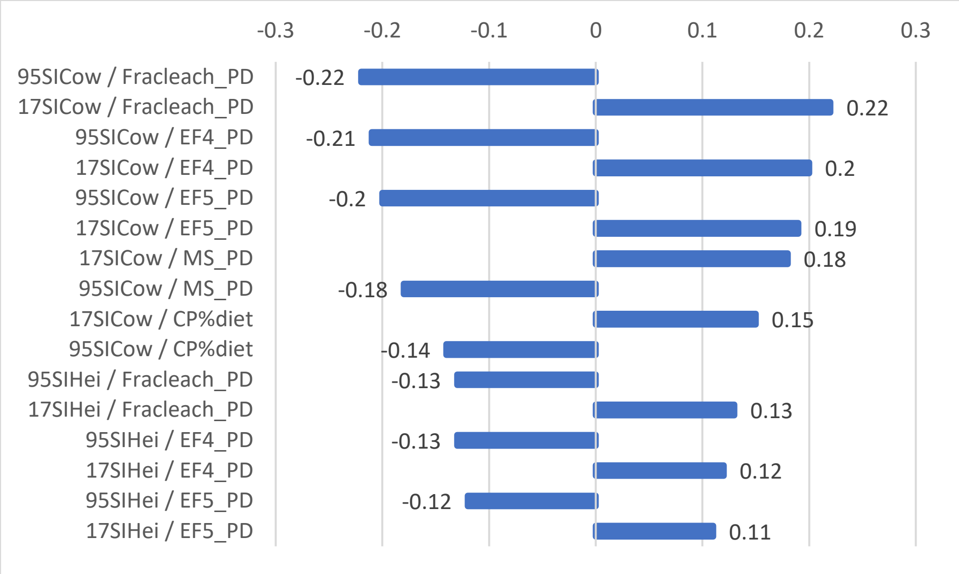


Figure A9.18 Correlation coefficients between 1995- 2017 trend in indirect nitrous oxide emissions from pasture deposit and input variables

9.8 Total uncertainty of dairy cattle emissions

The uncertainty analysis was run combining all dairy cattle emission sources and converting methane and nitrous oxide to CO_2 equivalents using the AR4 GWPs (methane = 25, nitrous oxide = 298). Total uncertainty of dairy cattle emissions in 2017 was (+18.2%,-14.8%). The main factors correlated with uncertainty of 2017 emissions were activity data (i.e. proportion of total national herd in different production systems, proportions of each sub-category in the herd in each production system), and feed digestibility for cows and heifers (Figure 9.19).

Total uncertainty of the trend 1995-2017 was (+65.0%,-55.3%). The main factors associated with uncertainty were the base year and 2017 values of feed digestibility, Ym, live weight and weight gain for cows and heifers in the semi-intensive and intensive systems (Figure 9.20).

