Estimation of greenhouse gas emissions from agriculture in the eastern Free State, South Africa

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PREFACE

The research contained in this dissertation was completed by the candidate while based in the Discipline of geography, faculty of natural and agricultural science, University of the Free State, QwaQwa campus, South Africa. The research was financially supported by Agricultural Research Council and Department of Agriculture Forestry and Fisheries (DAFF) (Project no: 57/011).

The contents of this work have not been submitted in any form to another university and, except where the work of others is acknowledged in the text, the results reported are due to investigations by the candidate.

Professor G Mukwada (Supervisor)

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Date:…………………………………………….

DECLARATION

I, Sewela Francinah Malaka, declare that:

(i) the research reported in this dissertation, except where otherwise indicated or acknowledged, is my original work;

(ii) this dissertation has not been submitted in full or in part for any degree or examination to any other university;

(iii) this dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons;

(iv) this dissertation does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

a) their words have been re-written but the general information attributed to them has been referenced;

b) where their exact words have been used, their writing has been placed inside quotation marks, and referenced;

(v) where I have used material for which publications followed, I have indicated in detail my role in the work;

(vi) this dissertation is primarily a collection of material, prepared by myself, published as journal articles or presented as a poster and oral presentations at conferences. In some cases, additional material has been included;

(vii) this dissertation does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the dissertation and in the References sections.

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ABSTRACT

The agriculture sector is responsible for global emissions and the emissions continue to grow rapidly. The food agriculture organization (FAO) reported emissions with 7.1 gigatonnes CO_{2eq} per annum, representing 14.5 % of human-induced GHG emissions; the livestock sector plays an important role in climate change. Beef and cattle milk production account for the majority of emissions, respectively contributing 41 and 20 % of the sector's emissions. While pig meat and poultry meat and eggs contribute respectively 9 % and 8 % to the sector's emissions. Feed production and processing, and enteric fermentation from ruminants are the two main sources of emissions, representing 45 and 39 % of sector emissions, respectively. Manure storage and processing represent 10 % in 2013. Contribution of agriculture sector to South Africa's total CO_2eq emissions was 11.6 % in 1990, 9.3 % in 1994 and 4.9 % in 2000. The livestock category was the major contributor to the Agriculture, Forestry and Other Land Use (AFOLU) sector, providing the average of 54.1 % to the total CH_4 emissions in 2010. The contribution from livestock has declined by 11.8 % over the 2000 -2010 period. The department of environmental affairs (DEA) reported that, the total enteric CH_4 emissions attained for the years (2000, 2004, and 2010) were 903.23 Gg, 1183.56 Gg and 1172.95 Gg. The contributions of dairy cattle to the total cattle emissions in 2004 was 14.3 % and 13.5 % in 2010. The overall objective of this research study was to estimate GHG emissions (CO_2, CH_4 and N_2O) resulting from agricultural farms in Tshiame Ward in the eastern Free State region of South Africa for the years 2010 to 2014. The importance of this research was to assess GHG emissions in agricultural farms for purposes of developing mitigation options. The available data allowed Tier 2 method to calculate all the GHG emission factors (EFs) and emissions from cattle, sheep and cropland farming. However, Tier 1 method was used to estimate EFs and

emissions from other livestock categories. Emissions were estimated from the agricultural sources including CH_4 emissions from enteric fermentation, CH_4 emissions from manure management, N_2O emissions from manure management, non-CO_2 emissions from biomass burning, Soil N_2O emissions from managed soils, and emissions from fuel use. The results have shown relatively high CH_4 EFs from enteric fermentation for mature female beef cattle (95-109 kg/head/year) at all farms. The dairy mature females followed with 71-105 kg/head/animal, dairy mature bulls (63-96 kg/head/animal), beef mature bulls (53-89 kg/head/animal), beef heifers (37-52 kg/head/animal), dairy heifers (33-56 kg/head/animal), dairy calves (10-25 kg/head/animal), and beef calves (10-24 kg/head/year). Ewes recorded an enteric CH_4 EF of about 7 kg CH_4/head/year, heifers 0.86 kg CH_4/head/year, rams with about 9 kg CH_4/head/year and lambs were calculated to have an enteric CH_4 EF of about 0.22 kg CH_4/head/year. The manure CH_4 EFs for MMSs varied per animal subcategories. Beef mature females had the highest average CH_4 manure EFs ranging from 1.2 to 1.5 kg CH_4/animal/year at all farms, followed by the dairy mature females with CH_4 manure EFs ranging from 0.8 to 2.2 kg CH_4/animal/year. The beef mature bulls had the CH_4 manure EFs of 0.9 to 1.2 kg CH_4/animal/year which was higher than the dairy mature bulls which ranged from 0.9 to 1 kg CH_4/animal/year. The other animal subcategories had the manure CH_4 EFs ranging from 0.1 to 1 kg CH_4/animal/year by MMSs. In summary, manure CH_4 EFs for beef category were higher than the dairy category at all animal subcategories. The livestock EFs in this study were higher than the EFs found in most studies and this might be due to the lower quality of the feeding situation used in the study area. However, the cropland EFs were consistent with those in literature for most of the studies. It was estimated that farm total emissions in the year 2010 ranged from (69220-580877 kg CO_2eq), (70977-585732 kg CO_2eq) in the 2011, (45338-676245 kg CO_2eq) in 2012, (54731-485264 kg CO_2eq) in 2013, and (36270-464119 kg CO_2eq) in 2014 at all farms. CH_4 enteric fermentation was the highest contributor to the total farm emissions at all farms by approximately 50% in all years, followed by CH_4 and N_2O from manure management respectively. GHG emissions from cropland farming were lower than the emissions produced during livestock farming. In this study, the mitigation options were analysed and evaluated, and as a result, six (6) mitigation options were regarded as the potential mitigation options for Tshiame farms. The six (6) potential mitigation options met the requirements of sustainability, environmental friendly as well as the profitability of farmers. Managing manure as solid storage had reduced the total emitted manure emissions by 21-75% in all years at all farms. Feeding manure to anaerobic digester had resulted in the reduction of manure emissions emitted by 9-24% at all farms. Manure left on pasture had reduced the manure emissions by 20-75%. However, the dry lot reduced the manure emissions by 20-74% in all years. Addition of supplements in feeding situations had reduced the emitted enteric emissions ranging from 81 to 92 percent.

