Strategic Climate Policy Fund

Improvement of the Greenhouse Gas Emissions Inventory for the Agricultural Sector

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LIST OF ABBREVIATIONS

ADG	Average daily gain
AFOLU	Agriculture, forestry and other land use
ALU	Agriculture and Land Use
ARC	Agricultural Research Council
B_0	Maximum methane-producing capacity
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
DAFF	Department of Agriculture, Forestry and Fisheries
DE	Digestible energy
DEA	Department of Environmental Affairs
EF	Emission factor
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organisation
FAOSTAT	Food and Agriculture Organisation Statistics
FSSA	Fertilizer Association of Southern Africa
GE	Gross energy
GHG	Greenhouse gas
GIS	Geographic Information System
GWP	Global warming potential
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial processes and product use
MCF	Methane conversion factor
MMS	Manure management system
MODIS	Moderate Resolution Imaging Spectroradiometer
N	Nitrogen
NEa	Net energy for activity
NEg	Net energy for growth

NEl	Net energy for lactation
NEm	Data on net energy for maintenance
NEp	Net energy for pregnancy
Nex	Nitrogen excretion rate
NH_3	Ammonia
NO	Nitrogen monoxide
NO_2	Nitrogen dioxide
NOX	Nitrogen oxide air pollutants NO and NO2 (nitric oxide and nitrogen dioxide)
N_2O	Nitrous oxide
O_3	Surface ozone
QA	Quality assurance
QC	Quality control
REG	Digestible energy consumed
REM	Digestible energy consumed
SAPA	South Africa Poultry Association
SO_2	Sulphur dioxide
TMR	Total mixed ration
UNFCCC	United Nations Framework Convention on Climate Change
VS	Volatile solids

DEFINITIONS OF COMMONLY USED TERMS

Anaerobic

In the absence of oxygen, i.e. conditions conducive to the conversion of organic carbon into CH_4 rather than CO_2.

CO_2 equivalent emission

The amount of CO_2 emissions that would cause the same time-integrated irradiative forcing, over a given time horizon, as an emitted amount of a mixture of GHGs. It is obtained by multiplying the emission of a GHG by its global warming potential (GWP) for the given time horizon. The CO_2 equivalent emission is a standard metric for comparing emissions of different GHGs (IPCC, 2013).

Crop residue

Material left in an agricultural field after the crop has been harvested (e.g. straw).

Emission factor

Factor that defines the rate at which a GHG is emitted, e.g. kg CH_4 per animal per year.

Global warming potential

Defined by the IPCC as an indicator that reflects the relative effect of a GHG in terms of climate change, considering a fixed time period, such as 100 years, compared with the same mass of CO_2.

Manure N

Nitrogen in manure.

Methane conversion factor

The percentage of the manure's maximum methane-producing capacity (B_0) that is achieved during manure management.

Synthetic N

Nitrogen in the form of manufactured fertilizers, such as ammonium nitrate.

Tier levels

Tier 1 is the use of simple equations with IPCC default emission factors, Tier 2 is the use of country-specific data to obtain emission factors, and Tier 3 is the use of country-specific complex tools in the estimation of emissions.

EXECUTIVE SUMMARY

Global temperatures have risen in the last century, with an average linear trend of between 0.65 and 1.06 °C from 1880 to 2012 (Intergovernmental Panel on Climate Change (IPCC), 2014). Global warming has a strong influence on natural systems, with its associated changes in rainfall patterns and the increasing frequency of natural climate-induced disasters. Increasing greenhouse gas (GHG) emissions have been attributed to impending global warming, which is a major threat to society through the increase in the GHG effect, which results in enhanced radiation absorption in the lower atmosphere. Anthropogenic GHGs have increased tremendously since the pre-industrial era with 40%, 150% and 20% for carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) respectively (IPCC, 2014). The agricultural sector plays a major role in anthropogenic emissions of GHGs through the intensification of livestock and crop production in response to population increase and civilisation. The main GHGs that originate from agricultural activities are CH_4, N_2O and CO_2.

In order to address issues related to climate change, the international community agreed on several treaties and conventions, among them the Kyoto Protocol and the United Nations Framework Convention on Climate Change (UNFCCC). The IPCC is another international body that has been assigned to set standards for the quantification of GHGs. There have been several initiatives and continuous improvements by the IPCC on guidelines for the quantification of national GHG emissions (IPCC, 1996; 2000; 2006). The first guidelines were completed in 1996 (IPCC, 1996), revised in 1997 (IPCC, 1997), updated and qualified in 2000 (IPCC, 2000), and the latest updates completed in 2006 (IPCC, 2006) with refinements to some of the sectors finalised in 2014 (IPCC, 2014). GHG inventories are required to be complete, consistent, transparent and accurate.

The aim of the project was to estimate the 2012 GHG emissions from the agricultural sector using the Agriculture and Land Use (ALU) National GHG Inventory software. The software utilises the recommended IPCC guidelines on compiling countrywide GHG inventories. The specific objectives were to approximate emissions for activities related to livestock and crop production in response to human needs. Livestock emissions are mostly CH_4 from enteric fermentation, as well as CH_4 and N_2O from manure management. Magnitudes of CH_4 and N_2O emissions depend on the type of manure management system implemented by farmers. Emissions from crop management can be a result of fertilisation, crop residue management and the liming of fields.

To estimate emissions, emission factor and activity data are required for each of the emissions subsectors. Activity data collected to estimate livestock GHG emissions includes the annual population of all domestic animals, live weights of animals, daily weight gain for growing animals, annual milk production and milk fat content, animal feed quality and the feeding situation, and the manure management system per livestock category. Emissions from managed soils require amounts of synthetic nitrogen (N) fertilizer, manure, sewage sludge, lime and urea applied to the soil, crop residues retained in the field, crop dry matter fraction, carbon fraction and nitrogen-carbon fraction. Activity data for biomass burning includes the area burned, as well as cropland and grassland boundaries.

The total South African GHG emissions from agriculture in 2012 are estimated at 62,906 Gg CO_2 equivalent (CO_2e), with livestock emissions contributing over 77% of the emissions, while agricultural soils account for 21%, and other emissions like biomass burning and crop residue management account for about 2% (Figure 1). Enteric fermentation CH_4 proportions for livestock and emissions for the entire agricultural value chain are 74 and 55% respectively, making this subcategory the highest emitting subcategory in the agricultural sector in South Africa. Manure management emissions are 26 and 19% of the total livestock emissions and overall agricultural emissions respectively. This makes manure management the second-highest agricultural contributor. The overall contribution value, combined with the application of animal manure on pasture, paddock or rangelands (reported under agricultural soils), is 35%. Other significant agricultural soil emissions emanate from the application of synthetic nitrogen fertilizer and the application of lime on soils, with the percentage contribution on agricultural soils (overall emissions) at 19% (4%) and 14% (3%) respectively. Emissions from crop residue management and the burning of savannas each account for approximately 1% of the total agricultural GHG emissions.

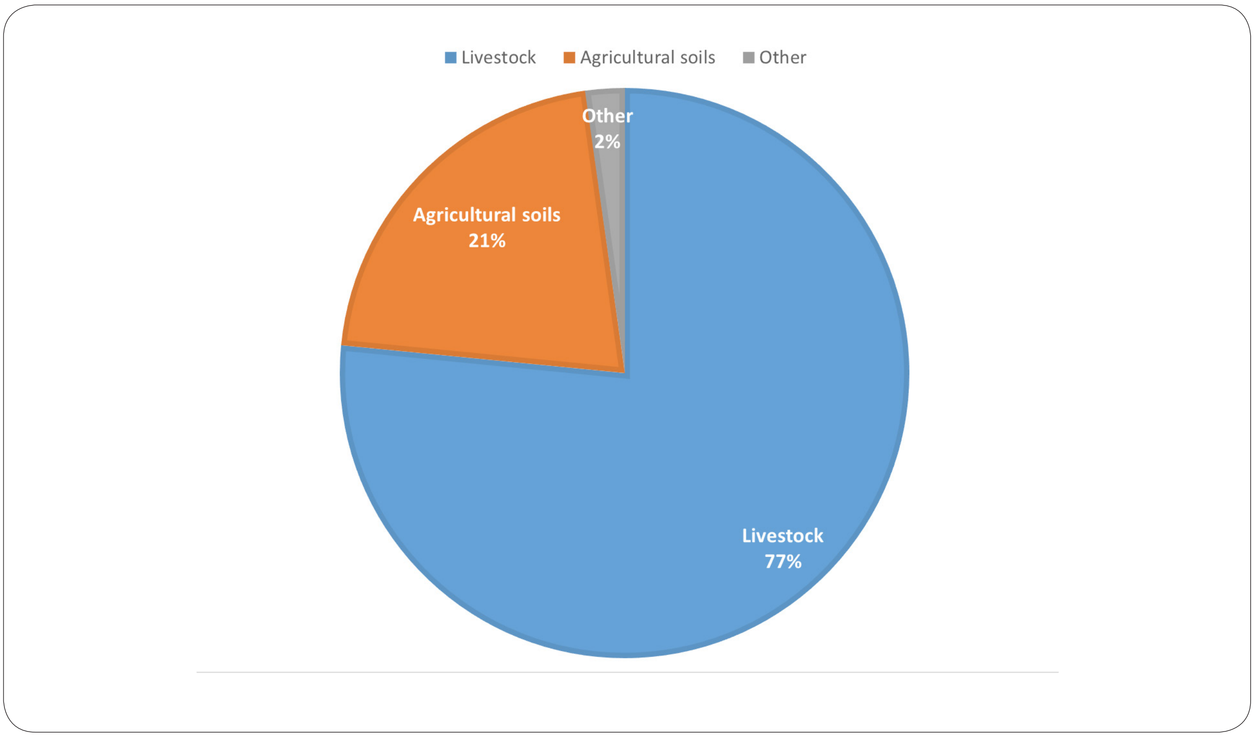


Figure 1: Proportional representation of different agricultural emission sources

1. INTRODUCTION

Greenhouse gas (GHG) emissions emanating from anthropogenic activities are considered the main cause of climate change (Caro, LoPresti, Davis, Bastianoni & Caldeira, 2014). There are five main GHGs: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), halocarbons and surface ozone (O_3). Coupled with these are indirect GHGs like carbon monoxide (CO), nitrogen monoxide (NO), nitrogen dioxide (NO_2) and sulphur dioxide (SO_2). According to the Intergovernmental Panel on Climate Change (IPCC) (2014), the levels of GHGs have increased drastically since the pre-industrial era, magnifying the GHG effect (heating of the earth due to the presence of GHGs), resulting in global warming (Figure 2 and Figure 3). The IPCC's fifth assessment report estimates that between 1750 and 2012, human activities caused global CO_2, CH_4 and N_2O concentrations to increase by 40, 150 and 20%, respectively (IPCC, 2014).

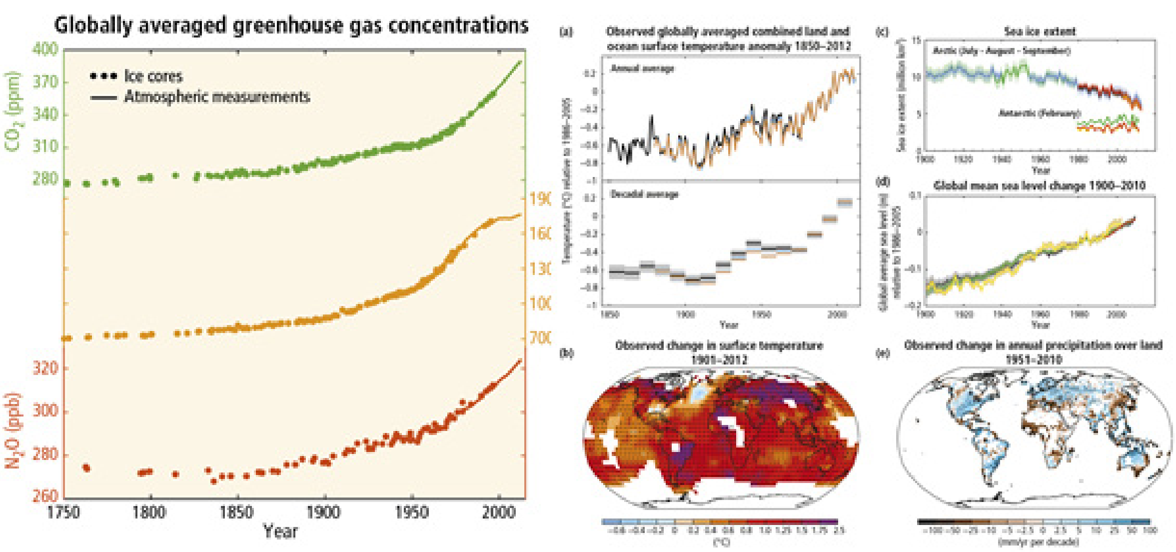


Figure 2: GHG concentration trends and corresponding changes in climate and ecosystem
Source: IPCC, 2014

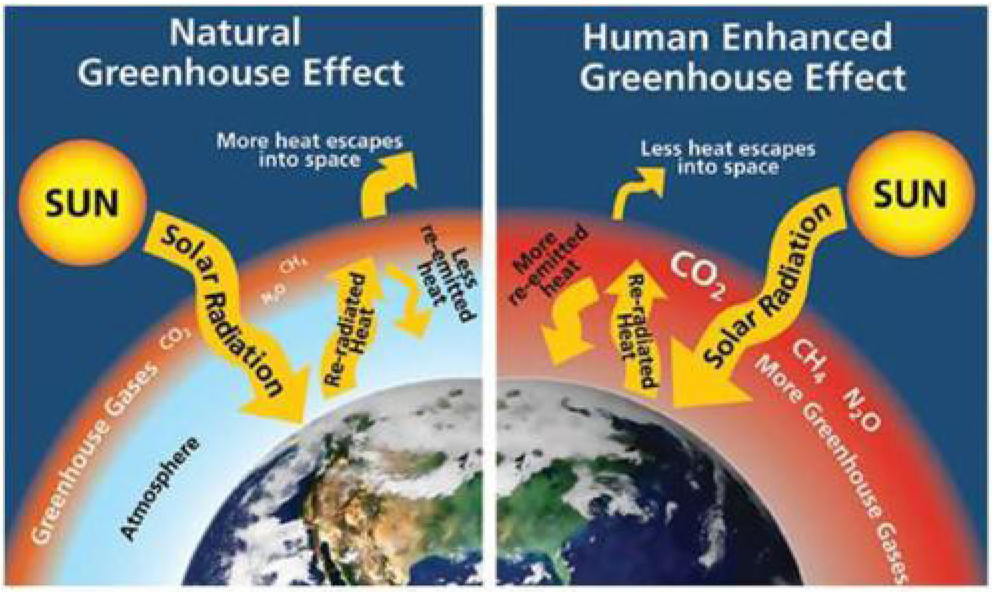


Figure 3: Natural and human enhanced GHG effect
Source: Walter, 2015

The international community realised the importance of understanding the science of global warming and its implications on existing global systems by forming an independent body, the IPCC, in 1988, which led to the United Nations Framework Convention on Climate Change (UNFCCC) and the formulation of the Kyoto Protocol (UNFCCC, 2015). The Kyoto Protocol represents the first international agreement to reduce GHG emissions. South Africa ratified the Kyoto Protocol on 31 July 2002 (Department of Environmental Affairs (DEA), 2004). The objective of the convention is to stabilise GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. The convention requires all the countries that ratified it to develop and periodically update national anthropogenic GHG inventories from sources and removals by sinks.

The IPCC has developed methodologies for estimating national GHG emissions (IPCC, 1996; 2000; 2006). The term GHG inventory is used to account for the amount of GHGs emitted into or removed from the atmosphere due to human activities over a specific period of time (IPCC, 1996). The quantification and reporting of GHG emissions should be based on the emission quantification methods that are most appropriate for that particular industry or application. According to the IPCC (2006), the estimation of GHG inventories should be complete, consistent, transparent and accurate. The accurate quantification of national GHG emissions is required to provide a sound basis for government policies and mitigation potential opportunities. Reliable information can also help in the identification of proper responses in line with food security and economic development in the country (Otter, Moeletsi, Swanepoel, Tswai & Kidson, 2010). The quantification of GHG emissions for inclusion in an inventory is a multi-step process, which includes the following (IPCC, 1996; 2000; 2006):

- Identification of all anthropogenic GHG sources and sinks
- Selection of the measurement, calculation or estimation approach

- Selection and collection of activity data
- Selection or development of GHG emission or removal factors
- Application of the calculation methodologies to quantify GHG emissions and/or removals

GHG emission and removal estimates are divided into the following five main sectors, grouped according to the closeness of their processes, emission sources and sinks: energy, industrial processes and product use (IPPU), agriculture, forestry and other land use (AFOLU), waste and other (IPCC, 2006). In each of the sectors, there are categories and subcategories. This report will concentrate on emissions from AFOLU and specifically agriculture, with categories like livestock, and subsequent categories like manure management (IPCC, 2000). Calculation of the emissions is normally approached through the utilisation of activity data (magnitude of the anthropogenic act causing the emissions) and the emission factor (coefficient quantifying the strength of the activity) using Equation 1.

Equation 1

Emissions = Activity data x emission factor

South Africa developed GHG inventories every five years until 2000, with individual inventories for 1990, 1994 and 2000 (DEA, 2009). In 2014, annual updates from 2000 to 2010 were developed (DEA, 2014). These past inventories identified significant emission sources in the country, and these key categories need the most attention during the preparation of the inventory (IPCC, 2006). Agricultural activities contribute to the increased GHG effect through the intensification of both crop and livestock farming. Otter et al. (2010) and DEA (2009; 2014) identified the following emission categories as important in South Africa: livestock (Chapter 2), managed soils (Chapter 3), cropland (Chapter 4) and biomass burning (Chapter 5).

2. GREENHOUSE GAS EMISSIONS FROM LIVESTOCK PRODUCTION

Livestock plays an important role in providing food, employment, income, draft power and nutritional security to societies all over the world (Banda, Phoya, Chilera, Mvula & Chiwayula, 2000; Singhal, Mohini, Jha & Gupta, 2005; Herrero, Gerber, Vellinga, Garnett, Leip, Opio, Westhoek, Thornton, Olesen & Hutchings, 2011). On the other hand, livestock activities can result in significant impact on the environment; this impact is growing and changing rapidly due to global pressures associated with population growth and urbanisation, among other things (Steinfeld, Gerber, Wassenaar, Castel, Rosales & De Haan, 2006). The consumption and utilisation of meat and other products from livestock are major sources of climate change, resulting from 14 to 18% of global anthropogenic GHG emissions (Bailey, Froggatt & Wellesley, 2014; Steinfeld et al., 2006). However, Goodland and Anhang (2009) argue that estimations of the global GHG contribution from domestic livestock is underestimated and could rise to 50% of total GHG emissions. The contribution from livestock is expected to increase in the future due to escalating demand for food, meat and milk (Attwood, Altermann, Kelly, Leahy, Zhang & Morrison, 2011). Livestock farming contributes directly and indirectly to GHG emissions through a number of procedures, including enteric fermentation in domestic livestock and livestock manure management (IPCC, 2006). The specific source categories are CH_4 emissions from enteric fermentation, and N_2O and CH_4 emissions from manure management (IPCC, 2000). In some parts of the world, livestock expansion to meet economic needs can accelerate deforestation by cutting down trees for pasture land or cropland for animal feed (Bailey et al., 2014).

In South Africa, livestock production accounts for about 70% of agricultural land due to extensive areas of marginal soils and low rainfall (Olander, Wollenberg, Tubiello & Herold, 2013; Scholtz, Van Ryssen, Meissner & Laker, 2013). The climate of South Africa varies across all the livestock-producing areas, with arid climate over the southwestern parts and mostly the varying temperate and subtropical climates in the rest of the country (Engelbrecht & Engelbrecht, 2015). Livestock production in South Africa varies substantially according to numbers, breeds and species, as well as grazing, environment and production systems (commercial, small-scale or communal) (Bennet & Barrett, 2000, Olander et al., 2013). These differences in the management of livestock in the country are also reflected in livestock manure management, which has an impact on GHG emissions from the livestock sector.

South African livestock production is mainly the result of dairy, beef, pig and poultry farming. The main dairy farming areas are the Free State, Western Cape, Eastern Cape and KwaZulu-Natal where different production systems are practised, based on the local environment (Gertenbach, 2007). The four main dairy breeds in South Africa are Holsteins, Jerseys, Ayrshires and Guernseys, with proportions of 0.56, 0.39, 0.04 and 0.01 respectively, based on the milk recording statistics of the Agricultural Research Council (ARC) (ARC, 2008). Beef farming is one of the largest farming activities in South Africa. Cattle are mostly reared at commercial scale throughout the country, with Mpumalanga, Free State, Gauteng and North West contributing 23%, 19%, 14% and 12% respectively (Department of Agriculture, Forestry and Fisheries (DAFF), 2012). Small-scale cattle farming in South Africa is dually geared for milk and meat production for subsistence use and the local market (Schwalbach, Groenewald & Marfo, 2001). Most of the small-scale farming animals are not pure breeds, but rather cross-breeds, resulting in low productivity (Moorosi, Schwalbach & Greyling, 2001). Subsistence cattle farmers in South Africa mostly own between two to 100 or more head of cattle, with most having less than 10 head of cattle (Schwalbach et al., 2001; Moorosi et al., 2001). South Africa has three different pig farming sectors: commercial, small and semi-commercial units, and partially to fully free-range, which are rural and have pigs roaming freely, mostly feeding off scraps that are thrown out by households (Mokoele, Janse van Rensburg, Van Lochem, Bodenstein, Du Plessis & Carrington, 2015). Poultry farming is the largest livestock commodity in South Africa, contributing around 47% of animal gross value. It is divided into two main production areas: meat production and egg production (South African Poultry Association (SAPA), 2013). Commercial intensive farming produces over 90% of poultry meat in South Africa, with small-scale and backyard farming contributing the rest (DAFF, 2013b).

2.1 Enteric fermentation

Enteric fermentation is a process whereby carbohydrates are broken down by microorganisms into simple molecules for absorption into the bloodstream of an animal (IPCC, 2006). Methane is produced as a by-product during the process of enteric fermentation.

2.1.1 Background

Methane emissions from the enteric fermentation of herbivorous animals are dependent on the type of digestive system, age and weight of an animal, level of production, quantity of feed consumed and the quality of feed devoured (IPCC, 2006). According to Brouèek (2014), methane is produced predominantly through the microbial fermentation of hydrolysed carbohydrates, and is considered an energy loss for the animal. Domestic animals are divided into three main groups according to their different methane-producing abilities (IPCC, 1996; Bull, McMillan & Yamamoto, 2005; Chhabra, Manjunath, Panigrahy & Parihar, 2009):

- **Ruminants:** These animals produce more CH_4 per unit of feed consumed than monogastric and pseudo-ruminant animals. Ruminant animals produce CH_4 during the digestion of feed intake inside the rumen (Chhabra et al., 2009; IPCC, 1996). Cattle, sheep and goats are the primary ruminant livestock species in South Africa.
- **Pseudo-ruminants:** These animals produce less CH_4 than ruminant livestock and more CH_4 than monogastric animals. Pseudo-ruminants do not have a rumen, but feed is fermented during digestion (Bull et al., 2005). Horses and donkeys fall under this group.
- **Monogastric animals:** Monogastric animals produce less CH_4 per head compared with ruminants and pseudo-ruminants, as less CH_4-producing fermentation takes place in their digestive systems (Bull et al., 2005; IPCC, 2006). They do not have a rumen, but produce small amounts of CH_4 during digestion.