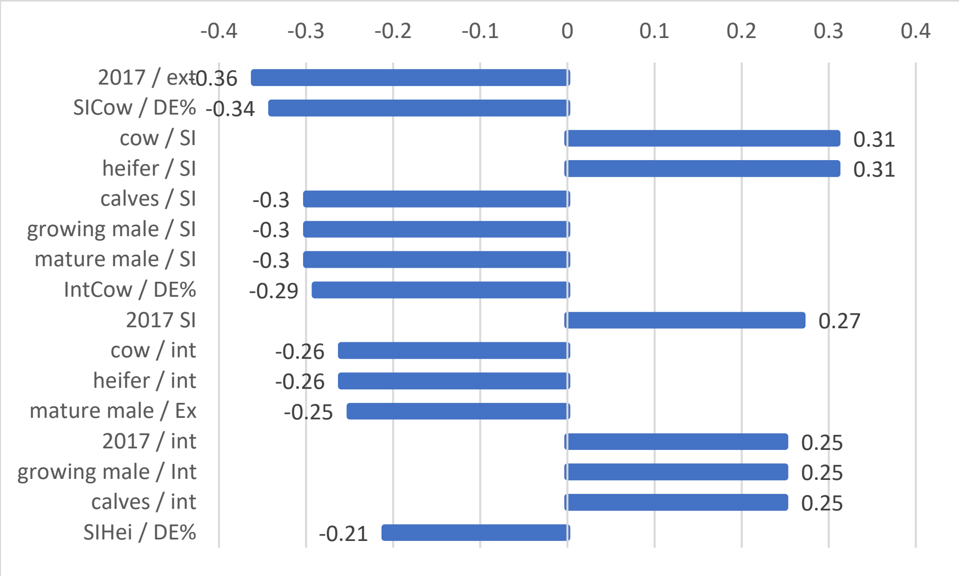


Figure A9.19 Correlation coefficients between total 2017 CO_2 equivalent emissions from all dairy cattle sources and input variables

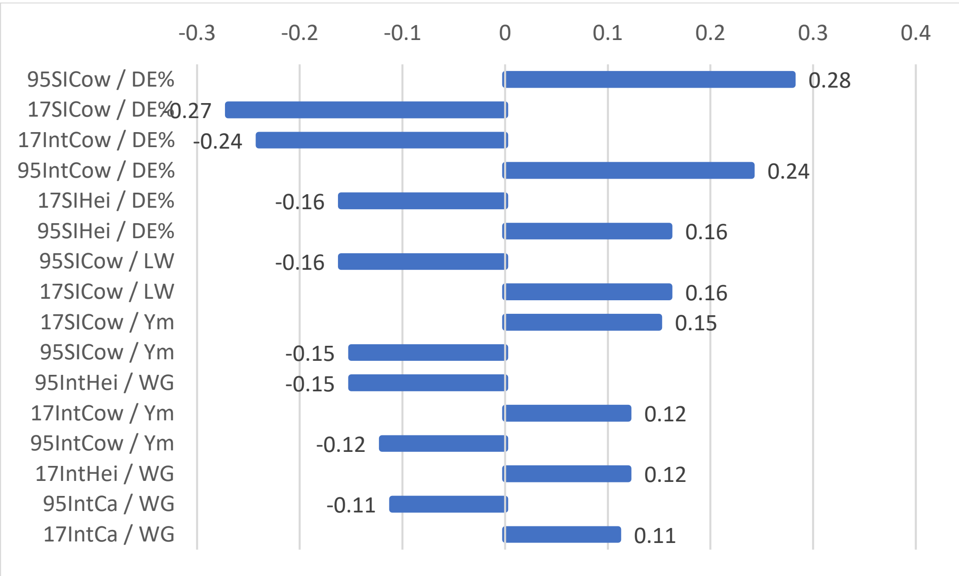


Figure A9.20 Correlation coefficients between uncertainty in the trend 1995-2017 in CO_2 equivalent emissions from all dairy cattle sources and input variables

Annex 10: Inventory improvement analysis

This annex summarizes assessment of the quality of data and shortcomings in methods used to compile the inventory, and highlights options and priorities for inventory improvement. In addition to general considerations, the main inputs to the assessment are:

- Data quality assessment scoring
- Sensitivity analysis, and
- Uncertainty analysis

The analysis considers both the improvement of the historical time series and future data collection.

1. Data quality assessment

For each activity data parameter, data quality of each data source was scored according to the quality objectives of the inventory (Table A10.1). Scoring was qualitative on a scale of:

4=no issues
3=minor issues
2=moderate issues
1=major issues

Some of the data sources used scored extremely low on one or more criteria. This reflects the need to use available data given the time and resource constraints faced. However, no parameter was estimated using data sources that scored a 1 on all criteria. The assessment is used to highlight potential areas for improvement in data quality for revision of the inventory.