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CHAPTER 1: INTRODUCTION

Estimating GHG emissions is an essential first step toward managing emissions. However, a complete, accurate, consistent, comparable and transparent GHG database is an essential tool for informing policy decisions and for understanding emissions and trends, projecting future emissions and identifying sectors for cost-effective emission reduction opportunities. Furthermore, this helps in preparing a national inventory as a core element of national communication reports to the United Nations Framework Convention on Climate Change (UNFCCC) by countries that are signatory parties to the treaty agreement.

Agricultural activities contribute directly and indirectly to emissions of GHGs through a variety of processes. These processes emit to the atmosphere significant amounts of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) (Cole et al., 1997; IPCC, 2001a; Paustian et al., 2004). CO_2 is largely released from microbial decay or burning of plant litter and soil organic matter (Janzen, 2004; Smith, 2004), while CH_4 is produced when organic materials decompose in oxygen-deprived conditions, notably from fermentative digestion by ruminant livestock, and manure management (Smith et al., 2007). N_2O is generated by the microbial transformation of nitrogen in soils and animal dung, and is often enhanced where available nitrogen exceeds plant requirements, especially under wet conditions (Smith and Conen, 2004; Oenema et al., 2005).

Agriculture is the largest emitter of N_2O and second largest emitter of CH_4 (Tubiello et al., 2013). Agriculture alone contributes between 10% and 25% of the global GHG emissions annually through production practices, land-use changes and land management (Scialabba and Muller-Lindelauf, 2010; Smith et al., 2007). FAO (2006) reported that, agriculture emits more GHGs than the transport sector worldwide. In livestock farming, particularly the high amount of GHGs is released from ruminants feed digestion (Rotz et al., 2010; Scialabba and Muller-Lindenlauf, 2010; Smith et al., 2007). Most field studies have reported cropland as a negligible source or sink of CO_2 (Chianese et al., 2009).

Agricultural practices at farm level are typically more complex than industrial agricultural practices or production systems (Henry et al., 2009). New data are often collected through farmer knowledge or records and field sampling in order to complement data on national level applications (FAO, 2009). At farm level detailed data may be available whereas for larger areas, it will be very hard to obtain the statistics required (Colomb et al., 2013). Many farmers are not familiar with the provision of detailed activity data concerning how their practices contribute towards the GHG emissions. Thus, it is unusual for farmers to monitor and hold detailed records of the input and output activity data (Keller et al., 2011). This is a huge challenge in the emerging and small-scale farming communities in South Africa and Africa as a whole. Even in the commercial farming sector, it is impossible to have records of all data required for a farm specific GHG assessment (NRC, 2003).

Rotz et al (2010) and Seebauer (2014) argue that, estimation and monitoring emissions of agricultural GHG on farms is difficult because of the complexity of integrated crop-livestock production. Crop and livestock farming are responsible for a significant fraction of GHG emissions (Tubiello et al., 2013). Agricultural GHG emissions can be estimated in separate or through combinations of different approaches (Montzka et al., 2011). It is important to study and examine the management practices for crop and livestock farming in a farm rather than quantifying GHGs from one component because farm emission sources are interconnected as a system (Stewart et al., 2009). The Intergovernmental Panel on Climate Change (IPCC) guidelines are used to guide users in estimating annual GHG emissions at different scales (IPCC, 1996; 2006).

1.1 Research problem and research questions

1.1.1 Problem statement

GHG emissions are rising more rapidly than predicted and the world is warming more quickly in response (IPCC, 2006). Despite compelling scientific evidence, governments and businesses have responded with painful slowness on measures to reduce the emissions (IPCC, 2007). In South Africa, there is lack of literature published on GHG emissions estimated on a small scale (provincially or at farm level), wherein estimates are made about agriculture based emissions. In South Africa, there is therefore a need to establish a searchable literature database on agriculture based GHG emissions on farms. There is lack of agricultural data as agricultural census data does not have detailed farm inventories. Municipal or farm inventories are needed in order to determine the actual sources of emissions from agriculture activities, and therefore allowing each municipality to most effectively set targets for its emissions reduction policies.