According to Ferreira (2003) and IPCC (2006), the amount of feed consumed depends on many factors, including live weight, milk production, stage of lactation, environmental conditions, previous feeding history, and type and quality of feed. High feed intake is strongly related to high CH_4 emission, and the poorer the feed quality, the higher the CH_4 emission (McGinn, Chen, Loh, Hill, Beauchemin & Denmead, 2008). In South Africa, cattle (per head) is among the largest contributing livestock species to enteric fermentation emissions (DEA, 2009; Otter et al., 2009).

In this study, enteric CH4 emission factors and national emissions are determined in accordance with the 2006 IPCC Guidelines for National GHG Inventories (IPCC, 2006).

2.1.2 Materials and methods

Estimation of CH_4 emissions from enteric fermentation requires three main steps: the collection of livestock population data per subcategory of animal, the estimation of emission factors for each subgroup or utilisation of default emission factors, and the multiplication of emission factors by their corresponding populations (IPCC, 2006). Based on the key category analysis and availability of data, emission factor determination can be approached in three ways: Tier I methodology utilises default emission factors that are predetermined from literature for different regions; Tier 2 methodology involves the determination of emission factors based on country-specific data; and Tier 3 methodology (an advancement of Tier 2 methodology) employs models to estimate emissions (IPCC, 1996; 2006). In this study, the Tier 2 approach was employed for cattle, sheep and pigs, while the Tier I approach was used to estimate emissions from other animals (goats, horses and donkeys) in accordance with the key category analysis (DEA, 2009; 2014). The collection of activity data for 2012 was conducted through structured questionnaire to farmers in all the provinces of South Africa, as well as a literature search and sourcing of information from experts. For each livestock category, the best available data was used to compile the inventory. In some cases, expert opinions were considered to compensate for or complement the lack of data as agricultural census data and available scientific information did not address the data requirements for Tier 2 calculations.

2.1.2.1 The collection of population data

Appendix A shows all the data requirements and how data was sourced. Animal population data for South Africa was obtained from agricultural census data (DAFF, 2013a). The animal types accounted for were cattle, sheep, goats and pigs. The annual population data for horses, donkeys and mules was obtained from the United Nations Food and Agriculture Organisation (FAO) (Food and Agriculture Organisation Statistics (FAOSTAT), 2014). In accordance with the recommendations of the IPCC, animal categories should be divided into subcategories to account for a variation in emission rates within the categories. Cattle were divided into commercial and subsistence, with further division according to their age and sex, as shown in Table 1. Dairy cattle were subdivided into three subcategories: total mixed ration (TMR) , pasture-based (pasture), and mixed pasture during summer and TMR during winter (mixed), according to the proportions 0.4, 0.2 and 0.4 respectively. The proportion of beef cattle and subsistence annual populations was accomplished using the proportions that were obtained from the survey and considerations from the proportions of the survey in the Free State by Moorosi et al. (2001). Proportions of annual sheep and pig numbers were also determined through the utilisation of farmers' questionnaire feedback and the opinions of experts. Growers (pigs), feedlot cattle and feedlot sheep were obtained from DAFF (2013a) as slaughterings with a life cycle of 156, 105 and 65 days respectively (Otter et al., 2010; LHC Group, 2014).

2.1.2.2 Estimation of emission factors

For the estimation of emission factors for cattle, the main subcategories were dairy cattle, commercial beef cattle and subsistence cattle farming. Sheep were categorised into wool and non-wool. These subcategories were further divided per age and performance (Table 1) based on the available census data (DAFF, 2013a). The main activity data required to estimate emission factors collected were for animal weight, daily weight gain, annual milk production and fat content, and percentage of pregnancy and lactation (IPCC, 2006). Default emission factors for African countries were applied for the other livestock categories according to the Tier I approach.

The feeding situation of the mixed farming system for dairy cattle was considered as the mixture of both pastures and stalls, because they spend time in pastures during the rainy season and in stalls in winter, while for TMR and pasture systems, stalls and pastures are utilised respectively (Gertenbach, 2007; Lassen, 2012). All feedlot animals and pigs are in stalls. Feedlot animals are fed high-protein concentrate, with the mixture including maize silage, molasses, vegetable by-products (palm oil cake, soya oil cake), chopped and maize gluten, urea and pollard (Esterhuizen, Gruenewald, Strydom & Hugo, 2008; Chipa, Siebrits, Ratsaka, Leeuw & Nkosi, 2010). Pig feeding is mostly composed of 50 to 70% grain, with other components including feed lime, protein sources like oilcakes, fishmeal and oil seeds, salt, minerals and phosphates (DAFF, 2014). Based on the relatively high quality of feed, the digestible energy (DE) percentage of 80% was utilised for all stall animals in accordance with the

Table 1: Activity data for different animal subcategories in estimating enteric methane emissions

Categories	Subcategories		Animal weight (kg)	Average daily weight gain (kg day^{-1})	Annual milk production (kg/cow)	MIlk fat content (%)
Dairy cattle	Mature females	Pasture	475	-	6.015	4.1
	Mature females	Mixed	590	0.549	-	-
	Mature females	TMR	650			
	Mature bulls		850			
	Young bulls		370	0.59		
	Heifers		350	0.432		
	Calves		160	0.37		
Commercial beef cattle	Feedlot cattle		236	1.5		
	Mature females		475	-	4.6	3.5
	Heifers (1 to 2 years)		338	0.432	-	-
	Young oxen		430	1.167	-	-
	Oxen		712	-	-	-
	Young bulls		426	1.167		
	Bulls		700	-	-	-
	Calves		140	0.618	-	-
Small-scale cattle farming	Mature females		400	-	3.3	3.4
	Heifers (1 to 2 years)		236	0.06	-	-
	Young oxen		340	0.08	-	-
	Oxen		510	-	-	-
	Young bulls		340	0.08		
	Bulls		510	-	-	-
	Calves		79	0.25	-	-
Commercial sheep	Wool	Mature ewe	59	-		
		Replacement ewe	43	0.05		
		Ram	89	-		
		Young ram	66	0.06		
		Castrate	80			
		Young castrate	68	0.06		
		Lamb	22	0.144		

Table 1 continued...

Categories	Subcategories		Animal weight (kg)	Average daily weight gain (kg day^{-1})	Annual milk production (kg/cow)	Milk fat content (%)
Commercial sheep	Non-wool	Mature ewe	84			
		Replacement ewe	51.5			
		Ram	102			
		Young ram	69.5	0.169		
		Castrate	102			
		Young castrate	69.5	0.169		
		Lamb	30	0.22		
	Feedlot sheep		30			
Subsistence sheep		Mature ewe	31			
		Replacement ewe	22	0.06		
		Ram	41			
		Young ram	28	0.06		
		Castrate	41			
		Young castrate	28	0.06		
		Lamb	18	0.083		

IPCC Guidelines (IPCC, 2006). Commercial beef cattle farming takes place on a mixture of pastures and large grazing areas, depending on their size and region, while subsistence beef cattle farming takes place on communal areas far away from kraals (Palmer & Ainslie, 2002). Commercial beef and sheep are raised under extensive ranching conditions, which rely heavily on natural pasture, occasionally supplemented by protein/mineral licks, while subsistence farming animals rely on communal land of very poor quality (Moorosi et al., 2001; Palmer & Ainslie, 2002). Based on this observation and the IPCC Guidelines (IPCC, 2006), DE percentage was estimated as 60 and 50% for commercial and subsistence farming respectively.

Live weights from all the cattle categories were obtained from the farmers' feedback with considerations from the South African literature (Banga, 2009; South African Studbook, 2012; Du Toit, Meissner & Van Niekerk, 2013a; SA Guernsey, 2014; Dairy Swiss, 2014). Animal weights for all the sheep categories were obtained from the survey, communication with experts (Swart, 2014), as well as literature (Du Toit, Meissner & Van Niekerk, 2013b; LHC Group, 2014). Average daily gain (ADG) for the growing cattle was obtained from South African Studbook (2012) for beef cattle, Banga, Neser and Garrick (2014) and Grobler and Erasmus (2008) for dairy cattle, and a survey of animals' weights in the Free State for subsistence cattle.

Data on the daily gain of feedlot cattle was obtained from the results of Chipa et al. (2012). The ADG for sheep was obtained from Van Zyl and Dugmore (2012), an expert opinion (Dr Swart[1]), Dorper (2015), Fourie, Vos and Abiola (2009) and Afrino Sheep Breeders' Society (2014).

The milk production per animal and milk fat content are shown in Table 1. Milk production for dairy cattle was obtained from the milk recordings of the ARC (2014), individual farmer survey and the literature (Theron & Mostert, 2009; Neser, Van Wyk & Ducrocq, 2014), while estimations for beef and subsistence cattle are from Maiwashe, Nengovhela, Nephawe, Sebei, Netshilema, Mashaba, Nesengani and Norris (2013). The percentage of the milk fat content was obtained from the averages of the Dexter, Red poll and Shorthorn production data (Camper, Hunlum & Van Zyl, 1998). IPCC default coefficients were utilised for mature sheep.

Agriculture and Land Use (ALU) National GHG Inventory software was used to determine emission factors and emissions for cattle, pigs, goats, donkeys and horses. The program is developed based on the revised 1996 and 2006 IPCC guidelines, the 2000 and 2003 IPCC Good Practice Guidance. The calculations for sheep subcategories were extensively done using the 2006 Guidelines based on the equations (IPCC, 2006). For the Tier 2 approach, the gross energy (GE) had to be calculated (IPCC, 2006) (Appendix B). This requires data on net energy for maintenance (NEm), net energy for activity (NEa), net energy for growth (NEg), net energy for lactation (NEl) and net energy for pregnancy (NEp). It also requires the ratio of net energy available in the diet for maintenance to digestible energy consumed (REM) and the ratio of net energy available for growth in a diet to digestible energy consumed (REG) to be calculated (Appendix C).

2.1.3 Results and discussion

The results of the enteric CH4 emissions and estimates of the emission factors are shown in Table 2. The aggregated emission factor for dairy cattle is 99.37 kg per head per year, which is the weighted average of the individual emission factors for the three production systems (TMR, pasture-based, and mixed pasture and TMR) (Appendix D). The total emissions from dairy animals are 92.41 Gg

Table 2: Enteric methane emissions for livestock in South Africa for 2012

Livestock type	Number of animals	Emission factors for enteric fermentation (kg/head/year)	Emissions from enteric fermentation (Gg/year)	Emissions in CO_{2e} (Gg)
	A	B	$C = (A \times B)/10^6$	$D = C \times 34$
Dairy cows	930 000	99.37	92.41	3 141.94
Non-dairy cattle	13 785 000	65.12	897.68	30 521.12
Sheep	25 488 102	8.48	216.14	7 348.76
Goats	2 028 000	5.00	10.14	344.76
Horses	308 000	18.00	5.54	188.36
Donkeys and mules	167 000	10.00	1.67	56.78
Pigs	2 901 000	1.00	2.9	98.6
Total			1 226.48	41 700.32

[1] Also referred to as veldfires in South Africa.

(2 310 Gg CO_2e), contributing around 7.5% towards the total enteric CH_4 emissions of 1 226.38 Gg (Figure 4). The highest contributions of over 70% are attained from non-dairy cattle, which is comprised of all the cattle categories except lactating dairy cattle. The second-highest emissions are from sheep farming with 216.14 Gg, equating to over 17% of total emissions. Emissions from other livestock (goats, donkeys and mules, horses and pigs) are less than 1%.

Enteric CH_4 emissions attained for the previous inventories (1990, 2000, 2004 and 2010) were 916.55 Gg, 903.23 Gg, 1,183.56 Gg and 1,172.95 Gg respectively (Van der Merwe & Scholes, 1998; DEA, 2009; Otter et al., 2010; Du Toit et al., 2013a; DEA, 2014). The estimated emissions for 2012 are higher by 34% (1990), 36% (2000), 3% (2004) and 5% (2010). The main dissimilarity in the first two inventories was due to the major differences in emission factors for cattle, where the Tier 2 approach was used in all the inventories. Emission factors for dairy and non-dairy cattle are found to be higher than those obtained in 1990 and 2000 by 20 kg per head per year and 15 kg per head per year respectively. In 1990 and 2000, the default emission factor for sheep and goats (5 kg per head per year) was utilised, compared with 8.48 kg per head per year for sheep (Tier 2), while the default value was used for goats. There was also a decrease in the total number of sheep and goats (37.2 million for 1990 and 27.52 million for 2012), while the number of cattle has increased slightly (13.5 million for 1990 and 14.715 million for 2012). The slight increase in emissions compared with the 2004 and 2010 figures is caused by a combination of factors, including the addition of feedlot sheep in the 2012 emissions. An increase in feedlot cattle from 420 000 to 815 000, as recorded in abattoir slaughterings (DAFF, 2013a), is still slightly less than the 1.1 million reported in 1990. In 2004, default emission factors for sheep were utilised.

2.1.4 Uncertainty analysis

An uncertainty analysis was conducted on the estimated CH_4 emissions from enteric fermentation to determine the inaccuracies associated with the results. The quantitative analysis for this source category and the subsequent categories were undertaken using ALU software. The ALU approach is based on the 95% confidence interval recommended by the IPCC (2000). Uncertainty was determined for each of the activity data entered into the software, based on the overall collected dataset and the understanding of associated bias. The process started with annual animal population data up to the determination of the emission factors. The results showed that the enteric CH_4 emissions ranged from 1 072

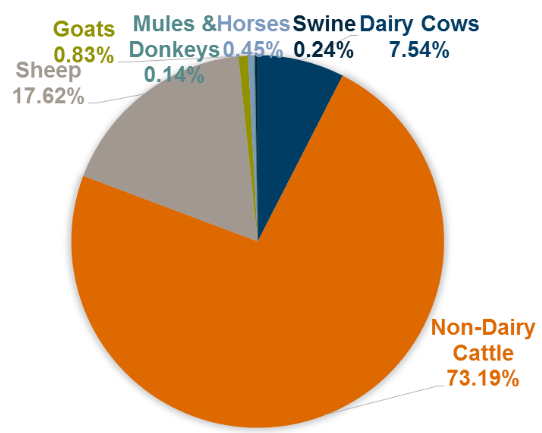


Figure 4: Percentage enteric methane contribution of different livestock categories

Table 3: Uncertainty estimates for enteric CH_4 emissions

Source	GHG	2012 estimate (Gg/year)	Uncertainty range and percentage		
			Lower bound	Upper bound	Uncertainty percentage
Enteric fermentation	CH_4	1 226.48	1 072.56	1 380.40	12.55%

Gg to 1 380 Gg, indicating 12.55% below and above the estimated value (Table 3).

2.1.5 Quality assurance/quality control and verification

Most of the quality control was undertaken while populating the raw data into the ALU National GHG Inventory software. The main quality control measures centred around the activity data and emission factors obtained. Activity data checks included the following:

- Animal population data was discussed by the team responsible and the checks that the data was entered correctly was performed by a project leader and research team manager.
- All activity was quality controlled through the utilisation of ALU quality assurance (QA)/quality control (QC) functionality. This function was operated by subsector leaders who were not populating the database.
- The determination of annual population data was not straightforward in some of the animal subcategories like broilers, the life span of which was around 35 days. Proper adherence to the IPCC Guidelines was ensured in cases like this.

Emission factors and emissions QC included the following activities:

- Emission factors obtained in all the animal subcategories were checked against the IPCC-recommended default emission factors and their corresponding activity data, and reasons for disparity were documented.
- Emission factors were compared with previous inventories' factors for consistencies, and explanations for any deviations were documented.
- Emission factors calculated by ALU were checked manually by utilising Microsoft Excel macros of the IPCC equations. This was carried out with the emissions as well.
- The utilisation of updated global warming potential (GWP) from the fifth IPCC assessment report for different GHG emissions was performed outside ALU software.

The compilation of this inventory has been a team effort with contributions from different government sectors and researchers at the ARC. Animal statistics were solely obtained from reports of the Agricultural Statistics Department and its database, with isolated interaction with staff of Statistics South Africa. Most of the activity data was collected with the help of animal scientists of the ARC.

The draft report of this subsection was reviewed by a number of scientists with an agricultural background, climate mitigation knowledge and knowledge of the compilation of GHG emission records.

2.1.6 Planned improvements

Based on the results obtained in this section, there was fairly adequate data to fully qualify this section as being a Tier 2 approach. Improvements can be attained by establishing voluntary reporting by farmers on the indices that are important to estimating enteric CH_4. Sourcing data from the farms has been challenging due to the mistrust of the commercial farming sector in the government structures, and it is critical to restore the association. It would be critical to utilise the commodity associations to obtain some of the information required. An accurate estimation of emissions in this category is key in the acceptability of the agricultural GHG emissions as this is the main contributor of the sector.

2.2 Manure management

GHG emissions for manure management are considered a key source category that needs to be estimated in South Africa (DEA, 2009). CH_4 and N_2O are produced through the storage, treatment, transportation and deposition of livestock manure on pastures (Environmental Protection Agency (EPA), 2014). The term 'manure' includes the combination of dung and urine produced by livestock (IPCC, 2006).

2.2.1 Background

Emissions from the management of livestock manure accounts for around 10% of the global agricultural GHG emissions (Owen & Silver, 2015). The type and quantity of GHG emissions are determined by the temperature of the manure, manure composition, storage, handling and application (EPA, 1999; Alberta Agriculture, 2015. The management system (storage and handling) determines some key factors that affect CH_4 and N_2O production, including contact with oxygen, water content, pH and nutrient availability (EPA, 1999). When manure is stored or treated as a liquid in a lagoon, pond or tank, it tends to decompose anaerobically and produce a significant quantity of CH_4. In contrast, when manure is handled as a solid or deposited on pastures, it tends to decompose aerobically, and little or no CH_4 is produced (IPCC, 2006). In contrast, high N_2O emissions are prevalent in manure stored in a solid form. According to Bull et al. (2005), EPA (2010) and Grant, Boehm and Bogan (2015), temperature, pH and moisture content also affect CH4 formation, with high temperature (ideally between 35 and 45 °C), high moisture level and neutral pH conditions favouring CH_4 production. N_2O is produced through the mixture nitrification and denitrification of manure nitrogen (IPCC, 2006). N_2O emissions from manure depend on the digestibility and composition of animal feed, manure management practices, the duration of the waste management, the nitrogen and carbon content of the manure and environmental conditions (IPCC, 2006). Nitrification is a prerequisite for N_2O emissions; it occurs when inorganic nitrogen in the form of ammonium is transformed into nitrate, which further provides nitrogen for the denitrification process (IPCC, 2006; Chadwick, Sommer, Thorman, Fangueiro, Cardenas, Amon & Misselbrook, 2011). High N_2O emissions are related to a high intake of feed with a high nitrogen concentration. N_2O emissions depend on the amount of oxygen and the moisture level of the managed manure (IPCC, 1997; Bull et al., 2005). Manure stored for long periods of time results in relatively high emissions of N_2O. The environmental conditions that favour the development of N_2O in managed manure are low pH, high temperature, increased aeration and low moisture (Dalal, Wang, Robertson & Parton, 2003).

In this section, CH_4 and N_2O emissions from manure management are assessed utilising the IPCC 2006 Guidelines for National GHG Inventory estimations. The emission factors are calculated for all animals based on country-specific data and default values where data gaps exist.

2.2.2 *Methodology*

To estimate emissions from manure management, animal categories presented in the previous subsection (enteric fermentation) were utilised. In addition, annual population data for poultry (broilers and layers) was acquired from SAPA (2012). As for the broilers, the life cycle was taken as 35 days (as recommended by national experts and survey results). Thus, annual population was adjusted in accordance with the 2006 IPCC Guidelines Equation 10.1 (IPCC, 2006). The data was entered into ALU software. As indicated, data on how farmers manage their manure is important (IPCC, 2006). The data on the manure management system (MMS) was obtained through a survey that took place from March to July 2015, targeting livestock farmers in all the provinces of South Africa. The data was also supported by expert opinions due to the diversity of animal production in South Africa. Table 4 shows the categorisation of the MMSs per livestock. Additional activity data required for pigs was the GE intake (MJ per head per year), which was obtained from Du Toit, Van Niekerk and Meissner (2013c) for piglets, and Kanga (2010) for breeding sows and growers. To estimate the ash content of manure in the calculation of volatile solids (VS), the 1996 IPCC default values were utilised for pigs, while the 2006 values were utilised for cattle (IPCC, 1996; 2006). Default values for maximum CH_4 producing capacity (B0), as well as the methane conversion factor (MCF) were used. Manure CH_4 emission factors were obtained from the IPCC Guidelines. Oceania values were utilised for dairy and commercial cattle, while Africa default values were utilised for all subsistence farming animals (IPCC, 1996; 2006). The use of Oceania values has been supported by Otter et al. (2010) and DEA (2014) due to the fact that activity data for most of the commercial animals in South Africa resembles that of the Oceania region (IPCC, 2006). The manure CH_4 emission factor is calculated using IPCC Equation 10.23, as shown below (Equation 2), as well as the results in Appendix E.

Equation 2

$$EF_T = (VS_T \times 365) \times \left[B_0 \times 0.67kg/m^3 \times \sum \frac{MCF_{S,k}}{100} \times MS_{T,S,k}\right]$$

Where:

EFT = annual CH_4 emission factor for livestock category T;

VST = daily volatile solid excreted for livestock category T;

B_0 = maximum methane-producing capacity for manure produced by livestock category T;

MCFs,k = methane conversion factor for MMS S by climate region k;

MST,S,k = MMS S for livestock category T by climate region k.

Table 4: 2012 Manure management system for different animal categories in percentages

Livestock category	Subcategory	Lagoon	Liquid/ slurry	Drylot	Solid storage	Daily spread	Com-post	Pasture	Manure with bed-ding > 1 month	Poultry ma-nure with-out litter	Poultry ma-nure with litter
Dairy cattle	Mixed – lactating cows	10		7	14	3		50	16		
	Pasture – lactating cows	11		8	10	3		60	8		
	TMR – lactating cows	95							5		
	Non-lactating dairy cattle	0	0		2	1	0	95	2	0	0
Commercial beef cattle	Feedlot cattle	0	0	0	20	0	0	0	80	0	0
	Other beef	0	0	0	2	1	0	95	2	0	0
Subsistence cattle	All animals	0	0	10	0	0	0	30	60	0	0
Sheep	All sheep	0	0	0		0	0	100	0	0	0
Goats	All goats	0	0	0		0	0	100	10	0	0
Horses		0	0	0		0	0	100	0	0	0
Donkeys		0	0	0		0	0	100	0	0	0
Pigs	All pigs	50	20	20	10	0	0	0	0	0	0
Poultry	Broilers and layers	0	0	10		5	2	0	0	5	78

For the estimation of N_2O, Africa default values for nitrogen excretion rate (Nex) were utilised. Table 5 shows the assigned N2O emission factors (IPCC, 2000), as determined by the ALU software. Emissions from pasture, paddocks and ranges are not reported in this section to avoid double counting, as they are covered under emissions from soils. Indirect emissions from the volatilisation of manure nitrogen were calculated using Equation 10.27 of the 2006 IPCC Guidelines (IPCC, 2006). The required data is Nex and its adjustment based on the size of the animal (e.g. 1 for mature cattle, 0.6 for a heifer and 0.3 for a calf), MMSs and percentage of managed manure nitrogen per livestock category that volatilises as NH_3 and NOx per MMS. The latter was estimated using data obtained from Table 10.23 of the 2006 IPCC Guidelines (Table 6).