Table A10.1: Quality assessment criteria

INDICATORS	DESCRIPTION
Transparency	The year, method of data collection, sampling method, sample size, definitions, units etc are clearly described in the data source
Accuracy – sampling	A representative sampling method was used that is representative of the region or category to which the data has been applied
Accuracy - non-sampling	Appropriate methods were used to collect and analyze data on the indicator
Comparability	The data source describes items and indicators using units consistent with those required by the inventory and by IPCC guidelines
Completeness	The data source describes all items contained within the concepts as defined in the inventory and IPCC guidelines
Consistency - same time series	The definitions, units and methods used in the data source are consistent with other data sources used in the time series for the same indicator
Coherence	The definitions, units and methods used in the data source are consistent with those used for other parameters in the inventory
Uncertainty	Statistical error of estimated values can be quantified from the data source

		Intensive production system							Semi-intensive production system							Extensive production system						
		Transp.	Acc.	Compar	Cons & Coher	Compl	Unc	sum (out of 24)	Transp.	Acc	Compar	Cons & Coher	Compl	Unc	sum (out of 24)	Transp.	Acc	Compar	Cons & Coher	Compl	Unc	sum (out of 24)
	Summary score	2.80	2.15	3.56	3.06	3.33	1.78	16.68	3.57	2.17	3.44	2.82	3.25	1.56	16.81	3.58	1.70	3.42	2.82	3.29	1.48	16.29
herd structure	Cow	3.00	2.75	2.50	2.50	2.50	1.50	2.94	3.00	2.75	2.50	2.50	2.50	1.50	2.94	3.00	2.75	2.50	2.50	2.50	1.50	2.75
	Heifer	3.33	2.83	3.00	3.00	3.00	2.00		3.33	2.83	3.00	3.00	3.00	2.00		3.33	2.83	3.00	3.00	3.00	2.00	
	Adult male	3.00	2.75	2.50	2.50	4.00	1.50		3.00	2.75	2.50	2.50	4.00	1.50		3.00	2.75	2.50	2.50	4.00	1.50	
	Growing males	3.33	2.83	3.00	3.00	3.00	2.00		3.33	2.83	3.00	3.00	3.00	2.00		3.33	2.83	3.00	3.00	3.00	2.00	
	Calves	3.33	2.83	3.00	3.00	3.00	2.00		3.33	2.83	3.00	3.00	3.00	2.00		3.33	2.83	3.00	3.00	3.00	2.00	
% milking		4	2	1	3	1	1	2.2	4	2	1	3	1	1	2.2	4	2	1	3	1	1	2.2
milk yield		2.75	1.75	3	2.375	2.5	2	2.48	3.67	2.17	2.67	2.08	3.00	2.17	2.72	4	1	1	2.5	1	1	1.9
Live weight	Cow	2.33	2.67	2.67	2.83	2.00	2.33	2.98	4	2.5	3.67	2.67	4	2	3.29	4.00	2.00	3.67	2.67	4.00	2.00	3.22
	Heifer	2.50	2.25	4.00	3.00	4.00	2.00		4	2	4	2.5	4	2.5		4.00	1.75	4.00	2.50	4.00	2.50	
	Adult male	2.50	1.00	4.00	3.00	4.00	2.00		4	2.25	3	3	4	2.5		4.00	1.75	3.00	3.00	4.00	2.50	
	Growing males	2.50	2.00	4.00	3.00	4.00	2.00		4	2.25	3	3	4	2.5		4.00	1.75	3.00	3.00	4.00	2.50	
	Calves	2.50	2.00	4.00	3.75	4.00	1.00		4	1.5	4	3	4	2		4.00	1.50	4.00	3.00	4.00	2.00	
Weight gain	Cow	2.50	2.25	4.00	2.75	4.00	2.00	3.03	4	1.75	4	2.75	4	1	3.18	4	1.5	4	2.75	4	1	
	Heifer	2.50	1.75	4.00	2.50	4.00	1.00		4	1.75	4	2.75	4	1		4	1.5	4	2.75	4	1	
	Adult male	2.50	1.25	4.00	2.75	4.00	2.00		4	1	4	2.5	4	1		4	1	4	2.5	4	1	
	Growing males	2.50	1.75	4.00	2.75	4.00	2.00		4	1	4	2.5	4	1		4	1	4	2.5	4	1	
	Calves	3.25	2.38	4.00	2.75	3.50	3.00		4	1	4	2.5	4	1		4	1	4	2.5	4	1	
% pregnant	Cows	3.50	2.67	3.00	3.50	2.00	2.67	3.02	4.00	2.33	2.67	3.50	2.00	2.33	2.95	4	1	4	3.5	3.333333	1	3.23
	Heifers	1.00	2.50	4.00	4.00	4.00	3.00		4.00	1.00	4.00	4.00	2.00	1.00		4	1	4	3.5	4	1	
milk fat %		4	1	4	3	4	1	3.2	4	1	4	3	4	1	3.2	4	1	4	3	4	1	3.2
DE%	Cow	2.5	2.25	3.75	3.5	3.75	1.5	3.14	3.2	2.2	3.8	3.2	3.8	1.2	3.288	3.2	1.2	3.8	3.2	3.8	1.2	3.04
	Heifer	2.5	2.25	3.75	3.5	3.75	1.5		3.2	2.2	3.8	3.2	3.8	1.2		3.2	1.2	3.8	3.2	3.8	1.2	