Godfray et al. (2010) predicted that the global population would reach 9 billion by 2050. Population growth will lead to a high demand of food consumption and this will consequently lead to increased GHG emissions (FAO, 2011), unless there is an improvement in production management practices. Agricultural GHG fluxes are complex and heterogeneous, but the active management of agriculture and land use activities offers possibilities for mitigation. Critical activity data (what crops or livestock are managed in what way) is poor or lacking for many agricultural systems, especially in developing countries including South Africa (Tubiello et al., 2012). In South Africa, as is the case with most developing countries, there is a scarcity of data on GHG sources and sinks (DEA, 2011), to quantify agricultural emissions and reductions using IPCC Tier 2 emissions factors (EFs) (Smith and Conen 2004; Oenema et al., 2005). In addition, most of the currently available methods for quantifying emissions are often too expensive or complex, and also not sufficiently user friendly for widespread use (Olander *et al* 2013). Consequentially, there is no reliable information on the agricultural GHG budgets at the farm level.

1.1.2 Research questions of the study

a) In Tshiame Ward, what are the emission factors for GHG emissions from agricultural sources at farm level?

b) What are the estimates for the GHG emissions from the agricultural activities practiced in different parts of Tshiame Ward?

c) Within Tshiame Ward, how can GHG emissions from the agricultural sector be mitigated?

1.2 Research aim and objectives of the study

1.2.1. Aim of the study

The aim of this research study is to estimate GHG emissions resulting from agriculture in the Tshiame Ward. The importance of this research is to assess GHG emissions in agricultural farms for purposes of developing mitigation options.

1.2.2 Objectives of the study

a) To estimate the emission factors for the agriculture GHG sources at farm level in the Tshiame Ward.

b) To estimate the GHG emissions from the agriculture in different parts of the Tshiame Ward.

c) To investigate potential mitigation options that can reduce GHG emissions in the agriculture sector within Tshiame Ward.

1.3 Motivation of the study

The anthropogenic GHG emissions should be estimated to provide advice and emission trends to decision makers in order to improve policy-relevant knowledge. Comparing the previous and current GHG emission trends is a crucial step for both science and emissions reduction policies (Tubiello et al., 2015). In addition, trends will also help in assessing progress in reducing the anthropogenic GHG emissions. Accurate measurements of GHG emissions also assist in improving the classification of anthropogenic climate forcing, resulting in a more profound understanding of climate change while also raising awareness and providing support for national action via policy instruments. However, climate change is a worldwide issue and successful potential mitigation options do require the concerted efforts of many governments (IPCC, 2007).

Agriculture is the major source of emissions in many developing countries (Olander et al., 2013), and agriculture contribute approximately 30% of total global anthropogenic emissions (Vermeulen et al. 2012). Most studies attribute 10-35% of all global anthropogenic GHG emissions to agriculture (Denman et al. 2007, EPA 2006, McMichael 2007, Stern 2006). Providing food security while at the same time reducing GHG emissions from agriculture to mitigate climate change will be a major challenge with a global population predicted by some sources to reach 9 billion by 2050 (Godfray et al. 2010). Therefore, better quantification and reporting capacity is needed for tracking emission trends and managing viable mitigation responses (Hansen et al., 2012). Improved estimation of GHG emissions and their evolution are needed to evaluate mitigation strategies (Houghton et al., 2012; Hansen et al., 2012). However, determining mitigation potential strategies requires an understanding of current emission trends and the influence of alternative land use and management practices on future emissions (Colomb et al., 2013). Smallholder farmers will receive benefits for GHG mitigation based on the adoption of sustainable agricultural and management practices (Seebauer, 2014).

On a smaller scale, researchers suggested that management practices aimed at environmental sustainability in agriculture are similar to those required to reduce agricultural GHG emissions at farm level (Janzen, 1999). On-farm GHG estimation surveys promote the exchange of information based on farmers' experience on management practices and assessing mitigation options. Paustian et al. (2013) noted that, there is a growing research demand for integrated assessment of GHG issues on farms. Farm scale GHG emissions data are needed for various purposes, such as guiding national planning for low emissions development and ensuring sustainable agricultural practices. Such data also informs consumer's choice with regard to reducing their carbon footprints and supporting farmers in adopting farming practices that reduce emissions (Olander et al., 2013 and Tubiello et al., 2013). Furthermore, field sampling can be costly especially for large areas (Olander et al., 2013). However, when moving to a smaller scale, lack of local activity data and relevant emission factors can reduce accuracy, therefore, estimation at farm scale can help aggregate changes in emissions across diverse land uses and enhance flexibility in mitigation options

(Olander et al., 2013). Farm GHG EFs will also help improve the country's annual GHG inventories in order to submit precise and regularly updated inventories to the UNFCCC as part of the Kyoto protocol.