2.2.3 Results and discussion

Methane emissions from manure management for 2012 totalled 318.30 Gg (7 957.5 Gg CO_{2e}), with the highest contributions from non-dairy and dairy cattle, with percentages around 61 and 29% respectively (Table 7; Figure 4). The results are significantly higher than those obtained in the previous inventory reports of 1990 (83.41 Gg), 2000 (90.65 Gg), 2004 (135 Gg) and 2010 (38.80 Gg) (Van der Merwe & Scholes, 1998; DEA, 2009; Moeletsi & Tongwane, 2015; DEA, 2014). The main differences in

Table 5: Default nitrous oxide emission factors assigned to each MMS

Manure management system	Emission factors (kg N_2O-N/kg N)
Aerobic treatment	0.02
Anaerobic digester	0.001
Anaerobic lagoon	0.001
Burnt for fuel	0.02
Cattle/swine deep litter < 1 month	0.005
Cattle/swine deep litter > 1 month	0.02
Compost extensive	0.02
Compost intensive	0.02
Daily spread	0
Dry lot	0.02
Liquid/slurry	0.001
Manure used as feed	0.02
Manure used in construction	0.02
Open pit storage < 1 month	0.001
Open pit storage > 1 month	0.001
Poultry manure with bedding	0.02
Poultry manure without bedding	0.005
Solid storage	0.02

Table 6: Default values used for nitrogen loss due to volatilisation of NH_3 and NOx from manure management (percentage)

Livestock category	UAL[1]	LS[2]	D[3]	SS[4]	DS[5]	C[6]	CB[7]	PML[8]	PM[9]
Dairy cattle	35	40	20	50					
Beef cattle			30				40		
Subsistence cattle			30				40		
Sheep							35		
Goats							35		
Pigs	78	48	25		45				
Poultry			55			55		50	55

[1]UAL: Uncovered anaerobic lagoon ; [2]LS: Liquid storage [3]D: Drylot ; [4]SS: Solid storage; [5]DS: Daily spread; [6]C: Composting; [7]CB: Cattle/swine/sheep/goats bedding; [8]PML: Poultry manure with litter; [9]PM: Poultry manure without litter

Table 7: South Africa methane emissions from livestock manure management for 2012

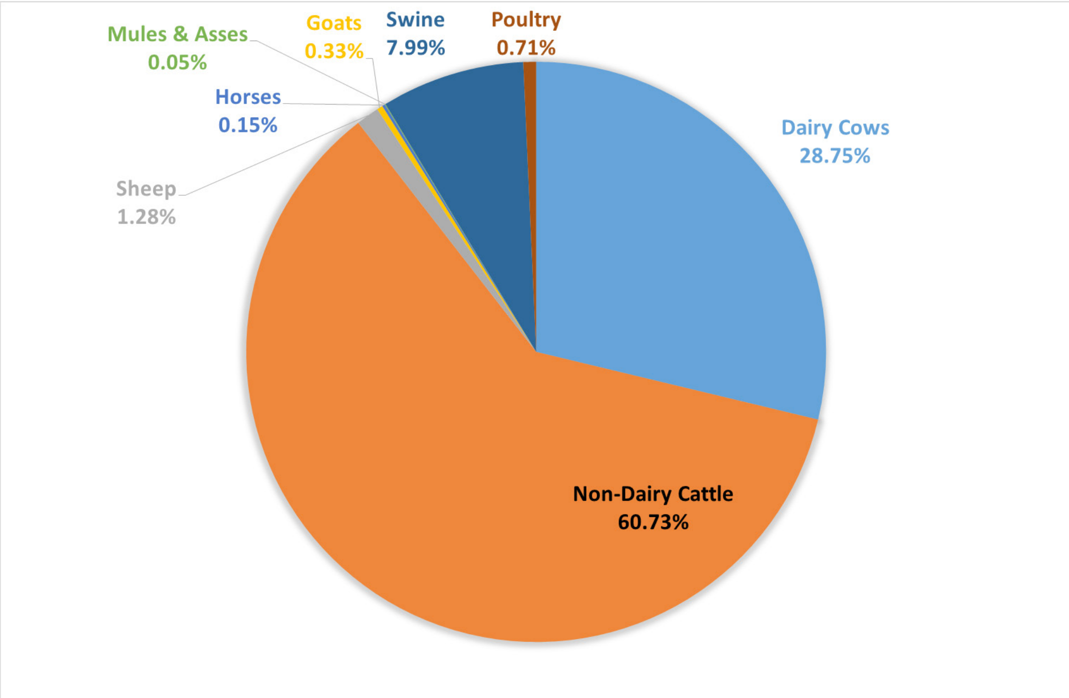
Livestock type	Number of animals	Emission factors for enteric fermentation (kg/head/year)	Emissions from manure management (Gg/year)	
			CH_4	CO_{2e}
	A	B	$E = (A \times B)/10^6$	$(E \times 34)$
Dairy cows	930 000	98.401	91.51	3 111.34
Non-dairy cattle	13 785 000	14.023	193.31	6 572.52
Sheep	25 488 102	0.16	4.08	138.72
Goats	6 141 817	0.17	1.04	35.36
Horses	308 000	1.6	0.49	16.66
Mules and asses	167 000	0.9	0.15	5.1
Swine	2 901 000	8.77	25.44	864.96
Poultry	125 829 260	0.018	2.26	76.84
Total			318.3	10 821.5

all the inventories are the MMSs that are perceived to be used by different livestock commodity farmers. This inconsistency is caused by a lack of proper national data on the management of animal manure. Findings from Otter et al. (2010) and Moeletsi and Tongwane (2015) were based on a survey of selected farmers from the ARC's animal improvements database, which included farmers from different provinces, but was limited to a small number of farmers. The MMS of the DEA (2014) was based on expert opinion. In this report, the combination of a national survey, which covered some parts of the country, and expert opinion was used. Most of the manure from non-dairy cattle was managed on pastures and rangelands, while manure from dairy cattle was mostly managed under lagoons with relatively high emission factors. The aggregated emission factor for all the dairy cattle is 98.40 kg per head per year, while for non-dairy cattle combined (all MMSs), an emission factor of 14 kg per head per year was attained (Table 7).

N_2O emissions from manure management in 2012 totalled 6.92 Gg (1 833.80 Gg CO_2e), as shown in Table 8. The main emissions are obtained from non-dairy cattle (4.04 Gg equalling over 50% of the total emissions) and poultry (2.17 Gg equalling over 30% of total emissions) (Table 9; Figure 5). In terms of MMSs, cattle/swine/sheep/goats bedding and poultry manure contribute high amounts because of the relatively high emission factor (0.02) and high population numbers associated with the system (Table 9).

The total N_2O from manure management is slightly lower than the results from the 2004 inventory (11.76 Gg) and higher than the 2010 emissions (3.59 Gg). There were no significant changes in the number of animals between 2004, 2010 and 2012, implying that the main difference is the MMS. The scale of both emissions of CH_4 and N_2O are deemed too low in the 1990 and 2010 inventory, based on the fact that MMSs that promote CH_4 emissions tend to inhibit N_2O emissions (IPCC, 2006)

Indirect N_2O emissions from the volatilisation of manure nitrogen varied significantly across the management systems, with high emissions from manure bedding and



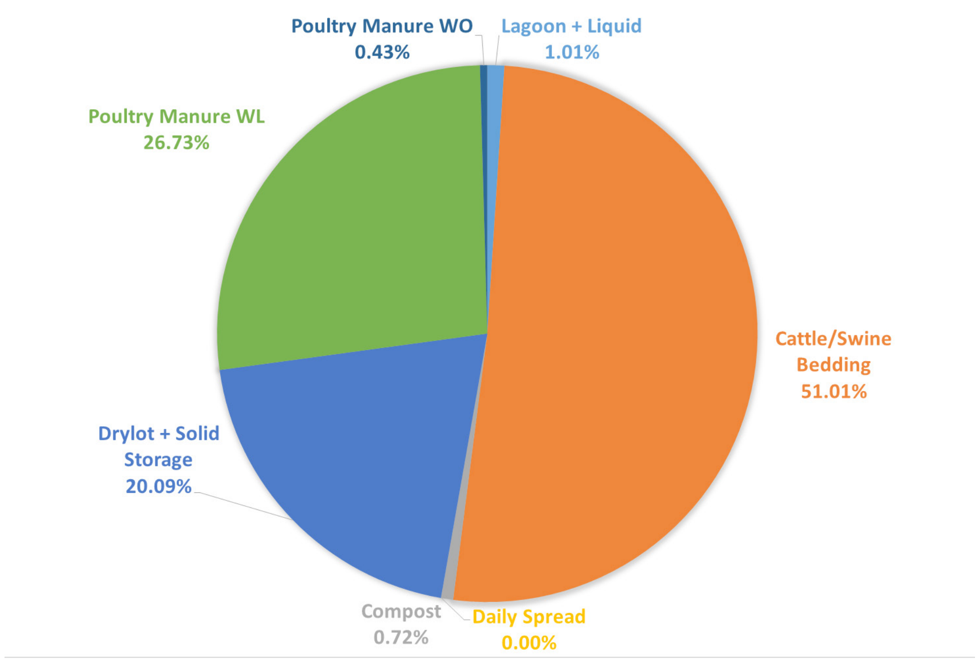
Firgure 5: Proportional representation of manure CH_4 emissions per livestock category

Table 8: South Africa N_2O emissions per animal category from manure management for 2012

Livestock type	Number of animals	Emissions from manure management (Gg/year)	
		N_2O	CO_2e
		A	B = A x 298
Dairy cows	930 000	0.42	125.16
Non-dairy cattle	13 785 000	4.04	1 203.92
Sheep	25 488 102	0	0
Goats	6 141 817	0	0
Horses	308 000	0	0
Mules and asses	167 000	0	0
Swine	2 901 000	0.29	86.42
Poultry	125 829 260	2.17	646.66
Total		6.92	2 062.16

Table 9: South Africa N_2O emissions per livestock MMS for 2012

Manure management system	Nex (MMS) (kg N/year)	Emission factor (EF) for MMS (kg N_2O-N/kg N)	Emissions of N_2O (Gg/year)	
	A	B	C = (A x B) [44/28]/10^6	CO_2-eq
Anaerobic lagoons	38 480 784	0.001	0.06	17.88
Liquid systems	5 526 874	0.001	0.01	2.98
Daily spread	35 066 256			
Solid storage and drylot	100 929 896	0.02	1.39	414.22
Pasture range and paddock	815 790 279.6			
Cattle/swine bedding	112 372 789	0.019	3.53	1 051.94
Poultry manure with litter	58 888 100	0.019	1.85	551.3
Poultry manure without litter	3 774 878	0.019	0.03	8.94
Compost	1 509 951	0.019	0.05	14.9
Total	**1 655 041 450**		**6.92**	**2 062.16**



Firgure 6: Proportional representation of manure CH_4 emissions per manure management system

Table 10: South Africa indirect N_2O emissions per livestock MMS for 2012

Manure management system	N volatization-MMS (kg N/year)	Emission factor for MMS (kg N_2O-N) / (kg NH_3-N+NOx-N volatilised)	Emissions of N_2O (Gg/year)	
	A	B	C = (A x B) [44/28]/10^6	CO_2e = C x 298
Anaerobic lagoons	48 795 059	0.01	0.77	229.46
Liquid systems	7 336 391	0.01	0.01	2.98
Daily spread	1 655 720	0.01	0.03	8.94
Solid storage and drylot	23 108 618	0.01	0.36	107.28
Cattle/swine bedding	86 836 793	0.01	1.36	405.28
Poultry manure with litter	29 444 056	0.01	0.01	2.98
Poultry manure without litter	2 076 183	0.01	0.01	2.98
Compost	754 976	0.01	0.01	2.98
Total	**1 655 041 450**		**3.14**	**935.72**

anaerobic lagoons (Table 10). The total emissions are 3.14 Gg (832.1 Gg CO_2e), which is comparable to the values (2.53 Gg) obtained in the 2004 Agricultural Inventory (Otter et al., 2010).

2.2.4 *Uncertainty analysis*

To quantify the uncertainty analysis for emissions from manure management, a 95% confidence interval was determined for each of the activity data and, where possible, expert opinion on perceived variation was utilised for qualitative data like MMSs. This was performed in accordance with the IPCC's recommendations (IPCC, 2000). The process was undertaken for all the activity data (Appendix F), and ALU already had predefined uncertainty ranges for all the default IPCC values embedded in the software. The uncertainty results yielded uncertainty of 29.34 and 35.48% for CH_4 and N_2O from manure management respectively (Table 11). High uncertainties for CH_4 manure management is attributed to the high error estimate attached to MMSs and the utilisation of default values in calculating emission factors, which carries uncertainties exceeding 50%. In estimating N_2O, most of the data utilised for estimating emission factors was obtained from the IPCC default values; hence the extremely high error estimate. The resulting 95% confidence interval for the CH_4 manure management ranges from 224.91 to 411.69 Gg, while N_2O emissions from manure management intervals are between 4.47Gg and 9.37Gg.

2.2.5 *Quality assurance/quality control and verification*

To ensure that collected data on manure management was attained, the training of the data collectors was done most specifically to educate them on the differences between the livestock MMSs. Their full understanding of the systems would ensure that when they asked farmers questions, they would probe intelligently. MMSs collected were then compared with the previous findings and, where possible, individual farmers were contacted to verify their choice of MMS. The data from the survey was complemented with reports from experts on different animal commodities.

Table 11: South Africa N_2O emissions per livestock MMS for 2012

Source	GHG	2012 estimate (Gg/year)	Uncertainty range and percentage		
			Lower bound	Upper bound	Uncertainty percentage
CH_4 manure management	CH_4	318.30	224.91	411.69	29.34%
N_2O manure management	N_2O	6.92	4.47	9.37	35.48%

Quality control on activity data in the previous section (enteric CH_4), as well as quality assurance outlined, also applies to this subsection.

2.2.6 Planned improvements

There is high uncertainty about manure management, mainly due to the varying MMSs across the country and lack of census data to trace the evolution of systems as farmers change their management in response to food demand, the sustainability of farming, environmental considerations and government policies. Incorporating the data requirements of this subsection in the yearly or ten-yearly agricultural census would solve most of the activity data challenges that agricultural GHG compilers face in South Africa. There should also be an initiative from government institutions and parastatals to support research on establishing country-specific emission factors in specialist areas like nitrogen cycles and dynamics.

3. GREENHOUSE GAS EMISSIONS FROM MANAGED AGRICULTURAL SOILS

3.1 Background

The acceleration of the global nitrogen cycle due to human activities is probably the major cause of the increase in the atmospheric N_2O concentration of 0.7 ppb per year, and of the increasing injection of N_2O into the atmosphere (Bouwman, Boumans & Batjes, 2002). Direct emissions of N_2O and NO from soils are caused by the application of mineral fertilizers and animal manure, while indirect emissions of N_2O occur through the degassing of N_2O from aquifers and surface water, stemming from N_2O dissolved in water leaching from soils, or from denitrification in groundwater of nitrogen leached from fertilized soils (Bouwman et al., 2002; Valentini, Arneth, Bombelli, Castaldi, Gatti, Chevallier, Ciais, Grieco, Hartmann, Henry, Houghton, Jung, Kutsch, Malhi, Mayorga, Merbold, Murray-Tortarolo, Papale, Peylin, Poulter, Raymond, Santini, Sitch, Laurin, Van der Werf, Williams & Scholes, 2014). The export of nitrogen from land to rivers that is generated by agricultural practices contributes minor indirect nitrogen emissions (Valentini et al., 2014).

Most of the N_2O emissions take place in soils and are related to agricultural activities (Kasimir-Klemedtsson, Klemedtsson, Berglund, Martikainen, Silvola & Oenema, 1997; Signor & Cerri, 2013; FAOSTAT, 2014). N_2O is produced in soils through the biological processes of nitrification and denitrification (Signor & Cerri, 2013). In most soils, an increase in available nitrogen enhances nitrification and denitrification rates, which then increases the production of N_2O (IPCC, 2006). Denitrification is responsible for most of the N_2O produced in the soil. Nitrification can also produce N_2O, when oxygen is limited (Signor & Cerri, 2013). Nitrification is an aerobic process, which is relatively constant across ecosystems, but denitrification is an anaerobic process, and rates are temporally and spatially more variable (Bouwman et al., 2002). The bacterial processes of denitrification and nitrification are the dominant sources of N_2O and NO in most soil systems, while denitrification is also a sink for N_2O (Bouwman et al., 2002). Amending the agricultural soil with urea increases the emission of N_2O and CO_2 (Serrano-Silva, Luna-Guido, Fernández-Luqueno, Marsch & Dendooven, 2011; Signor et al., 2013). Urea has several advantages over other fertilizers, as it is easier to handle, is less corrosive to machinery, less likely to explode or burn, and its high nitrogen content guarantees substantial savings in transport and storage (Serrano-Silva et al., 2011).

Natural sources of N_2O are soils and oceans, and the anthropogenic increase is mainly caused by accelerated soil emissions through the application of nitrogen fertilizers, crop residue and animal manure in agriculture (Stehfest & Bouwman, 2006). Soils in crop and grazing land systems can also be a source or sink for CH_4, depending on the conditions and management of the soil (Ogle, Adler, Breidt, Del Grosso, Derner, Franzluebbers, Liebig, Linquist, Robertson, Schoeneberger, Six, Van Kessel, Venterea & West, 2014). Two counteracting processes – methanogenesis and methanotrophy – drive the net exchange of CH_4 between agricultural soils and the atmosphere (Hiller, Bretscher, Del Sontro, Diem, Eugster, Henneberger, Hobi, Hodson, Imer, Kreuzer, Künzle, Merbold, Niklaus, Rihm, Schellenberger, Schroth, Schubert, Siegrist, Stieger, Buchmann & Brunner, 2014). CH_4 is also produced in soil during microbial decomposition of organic materials and CO_2 reduction under strictly anaerobic conditions (Hiller et al., 2014; Ogle et al., 2014). CH_4 can be removed from the atmosphere through the process of methanotrophy in soils. Methanotrophy occurs under aerobic conditions and is common in most soils that do not have standing water (Ogle et al., 2014).

Global mean fertilizer-induced emissions for N_2O and NO amount to 0.9 and 0.7%, respectively of the nitrogen applied (Bouwman et al., 2002; Stehfest & Bouwman, 2006). A fine soil texture restricts drainage, and neutral to slightly acidic conditions favour N_2O emission, while a good soil drainage, coarse texture and neutral soil reaction favour NO emission (Bouwman et al., 2002). Temperature and moisture are of great importance for nitrification and denitrification because they determine the activity of microorganisms (Imer, Merbold, Eugster & Buchmann, 2013; Signor & Cerri, 2013). Anaerobic conditions may be more easily reached and maintained for longer periods within aggregates in fine textured soils than in coarse-textured soils (Bouwman et al., 2002; Valentini et al., 2014), which may be a common feature in cultivated croplands. In moist soils, the rate of gas diffusion and aeration is smaller, and a greater amount of NO would react before being released into the atmosphere (Signor & Cerri, 2013). There is a strong increase of both N_2O and NO emissions accompanying nitrogen application rates, and soils with high organic carbon content show higher emissions than less fertile soils (Bouwman et al., 2002). South Africa is characterised by soils with very low organic matter levels (Du Preez, Mnkeni & Van Huyssteen, 2010; Du Preez, Van Huyssteen & Mnkeni, 2011).

Natural veld (grassland) cannot fulfil the increasing demand for food as a result of growing human populations unless it is supplemented with managed pastures (Fessehazion, Annandale, Everson, Abraha & Truter, 2012). Grazing is the common land use throughout the arid regions of the world (Al-Rowaily, El-Bana, Al-Bakre, Assaeed, Hegazy & Ali, 2015). Livestock production in the pastoral parts of South Africa strongly depend on the condition of the available natural pasture (Van Rensburg, Snyman & Kellner, 2004). Communal rangeland (about 14% of South Africa's used land) holds about half of all livestock in South Africa and is often associated with land degradation as a result of continuous grazing at high stocking densities (Linstädter, Schellberg, Brüser, García, Oomen, Du Preez, Ruppert & Ewert, 2014). The capacity of degraded, over-exploited natural pasture to sustain high levels of livestock production is severely limited (Van Rensburg et al., 2004). During drought and heavy rainfall periods, cattle performance gets worse at high stocking rates on rangeland of a poor condition than on rangeland of a good condition (Fynn & O'Connor, 2000). Managed pastures are usually grown and grazed periodically in the country to cope with the food demand (Van Heerden, 2012). Livestock manure in South Africa is mostly left in the pasture, range or paddocks, or managed as drylot (Moeletsi & Tongwane, 2015). As a result, in addition to fertilizer application rate, N_2O emissions are sensitive to manure amendment and residue return rate (Wang, Sun, Zhang, Qi & Zhao, 2011).

N_2O emissions generated by manure in pasture, range and paddock systems occur directly and indirectly from the cultivated soil layer, groundwater, surface water by leaching and runoff (Zheng, Liu & Han, 2008; Cornejo & Wilkie, 2010). Urine and dung nitrogen deposited in pasture, range and paddocks by animals contribute to indirect N_2O emissions from soils (Cornejo & Wilkie, 2010). Other agricultural practices also tend to increase nitrogen volatilisation and NO_3 leaching (Del Grosso, Parton, Mosier, Walsh, Ojima & Thornton, 2006). The direct application of synthetic fertilizer increases the pool of mineral nitrogen available for nitrification and denitrification (Del Grosso et al., 2006; Cornejo & Wilkie, 2010). Cultivation, particularly of soils with high levels of organic matter, transfers nitrogen from the organic to the mineral form, thus also increasing nitrogen availability for nitrification. CO_2 emission increases with increasing manure amendment, residue return rate and initial soil organic carbon (Wang et al., 2011). More importantly, fertilizing agricultural fields with manure rather than synthetic fertilizers results in lower emissions, as well as increased soil carbon storage (Owen, Kebreab & Silver, 2014).