	Adult male	2.5	2.25	3.75	3.5	3.75	1.5		3.2	2.6	3.8	3.2	3.8	1.2		3.2	1.2	3.8	3.2	3.8	1.2	
	Growing males	2.5	2.25	3.75	3.5	3.75	1.5		3.2	2.6	3.8	3.2	3.8	1.2		3.2	1.2	3.8	3.2	3.8	1.2	
	Calves	2.5	2	3.75	3.5	3.75	1.5		3.2	2.6	3.8	3.2	3.8	1.2		3.2	1.2	3.8	3.2	3.8	1.2	
MMS	Cow	2.67	2.00	4.00	3.00	3.00	1.33	2.93	3.00	2.63	3.50	2.25	2.25	1.25	2.73	3.00	1.88	3.50	2.25	2.25	1.25	2.58
	Heifer	2.67	2.00	4.00	3.00	3.00	1.33		3.00	2.63	3.50	2.25	2.25	1.25		3.00	1.88	3.50	2.25	2.25	1.25	
	Adult male	2.67	2.00	4.00	3.00	3.00	1.33		3.00	2.63	3.50	2.25	2.25	1.25		3.00	1.88	3.50	2.25	2.25	1.25	
	Growing males	2.67	2.00	4.00	3.00	3.00	1.33		3.00	2.63	3.50	2.25	2.25	1.25		3.00	1.88	3.50	2.25	2.25	1.25	
	Calves	2.67	2.00	4.00	3.00	3.00	1.33		3.00	2.63	3.50	2.25	2.25	1.25		3.00	1.88	3.50	2.25	2.25	1.25	
Work		4	2.5	4	3.5	3	3	3.4	4	2.5	4	3.5	3	3	3.4	4	2.5	4	3.5	3	3	3.4

The overall results of data quality assessment indicate the following:

- Data quality for the semi-intensive system is highest, followed by intensive, and lowest for the extensive system. The main reasons are
  - The intensive system has a lower transparency score, mainly because UNIQUE (2018) was widely used but data was not published at the time this inventory was compiled. Transparency can be increased if UNIQUE publishes the data.[31]
  - Most parameters for the extensive system were by assumption the same as the semi-intensive system, so accuracy scores were lowest. If survey data or literature reports is used for the extensive system, data quality would improve.
- Comparing between quality criteria, quantification of uncertainty scores lowest. Many data sources used did report standard deviations, and pooled variance can be calculated to quantify uncertainty. This was later done as part of the uncertainty analysis.
- The next lowest score was accuracy. Accuracy consists of sampling accuracy and measurement accuracy. Sampling accuracy was often low because literature used came from individual study sites and was not representative of the production systems being characterized. Even where regional survey data was used, this did not overlap 100% with the definition of the counties in each production system. Measurement accuracy was often scored low because of (a) widespread reliance on household surveys using farmer estimation and recall of data, (b) use of assumptions to fill data gaps, and (c) use of interpolation to fill data gaps.
- Comparability was scored lower where proxies were used to represent the concepts required for the inventory.
- Consistency was mostly relatively high, where consistent methods were applied to the same time series, but coherence was often lower if the data and methods used for one parameter were not the same as the data and methods used for another parameter.
- Completeness was relatively high but scored lower where data sources used categories that were not aligned with the IPCC or with the inventory categories (e.g. for herd structure and manure management systems).