1.4 Design of the study

The research design adopted in this study provides the scope for organizing the quantification of GHG study from the initial identification of objectives, through planning and implementation of fieldwork, data management and analysis, to reporting outcomes and promoting full and effective use of the outputs of the study. The design contains five sections (Figure 1.1): Chapter 1 sets out the conceptual and theoretical background to the practical guidance presented in other studies made on quantification of agricultural GHG emissions. This is followed by Chapter 2, provides an overview of the principles and methods for agricultural activity data collection and of the constituent elements of GHG emissions characterization. Chapter 2 also covers the descriptions and the background literature on how emission factors were calculated and how the emissions were estimated. In chapter 3, the focus shifts to the preparatory activities for GHG quantification, it describes the methodology. The tasks of collecting background information and clarification of the objectives of the study are undertaken. Chapter 3 describes the data collection activities from agricultural source categories. Chapter 4, provides the results and the discussions. It describes data management (including checking data quality, data entry and processing), as well as data analysis, including a discussion of the resources and statistical packages used and the critical steps followed in the process of analyzing and interpretation of results. Chapter 5 provides the conclusions of the study and the recommendations.

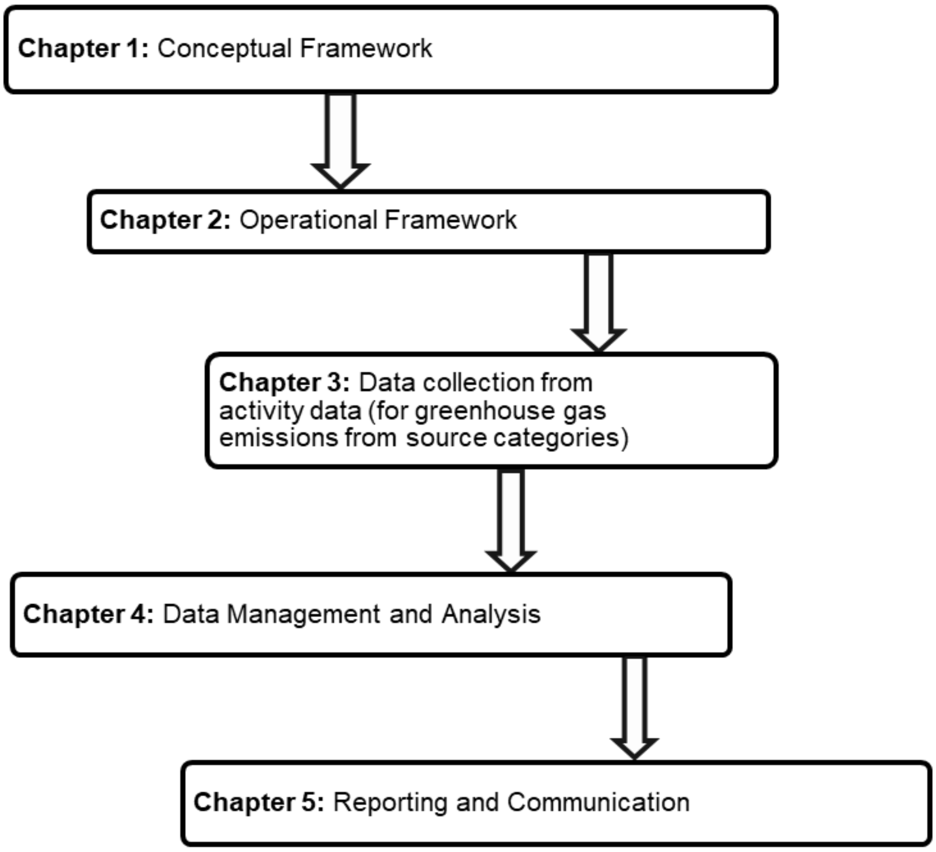

Figure 1.1 Design of the study

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The major GHGs emitted into the atmosphere through human activities are CO_2, CH_4, N_2O and fluorinated gases (Smith et al., 2008; Lokupitiya and Paustian, 2006). Globally, CH_4, N_2O and CO_2 are considered to be the most important GHG emitted from agriculture (Cole et al., 1997; Huffman, 2010; IPCC 2001; Paustian et al., 2004; Smith et al., 2007; Smith et al., 2010). In South Africa CO_2 is the most significant of the three main GHGs (CO_2, CH_4, and N_2O). CO_2 emissions increased by 24.3% between 2000 and 2010, however, the energy sector was the most contributor to CO_2 emissions in South Africa with 89.1% contribution between 2000 and 2010 (DEA, 2014). Globally, agricultural CH_4 and N_2O are the main agricultural GHG emissions and have increased by nearly 17% from 1990 to 2005 (US-EPA, 2006; Smith et al., 2008).

GHGs vary in their ability to absorb and hold heat in the atmosphere, for example, N_2O absorbs 270 times more heat per molecule than CO_2, and CH_4 absorbs 21 times more heat per molecule than CO_2 (IPCC, 2014). Emissions of non-CO_2 GHGs contribute significantly to radiative forcing since they are more effective at trapping heat than CO_2 (IPCC, 2007). However, CO_2 contributes the most, since its level in the atmosphere is the highest (Massey and Ulmer, 2010). A common measure, termed the global warming potential (GWP), is used to equate the effect of different GHGs on a mass basis (Forster et al., 2007). By convention, the effect of CO_2 is assigned a value of one (1) and the GWP of other gases are expressed relative to CO_2-eq basis as a standard (IPCC, 2006; Ramaswamy et al., 2001).