Globally, during the last four decades, agricultural land has increased due to conversion from other land uses, a change driven largely by increasing demand for food from a growing population (IPCC, 2006). A similar trend in South Africa is observed where cropland, grasslands and settlements are estimated to have increased by 16.7, 1.2 and 1.2% respectively in recent years (DEA, 2014). Land-use conversions to cropland from forestland, grasslands and wetlands usually result in a net loss of carbon from biomass and soils, as well as N_2O to the atmosphere (IPCC, 2006). Agricultural land consists of arable land, permanent pasture and permanent crops, including agro-forestry and bio-energy crops, where the vegetation structure falls below the thresholds used for the forestland category, and is not expected to exceed those thresholds at a later time (IPCC, 2006). Arable land, which is normally used for the cultivation of annual crops, but which is temporarily used for forage crops or grazing as part of an annual crop-pasture rotation, is included under cropland. Main annual crops produced in South Africa include cereals, oil seeds, vegetables, root crops and forages. Perennial crops include trees and shrubs, in combination with herbaceous crops or as orchards and tea. Land cover in South Africa is dominated by woodland/savanna (30%) and grasslands (20%), with agricultural activities covering 7% of the national land area (DEA, 2014). Perennial crops contributes about 8% towards the total cropland area (DEA, 2014). Maize, soybean, wheat and sunflower were the main crops in the country in 2012.

All land-use categories were net emission sources globally, the largest being forestland (63%), followed by cropland (25%) and grasslands (11%) (FAOSTAT, 2014). However, land sector in South Africa is a net sink, which is dominated by the biomass carbon pool with small contributions from soils (DEA, 2014). Relevant carbon pools for cropland are biomass (above-ground biomass and below-ground biomass), dead organic matter (dead wood and litter) and soils (soil organic matter) (IPCC, 2006). Cropland and grazing land systems are managed in a variety of ways, resulting in varying degrees of GHG emissions or sinks (Ogle et al., 2014). For annual crops, an increase in biomass stocks in a single year is assumed to be equal to biomass losses from harvest and mortality in that same year – thus there is no net accumulation of biomass carbon stocks (IPCC, 2006). These are those associated with CO_2 following soil drainage due to the cultivation of organic soils for crop production (FAOSTAT, 2014). The amount of carbon stored in and emitted or removed from permanent cropland depends on crop type, management practices, and soil and climate variables (IPCC, 2006). Application of manure either as synthetic fertilizer or organic manure, tillage methods and crop residue management are some of the things that influence GHG emissions. Conservation tillage and zero-tillage are increasingly being adopted globally, thus reducing the use of energy and often increasing carbon storage in soils (IPCC, 2006).

3.2 Methodology

In this section, GHG emissions were calculated from manure amendments applied to soil. A detailed workflow is presented in Appendix G.

3.2.1 Development of soil map

The following nitrogen sources are included in the methodology for estimating direct N_2O emissions from managed soils (IPCC, 2006):

- Synthetic nitrogen fertilizers
- Organic nitrogen applied as a fertilizer (e.g. animal manure, compost, sewage sludge, rendering waste)
- Urine and dung nitrogen deposited on pasture, range and paddocks by grazing animals
- Nitrogen in crop residues (above ground and below ground), including from nitrogen-fixing crops and from forages during pasture renewal
- Nitrogen mineralisation associated with loss of soil organic matter resulting from change of land use or the management of mineral soils
- Drainage/management of organic soils

The IPPC (2006) provides a three-tiered methodology, which can be applied to calculate GHG emissions in agricultural soils at varying levels of detail and complexity. Tier 1, which is a basic approach that uses emission factors that are aggregated and represent global conditions, was used in this part of the inventory. The emission factors for Tier 1 refer to the amount of N_2O emitted from the various synthetic and organic nitrogen applications to soils, including crop residue and the mineralisation of soil organic carbon in mineral soils due to land-use management (IPCC, 2006). The level of detail and complexity increases with Tier 2 and Tier 3, where disaggregated local conditions should be used.

A geographic information system (GIS) soil map layer of South Africa was developed and imported into ALU. The soil classification was based on soil taxonomic description and textural data (IPCC, 2006). The soil information was derived from the 1:250 000-scale Land-type Survey of South Africa. This survey mapped over 7 000 unique land types, each of which has a specific combination of soil, terrain form and macroclimate. Within each land-type mapping unit, a number of different soil forms, as well as other land classes, such as rock, stream beds and pans, are recorded, and their percentage within the land type is used to allocate the land type to a specific broad soil pattern. The following soil type descriptions were used in the ALU:

a. Sandy mineral soils

Sandy mineral soils comprise all soils where the texture class is sandy (irrespective of taxonomy). These areas generally have either sandy parent materials, or have been subject to aeolian (wind-blown) deposition (such as the Kalahari sands of the Northern Cape).

Criteria: Land types where soils with an average topsoil clay content less than 8% comprise more than 40%.

b. Wetland mineral soils

This map unit comprises all land types where soils with wetland characteristics are dominant. Most land types will have wetland soils in the lower parts of the landscape, but only a few land types have these soils as dominant, mainly in the north-east of KwaZulu-Natal.

Criteria: Land types where Katspruit and Fernwood (series 30-42) soil forms, along with streambeds and pans, comprise more than 40%.

c. Organic soils

This map unit comprises all land types dominated by 'peat' soils. These soils typically occur in cool, often upland areas, so their distribution is limited to small zones in KwaZulu-Natal.

Criteria: Land types where champagne soil forms comprise more than 40%.

d. Spodic mineral soils

This map unit comprises all land types where podzols (where leaching of iron/aluminium and organic matter has occurred) predominate. These areas are restricted to small zones in the south and south-west of the Western Cape.

Criteria: Land types where Houwhoek and Lamotte soil forms comprise more than 30%.

e. Rocky areas

All Ib and Ic land types (rock outcrops more than 60%).

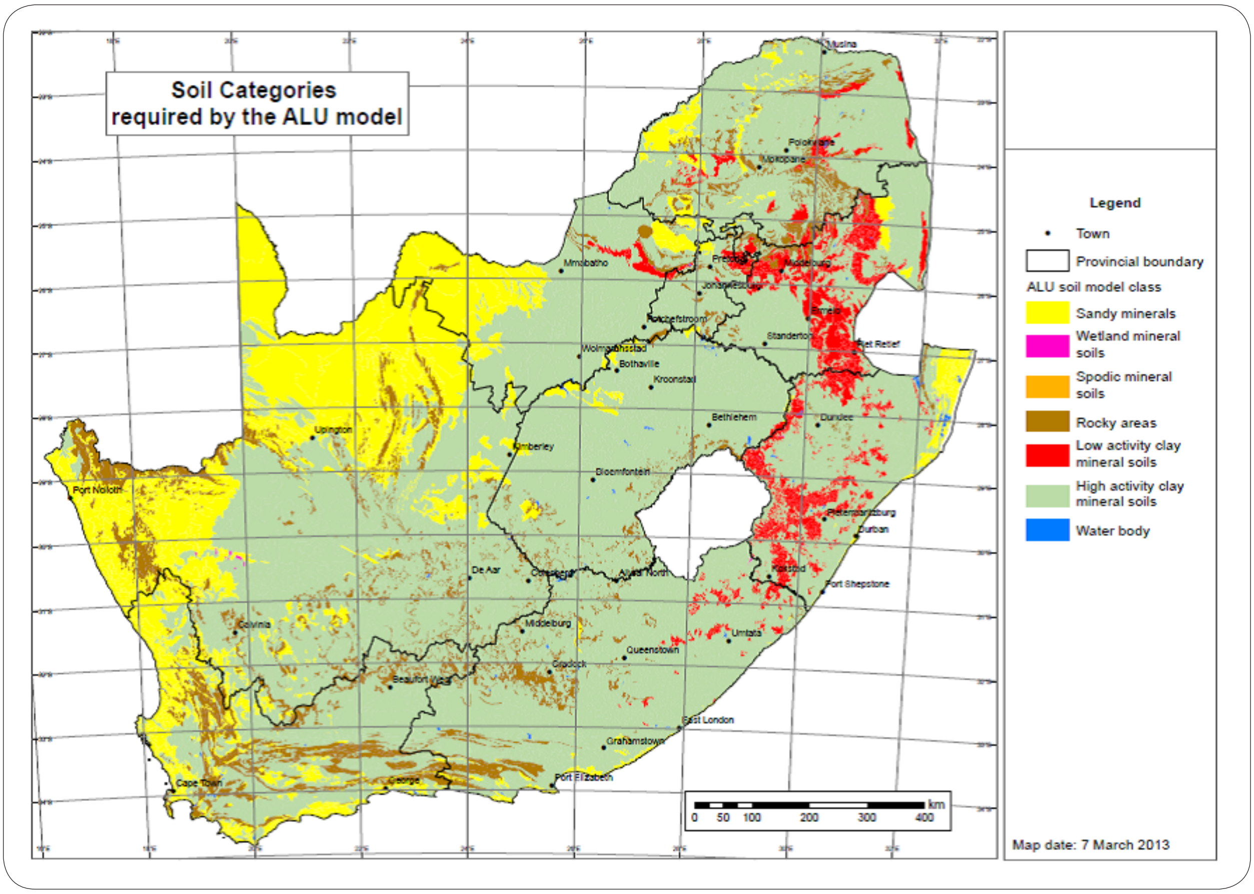
f. Low activity clay mineral soils

This map unit comprises all land types dominated by highly weathered, apedal (structureless) soils dominated by low activity (1:1) clay minerals such as kaolinite. Only soils where the base status is defined as part of the soil classification could be used, so it is very probable that the extent of such soils is larger than that shown on the map. These soils are found mainly in the warmer, higher rainfall areas, such as KwaZulu-Natal and Mpumalanga.

Criteria: Land types where Kranskop, Magwa, Inanda, Nomanci, Avalon (series 10–17), Glencoe (series 10–17), Pinedene (series 10–17), Griffin (10–13), Clovelly (series 10–18), Bainsvlei (series 10–17), Hutton (series 10–18) and Shortlands (all series) comprise more than 40%, and where average topsoil clay percentage is more than 8%.

g. High-activity clay mineral soils

This map unit comprises all land types dominated by



Firgure 7: Soil categories in South Africa that are required by ALU

lightly to moderately weathered soils, dominated by 2:1 silicate clay minerals, including vertisols, mollisols, calcareous soils, shallow soils and various others. This group covers most of South Africa.

Criteria: Land types not falling into one of the categories A to F, as defined aboved.

h. Volcanic mineral soils

This refers to soils derived from volcanic ash with allophanic mineralogy. However, such soils do not occur in South Africa, so no map unit could be identified.

Soil map

The above definitions were used to develop a soil map for South Africa, as shown in Figure 7.

3.2.2 Climate classification

Climate regions are based on mean annual temperatures and precipitation, elevation, the occurrence of frost, and potential evapotranspiration (IPCC, 2006). Climate classification was done using rainfall, temperature and evapotranspiration data obtained from the ARC and the South African Weather Service. The climate network, which had data from 1920 up to 2010, had more than 200 and 500 stations with temperature and rainfall records respectively.

3.2.2.1 Mean annual temperature

Long-term mean monthly temperature grids were made utilising temperature data per month. Regression analysis was used to relate available minimum/maximum temperature data averaged over the month to topographic indices, such as altitude, aspect, slope and distance to the sea. These relationships were used to model a temperature surface (1 x 1 km cells) from spatial topographic indices in ArcGIS 9.3. The actual monthly minimum/maximum temperature surface for South Africa gives an indication of the minimum/maximum temperatures in degrees centigrade, recorded for each grid cell. The inverse distance weight interpolation was used to interpolate the difference values between the stations and the resulting 'difference' surface was added to the long-term mean surface for the month. Mean annual temperature was then obtained from the mean monthly temperatures (mean of minimum and maximum temperature per month) for the entire year. All the grids were projected to geographic, datum and spheroid – WGS 84.

3.2.2.2 Annual precipitation

The stations used had minimum data records of 10 years. A trend surface was created from the monthly data. Regression analysis was used to relate the difference between station rainfall values and trend surface values for specific months to topographic indices like rain shadow and aspect. The relationships and the trend surfaces were used to model a rainfall satellite. Rainfall estimate data for 11 500 points throughout the country was downloaded from the African Data Dissemination Service, and was combined with rainfall data from stations. The interpolation method used assigns a rainfall value to a specific point based on the measured rainfall at the five closest rainfall stations, and the satellite rainfall estimate at the point relative to the satellite rainfall estimates at the closest stations. New combined estimate values are interpolated through the inverse distance weight method. These monthly mean surfaces were then totalled to produce a mean annual rainfall grid. The grids were also projected to geographic, datum and spheroid – WGS 84.

3.2.2.3 Evapotranspiration

Evapotranspiration was calculated using the Hargreaves and Samani equation (Equation 3) (Hargreaves & Samani, 1985). This empirical formula resembles the Penman Monteith approach, which is highly recommended all over the world in calculating potential evapotranspiration, but it is less data intensive. The Hargreaves and Samani approach is very important in regions where solar radiation, air humidity and wind speed data are lacking or are of low or questionable quality, but the maximum and minimum air temperatures are available (Raziei & Pereira, 2013). This approach correlates adequately with the Penman Monteith method in some parts of South Africa (i.e. the Free State) in summer, but its application in winter is limited (Moeletsi, Walker & Hamandawana, 2013).

Equation 3

$$ET_H = 0.408*0.0023*(T_{av} + 17.8)*(T_{max} - T_{min})^{0.5}*Ra$$

3.2.2.4 Climate zones

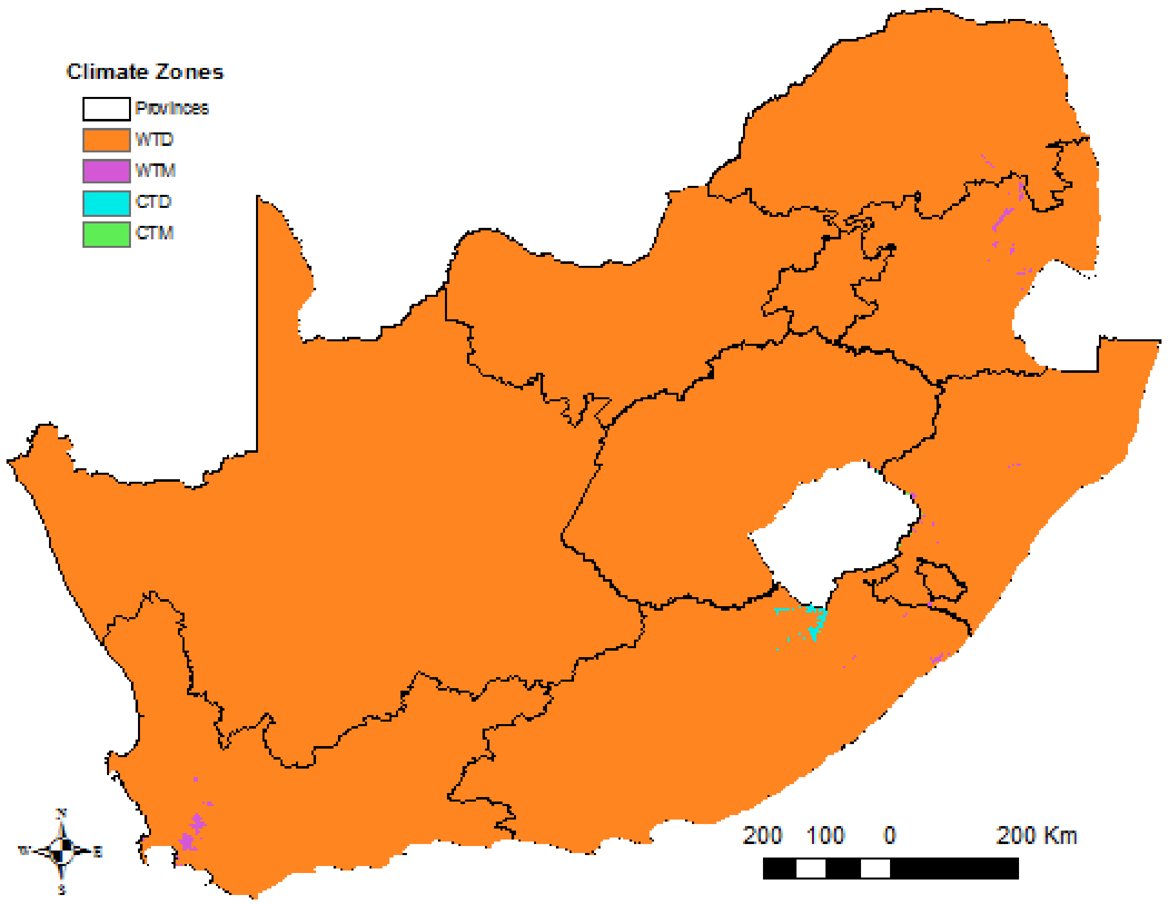
The calculated mean temperature, rainfall and evapotranspiration were reclassified according to the requirements of the IPCC Guidelines (Table 14). These climate surfaces were then overlaid using Raster Calculator in ARC-GIS, resulting in a climate zone map (Figure 8).

3.2.3 *Nitrous oxide emissions from managed soils*

Data for the total amount of synthetic nitrogen fertilizer and urea used in agricultural soils in 2012 was obtained from the Fertilizer Society of South Africa (FSSA) and the FAOSTAT database. The total generic synthetic nitrogen fertilizer amount applied to soil was 430 000 tons in 2012. Default emission factors were obtained from the IPCC (2006).

Table 12: Climate zones required by ALU for updating the land-use GHG Inventory

Climate name	Acronym	Description
Boreal dry	BOD	Mean annual temperature < 0 °C and annual precipitation < evapotranspiration
Boreal moist	BOM	Mean annual temperature < 0 °C and annual precipitation ≥ evapotranspiration
Cool temperate dry	CTD	Mean annual temperature < 10 °C and annual precipitation < evapotranspiration
Cool temperate moist	CTM	Mean annual temperature < 10 °C and annual precipitation ≥ evapotranspiration
Polar dry	POD	Polar regions, little precipitation
Polar moist	POM	Polar regions, significant precipitation
Tropical dry	TRD	Tropical region; elevation < 1 000 m; precipitation < 1 000 mm
Tropical moist, long dry season	TMLD	Tropical region; elevation < 1 000 m; annual precipitation ≥ 1 000 mm and annual precipitation < 2 000 mm; dry season > 5 months
Tropical moist, short dry season	TMSD	Tropical region; elevation < 1 000 m; annual precipitation ≥ 1 000 mm and annual precipitation < 2 000 mm; dry season ≤ 5 months
Tropical montane dry	TRMD	Tropical region; elevation ≥ 1 000 m; annual precipitation < 1 000 mm
Tropical montane moist	TRMM	Tropical region; elevation ≥ 1 000 m; annual precipitation ≥ 1 000 mm
Tropical wet	TRW	Tropical region; elevation < 1 000 m; annual precipitation ≥ 2 000 mm
Warm temperate dry	WTD	Mean annual growing season temperatures in this zone usually range from 10 to 20 °C and with annual precipitation ≤ potential evapotranspiration
Warm temperate moist	WTM	Mean annual growing season temperatures range from 10 to 20 °C and with annual precipitation ≥ potential evapotranspiration



Firgure 8: ALU climate zones for South Africa based on long-term climate data

3.2.4 *Carbon dioxide emissions from the application of lime*

Data on lime applied to agricultural soil in the country was not available and had to be estimated from the area planted and average lime application rate and frequency (Table 13). Data on lime application rate and frequency per crop type was based on the results of the survey conducted on farms around the country. Annual equivalent amount of lime applied was estimated to be a product of area harvested and lime application rate divided by frequency of application. Fractions of dolomite (63%) and limestone (37%) were worked out from the total based on Otter et al. (2010). The amount of lime calculated in this study exceeded the 1 155 380 tons reported by the DEA (2014), but it can make a good comparable increment of the reported historical data. Consumption of limestone and lime for agricultural purposes increased from about 40 000 tons in 1950 to 800 000 tons per year in the late 1960s (Douglas, 1969). These values could have steadily increased due to the expansion of agricultural production and advancements in farming approaches. The carbon emission factors were 0.13 ton C/ton for dolomite and 0.12 ton C/ton for limestone (IPCC, 2006).

Table 13: Emission factors for direct and indirect N_2O emissions from synthetic nitrogen fertilizer

	Synthetic nitrogen fertilizer	Urea
	kg N_2O-N/kg N	
Direct	0.01	0.01
Indirect emissions		
Deposited (volatilised)	0.01	0.01
Leaching/runoff	0.007	0.007

3.2.5 Nitrous oxide and carbon dioxide emissions from urea application

Adding urea to soils during fertilization leads to a loss of CO_2 that was fixed in the industrial production process (IPCC, 2006). CO_2 emissions from urea fertilization were estimated using the Tier 1 approach of the IPCC (2006). The IPCC default emission factor of 0.2 was used, and the conversion from carbon emissions to CO_2 was done through multiplication of the right-hand side of Equation 4 by 44/12. N_2O emissions from urea application to agricultural soils was done in ALU. The default emission factor for N_2O was 0.01 kg N_2O-N/kg N. The amount of urea (0.757 tons) applied to agricultural soils in 2012 was obtained from the FAOSTAT Database.

Equation 4

$$CO_2\text{-}C\ Emission = M \cdot EF$$

Where:

CO_2-C emission = annual C emissions from urea application, tonnes C yr^{-1};

M = annual amount of urea fertilization, tonnes urea $year^{-1}$;

EF = emission factor, tonne of C $(tonne\ of\ urea)^{-1}$

3.2.6 Nitrous oxide emissions from application of sewage sludge

Data on volumes of sewage sludge used on agricultural soils in South Africa was not available. Therefore, GHG emissions from the application of sewage sludge to agricultural soils were assumed to be equal to those of 2004 as explained and reported by Otter et al. (2010).

3.2.7 Nitrous oxide emissions from crop residue management

GHG emissions from cropland were calculated using the ALU software developed by the Natural Resource Ecology Laboratory at Colorado State University, USA. For proper calculations of cropland GHG emissions, cropland must be classified according to climate regions and major soil types (IPCC, 2006). Activity data needed to calculate emissions from cropland, consisting of remaining cropland, summarised by major cropland types and management practices (IPCC, 2006). This condition is well represented in ALU. The Tier 1 approach was used to calculate cropland GHG emissions. This approach multiplies the area of each cropland type by a net estimate of biomass accumulation from growth and subtracts losses associated with harvest, gathering or disturbance (IPCC, 2006).

The area planted and crop production statistics for major crops (maize, sorghum, wheat, canola, sunflower, soybeans, groundnut and barley) in 2012 were obtained

Table 14: Estimated lime applied to agricultural soils in South Africa

Crop type	Area planted	Lime application rate	Applied after	Lime amount
	(ha)	(ton/ha)	(years)	(ton)
Maize[1]	2 699 200	2.0	4	1 428 148
Wheat[1]	511 200	1.9	3	328 135
Sunflower[1]	453 350	1.7	3	226 675
Sorghum[1]	48 550	2.3	2	72 825
Groundnuts[1]	45 450	2.0	5	19 137
Canola[1]	44 100	1.4	3	21 919
Barley[1]	85 000	3.0	4	72 857
Soybeans[1]	472 000	2.7	3	489 677
Dry beans[1]	42 800	2.4	4	26 108
Cotton[1]	8 600	2.0	2	7 382
Rooibos	36 000	1.0	8	4 500
Lucerne[2]	167 644	3.2	6	94 410
Macadamia[2]	40 000	1.7	2	36 667
Oats[3]	26 000	1.6	2	17 625
Sugarcane[3]	320 000	3.3	3	419 840
Pumpkins squash[3]	13 000	1.8	3	8 039
Potatoes[3]	65 000	2.4	3	47 727
Tomatoe[3]	7 500	3.0	3	6 667
Carrots[z]	6 250	1.8	3	3 729
Cabbage[3]	2 200	2.3	3	1 492
Onions[3]	27 500	2.3	4	17 679

Table 14 continued...