Directly related recommendations are:

1) UNIQUE should publish the data used in this inventory.[31]
2) Future representative sample surveys in each production system would increase sampling accuracy.
3) A representative sample survey in the extensive system would mean that instead of assuming the same values as the semi-intensive system, actual data from farms in that system could be used and increase sampling accuracy.
4) Uncertainty should be quantified and assessed. This was done as part of the uncertainty analysis in Annex 9.

[31] Subsequently published at https://ccafs.cgiar.org/publications/methods-and-guidance-support-mrv-livestock-emissions-methods-data-collection-analysis#.XmYB5aj7Q2w

2. Data quality for key parameters

(a) Population data

The data used in this inventory to estimate population of dairy cattle sub-categories include:

- total population (data from SDL)
- Allocation of counties to production systems (expert judgement)
- herd structure (based on multiple surveys and literature sources).

Total population data were provided by SDL. The data are aggregated from estimates reported by each county. Regarding the historical time series, the population in each county in each year was estimated through a pragmatic method of adjusting county data to the national total, assuming the national total is the official count. An improvement would be to understand in detail how the official national total was adjusted on the basis of county reported data (for 2012 onwards) and to replicate those methods in the inventory.

Regarding future data collection, the estimation methods at county level are not reliable. In particular, population of dairy cattle is not counted, but uses a variety of estimation methods at county level. County statistics are validated through a validation exercise conducted by SDL. An assessment of agriculture statistics capacity needs has recently been completed (World Bank 2019). That assessment has made proposals within the framework of Kenya Strategic Plan for Agriculture and Rural Statistics (SPARS) for improvement of livestock population data collection, including development of standardized concepts and definitions and legal instruments to support improved statistical data collection at county level and data flows to national level.

The **allocation of counties to production systems** was done on the basis of expert judgement. Following the definition used (i.e. the most common feeding system in each county determines the allocation of counties to production systems), the biggest improvement would be made if this allocation was based on survey data, or at a minimum directly informed by expert judgement from local experts. There is significant uncertainty about the most common feeding systems in counties categorized as 'extensive', since there is almost no available survey data from these counties.

Herd structure is assumed to consist of 5 sub-categories. Growing males (1-2 years and 2-3 years) were combined owing to lack of disaggregated data. Calves less than 1 year include both suckling and weaned calves, male and female. Disaggregation for suckling and weaned would be more accurate, but would require better data on calf feeding practices in each production system. Herd structure was estimated using Tegemeo repeat survey data (2000-2014) and other literature reports. The Tegemeo data used definitions of animal sub-categories that are not in line with conventional livestock definitions and had to be adjusted using herd structure data from other sources. Regarding future data collection, herd structure estimates would be more reliable if based on representative survey data and use a common set of definitions. Those definitions should be harmonized between the GHG inventory and any definitions developed for livestock census or administrative statistics. At present, the proportion of cows in the herd is estimated at county level using inconsistent data sources and methods. Improvement at county level would flow through to the national statistics, but only if there is a data sharing arrangement in place to enable systematic reporting from county to national level of more detailed data than the total population and total milk output.

Uncertainty associated with herd structure is a major determinant of overall inventory uncertainty (Annex 9). Improved representative sample survey data in each production system would reduce this uncertainty in future years.

(b) Enteric fermentation

Table A10.2 shows the contribution of different dairy cattle sub-categories to total enteric fermentation emissions. 55% of total enteric fermentation emissions are from cows, 22% from heifers, 9% from calves, 8% from growing males, and 5% from adult males. This suggests that improving the accuracy of emission factors for cows is the priority. Within cows, 45% is from the semi-intensive production system, 37% from the intensive system, and 18% from the extensive system.