Different types of GHGs have different impacts on the climate, depending on such factors as how much of the gas is produced, how long it stays in the atmosphere, and how much heat it traps (Scialabba and Muller-Lindelauf, 2010). GHG emissions and their effect on the environment is now a national and international issue (Rots et al., 2010). Among other sectors agriculture, forestry and other land use (AFOLU) presents a unique challenge to the inventory compilers, especially from developing countries, due to the lack of national data in most developing countries (DEA, 2014; FAOSTAT, 2014). It is also a challenge in modelling agricultural emissions at farm level due to lack of specific farm data (Keller et al., 2011). Dave et al., (2012), also concluded that the GHGs from agriculture are difficult to measure due to shortage of activity data for sources. The availability of activity data for compiling the national GHG inventory continued to be a challenge in South Africa (DEA, 2014).

Vermeulen et al. (2012) reported that food systems contribute 19-29% of global anthropogenic GHG emissions since crop and livestock farming are responsible for a significant fraction of GHG emissions (Tubiello et al., 2013). The underlying cause for an increase in GHG emissions is perceived to be an ever increasing demand for agricultural products due to a growing population (Alexandratos and Bruinsma, 2012). Crop, dairy and beef production caused emissions were estimated to increase on an average of 2.2% to 6.4% annually from 1961 to 2010 FAO (2012). However, Godfray et al. (2010) predicted that the global population will reach 9 billion by 2050. Population growth will lead to a high demand of food consumption and this will consequently lead to an increased GHG emissions (FAO, 2011), unless there is an improvement in production management practices. Therefore, it is important to study and examine the management practices for crop and livestock farming as a whole farm rather than quantifying GHGs from one component in a farm (Stewart et al., 2009). GHG quantification is essential for emission reductions and the opportunity for mitigation in agriculture is thus significant, and, if realized, would contribute to making this sector carbon neutral and GHGs will be minimized (Olander et al., 2013).

South Africa has a large extent and intensive management system of agricultural lands and because of that, it has a significant impact on GHG emissions (Stern, 2006). South Africa was also reported as one of the world's most carbon-intensive economies contributing to 1.49% of the total global emissions and a bigger emitter of CO_2 than all other Sub-Saharan African (SSA) countries combined (Du plooy and Jooste, 2011). However, the contribution of agricultural GHG emissions from a country depends mainly on the structure of the economy (Van der werf et al., 2009). In South Africa, production activities that use large quantities of coal or electricity and the transportation sector generate the most CO_2 emissions than all other sectors (Stern, 2006). Furthermore, the agriculture sector's direct contribution of less than 5% to gross domestic product (GDP) and 13% to employment appears low but increases to 12% and 30% respectively when agribusinesses income and labour are included (DAFF, 2010).

2.2 Greenhouse effect

Greenhouse effect is the phenomenon whereby the earth's atmosphere traps solar radiation, caused by the presence in the atmosphere of GHGs that allow incoming sunlight to pass through but absorb heat radiated back from the earth's surface (Turner et al., 2007). GHGs effectively absorb thermal infrared radiation, emitted by the Earth's surface, by the atmosphere itself due to the same gases, and by clouds (IPCC, 2007).

The greenhouse effect is primarily a function of the concentration of water vapor, CO_2, CH_4, (N_2O), and other trace gases in the atmosphere that absorb the terrestrial radiation leaving the surface of the Earth (IPCC 2013). Changes in the atmospheric concentrations of these GHGs does alter the balance of energy transferred between the atmosphere, space, land, and the oceans (NRC, 2001). Therefore, GHGs in the atmosphere keep the earth warm through the greenhouse effect (Metz et al., 2005, IPCC, 2013). Figure 2.1 below illustrate how the process of greenhouse effect takes place.