Crop type	Area planted	Lime application rate	Applied after	Lime amount
	(ha)	(ton/ha)	(years)	(ton)
Grapes[3]	134 500	2.2	4	80 589
Tobacco[3]	5 139	2.0	3	3 426
Orange[3]	45 000	1.4	2	26 250
Pineapple[3]	7 500	2.5	4	4 594
Sweet potatoes[3]	18 500	1.8	3	11 038
Apples[3]	22 900	2.0	3	17 821
Pears[3]	13 000	2.0	2	15 663
Bananas[3]	7 600	2.0	3	6 080
Mango[3]	3 520	2.5	4	2 200
Other citrus (lemons etc.)[3]	12 500	1.0	1	9 277
Peaches[3]	10 200	2.0	1	20 400
Rye[3]	3 650	2.4	3	3 021
Total				**3 551 597**
Dolomite				2 237 506
Limestone				1 314 091

[1] Harvested area obtained from DAFF
[2] Harvested area obtained from Statistics South Africa (2007)
[3] Harvested area obtained from FAOSTAT Database

from DAFF. Similar data for the base year was not available for other crops, and 2007 data from Statistics South Africa was used, assuming that the situation remained the same in 2012. Crop residue to crop ratios for some crops were obtained from the IPCC (2006), while other fractions were obtained from Scarlat, Martinov and Dallemand (2010), Jain, Tao, Yang and Gillespie (2014) and Jiang, Zhuang, Fu, Huang and Wen (2012). Data for residue management in percentages for different crops in the country were obtained by farmers completing guided questionnaires. The direct emission factor for crop residue, dry matter fraction of residue, carbon fraction, and nitrogen to carbon ratio factors were obtained from the IPCC (2006).

Crop yields for various crops (Table 15) were calculated from Abstracts of agriculture (DAFF, 2013a). Residue to yield ratios were obtained from the IPCC (2006), Scarlet et al. (2010), Jaing et al. (2012; 2014). There was generally a reasonable agreement between the harvested area estimated by ALU and the official statistics. Statistics, especially of major crops, are based on commercial production only, which is a cause of uncertainty in the data. Another cause of uncertainty in the data is the irregular collection of agricultural statistics, where a comprehensive census was only done more than a decade ago (Statistics South Africa, 2007).

3.3 Results and discussion

3.3.1 Greenhouse gas emissions from managed soils

GHG emissions from managed soils in South Africa made up 14 006.52 Gg CO_{2e} in 2012. These total emissions are low when compared with the 2010 values calculated by DEA (2014). The majority of these emissions are from urine and dung deposited by animals on the pasture, range and paddocks, followed by the application of synthetic nitrogen fertilizer on soils (Figure 9). These emissions are consistent with the observation that agricultural GHG emissions from South Africa and Africa as a whole are dominated by grazing livestock (Hickman, Havlikova, Kroeze & Palm, 2011). This is because the majority of animals in South Africa spend most or part of their lives on pastures and rangelands (DEA, 2014). The application of sewage sludge to soils contributes least to the emissions from managed soils.

3.3.2 Nitrous oxide emissions from application of manure on pasture, range and paddock

Nitrous oxide from grazing animals made up 9 206.36 Gg of CO_{2e} in 2012 through urine and dung deposited in the pasture, range and paddocks. Direct emissions accounted for 83% of these emissions, and the other fraction was

Table 15: Harvested crop area, yield residue to yield ratio and total residue for 2012

Crop	Harvested area (ha)		Applied after	Lime amount	Residue: yield
	ALU	*National statistics	(ton/ha)	(ton)	Ratio
Barley	102 660	85 000	3.5	360 337	1.2
Beans, dry	63 773	42 800	1.2	76 528	2.1
Cabbage	14 900	2 200	40.5	603 152	0.4
Cotton	27 278	8 600	3.3	89 199	3
General vegetable	55 068	31 500	27.2	1 427 856	0.4
Ground nut	77 386	85 450	1.3	100 602	2
Hay	303 116	315 144	3	909 348	1.6
Legumes	9 642	2 855	1.1	10 703	2
Maize	4 565 814	2 699 200	4.2	19 267 730	1.5
Onion	14 348	27 500	31	445 075	2
Other field crops	17 463	310 693	53.9	941 081	1
Other fodder	332 284	206 355	3.7	1 226 128	1.5
Other oil seeds	37 572	20 893	1.2	46 214	2.5
Other summer cereal	41 745	14 092	2.5	103 110	1.5
Other winter cereal	163 276	67 120	1.8	285 733	1.5
Potatoes	96 214	65 000	30.3	2 918 171	0.4
Sorghum	146 768	48 550	2.8	409 483	1.4
Soybeans	200 516	472 000	1.4	276 712	2.1
Sugar cane	305 380	320 000	61.1	18 661 770	0.3
Sunflower	460 122	453 350	1.2	529 140	2.5
Tobacco	29 522	5 139	2.6	75 281	0.4
Tomatoes	18 082	7 500	37.9	685 669	2
Wheat	1 059 443	511 200	3.7	3 877 562	1.3
*Data source: Abstracts of Agriculture (2013); Statistics South Africa (2007)					

Table 16: Crop factors used to calculate N_2O emissions from crop residue management

Crop	DMF	CF	N-C ratio	CR N
	(ton dm/ton residue)	(ton C/ton dm)	(ton N/ton C)	(ton)
Barley	0.89	0.5	0.015	520
Beans, dry	0.91	0.5	0.015	461
Cabbage	0.14	0.5	0.015	218
Cotton	0.8	0.5	0.015	1 606
General vegetable	0.18	0.5	0.015	509
Ground nut	0.8	0.5	0.015	1 207
Hay	0.88	0.5	0.015	1 248
Legumes	0.9	0.5	0.015	40
Maize	0.87	0.5	0.015	90 520
Onion	0.14	0.5	0.015	935
Other field crops	0.8	0.5	0.015	462
Other fodder	0.8	0.5	0.015	1 435
Other oil seeds	0.9	0.5	0.015	224
Other summer cereal	0.88	0.5	0.015	816
Other vegetables	0.18	0.5	0.015	183
Other winter cereal	0.8	0.5	0.015	950
Potatoes	0.22	0.5	0.015	1 926
Sorghum	0.89	0.5	0.015	459
Soybeans	0.91	0.5	0.015	1 428
Sugar cane	0.88	0.5	0.015	11 393
Sunflower	0.88	0.5	0.015	4 103
Tobacco	0.8	0.5	0.015	181
Tomatoes	0.2	0.5	0.015	1 646
Wheat	0.89	0.5	0.015	16 151
Total				**138 619**

CR: Crop residue N; CF: Carbon fraction; N-C: Nitrogen-carbon; DMF: Dry matter fraction from two forms of indirect emissions. Emissions from dairy cattle obtained in this study make up about a half of the results of Du Toit et al. (2013a) for 2010.

3.3.2.1 Direct N_2O from pasture, range and paddocks

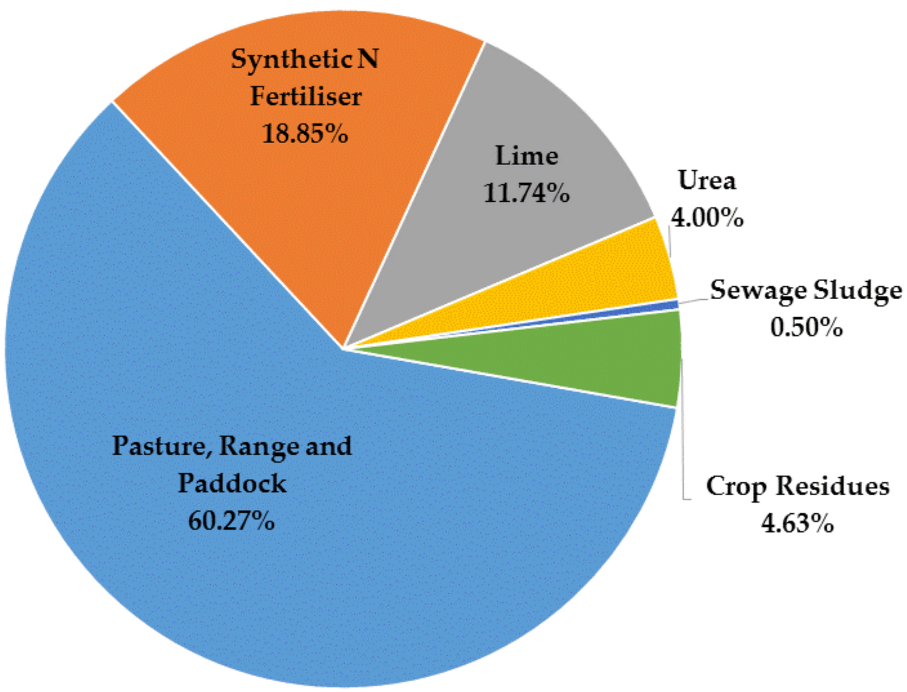
Direct CO_{2e} emissions from animal manure left in the pasture, range and paddocks make up 7 640.06 Gg (Table 18). Sheep contribute the largest emissions, followed by nearly equal amounts from goats and cattle. Disaggregated beef cattle accounts for 69% of the total cattle emissions. The fraction of the contribution of direct N_2O emissions from the deposition of animal urine and dung in the pasture, range and paddocks to the total direct N_2O emissions from managed soils is 74%, which is similar to the 2004 value reported by Otter et al. (2010). Crop residue is the second-largest contributor of direct N_2O emissions on managed lands (19%).

3.3.2.2 Indirect N_2O emissions from pasture range and paddocks

Indirect N_2O emissions from pasture, range and paddocks make up 1 566.30 Gg of CO_{2e} (Table 19). The contributions of the emissions due to deposition and leaching/runoff are nearly equal. Sheep account for the largest subcategory contribution, while mature beef cows are the largest emitters from the cattle category.

3.3.3 *N_2O emissions from synthetic nitrogen fertilizer*

Application of synthetic nitrogen fertilizer to agricultural soil makes up 2 640.28 Gg of CO_2e emissions (Table 20). Direct emissions account for 76% of the total emissions from synthetic nitrogen fertilizer. The direct emissions are similar to the 2004 values as a result of nearly equal amounts of synthetic nitrogen fertilizer used during these years.



Firgure 9: Breakdown of CO_2e from managed soils in 2012

Table 17: Crop residue management in 2012

Crop	Total residues	Residue retained	Amount retained	Residue burnt	Amount burnt	Residue grazed	Amount grazed	Residue collected	Amount collected
	(ton)	(%)	(ton)	(%)	(ton)	(%)	(ton)	(%)	(ton)
Barley	432 404	18	77 833	20	86 481	26	112 425	36	155 665
Beans, dry	160 708	42	67 497	0	0	52	83 568	6	9 642
Cabbage	241 261	86	207 484	0	0	12	28 951	2	4 825
Cotton	267 597	100	267 597	0	0	0	0	0	0
General vegetable	571 142	66	376 954	0	0	28	159 920	6	34 269
Ground nut	201 204	100	201 204	0	0	0	0	0	0
Hay	1 454 957	13	189 144	0	0	51	742 028	36	523 785
Legumes	21 405	28	5 976	0	0	33	7 145	39	8 284
Maize	28 901 600	48	13 872 770	2	578 032	48	13 872 770	2	578 032
Onion	890 150	100	890 150	0	0	0	0	0	0
Other field crops	941 081	8	77 075	0	0	24	228 589	68	635 512
Other fodder	1 839 192	13	239 095	0	0	51	937 988	36	662 109
Other oil seeds	115 534	29	33 158	0	0	35	40 911	36	41 465
Other summer cereal	154 665	80	123 670	0	0	20	30 995	0	0
Other vegetables	135 583	100	135 583	0	0	0	0	0	0
Other winter cereal	428 600	37	158 282	0	0	55	235 730	8	34 588
Potatoes	1 167 268	100	1 167 268	0	0	0	0	0	0
Sorghum	573 276	12	68 793	0	0	88	504 483	0	0
Soybeans	581 095	36	209 194	8	46 488	36	209 194	20	116 219
Sugar cane	4 665 443	37	1 726 214	16	746 471	5	233 272	42	1 959 486
Sunflower	1 322 851	47	621 740	0	0	38	502 683	15	198 428
Tobacco	30 112	100	30 112	0	0	0	0	0	0
Tomatoes	1 371 339	80	1 097 071	1	13 713	18	246 841	1	13 713
Wheat	5 040 830	48	2 419 598	1	50 408	34	1 713 882	17	856 941

Table 18: Direct N_2O emissions from pasture, range and paddocks

Population	Livestock	Nm	Emission factor	N_2O	CO_2e
Name	**Subcategory**	**(ton)**	**(kg N_2O-N/ kg N)**	**(ton)**	**(Gg)**
Mixed – lactating cows	Mature females	11 160	0.02	351	104.52
PAS – lactating cows	Mature females	6 696	0.02	210	62.71
Goats	N/A	245 673	0.02	7 721	2 300.90
Horses	N/A	12 320	0.02	387	115.39
Mules and asses	N/A	6 680	0.02	210	62.56
Beef – calves	Young females – Age 0–1	13 121	0.02	412	122.89
Beef – calves	Young intact males – Age 0–1	13 121	0.02	412	122.89
Beef – heifer	Young females – Age 1–2	16 416	0.02	516	153.75
Beef – mature bulls	Mature bulls	6 080	0.02	191	56.94
Beef – mature female	Mature females	91 960	0.02	2 890	861.27
Beef – mature oxen	Mature male castrates	9 120	0.02	287	85.42
Beef – young bulls	Young intact males – Age 1–2	14 111	0.02	443	132.16
Beef – young oxen	Young male castrates – Age 1–2	4 585	0.02	144	42.94
Dairy – calves	Young females – Age 0–1	1 984	0.02	62	18.58
Dairy – calves	Young intact males – Age 0–1	1 984	0.02	62	18.58
Dairy – heifer	Young females – Age 1–2	7 068	0.02	222	0.4
Dairy – mature bulls	Mature bulls	221	0.02	7	66.20
Subsistence – calves	Young females – Age 0–1	3 236	0.02	102	2.07
Subsistence – calves	Young intact males – Age 0–1	3 236	0.02	102	30.31
Subsistence – heifer	Young females – Age 1–2	6 506	0.02	204	30.31
Subsistence – mature bulls	Mature bulls	1 818	0.02	57	17.03
Subsistence – mature female	Mature females	31 213	0.02	981	292.33
Subsistence – mature oxen	Mature male castrates	566	0.02	18	5.30
Subsistence – young bulls	Young intact males – Age 1–2	768	0.02	24	7.19
Subsistence – young oxen	Young male castrates – Age 1–2	249	0.02	8	2.33
Sheep	N/A	305 857	0.02	9 613	2 864.57
Total		**815 748**		**25 638**	**7 640.06**

Table 19: Indirect CO_2e emissions from pasture, range and paddock

Population name	Livestock	Nm	Deposition			Leaching/Runoff		
			FNv	EFv	CO_2e	FNlr	EFlr	CO_2e
	subcategory	(ton)			(Gg)			(Gg)
Mixed – lactating cows	Mature females	11 160	0.2	0.01	10.45	0.3	0.007	10.97
PAS – lactating cows	Mature females	6 696	0.2	0.01	6.27	0.3	0.007	6.58
Goats	N/A	245 673	0.2	0.01	230.09	0.3	0.007	241.59
Horses	N/A	12 320	0.2	0.01	11.54	0.3	0.007	12.12
Mules and asses	N/A	6 680	0.2	0.01	6.26	0.3	0.007	6.57
Beef – calves	Young females – Age 0–1	13 121	0.2	0.01	12.29	0.3	0.007	12.90
Beef – calves	Young intact males – Age 0–1	13 121	0.2	0.01	12.29	0.3	0.007	12.90
Beef – heifer	Young females – Age 1–2	16 416	0.2	0.01	15.37	0.3	0.007	16.14
Beef – mature bulls	Mature bulls	6 080	0.2	0.01	5.69	0.3	0.007	5.98
Beef – mature female	Mature females	91 960	0.2	0.01	86.13	0.3	0.007	90.43
Beef – mature oxen	Mature male castrates	9 120	0.2	0.01	8.54	0.3	0.007	8.97
Beef – young bulls	Young intact males – Age 1–2	14 111	0.2	0.01	13.22	0.3	0.007	13.88
Beef – young oxen	Young male castrates – Age 1–2	4 585	0.2	0.01	4.29	0.3	0.007	4.51
Dairy – calves	Young females – Age 0–1	1 984	0.2	0.01	1.86	0.3	0.007	1.95
Dairy – calves	Young intact males – Age 0–1	1 984	0.2	0.01	1.86	0.3	0.007	1.95
Dairy-Heifer	Young females – Age 1–2	7 068	0.2	0.01	6.62	0.3	0.007	6.95

Table 19 continued...

			Deposition			Leaching/Runoff		
Population name	**Livestock**	**Nm**	**FNv**	**EFv**	**CO_2e**	**FNlr**	**EFlr**	**CO_2e**
	subcategory	(ton)			(Gg)			(Gg)
Dairy – mature bulls	Mature bulls	221	0.2	0.01	0.21	0.3	0.007	0.22
Dairy – young bulls	Young intact males – Age 1–2	42	0.2	0.01	0.04	0.3	0.007	0.04
Subsistence – calves	Young females – Age 0–1	3 236	0.2	0.01	3.03	0.3	0.007	3.18
Subsistence – calves	Young intact males – Age 0–1	3 236	0.2	0.01	3.03	0.3	0.007	3.18
Subsistence – heifer	Young females – Age 1–2	6 506	0.2	0.01	6.09	0.3	0.007	6.40
Subsistence – mature bulls	Mature bulls	1 818	0.2	0.01	1.70	0.3	0.007	1.79
Subsistence – mature female	Mature females	31 213	0.2	0.01	29.23	0.3	0.007	30.69
Subsistence – mature oxen	Mature male castrates	566	0.2	0.01	0.53	0.3	0.007	0.56
Subsistence – young bulls	Young intact males – Age 1–2	768	0.2	0.01	0.72	0.3	0.007	0.75
Subsistence – young oxen	Young male castrates – Age 1–2	249	0.2	0.01	0.23	0.3	0.007	0.25
Sheep	N/A	305 857	0.2	0.01	286.46	0.3	0.007	300.78
Total		**815 790**			**764.05**			**802.25**

CO_2e emissions less than unity (1) are not shown in the table
FNv: Fraction of manure nitrogen volatised
EFv: Emission factor for manure nitrogen volatised
FNLr: Fraction of manure nitrogen leaching/runoff
EFLr: Emission factor for manure nitrogen leaching/runoff
L&R: Leaching/runoff
Dep: Deposited

3.3.4 Carbon dioxide emissions from lime application

Lime application to agricultural soils emitted a total of 1 644 Gg of CO_2 (Table 21). Dolomitic lime contributes 65% of these emissions. Even though emissions from lime are highly inconsistent with time (DEA, 2014), the values for 2012 are large and exceed the variability observed in previous inventories. The 2012 emissions are about three times the values for 2010, primarily due to the approach used to estimate agricultural lime. However, the overall emissions can still be expected to be larger than the current value if activity data for all crops (including managed forests) were available when estimating the lime.

3.3.5 Emissions from application of urea

GHG emissions from urea application to agricultural soils in 2012 made a combined contribution of 559.78 Gg of CO_{2e} (Table 22). These emissions are primarily CO_2, as N_2O contributed small amounts. The majority (75%) of the N_2O emissions are from the direct application of urea.

3.3.6 Nitrous oxide emissions from sewage sludge application

N2O emissions from the application of sewage sludge to agricultural soils contributed 70.03 Gg CO_{2e} (Table 23). Two thirds of these emissions are from direct nitrogen emissions, and a third from indirect emissions.

3.3.7. Crop residue N_2O emissions

Residues retained in croplands emitted a total of 649.13 Gg CO_2e (Table 24) in 2012. Residues from cereal crops are the main sources of emissions, while vegetables and other field crops contributed the least. The largest contributions of these emissions were from maize, residues retained and ploughed back into the soil accounted for 65% of the emissions.

Table 20: CO_2e emissions from application of synthetic nitrogen fertilizer

	N_2O (Gg)	CO_2e (Gg)
Direct N_2O	6.76	2 014.48
Indirect N_2O		
Atmospheric nitrogen deposition	0.68	202.64
Leaching/runoff	1.42	423.16
Total	**8.86**	**2 640.28**

Table 21: CO_2 emissions from application of lime to agricultural soils in 2012 in South Africa

Lime type	Carbon emissions (ton)	CO_2 emissions (Gg)
Dolomite	290 876	1 066
Limestone	157 691	578
Total	**448 567**	**1 644**

Table 22: GHG emissions from the application of urea into agricultural soils

	N_2O (Gg)	CO_2e (Gg)
CO_2		**555.01**
Direct N_2O	0.012	3.58
Indirect N_2O		
Atmospheric nitrogen deposition	0.001	0.30
Leaching/runoff	0.003	0.89
Total	**0.016**	**559.78**

Table 23: N_2O emissions from the application of sewage sludge on agricultural soil

	SS	EF	FNv	EFv	FNlr	EFlr	N_2O	CO_2e
	(Gg N)	(kg N_2O-N/ kg N)	(kg Nv/kg N)	(kg N_2O-N/ kg Nv)	(kg Nlr/kg N)	(kg N_2O-N/ kg Nlr)	(ton)	(Gg)
Direct nitrogen	10.62	0.01					167	49.77
Indirect nitrogen								9.83
Deposited nitrogen	10.62		0.2	0.01			33	9.83
Leaching/ runoff	10.62				0.3	0.007	35	10.43
Total	**0.016**						**235**	**70.03**

SS: Sewage sludge nitrogen
EF: Direct emission factor
FNv: Fraction of sewage volatilised nitrogen
EFv: Indirect emission factor for nitrogen volatilised
FNlr: Fraction of sewage nitrogen leaching/runoff
EFlr: Indirect emission factor for nitrogen leaching/runoff

Table 24: N_2O emissions from crop residue management

Crop	Crop residue N	EF	N_2O	CO_2e
	(ton)	(kg N_2O-N/kg N)	(ton)	Gg
Barley	520	0.01	8	2.43
Beans, dry	461	0.01	7	2.16
Cabbage	218	0.01	3	1.02
Cotton	1 606	0.01	25	7.52
General vegetable	509	0.01	8	2.38
Ground nut	1 207	0.01	19	5.65
Hay	1 248	0.01	20	5.85
Legumes	40	0.01	1	0.19
Maize	90 520	0.01	1 422	423.89
Onion	935	0.01	15	4.38
Other field crops	462	0.01	7	2.17
Other fodder	1 435	0.01	23	6.72
Other oil seeds	224	0.01	4	1.05
Other summer cereal	816	0.01	13	3.82
Other vegetables	183	0.01	3	0.86
Other winter cereal	950	0.01	15	4.45
Potatoes	1 926	0.01	30	9.02
Sorghum	459	0.01	7	2.15
Soybeans	1 428	0.01	22	6.69
Sugar cane	11 393	0.01	179	53.35
Sunflower	4 103	0.01	64	19.22
Tobacco	181	0.01	3	0.85
Tomatoes	1 646	0.01	26	7.71
Wheat	16 151	0.01	254	75.63
Total	**138 619**		**2 178**	**649.13**

3.4 Uncertainty analysis

Uncertainties associated with emissions of N_2O from managed soils are high (Table 25). These results are due to high uncertainty levels of the emission factors and activity data. Uncertainty levels of the IPCC default emission factors were used in this inventory. These high uncertainty levels are consistent with the results of Del Grosso, Ogle, Parton and Breidt (2010) and Monni, Perala and Regina (2007). High uncertainty of the emissions are due to both large natural variability and lack of knowledge of emission-generating processes (Monni et al., 2007). Uptake of N_2O in agricultural soils is difficult to quantify due to constraints such as instrumental precision and methodological uncertainties (Cowan, Famulari, Levy, Anderson, Reay & Skiba, 2014). The contribution of agriculture to the uncertainty of total GHG emissions can be more than 20%, and it is significantly affected by N_2O from agricultural soils (Monni et al., 2007).