Table A10.2 Percentage of total enteric fermentation emissions from different inventory sub-categories

	Intensive				
	Cows	**Heifers**	**Adult males**	**Growing males**	**Calves**
2017	20.4%	5.7%	2.1%	2.8%	3.6%
	Semi-Intensive				
	Cows	**Heifers**	**Adult males**	**Growing males**	**Calves**
2017	24.8%	11.9%	2.2%	3.6%	4.0%
	Extensive				
	Cows	**Heifers**	**Adult males**	**Growing males**	**Calves**
2017	9.9%	4.76%	1.1%	1.5%	1.6%
SUM	**55.1%**	**22.4%**	**5.4%**	**7.9%**	**9.2%**

Throughout the inventory, the characteristics of dairy cattle in the extensive system have been assumed to be the same as in the semi-intensive system. This is due to almost total lack of data on production practices and animal performance from the extensive system. Data for the intensive system mainly come from central Kenya and are not representative of intensive production systems in the arid counties. However, in 2017 the total population of dairy cattle in the arid counties accounted for only 1% of the population in the intensive system. Therefore, improved estimates of animal performance in these counties would not be a priority.

A simple sensitivity analysis was conducted for the enteric methane emission factor for dairy cows in each system. The results are broadly like that shown in Figure A10.1 for cows in the intensive system. When input parameters are adjusted by ±10%, seven parameters result in change in the emission factor by >1%. They are, in order of sensitivity: Digestibility, methane conversion factor, Coefficient for maintenance (Cfi), live weight / mature weight, % of cows lactating, milk yield per cow and fat content of milk. Apart from the methane conversion factor, milk fat content and Cfi which used the IPCC default value, the other values were estimated in this inventory using country-specific data and methods.

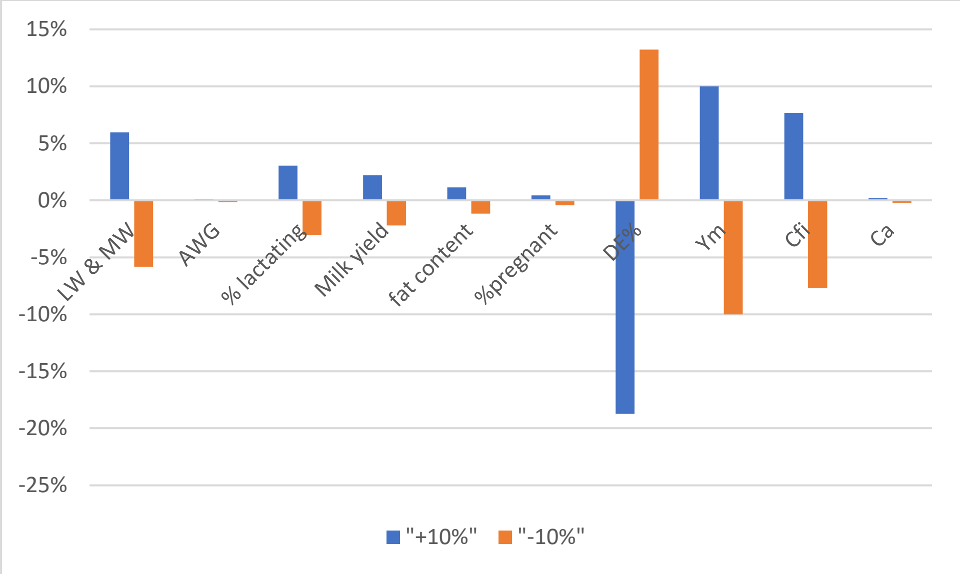


Figure A10.1: Sensitivity of key parameters for enteric fermentation of dairy cows

Digestibility of feed: There are no authoritative survey estimates of feed composition for cows in different production systems or feeding systems. Representative household surveys (e.g. UNIQUE 2018 for the intensive system) rely on questionnaire methods and accuracy is affected by farmer estimates and conversion of farmer reported units to kg and lack detail on harvesting and feeding practices that affect diet quality. More detailed measurements are reported in some published studies, but are for a limited number of sites only, and diets may not be characterised by animal type, feeding system or other categories that can be used in inventory compilation. There is considerable literature on feed quality and nutrient contents. Further research is required to develop cost-effective methods for quantification of diet composition by animal sub-category and feeding system.