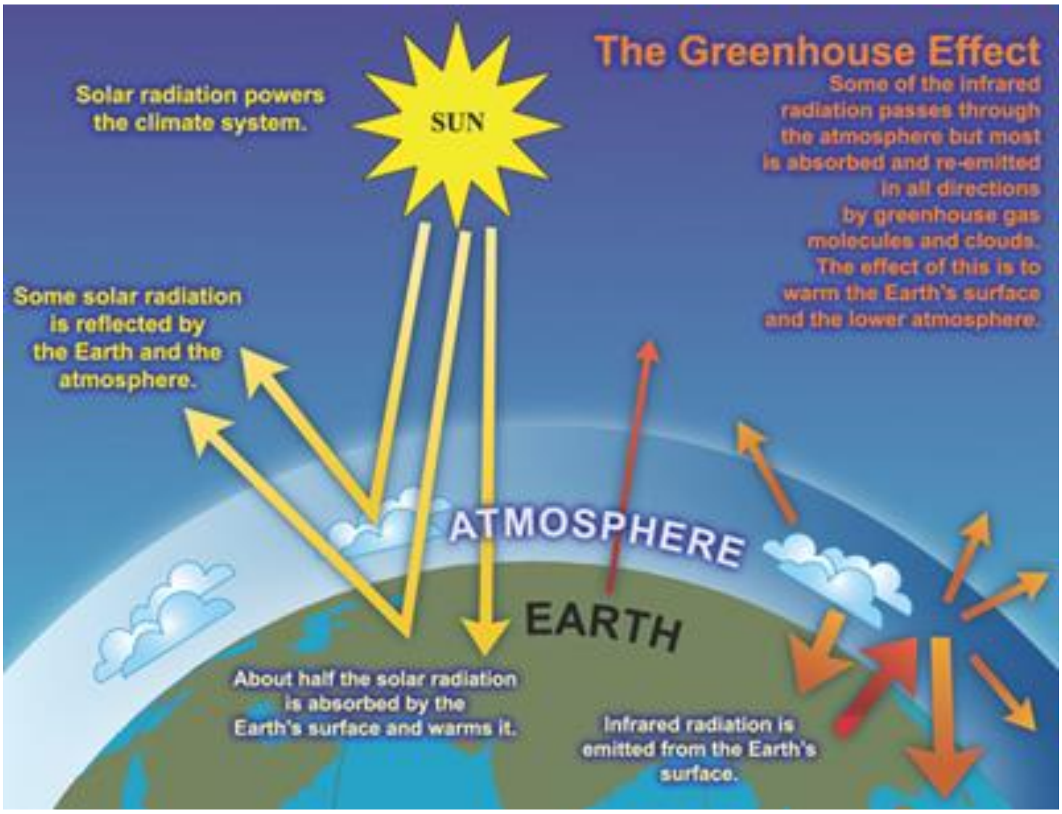

Figure 2.1 A simplified model of the greenhouse effect (IPCC, 2007, 115)

Energy radiated by the sun is converted to heat when it reaches the earth's surface. Some of the heat is reflected back through the atmosphere, while some is absorbed by atmospheric gases and radiated back to earth (Lockwood, 2009). Solar energy, mostly in the form of short-wavelength visible radiation, penetrates the atmosphere and is absorbed by the Earth's surface (UNFCCC, 2005). The heated surface then radiates some of that energy into the atmosphere in the form of longer-wavelength infrared radiation (Aldy, 2006). Although some of this radiation escapes into space, much of it is absorbed by GHGs in the lower atmospheres, which in turn re-radiate a portion back to the Earth's surface (Hovi and Holtsmark, 2006).

The physics of the greenhouse effect are similar for all GHGs; however, they differ in their overall effect on the earth's radiation balance, depending on the concentration of a gas, its residence time in the atmosphere, and its physical properties with respect to absorbing and emitting radiant energy (Keller et al., 2011; Le Treut et al., 2007). Increased concentrations of GHGs in the atmosphere has contributed to an increase in the global surface temperature (IPCC, 2001a). GHGs have the ability to trap heat over a given period of time (Forster et al., 2007). However, the intensification of greenhouse effect due to increased levels of GHGs in the atmosphere is considered the main contributing factor to global warming (IPCC, 2007). This is because human activities such as agricultural practices that produce GHGs modify the earth's energy balance between incoming solar radiation and the heat released back into space, resulting in climate change (EPA, 2010).

2.3 Climate change

The IPCC defines climate change as any variation in climate over time whether due to natural variability or as a result of human activity (IPCC, 2007). Furthermore, it is a long-term shift in the statistics of the weather (including its averages), e.g. change in climate normal (expected average values for temperature and precipitation) for a given place and time of the year, from one decade to the next (IPCC, 2012; NOAA, 2007; OECD, 2011). The Earth's climate has varied considerably in the past, as shown by the geological evidence of ice ages and sea-level changes, and by the records of human history over many hundreds of years (Taylor, 2001). However, climate changes prior to the Industrial Revolution in the 1700s is explained by the natural causes, such as changes in solar energy, changes in ocean currents, volcanic eruptions, natural changes in GHGs concentrations and other natural factors (IPCC, 2007 and 2014; Taylor, 2001). Though, climate changes since 1950 cannot be explained by natural factors, and can only be explained by human factors (Huber and Knutti, 2012). In addition, recent rapid increases of GHG emissions are thought to have resulted due to the anthropogenic GHG emissions (IPCC, 2007; 2014; UNFCCC, 2012). The IPCC (2001, 2007; 2013; 2014) also concluded in their assessment reports with the compelling scientific evidence that the activities of human activities are responsible for changing the earth 's climate (Figure 2.2).