3.5 Quality control and quality assurance

The amount of fertilizer that was obtained from FSSA was checked against other datasets, including the FAOSTAT Database, and they were found to be similar. Data on lime that was calculated was compared against historical values that were published in other national reports, and there was generally a significant difference. Data on manure management that was obtained from the survey was compared with limited available information from the literature, and expert opinions within ARC were sought.

Cropland management data that was collected from the farmers was compared against average practices and values according to the literature to remove outliers. The data collection team checked the quality of the cropland areas and other management practices by crop type against various statistics, including official reports, published data and expert judgments where information was lacking. Data quality was also checked by other experts at the ARC.

3.6 Planned improvements

Organic and inorganic soil amendments contribute large amounts of GHG emissions. Their effect on emissions is influenced by farm management systems. This inventory exercise demonstrated that ALU is a software that can incorporate various aspects of soil emissions. However, data on the farm management systems in the country is limited. This needs to be improved. Research efforts are therefore needed to generate appropriate information on soil management in the country.

GHG emissions from remaining cropland are demonstrated in this inventory to be from major cereal crops. It would therefore be important to do key source analysis for major crops and to determine their trend emissions. However, this will require improved and sustainable information on their farm management. This can be attained if periodic collection of national agricultural statistics can include data on farm management, especially for the main crops in the country.

Table 25: Uncertainties associated with GHG emissions on managed soils

Description	Lower uncertainty (percentage)	Upper uncertainty (percentage)	Emissions uncertainty (percentage)
Crop residues management			**112.72**
Emission factor (direct)	80	200	
Dry matter fraction	12.5 – 50	12.3 – 50	
Carbon fraction	50	50	
Nitrogen-carbon ratio	33.3	33.3	
Manure nitrogen amendments			**46.47**
Emission factor (direct)	70	200	
Emission factor (indirect – volatised)	100	100	
Emission factor (indirect – leaching/runoff)	93.3	233.3	
Fraction of manure nitrogen volatised	50	50	
Fraction of manure nitrogen leaching/runoff	50	50	
Manure in pasture, range and paddock			**43.89**
Emission fraction (direct)	50	100	
Emission factor (indirect – volatised)	100	100	
Emission factor (indirect – leaching/runoff)	93.3	233.3	
Fraction of manure nitrogen volatised	50	50	
Fraction of manure nitrogen leaching/runoff	50	50	
Sewage sludge			
Emission factor (direct)	70	200	**102.74**
Emission factor (indirect – volatised)	100	100	
Emission factor (indirect – leaching/runoff)	93.3	233.3	
Fraction of manure nitrogen volatised	50	50	
Fraction of manure nitrogen leaching/runoff	50	50	

Table 25 continued...

Description	Lower uncertainty (percentage)	Upper uncertainty (percentage)	Emissions uncertainty (percentage)
Synthetic nitrogen fertilizer and urea			**106.97**
Emission factor (direct)	70	200	
Emission factor (indirect – volatised)	100	100	
Emission factor (indirect – leaching/runoff)	93.3	233.3	
Fraction of manure nitrogen volatised	50	50	
Fraction of manure nitrogen leaching/runoff	50	50	

4. BIOMASS BURNING

4.1 Background

Projected changes within the SADC region into the future are variable, as a result of the different climatic forces controlling the weather patterns. In terms of temperature, the changes are less distinct, with an overall warming projected, regardless of the region indicated in the figure below. Overall temperatures in the western regions of SADC are projected to increase more than those in the east.

Climatically there are distinct regions within SADC with particular climate forcing. The northern regions of SADC, which include the Congo basin and Zambezi valley, are impacted by the movement of the ITCZ (Figure 15). This is especially the case for the Zambezi valley. Drought-prone areas of Namibia, Botswana, and Zimbabwe are likely to be more vulnerable than the more humid areas of Tanzania or Zambia.

The IPCC Fourth Assessment Report (IPCC 2007) indicates that land surface warming in southern Africa is likely to exceed the global mean land surface temperature increase in all seasons. As indicated in Figure 16 below, high warming rates are projected over the semi-arid south-western parts of the subregion covering north-western South Africa, Botswana and Namibia in particular(IPCC 2014). Projections show that changes will not be uniform over the region with the central, southern land mass of SADC, extending over Botswana, parts of north-western South Africa, Namibia and Zimbabwe being likely to experience the greatest warming of 0.2 °C to 0.5 °C per decade. In this area, the frequency of extremely dry winters and springs will increase to ~20%, while the frequency of extremely wet summers will double. Warming is also predicted to increase the frequency and intensity of tropical storms in the Indian Ocean (Young et al. 2010). There is a 90% probability that the extent of drought-affected areas will increase. Drought prone areas of Namibia, Botswana and Zimbabwe are likely to be more vulnerable than the more humid areas of Tanzania or Zambia (Davis 2011). In the northern regions of SADC, the role of the ITCZ, the major driver of rainfall in the region is less certain. Depending on where the ITCZ moves, (northwards or southwards), the areas around the Zambezi basin and Congo are affected, becoming drier or wetter.

Biomass burning is described as the burning of living and dead vegetation caused by factors such as natural and lightning-induced fires and man-made fires where vegetation is burnt (Koppmann, Von Czapiewski & Reid, 2005; Akagi, Yokelson, Wiedinmyer, Alvarado, Reid, Karl, Crounse & Wennberg, 2011). According to Cole (2001) and Koppmann et al. (2005), human beings are responsible for nearly 90% of biomass burning, with a small percentage of burning resulting from natural causes. Savanna fires are thought to account for the most global biomass consumption (Akagi et al., 2011). Savannas are broadly defined as tropical and subtropical grasslands. With varying densities of tree cover, they constitute the most fire-prone ecosystems on earth (Russell-Smith, Cook, Cooke, Edwards, Lendrum, Meyer & Whitehead, 2013). The combustion completeness of biomass is highly variable for different ecosystem types and can be loosely associated with fuel types, fuel loads, fuel configurations, and resulting combustion processes associated with those ecosystems (Jain, Tao, Yang & Gillespie, 2006). The emissions from grasslands are those associated with CO_2 following soil drainage due to the cultivation of organic soils for livestock production (FAOSTAT, 2014). Biomass burning plays a central role in carbon cycling through the direct release of CO_2, the single-most important anthropogenic GHG, into the atmosphere during biomass burning (Jain et al., 2006). The reason for the high incidence of savanna fires is the seasonal cycle of the wet season, during which biomass is produced, and the dry season, during which the biomass is turned into highly flammable material (Koppmann et al., 2005). According to the IPCC (2006), CO_2 emissions are not calculated, but are assumed to be zero because it is assumed that annual

CO_2 removals (through growth) and emissions (whether by decay or fire) by biomass are in balance.

Crop residue burning emissions are a source of particulate and gaseous emissions that can be important in the national context of air quality. In her study of annual and seasonal emission estimates from crop residue burning, McCarthy (2011) used remote sensing techniques to quantify burned area and crop type for subsequent emission. Their use of remote sensing-based burnt area products allowed for a high temporal resolution for the analysis of emissions. Moreover, the crop type maps permitted calculations of crop-specific emissions. The findings from the study on N_2O, NOx and NH_3 emissions from a typical rural catchment in Eastern China (Yang, Ti, Li, Deng & Yan, 2010) indicated that for the 45 km^2 catchment, gaseous emission was 279 ton of nitrogen, of which 7% was N_2O, 16% NOx and 77% NH_3. Their results further indicated that crop residue burning was the dominant source of NOx emission. This clearly indicates the contribution and effect of agricultural activities to atmospheric GHGs.

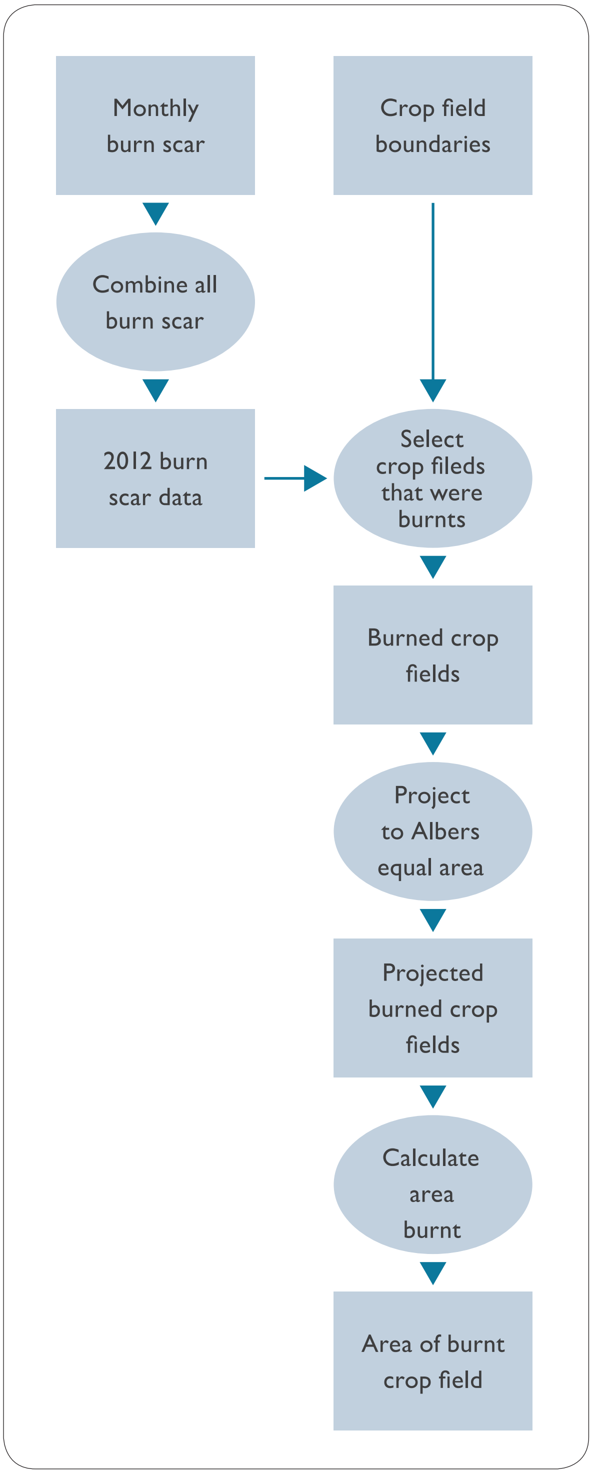
4.2 Methodology

This section provides the methodology for estimating the GHG emissions from biomass burning in croplands. The GHG emission assessment from croplands was done for the entire country for the 2012 assessment year.

4.2.1 Activity data

In order to calculate emissions from biomass burning from croplands, the prerequisite was to calculate the area of cropland burned. The crop field boundaries for 2012 were acquired from the Crop Estimate Consortium. The savanna data was extracted from the land-cover dataset. The monthly Moderate Resolution Imaging Spectroradiometer (MODIS) burn scar data was downloaded from the WAMIS website. MODIS is a key instrument aboard the Terra (originally known as EOS AM-1) and Aqua (originally known as EOS PM-1) satellites. Terra MODIS and Aqua MODIS view the entire earth's surface day or two, acquiring data in 36 spectral bands or groups of wavelengths. This data helps improve our understanding of global dynamics and processes that occur on land and in the oceans. The composite data sets derived from daily MODIS observation serves as input to the algorithm used to generate burn scars (USDA Forest Services, 2015). MODIS burn scar data is available at a spatial resolution of 500 m. Figure 10 shows the methodology described above that was used to calculate burnt cropland and the area of cropland burnt. The same process was followed where the inputs were savannas and MODIS burn scar data.

The input activity data is crop field boundaries and MODIS burn scar data. The 2012 monthly burn scar shape files were downloaded from the WAMIS website. These



Firgure 10: Methodology used to calculate burnt cropland and area burned

shape files were combined into one burn scar shape file for 2012 using GIS tools (Figure 11). Burnt cropfield data was derived from selecting the crop fields (Figure 12) that intersect the burn scar area. Since the dataset was in geographic projection, it was projected into Albers equal area projection. The total area (A) of burnt crop fields was calculated and used as an input in calculating the mass of GHG from biomass burning.

4.2.2 Emissions estimation

The IPCC has generated a number of methodology reports on national GHG inventories with a view to providing internationally acceptable inventory methodologies. The GHG emission from agriculture (biomass burning) was calculated following the IPCC Guidelines (IPCC, 2006).

The source of emissions in this section is biomass burning from cropland (crop residues in the cropland). According to the IPCC (2006), emission is estimated as follows:

$$Lfire = A*M_B*Gef*10^{-3}$$

Where:

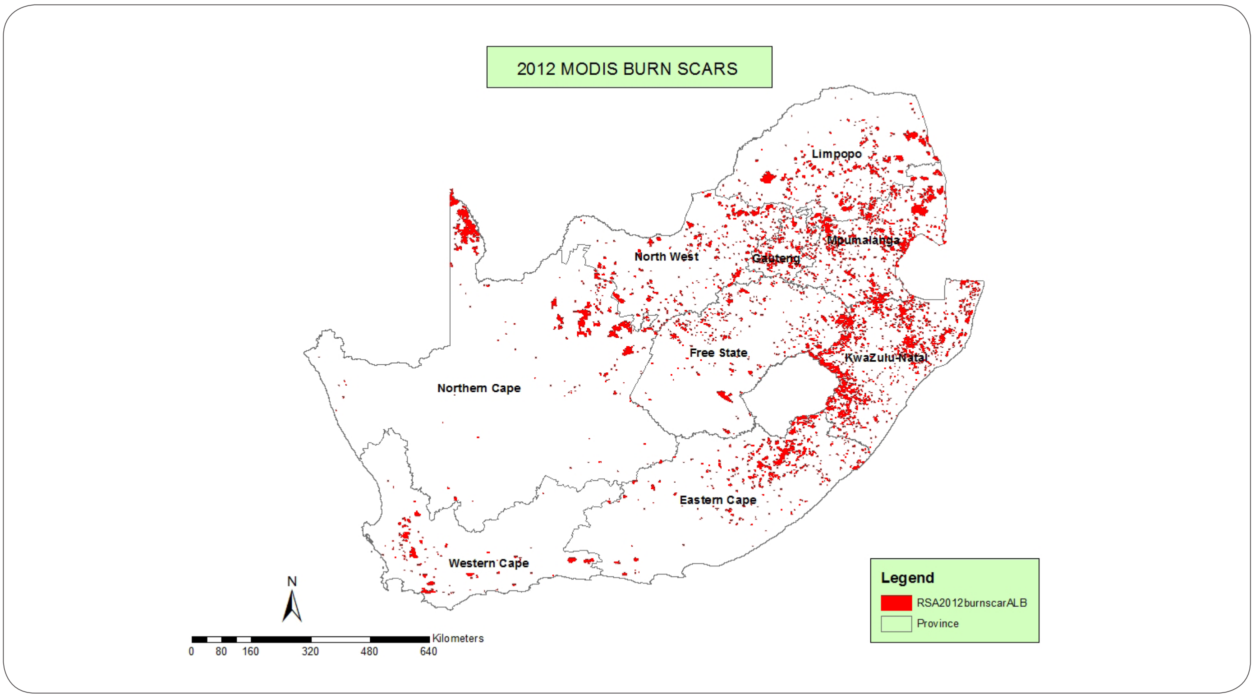
Lfire is mass of GHG from fire in tons of each GHG;

A is area burnt in hectares (ha);

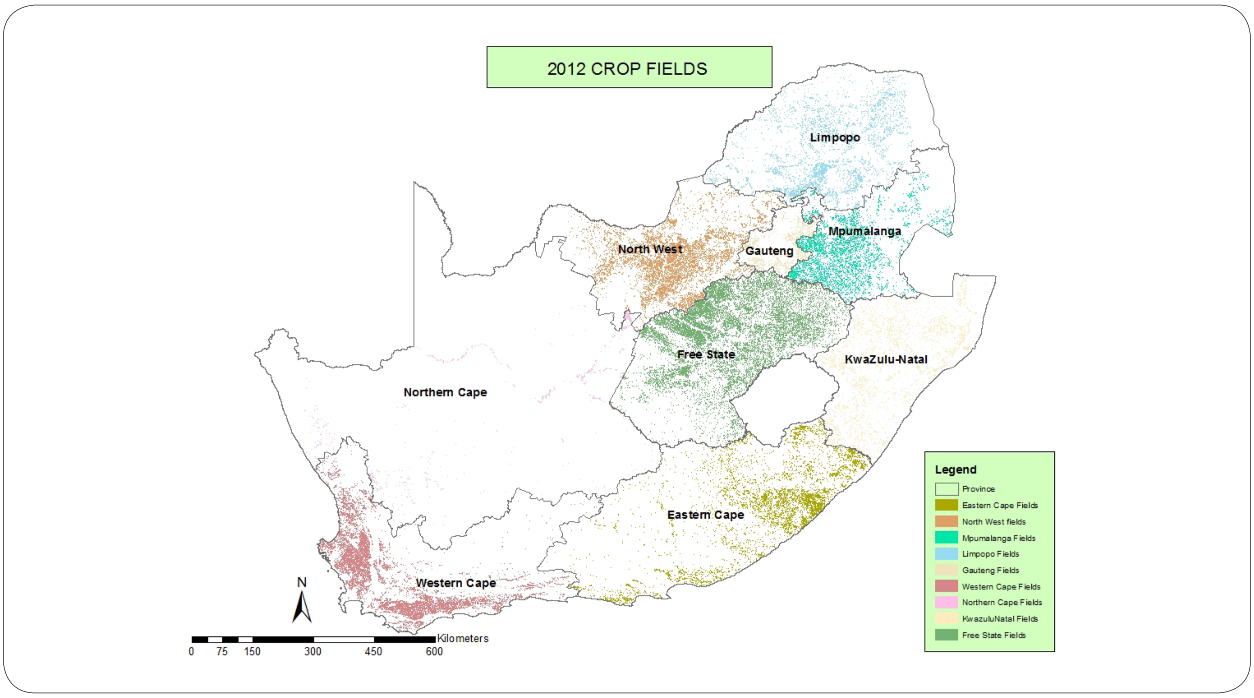
MB is mass of fuel available for combustion in tons per hectares (tonnesha-1); this include biomass, ground litter and dead wood;

Cf is combustion factor and it is dimensionless (default in IPCC, 2006, Table 2.5);

Gef is an emission factor, g kg-1 dry matter burnt (default values in IPCC, 2006, Table 2.5).



Firgure 11: MODIS burn scar acquired in 2012



Firgure 12: Crop field boundaries for 2012

Table 26: Emission factors of GHGs from biomass burning used in the emission estimation

Emission factor	Source	N_2O	NOx	CH_4	CO
EF_{BM}	Crop residue burning	0.07	2.5	2.7	92
EF_{LC}	Savannas	0.21	3.9	2.3	65

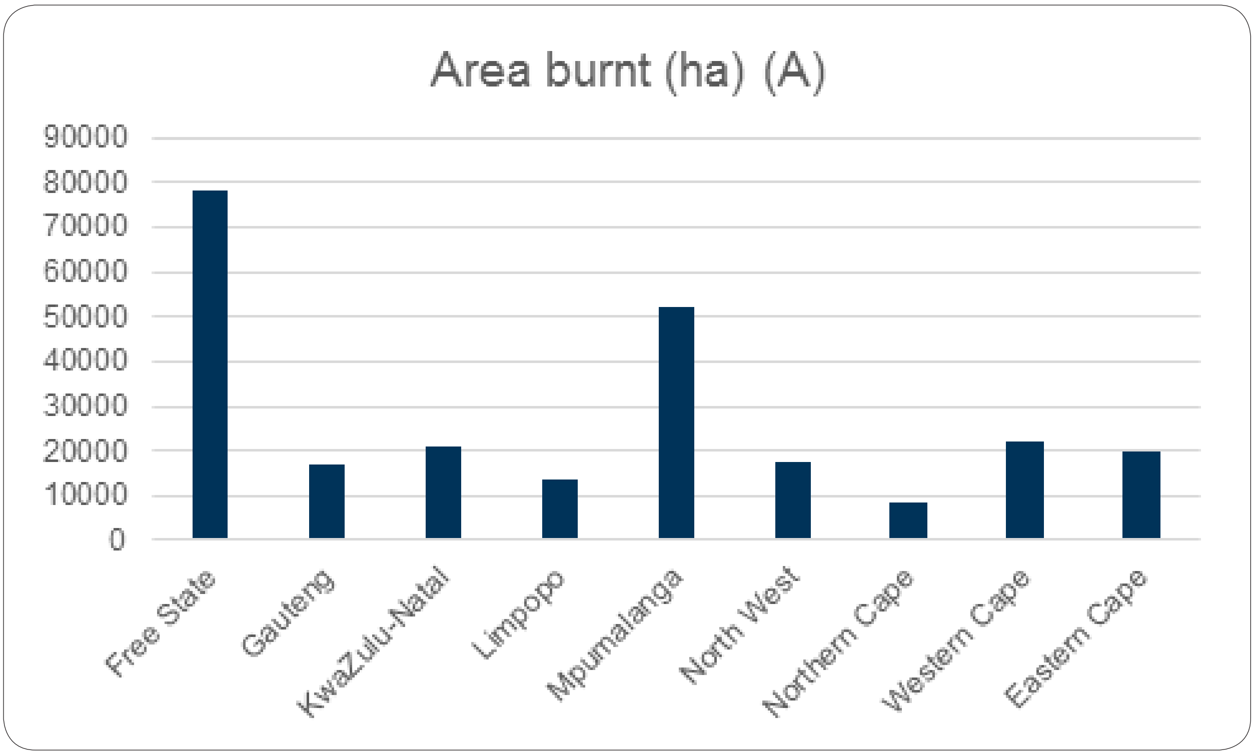
4.3 Results and discussion

Emission factors used (Table 26) were obtained from Table 2.5 in the IPCC Guidelines (IPCC, 2006).

Emissions from biomass burning of cropland calculated at provincial scale are shown in Table 27. These consist of burning crop residues from cultivated land. The GHGs assessed are CO, CH_4, N_2O and NOx. Table 2.6 in the 2006 IPCC Guidelines provided values for combustion factors. A default combustion (Cf) value of 1 was used in this current inventory as it was used in the 2004 inventory.