The coefficient for maintenance uses the IPCC default value, which is weighted for lactating and dry cows, and is thus affected by the estimate of the proportion of cows that are lactating. The proportion of cows in milk in this inventory was assumed to be the same as the proportion of cows giving birth. This is not supported by survey data, which typically show long average lactation duration and higher proportions of cows in milk than calving rates. However, literature reports on proportions of cows in milk were limited. Calving interval, from which calving rates can be calculated are more commonly reported. Further work is required to enable the inventory to account for extended lactations in the estimates of the proportion of dairy cows lactating.

Live weight and mature weight were estimated using two different sources of survey data: UNIQUE (2018) measurements of heart girth in the intensive system and Lukuyu et al (2016) measurements of live weight in 3 locations in the semi-intensive production system. Inventory live weight estimates were then interpolated based on the proportions of breeds and genotypes in the herd, again based on limited survey data in different years. Thus, live weight in the inventory would change if breed composition changes. The rate of change estimated is small (ca. 0.1 kg per annum) and a remarkably high sample size would be required to detect change on an annual basis. Using the same method as used in the inventory, the biggest improvement would be achieved by obtaining a better estimate of the proportion of animals of different breeds or genotypes in the herd. This could be done using representative survey data at production system level for cows. Since live weights of other sub-categories and mature weight are estimated based on their relationship to cow live weight, improved estimates for cows would be key.

Milk yield per cow was also estimated using the relationship between reported milk yields and breed or genotype. The data on milk yield came from questionnaire surveys that use farmer recall. A study to better understand the accuracy of farmer recall data and alternative methods for estimating annual average milk yield from farmer reported data would be useful to understand the uncertainty in survey reported estimates. Better characterization of the breed / genotype milk yield relationship would also improve the estimate. In the longer-term, and ideal option would be that the national inventory reports milk yield using county reported data. Some counties or sub-counties use dairy cooperative or donor project data on milk yield, while in other counties desk-based estimation is used. Options for improving county estimates need to be explored. In the absence of cost-effective methods at county level, estimating the national trend can be done on the basis of survey data on milk yields and breed, with any necessary adjustment to farmer reported yields based on results of a validation study.

Furthermore, this inventory did not consider calf milk consumption. Better data on calf suckling management methods is required.

Fat content of milk used the IPCC default value. LRC has a database on milk fat and protein (1996 to 2016) but it is not possible to calculate the averages representative of smallholder-dominated farming. Given that a 10% change in fat content leads to a 1.1% change in the emission factor, improvements in this parameter may not be a priority at this stage.

(c) Manure management

Manure management CH_4 and direct N_2O emissions account for about 11% of the total dairy cattle emissions and are likely to be a key inventory source.

The key input data is manure management system activity data. There was very limited data to draw on; the definitions and results used in different studies were not standardized and did not always account fully for the diversity of manure management practices; data for semi-intensive and extensive production systems was almost totally absent. Future research in each production system that aligns manure management practice definitions with the IPCC definitions would be essential. In addition, such research should identify appropriate ways to account for the relative proportions of manure excreted on pasture and in on-farm manure management systems.

3. Uncertainty analysis

Uncertainty analysis reported in Annex 9 suggests that total dairy cattle emissions are most strongly influenced mainly by data on the structure of livestock populations, in particular:

- Proportion of total national herd in different production systems, and
- Herd structure in the semi-intensive and intensive production systems.

Feed digestibility for cows in the semi-intensive and intensive production systems and for heifers in the semi-intensive production system were also important factors.

To illustrate the effects of obtaining improved activity data and reducing input value uncertainty, a simulation was carried out in which the uncertainty range of the allocation to production systems and herd structure in each production system was halved. As a result, the uncertainty of total 2017 dairy cattle emissions reduced by 2% to 16.2%.

INVENTORY OF GHG EMISSIONS FROM DAIRY CATTLE IN KENYA - 1995-2017

Comments and Views are invited from the public.
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