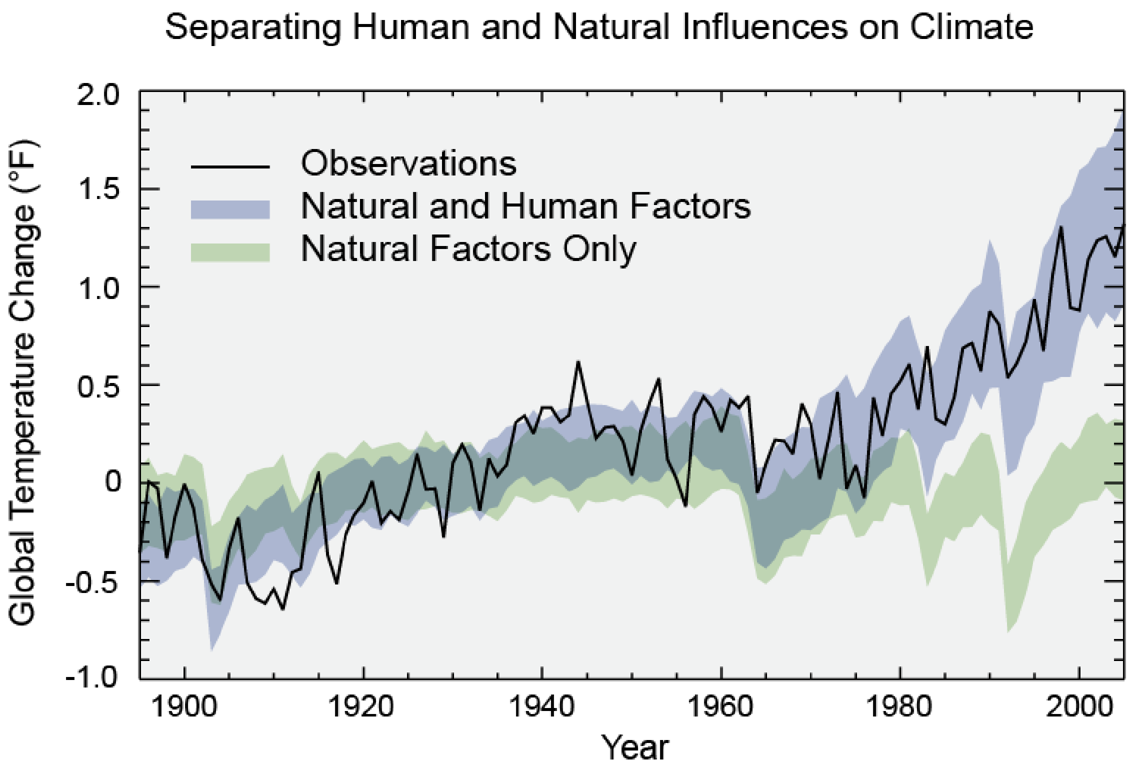

Figure 2.2 Separating human and natural influences on climate (Walsh et al., 2014, 803)

Figure 2.2 illustrate the factors of climate change including the natural and human factors. The atmospheric concentrations of the main GHGs (CO_2, CH_4, and N_2O) long term, for 2000 years have increased since the industrial era (around 1750) due to human activities (IPCC, 2007; Parry *et al*., 2007). The results are presented on (Figure 2.3) expressed in parts per million (ppm) or parts per billion (ppb) with the number of molecules of GHGs in an atmospheric sample given per million or billion air molecules, respectively. These gases accumulated in the atmosphere with increasing concentration over time (IPCC, 2007). The concentration has increased gradually during the industrial era (Figure 2.3).

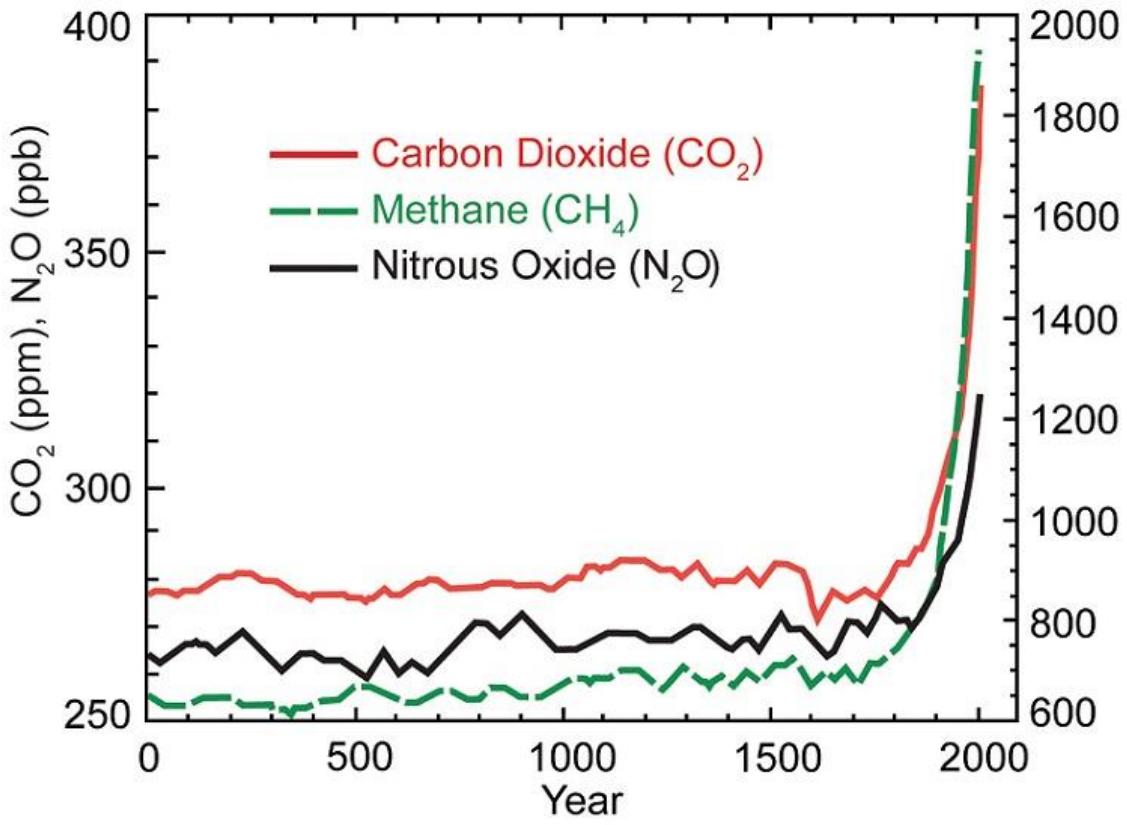

Figure 2.3 Concentration of GHGs CO_2, CH_4 and N_2O from the year 0 – 2000 (IPCC Forth Assessment Report: Climate change 2007; Parry *et al*., 2007).