The Free State has the largest crop area burnt, followed by Mpumalanga, KwaZulu-Natal and Western Cape (Figure 13). The Northern Cape is the province with least amount of crop area burnt.

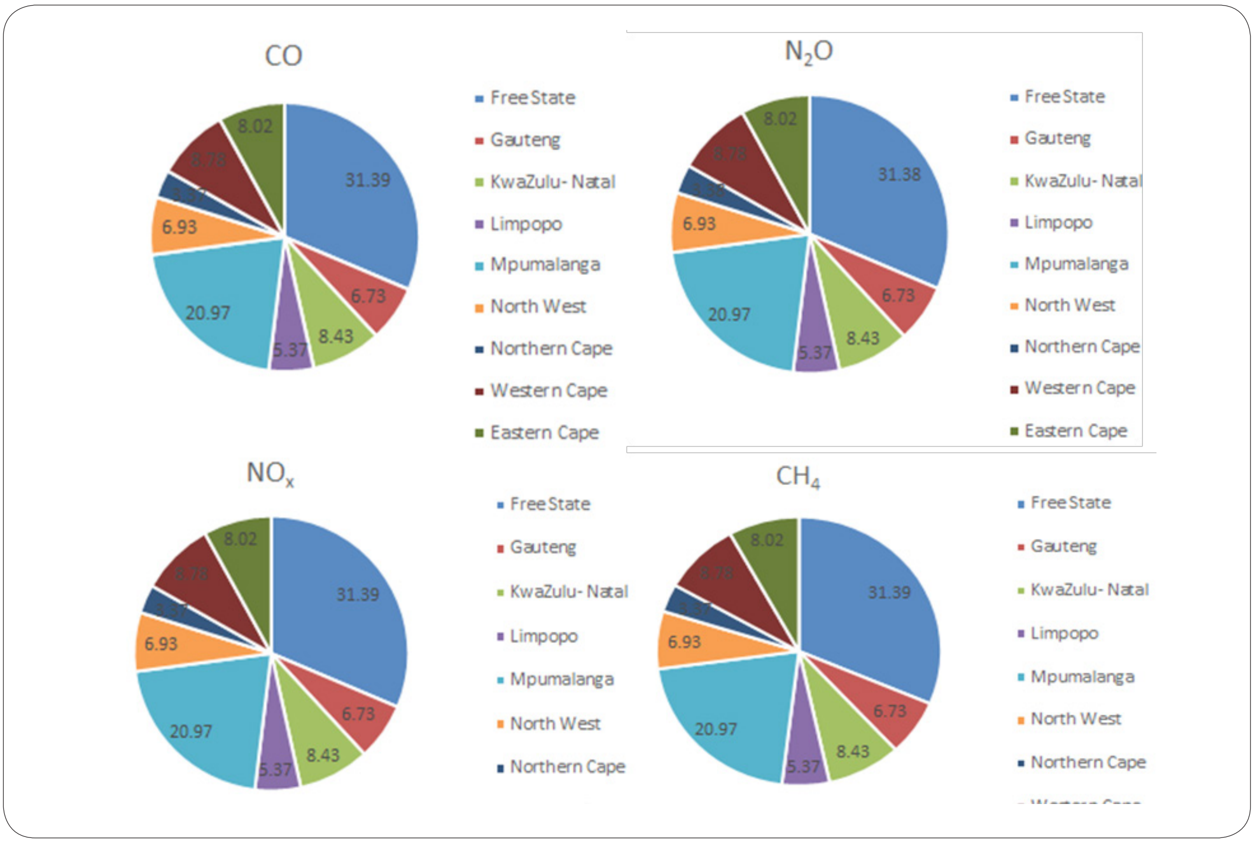
Figure 14 shows the provincial distribution of GHG emissions from cropland. With regard to CO, the Free State leads with 50.44 tons, followed by Mpumalanga. The Northern Cape is the lowest contributor of GHG emissions. N_2O is released in large quantities in the Free State, followed by Mpumalanga. Similar to N_2O, large quantities of NOx were released in Mpumalanga, while



Firgure 13: Cropland area burnt per province

Table 27: CO, N_2O, NOx and CH_4 emission from biomass burning from cropland

		M_B	C_f	CO	DS[5]	C[6]	CB[7]
		ton/ha		Emissions (ton/year)			
Free State	Cultivated land	7	1	50 443.77	38.38	1 370.75	1 480.42
Gauteng	Cultivated land	7	1	10 819.41	8.23	294.01	317.53
KwaZulu-Natal	Cultivated land	7	1	13 544.07	10.31	368.05	397.49
Limpopo	Cultivated land	7	1	8 633.23	6.57	234.60	253.37
Mpumalanga	Cultivated land	7	1	33 697.38	25.64	915.69	988.94
North West	Cultivated land	7	1	11 144.75	8.48	302.85	327.07
Northern Cape	Cultivated land	7	1	5 423.63	4.13	147.38	159.17
Western Cape	Cultivated land	7	1	14 112.49	10.74	383.49	414.17
Eastern Cape	Cultivated land	7	1	12 895.66	9.81	350.43	378.46



Firgure 14: Percentage proportion of GHG emission per province

Table 28: The 2012 inventory compared to other years

Inventory year	Gas	Emission (Gg)		CO_2e	
		Cropland	Savannas	Cropland	Savannas
1990	CO	45.0	1 241.0		
	CH_4	1.7	62.2	57.8	2 114.8
	NOx	2.2	36.9		
	N_2O	0.1	2.14	29.8	637.72
2000	CO				
	CH_4	1.79	39.47	60.86	1 341.98
	NOx				
	N_2O	0.05	2.47	14.9	736.06
2004	CO	212.6	472.6		
	CH_4	6.24	16.8	212.16	571.2
	NOx	5.78	28.4		
	N_2O	0.16	1.53	47.68	455.94
2012	CO	160	321.65		
	CH_4	4.72	11.38	160.48	386.92
	NOx	4.37	19.23	62	
	N_2O	0.12	1.04	35.76	309.92

only the Northern Cape produced less. In general, carbon monoxide is released in large quantities, followed by CH_4, N_2O and NOx.

Table 28 shows the emission inventory of previous yeas compared to the emission results of the 2012 assessment year. The lower values for burnt areas in 2012 resulted in lower emission values for CO, CH_4, NOx and N_2O, compared to other years for croplands, as well as for savannas.

The emission results calculated according to the IPCC Guidelines for the 2012 inventory year indicated an overall decrease in the amount of GHGs released into the atmosphere from biomass burning from cropland. The CO emitted from biomass burning in 2012 is higher in all inventories than other gases, such as CH_4, N_2O and NOx. The Free State is the leading province with a burn scar area of 78 328.84 ha, followed by Mpumalanga with 52 325.12 ha of burnt area. The Northern Cape has a burn scar area of 8 421.79 ha, which is the lowest among all provinces. The lower emission values of the 2012 inventory is attributed to smaller areas of cropland burned in 2012.

The previous inventory (2004) indicated that the province with the largest area burnt was Mpumalanga, followed by North West. The Western Cape has the smallest burnt area. The results of the 2012 inventory indicate that the Free State has the largest burnt area, followed by Mpumalanga. The province with the smallest burnt area in 2012 is the Northern Cape. The total GHGs emitted from biomass burning of cropland is 169.21 tons, of which

94.56% is for CO, 2.79% for CH_4, 2.58% for NOx and 0.07% for N_2O. The emission from burning savannas shows that the most emitted gas is CO (91.04%), followed by NOx (5.44%). The least emitted gas is N_2O (0.24%). These results show the contribution of biomass burning from croplands and savannas to the emission of GHGs, and has relevance to both policy and individuals. The 2012 inventory will serve as an indicator to further develop the country's action plans for GHG emission reduction.

4.4 Uncertainties analysis

Possible uncertainties in this project were considered in the estimated 2012 burn scars. They are associated with the omission of small or patchy burns due to the course spatial resolution of MODIS data. The woodland and grassland savannas were extracted from the 2004 National Land-cover Dataset, and it is highly possible that the savannas could have decreased due to human-induced activities.

4.5 Quality control and quality assurance

The quality of the product often depends on the quality of data input. The crop field boundaries were digitised from 5 m SPOT 5 imagery. These are so far the best quality datasets available from the Crop Estimation Committee.

4.6 Planned improvements

The results may be improved by dividing the crop field into a winter and a summer crop field. The identification of individual crop types for the entire country will also help improve the accuracy of the results.

5. OVERALL CONCLUSIONS

Total estimated agricultural GHG emissions for 2012, utilising the combination of 1996 the IPCC Guidelines (IPCC, 1996), the 2000 Good Practice Guidelines (IP, 2000) and the 2006 IPCC Guidelines (IPCC, 2006) is 62 906 Gg (Table 29). Over 77% of the emissions are from livestock farming, with over 54% of the emissions being from methane emissions from enteric fermentation. Manure management contributes over 21% of the total emissions, with most emissions being methane. Emissions from agricultural soils contribute 21% of the total emissions, with N_2O emissions from the application of manure on pastures, paddocks and rangelands having the highest sectorial contribution (overall contribution) of 63% (13%). The application of synthetic fertilizers and biomass burning contributes 4 and 2% respectively on total agricultural emissions, while other emissions account for less than 1%.

Table 29: South Africa agricultural GHG emissions for 2012

Categories	Source	Emissions (Gg CO_2e)		
Livestock				
Enteric fermentation			***34 338.68***	
Manure management	CH_4	10 822.2		
	Direct N_2O	2 062.16		
	Indirect N_2O	935.72		
Subtotal (manure management)			***13 820.08***	
Subtotal (Livestock)				**48 158.76**
Agricultural soils				
Application of nitrogen fertilizer	Direct N_2O	2 014.03		
	Indirect N_2O atmospheric nitrogen deposition	201.29		
	Indirect N_2O from leaching	422.82		
Subtotal (application of synthetic fertilizer)			***2 638.14***	
N_2O from manure applied on pasture/ paddock/rangelands	Direct N_2O	7 640.05		
	Indirect N_2O	801.79		
Subtotal (manure nitrogen applied on pasture/paddock/rangelands			8 441.84	

Categories	Source	Emissions (Gg CO_2e)		
Lime application			***1644***	
Urea application	Direct N_2O	**3.58**		
	Indirect N_2O atmospheric nitrogen deposition	0.3		
	Indirect N_2O from leaching	0.9		
	CO_2	**559.25**		
Subtotal (urea application)			564.03	
Sewage sludge application	Direct N_2O	**49.73**		
	Indirect N_2O atmospheric nitrogen deposition	9.94		
	Indirect N_2O from leaching	**10.45**		
Subtotal (sewage sludge application)			70.12	
Subtotal (agricultural soils)				**13 358.13**
Crop residues			**517**	
Biomass burning	CH_4	140.08		
	N_2O	35.76		
Subtotal (biomass burning)			175.84	
Subtotal (crop residues)				**692.84**
Biomass burning (savanna)	CH_4		386.92	
	N_2O		309.92	
Subtotal (savanna burning)				**696.84**
Total (all agricultural emissions)				**62 906.57**

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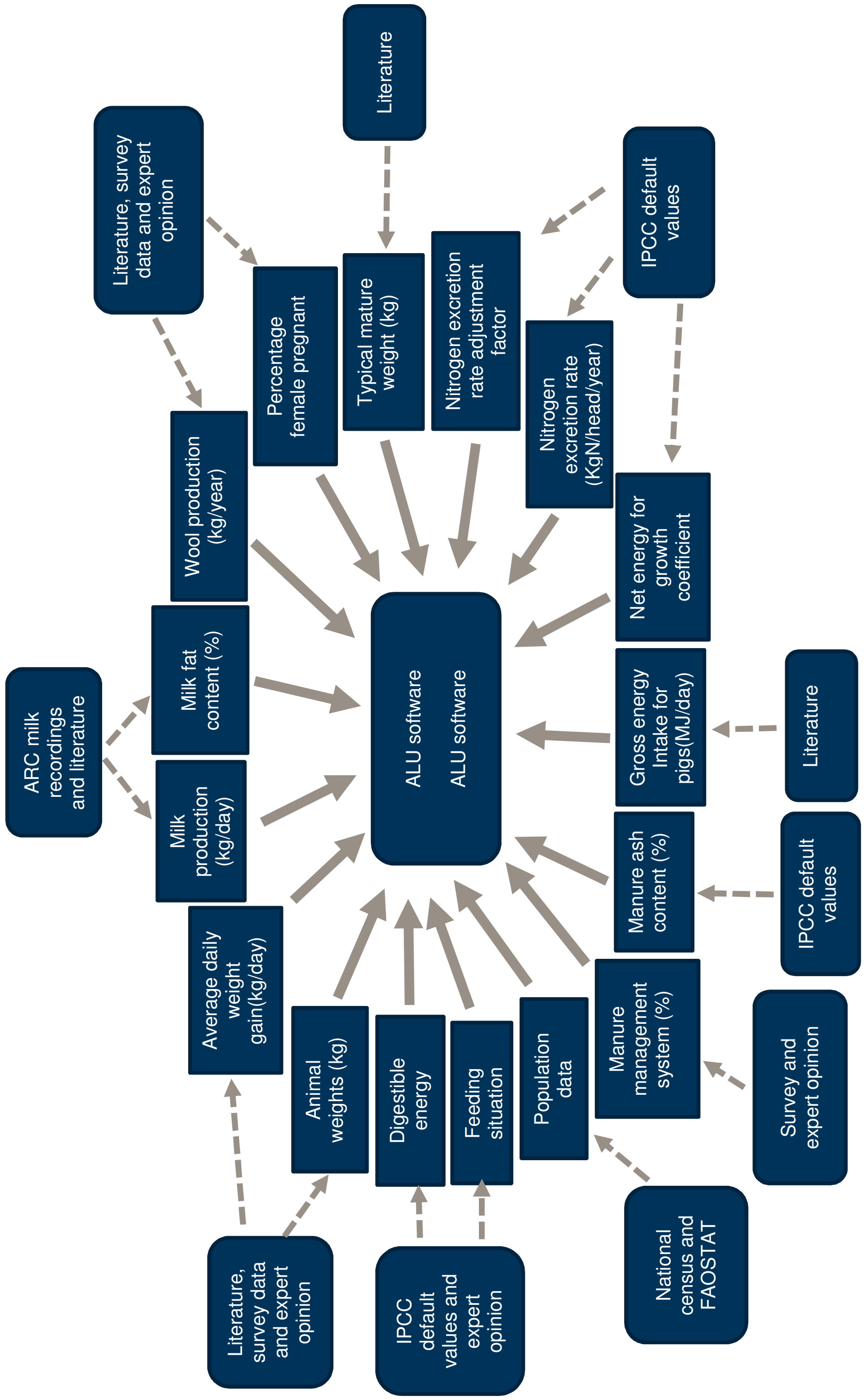
APPENDIX A: FLOW MAP FOR COLLECTION OF LIVESTOCK ACTIVITY DATA



APPENDIX B: GROSS ENERGY INTAKE AND COEFFICIENTS

Livestock category	Population name	Livestock subcategory	NEm	NEa	NEl	NEw	NEp	Rnem	NEg	Rneg	DE	GEc	U{95%}
Dairy cows	Mixed – lactating cows	Mature females	39.95	3.4	59.09	0	3.6	0.53	0	0.34	72	275.79	14.15
Dairy cows	PAS – lactating cows	Mature females	33.95	5.48	52.87	0	3.06	0.51	0	0.31	65	285.53	13.69
Dairy cows	TMR - lactating cows	Mature females	43.04	0	93.3	0	4.09	0.55	0	0.37	80	319.04	11.99
Non-dairy cattle	Beef – calves	Young females – Age 0–1	12.75	2.17	0	0	0	0.49	5.02	0.28	60	80.33	32.41
Non-dairy cattle	Beef – calves	Young intact males – Age 0–1	13.11	2.23	0	0	0	0.49	5.61	0.28	60	85.3	33.58
Non-dairy cattle	Beef – feedlot	Young females – Age 0–1	19.39	0	0	0	0	0.55	20.18	0.37	80	112.69	46.96
Non-dairy cattle	Beef – feedlot	Young intact males – Age 0–1	19.39	0	0	0	0	0.55	17.07	0.37	80	102.11	44.29
Non-dairy cattle	Beef – heifer	Young females – Age 1–2	25.38	6.73	0	0	0	0.49	6.74	0.28	60	148.58	26.67
Non-dairy cattle	Beef – mature bulls	Mature bulls	43.82	11.61	0	0	0	0.49	0	0.28	60	186.76	16.69
Non-dairy cattle	Beef – mature female	Mature Females	33.89	8.98	12.83	0	2.88	0.49	0	0.28	60	197.37	14.72
Non-dairy cattle	Beef – mature oxen	Mature male castrates	44.38	15.98	0	0	0	0.49	0	0.28	60	203.37	12.99
Non-dairy cattle	Beef – young bulls	Young intact males – Age 1–2	30.19	8	0	0	0	0.49	13.01	0.28	60	206.61	30.52
Non-dairy cattle	Beef – young oxen	Young male castrates – Age 1–2	30.41	10.95	0	0	0	0.49	13.1	0.28	60	217.8	29.4
Non-dairy cattle	Dairy – calves	Young females – Age 0–1	14.49	2.46	0	0	0	0.51	3.33	0.31	65	67.35	22.98
Non-dairy cattle	Dairy – calves	Young intact males – Age 0–1	14.49	2.46	0	0	0	0.51	2.82	0.31	65	64.79	21.55
Non-dairy cattle	Dairy – heifer	Young females – Age 1–2	26.06	6.9	0	0	0	0.51	7.1	0.31	65	134.09	23.65
Non-dairy cattle	Dairy – mature bulls	Mature bulls	50.69	13.43	0	0	0	0.51	0	0.31	65	191.99	16.41
Non-dairy cattle	Dairy – young bulls	Young intact males – Age 1–2	27.16	7.2	0	0	0	0.51	4.81	0.31	65	126.88	20
Non-dairy cattle	Subsistence – calves	Young females – Age 0–1	8.53	3.07	46 488	0	0	0.44	1.69	0.19	50	70.6	46.04
Non-dairy cattle	Subsistence – calves	Young intact males – Age 0–1	8.53	3.07	746 471	0	0	0.44	1.43	0.19	50	67.88	44.42
Non-dairy cattle	Subsistence – heifer	Young females – Age 1–2	24.76	8.91	0	0	0	0.44	1.02	0.19	50	164.3	47.33
Non-dairy cattle	Subsistence – mature bulls	Mature bulls	34.56	12.44	0	0	0	0.44	0	0.19	50	214.33	48.64
Non-dairy cattle	Subsistence – mature female	Mature Females	29.5	10.62	9.21	0	1.77	0.44	0	0.19	50	233.02	45.21
Non-dairy cattle	Subsistence – mature oxen	Mature male castrates	34.56	12.44	0	0	0	0.44	0	0.19	50	214.33	48.64
Non-dairy cattle	Subsistence – young bulls	Young intact males – Age 1–2	25.5	9.18	0	0	0	0.44	0.9	0.19	50	167.58	47.59
Non-dairy cattle	Subsistence – young oxen	Young male castrates – Age 1–2	25.5	9.18	0	0	0	0.44	0.9	0.19	50	167.58	47.59

APPENDIX C: EQUATIONS FOR THE CALCULATION OF COEFFICIENTS FOR CATTLE USING THE TIER 2 APPROACH

(Intergovernmental Panel on Climate Change, 2006)

IPCC 2006 equations for emission factor calculation	Variables/constants/assumptions
$ME_m = Cf_i \times (weight)^{0.75}$	NEm = net energy for maintenance Cfi (MJ/day/kg) = 0.322 for non-lactating cows; 0.386 for non-lactating cows Weight (kg) = live weight of animal
$NE_2 = C_a \times NEm$	NEa = net energy for activity Ca = 0 for animals in stalls; 0.17 for animals in pastures; 0.36 for animals grazing large areas
$NE_g = 22.02 \times \left(\frac{BW}{C \times MW} \right)^{0.75} \times (WG)^{1.097}$	NEg = net energy for growth C = 0.8 for females; 1.0 for castrates; 1.2 for bulls BW = average live body weight of animals in kg MW = mature live body weight of an adult female in moderate condition WG = average daily gain of animals kg/day
$NE_l = \mathit{Milk} \times (1.47 + 0.40 \times Fat)$	NEl = net energy for lactation Milk = amount of milk production in kg/day Fat = milk fat content in %
$NE_p = C_{preg} \times NE_m$	NEm = net energy for pregnancy Cpreg = 0.10 for cattle
$NE_w = 0.10 \times NE_m \times \mathit{Hours}$	NEw = net energy for work Hours = number of hours of work daily
$REM = \left[1.123 - (4.092 \times 10^{-3} \times DE\%) + [1.126 \times 10^{-5} \times (DE\%)^2] - \left(\frac{25.4}{DE\%} \right) \right]$	REM = ratio of net energy available in a diet for maintenance to digestible energy consumed DE% = digestible energy as a percentage of gross energy ranges
$REG = \left[1.146 - (5.160 \times 10^{-3} \times DE\%) + [1.308 \times 10^{-5} \times (DE\%)^2] - \left(\frac{37.4}{DE\%} \right) \right]$	REG = ratio of net energy available in a diet to digestible energy consumed
$GE = \left[\frac{\left(\frac{NE_m + NE_a + NE_l + NE_{work} + NE_p}{REM} \right) + \left(\frac{NE_g}{REG} \right)}{\frac{DE\%}{100}} \right]$	GE = gross energy
$EF = \left[\frac{GE \times \left(\frac{Y_m}{100} \right) \times 365}{55.65} \right]$	EF = emission factor Ym = 6.5% for cattle 55.65 (MJ/kg CH_4) = the energy content of methane constant

APPENDIX D: ENTERIC METHANE EMISSION FACTORS AND CONTRIBUTION OF DIFFERENT LIVESTOCK SUBCATEGORIES

Animal subcategories	Name	Population	EF (kg/head/year)	Emissions (Gg)
Dairy cows	Mixed – lactating cows	372 000	108.53	40 373.54
Dairy cows	PAS – lactating cows	186 000	112.36	20 899.66
Dairy cows	TMR - lactating cows	372 000	83.7	31 137.07
Non-dairy cattle	Beef – calves	1 150 942	31.61	36 384.72
Non-dairy cattle	Beef – calves	1 150 942	33.57	38 635.39
Non-dairy cattle	Beef – feedlot	210 000	44.35	9 312.87
Non-dairy cattle	Beef – feedlot	210 000	40.18	8 438.69
Non-dairy cattle	Beef – heifer	720 000	58.47	42 098.87
Non-dairy cattle	Beef – mature bulls	160 000	73.5	11 759.55
Non-dairy cattle	Beef – mature female	2 420 000	77.67	187 963.62
Non-dairy cattle	Beef – mature oxen	240 000	80.03	19 207.33
Non-dairy cattle	Beef – young bulls	618 912	81.31	50 322.75
Non-dairy cattle	Beef – young oxen	201 088	85.71	17 235.29
Non-dairy cattle	Dairy – calves	174 058	26.51	4 613.5
Non-dairy cattle	Dairy – calves	174 058	25.5	4 438.21
Non-dairy cattle	Dairy – heifer	310 000	52.77	16 358.7
Non-dairy cattle	Dairy – mature bulls	5 803	75.55	438.44
Non-dairy cattle	Dairy – young bulls	1 853	49.93	92.52
Non-dairy cattle	Subsistence – calves	898 901	32.41	29 137.19
Non-dairy cattle	Subsistence – calves	898 902	31.16	28 012.79
Non-dairy cattle	Subsistence – heifer	903 551	75.43	68 155.94
Non-dairy cattle	Subsistence – mature bulls	151 490	98.4	14 907.09
Non-dairy cattle	Subsistence – mature female	2 601 097	106.98	27 8270.4
Non-dairy cattle	Subsistence – mature oxen	47 172	98.4	4 641.87
Non-dairy cattle	Subsistence – young bulls	106 609	76.94	8 202.26
Non-dairy cattle	Subsistence – young oxen	34 622	76.94	2 663.74
Wool sheep	Mature ram	716 421	13.29	9 521.24
Wool sheep	Mature ewe	8 820 084	10.23	90 229.46
Wool sheep	Replacement ram	716 421	11.93	8 546.90
Wool sheep	Replacement ewe	1 516 590	8.8	13 345.99
Wool sheep	Lamb	3 621 484	3.96	14 341.08
Non-wool sheep	Mature ram	280 964	15.04	4 225.70
Non-wool sheep	Mature ewe	3 459 036	12.5	43 237.95
Non-wool sheep	Replacement ram	280 964	11.93	3 351.90
Non-wool sheep	Replacement ewe	594 772	8.32	4 948.50
Non-wool sheep	Lamb	1 420 264	5.42	7 697.83
Non-wool sheep	Feedlot sheep	1 096 630	1.95	2 138.43
Subsistence sheep	Mature ram	137 990	6.46	891.42
Subsistence sheep	Mature ewe	1 698 843	5.61	9 530.51
Subsistence sheep	Replacement ram	137 990	4.77	658.21
Subsistence sheep	Replacement ewe	292 112	3.08	899.70
Subsistence sheep	Lamb	697 537	3.59	2 504.16

APPENDIX E: MANURE METHANE VOLATILE SOLIDS, METHANE-PRODUCING POTENTIAL, METHANE CONVERSION FACTOR AND EMISSION FACTORS PER LIVESTOCK SUBCATEGORY

Livestock	Subcategories		Manure management system	VS	B_0	MCF	EF
Dairy cows	Mixed – lactating cows	Mature females	Anaerobic lagoon	3.85	0.24	1	225.995
Dairy cows	Mixed – lactating cows	Mature females	Cattle/swine deep litter > 1 month	3.85	0.24	0.45	101.698
Dairy cows	Mixed – lactating cows	Mature females	Daily spread	3.85	0.24	0.005	1.13
Dairy cows	Mixed – lactating cows	Mature females	Dry lot	3.85	0.24	0.015	3.39
Dairy cows	Mixed – lactating cows	Mature females	Pasture/range/paddock	3.85	0.24	0.015	3.39
Dairy cows	Mixed – lactating cows	Mature females	Solid storage	3.85	0.24	0.015	3.39
Dairy cows	PAS – lactating cows	Mature females	Anaerobic lagoon	4.98	0.24	1	292.47
Dairy cows	PAS – lactating cows	Mature females	Cattle/swine deep litter > 1 month	4.98	0.24	0.45	131.612
Dairy cows	PAS – lactating cows	Mature females	Daily spread	4.98	0.24	0.005	1.462
Dairy cows	PAS – lactating cows	Mature females	Dry lot	4.98	0.24	0.015	4.387
Dairy cows	PAS – lactating cows	Mature females	Pasture/range/paddock	4.98	0.24	0.015	4.387
Dairy cows	PAS – lactating cows	Mature females	Solid storage	4.98	0.24	0.015	4.387
Dairy cows	TMR – lactating cows	Mature females	Anaerobic lagoon	3.18	0.24	1	186.743
Dairy cows	TMR – lactating cows	Mature females	Cattle/swine deep litter > 1 month	3.18	0.24	0.45	84.034
Non-dairy cattle	Beef – calves	Young females – Age 0 – 1	Cattle/swine deep litter > 1 month	1.6	0.17	0.45	29.975
Non-dairy cattle	Beef – calves	Young females – Age 0 – 1	Daily spread	1.6	0.17	0.005	0.333
Non-dairy cattle	Beef – calves	Young females – Age 0 – 1	Pasture/range/paddock	1.6	0.17	0.015	0.999
Non-dairy cattle	Beef – calves	Young females – Age 0 – 1	Solid storage	1.6	0.17	0.015	0.999
Non-dairy cattle	Beef – calves	Young intact males – Age 0–1	Cattle/swine deep litter > 1 month	1.7	0.17	0.45	13.829
Non-dairy cattle	Beef – calves	Young intact males – Age 0–1	Daily spread	1.7	0.17	0.005	0.354
Non-dairy cattle	Beef – calves	Young intact males – Age 0–1	Pasture/range/paddock	1.7	0.17	0.015	1.061
Non-dairy cattle	Beef – calves	Young intact males – Age 0–1	Solid storage	1.7	0.17	0.015	1.061
Non-dairy cattle	Beef – feedlot	Young females – Age 0–1	Cattle/swine deep litter > 1 month	1.12	0.17	0.45	21.025
Non-dairy cattle	Beef – feedlot	Young females – Age 0–1	Solid storage	1.12	0.17	0.015	0.701
Non-dairy cattle	Beef – feedlot	Young intact males – Age 0–1	Cattle/swine deep litter > 1 month	1.02	0.17	0.45	19.051

Continued...

Livestock	Subcategories		Manure management system	VS	B_0	MCF	EF
Non-dairy cattle	Beef – feedlot	Young intact males – Age 0–1	Solid storage	1.02	0.17	0.015	0.635
Non-dairy cattle	Beef – heifer	Young females – Age 1–2	Cattle/swine deep litter > 1 month	2.96	0.17	0.45	55.442
Non-dairy cattle	Beef – heifer	Young females – Age 1–2	Daily spread	2.96	0.17	0.005	0.616
Non-dairy cattle	Beef – heifer	Young females – Age 1–2	Pasture/range/paddock	2.96	0.17	0.015	1.848
Non-dairy cattle	Beef – heifer	Young females – Age 1–2	Solid storage	2.96	0.17	0.015	1.848
Non-dairy cattle	Beef – mature bulls	Mature bulls	Cattle/swine deep litter > 1 month	3.73	0.17	0.45	69.69
Non-dairy cattle	Beef – mature bulls	Mature bulls	Daily spread	3.73	0.17	0.005	0.774
Non-dairy cattle	Beef – mature bulls	Mature bulls	Pasture/range/paddock	3.73	0.17	0.015	2.323
Non-dairy cattle	Beef – mature bulls	Mature bulls	Solid storage	3.73	0.17	0.015	2.323
Non-dairy cattle	Beef – mature female	Mature females	Cattle/swine deep litter > 1 month	3.94	0.17	0.45	73.647
Non-dairy cattle	Beef – mature female	Mature females	Daily spread	3.94	0.17	0.005	0.818
Non-dairy cattle	Beef – mature female	Mature females	Pasture/range/paddock	3.94	0.17	0.015	2.455
Non-dairy cattle	Beef – mature female	Mature females	Solid storage	3.94	0.17	0.015	2.455
Non-dairy cattle	Beef – mature oxen	Mature male castrates	Cattle/swine deep litter > 1 month	4.06	0.17	0.45	75.884
Non-dairy cattle	Beef – mature oxen	Mature male castrates	Daily spread	4.06	0.17	0.005	0.843
Non-dairy cattle	Beef – mature oxen	Mature male castrates	Pasture/range/paddock	4.06	0.17	0.015	2.529
Non-dairy cattle	Beef – mature oxen	Mature male castrates	Solid storage	4.06	0.17	0.015	2.529
Non-dairy cattle	Beef –young bulls	Young intact males – Age 1–2	Cattle/swine deep litter > 1 month	4.12	0.17	0.45	77.096
Non-dairy cattle	Beef –young bulls	Young intact males – Age 1–2	Daily spread	4.12	0.17	0.005	0.857
Non-dairy cattle	Beef –young bulls	Young intact males – Age 1–2	Pasture/range/paddock	4.12	0.17	0.015	2.57
Non-dairy cattle	Beef –young bulls	Young intact males – Age 1–2	Solid storage	4.12	0.17	0.015	2.57
Non-dairy cattle	Beef – young oxen	Young male castrates – Age 1–2	Cattle/swine deep litter > 1 month	4.34	0.17	0.45	81.27
Non-dairy cattle	Beef – young oxen	Young male castrates – Age 1–2	Daily spread	4.34	0.17	0.005	0.903
Non-dairy cattle	Beef – young oxen	Young male castrates – Age 1–2	Pasture/range/paddock	4.34	0.17	0.015	2.709
Non-dairy cattle	Beef – young oxen	Young male castrates – Age 1–2	Solid storage	4.34	0.17	0.015	2.709
Non-dairy cattle	Dairy – calves	Young females – Age 0–1	Cattle/swine deep litter > 1 month	1.18	0.17	0.45	21.991
Non-dairy cattle	Dairy – calves	Young females – Age 0–1	Daily spread	1.18	0.17	0.005	0.244
Non-dairy cattle	Dairy – calves	Young females – Age 0–1	Pasture/range/paddock	1.18	0.17	0.015	0.733
Non-dairy cattle	Dairy – calves	Young females – Age 0–1	Solid storage	1.18	0.17	0.015	0.733

Continued...

Livestock	Subcategories		Manure management system	VS	B_0	MCF	EF
Non-dairy cattle	Dairy – calves	Young intact males – Age 0–1	Cattle/swine deep litter > 1 month	1.13	0.17	0.45	21.155
Non-dairy cattle	Dairy – calves	Young intact males – Age 0–1	Daily spread	1.13	0.17	0.005	0.235
Non-dairy cattle	Dairy – calves	Young intact males – Age 0–1	Pasture/range/paddock	1.13	0.17	0.015	0.705
Non-dairy cattle	Dairy – calves	Young intact males – Age 0–1	Solid storage	1.13	0.17	0.015	0.705
Non-dairy cattle	Dairy – heifer	Young females – Age 1–2	Cattle/swine deep litter > 1 month	2.34	0.17	0.45	43.782
Non-dairy cattle	Dairy – heifer	Young females – Age 1–2	Daily spread	2.34	0.17	0.005	0.486
Non-dairy cattle	Dairy – heifer	Young females – Age 1–2	Pasture/range/paddock	2.34	0.17	0.015	1.459
Non-dairy cattle	Dairy – heifer	Young females – Age 1–2	Solid storage	2.34	0.17	0.015	1.459
Non-dairy cattle	Dairy – mature bulls	Mature bulls	Cattle/swine deep litter > 1 month	3.35	0.17	0.45	62.685
Non-dairy cattle	Dairy – mature bulls	Mature bulls	Daily spread	3.35	0.17	0.005	0.697
Non-dairy cattle	Dairy – mature bulls	Mature bulls	Pasture/range/paddock	3.35	0.17	0.015	2.09
Non-dairy cattle	Dairy – mature bulls	Mature bulls	Solid storage	3.35	0.17	0.015	2.09
Non-dairy cattle	Dairy – young bulls	Young intact males – Age 1–2	Cattle/swine deep litter > 1 month	2.21	0.17	0.45	41.427
Non-dairy cattle	Dairy – young bulls	Young intact males – Age 1–2	Daily spread	2.21	0.17	0.005	0.46
Non-dairy cattle	Dairy – young bulls	Young intact males – Age 1–2	Pasture/range/paddock	2.21	0.17	0.015	1.381
Non-dairy cattle	Dairy – young bulls	Young intact males – Age 1–2	Solid storage	2.21	0.17	0.015	1.381
Non-dairy cattle	Subsistence – calves	Young females – Age 0–1	Cattle/swine deep litter > 1 month	1.76	0.1	0.45	19.371
Non-dairy cattle	Subsistence – calves	Young females – Age 0–1	Dry lot	1.76	0.1	0.015	0.646
Non-dairy cattle	Subsistence – calves	Young females – Age 0–1	Pasture/range/paddock	1.76	0.1	0.015	0.646
Non-dairy cattle	Subsistence – calves	Young intact males – Age 0–1	Cattle/swine deep litter > 1 month	1.69	0.1	0.45	18.623
Non-dairy cattle	Subsistence – calves	Young intact males – Age 0–1	Dry lot	1.69	0.1	0.015	0.621
Non-dairy cattle	Subsistence – calves	Young intact males – Age 0–1	Pasture/range/paddock	1.69	0.1	0.015	0.621
Non-dairy cattle	Subsistence – heifer	Young females – Age 1–2	Cattle/swine deep litter > 1 month	4.1	0.1	0.45	45.078
Non-dairy cattle	Subsistence – heifer	Young females – Age 1–2	Dry lot	4.1	0.1	0.015	1.503
Non-dairy cattle	Subsistence – heifer	Young females – Age 1–2	Pasture/range/paddock	4.1	0.1	0.015	1.503
Non-dairy cattle	Subsistence – mature bulls	Mature bulls	Cattle/swine deep litter > 1 month	5.34	0.1	0.45	58.806
Non-dairy cattle	Subsistence – mature bulls	Mature bulls	Dry lot	5.34	0.1	0.015	1.96
Non-dairy cattle	Subsistence – mature bulls	Mature bulls	Pasture/range/paddock	5.34	0.1	0.015	1.96
Non-dairy cattle	Subsistence – mature female	Mature females	Cattle/swine deep litter > 1 month	5.81	0.1	0.45	63.933

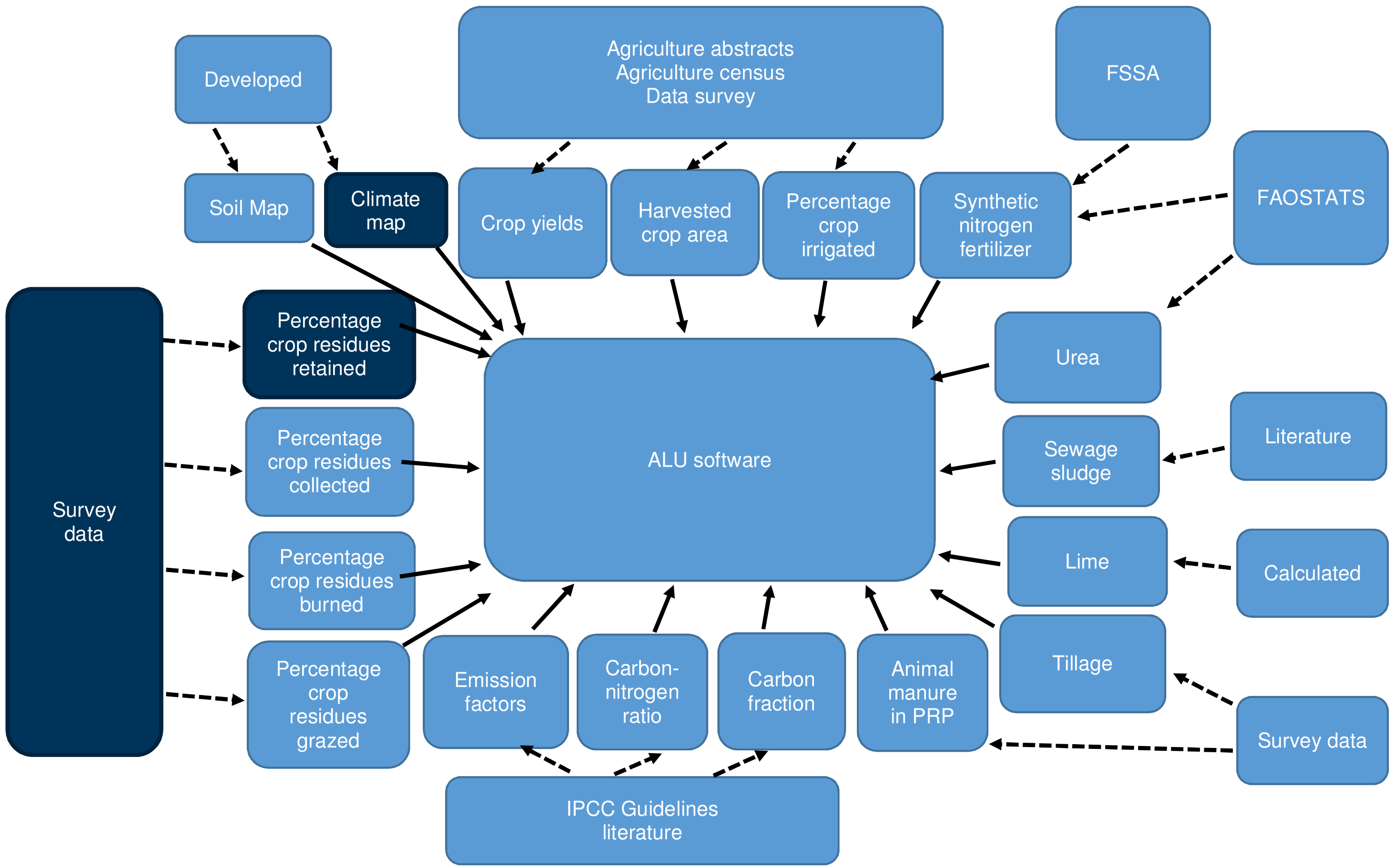
Continued...

Livestock	Subcategories		Manure management system	VS	B_0	MCF	EF
Non-dairy cattle	Subsistence – mature female	Mature females	Dry lot	5.81	0.1	0.015	2.131
Non-dairy cattle	Subsistence – mature female	Mature females	Pasture/range/paddock	5.81	0.1	0.015	2.131
Non-dairy cattle	Subsistence – mature oxen	Mature male castrates	Cattle/swine deep litter > 1 month	5.34	0.1	0.45	58.806
Non-dairy cattle	Subsistence – mature oxen	Mature male castrates	Dry lot	5.34	0.1	0.015	1.96
Non-dairy cattle	Subsistence – mature oxen	Mature male castrates	Pasture/range/paddock	5.34	0.1	0.015	1.96
Non-dairy cattle	Subsistence – young bulls	Young intact males – Age 1–2	Cattle/swine deep litter > 1 month	4.18	0.1	0.45	45.978
Non-dairy cattle	Subsistence – young bulls	Young intact males – Age 1–2	Dry lot	4.18	0.1	0.015	1.533
Non-dairy cattle	Subsistence – young bulls	Young intact males – Age 1–2	Pasture/range/paddock	4.18	0.1	0.015	1.533
Non-dairy cattle	Subsistence – young oxen	Young male castrates – Age 1–2	Cattle/swine deep litter > 1 month	4.18	0.1	0.45	45.978
Non-dairy cattle	Subsistence – young oxen	Young male castrates – Age 1–2	Dry lot	4.18	0.1	0.015	1.533
Non-dairy cattle	Subsistence – young oxen	Young male castrates – Age 1–2	Pasture/range/paddock	4.18	0.1	0.015	1.533
Swine	Boars	Boars	Anaerobic lagoon	0.24	0.45	1	26.903
Swine	Boars	Boars	Dry lot	0.24	0.45	0.015	0.404
Swine	Boars	Boars	Liquid/slurry	0.24	0.45	0.45	12.106
Swine	Boars	Boars	Solid storage	0.24	0.45	0.015	0.404
Swine	Growers	Young	Anaerobic lagoon	0.15	0.45	1	16.142
Swine	Growers	Young	Dry lot	0.15	0.45	0.015	0.242
Swine	Growers	Young	Liquid/slurry	0.15	0.45	0.45	7.264
Swine	Growers	Young	Solid storage	0.15	0.45	0.015	0.242
Swine	Piglets	Young	Anaerobic lagoon	0.06	0.45	1	6.405
Swine	Piglets	Young	Dry lot	0.06	0.45	0.015	0.096
Swine	Piglets	Young	Liquid/slurry	0.06	0.45	0.45	2.882
Swine	Piglets	Young	Solid storage	0.06	0.45	0.015	0.096
Swine	Sows	Sows	Anaerobic lagoon	0.24	0.45	1	26.903
Swine	Sows	Sows	Dry lot	0.24	0.45	0.015	0.404
Swine	Sows	Sows	Liquid/slurry	0.24	0.45	0.45	12.106
Swine	Sows	Sows	Solid storage	0.24	0.45	0.015	0.404

APPENDIX F: UNCERTAINTY VALUES FOR LIVESTOCK ACTIVITY DATA

Livestock category	Livestock subcategory	Lower uncertainty (%)	Upper uncertainty (%)
Feeding situation			
Dairy cows	Mixed – lactating	186 000	112.36
Dairy cows	PAS – lactating	372 000	83.7
Dairy cows	TMR – lactating	1 150 942	31.61
Non-dairy cattle	Beef – calves	1 150 942	33.57
Non-dairy cattle	Beef – feedlot	210 000	40.18
Non-dairy cattle	Beef – heifer	720 000	58.47
Non-dairy cattle	Beef – mature bulls	160 000	73.5
Non-dairy cattle	Beef – mature female	2 420 000	77.67
Non-dairy cattle	Beef – mature oxen	240 000	80.03
Non-dairy cattle	Beef – young bulls	618 912	81.31
Non-dairy cattle	Beef – young oxen	201 088	85.71
Non-dairy cattle	Dairy – calves	174 058	26.51
Non-dairy cattle	Dairy – heifer	310 000	52.77
Non-dairy cattle	Dairy – mature bulls	5 803	75.55
Non-dairy cattle	Dairy – young bulls	1 853	49.93
Non-dairy cattle	Subsistence – calves	898 902	31.16
Non-dairy cattle	Subsistence – heifer	903 551	75.43
Non-dairy cattle	Subsistence – mature bulls	151 490	98.4
Non-dairy cattle	Subsistence – mature female	2 601 097	106.98
Non-dairy cattle	Subsistence – mature oxen	47 172	98.4
Non-dairy cattle	Subsistence – young bulls	106 609	76.94
Non-dairy cattle	Subsistence – young oxen	34 622	76.94
Livestock population			
Dairy cows	Mixed– lactating cows	10	10
Dairy cows	PAS – lactating cows	10	10
Dairy cows	TMR – lactating cows	10	10
Non-dairy cattle	Beef – calves	5	5
Non-dairy cattle	Beef – feedlot	5	5
Non-dairy cattle	Beef – heifer	10	10
Non-dairy cattle	Beef – mature bulls	10	10
Non-dairy cattle	Beef – mature female	10	10
Swine	Boars	10	10
Swine	Growers	10	10
Swine	Piglets	25	25
Swine	Sows	10	10
Swine	Mixed – lactating cows	15	15
Swine	PAS – lactating cows	10	10
Swine	TMR – lactating cows	10	10
Manure management			
Dairy cows	Mixed – lactating cows	20	20
Dairy cows	PAS – lactating cows	25	25
Dairy cows	TMR – lactating cows	10	10
Goats		5	5
Horses		5	5
Mules and asses		2	2
Non-dairy cattle		15	15
Poultry		15	15
Sheep		2	2
Swine		15	15

APPENDIX G: WORKFLOW OF GHG EMISSIONS FROM MANAGED SOILS



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