The fifth assessment report of the IPCC (2014) recently concluded that GHG emissions from human activity between 2000 and 2010 were the highest in history, contributing to levels in the atmosphere record in at least 800.000 years. As the levels of GHGs rise due to natural and manmade causes, more heat is trapped and global temperatures increases (IPCC, 2007; Rotz et al., 2010). The global average temperature increased by 0.6 to 0.9 °C (degrees Celsius) between 1906 and 2005 and the rate of temperature growth has nearly doubled in the last

50 years (IPCC, 2007). Therefore, the earth‘s surface temperature would have been - 18° C if there were no trace of atmospheric GHGs (IPCC, 2007).

The IPCC (1990) projected the global temperature increasing simultaneously with the concentration of GHGs during the period of 1990 to 2010, however, their projections (IPCC, 1990) were consistent with the observed global temperatures (IEA, 2011; USGS, 2012; WSA, 2012; NOAA, 2012) (Figure 2.4).

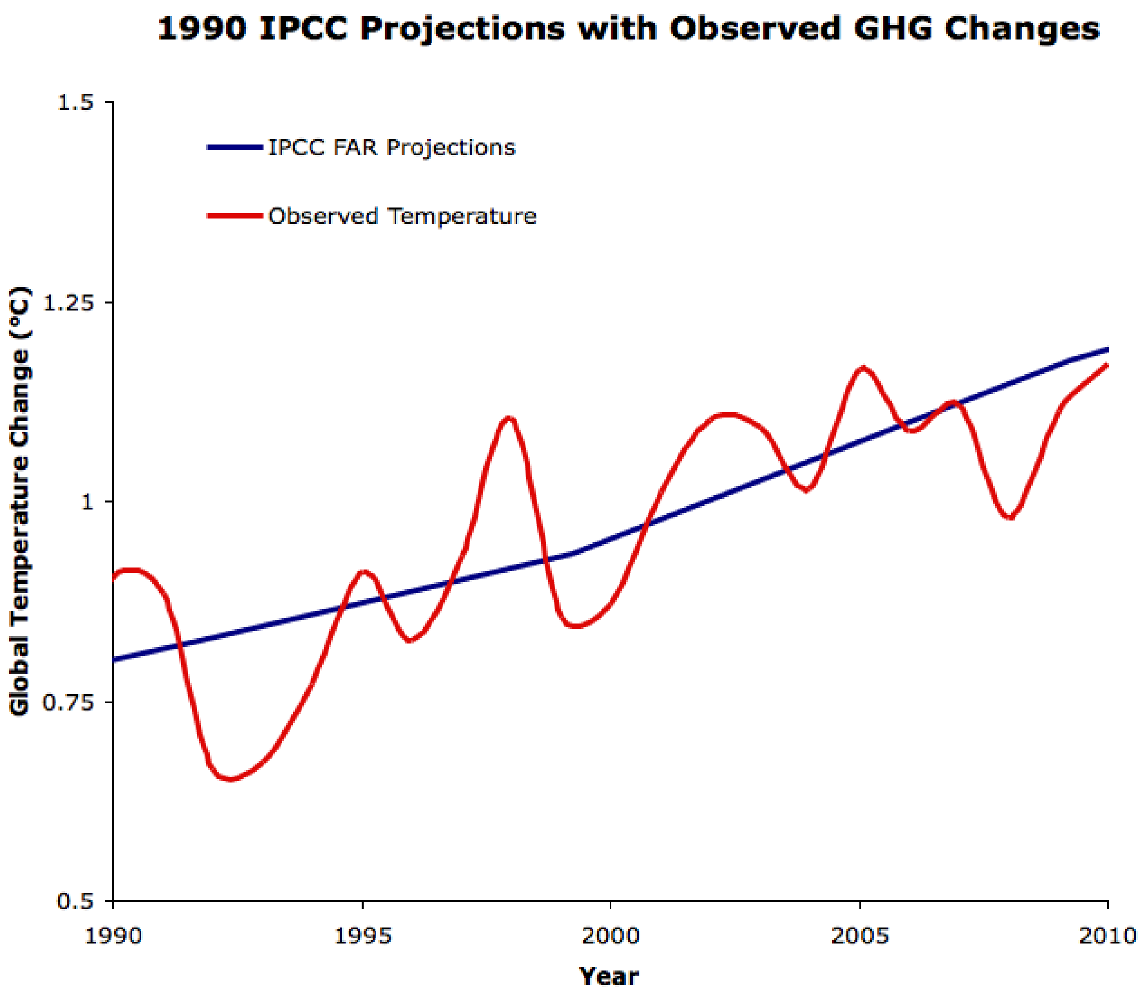

Figure 2. 4 The 1990 projections with the observed GHG changes (IPCC, 1990; IEA, 2011; USGS, 2012; WSA, 2012; NOAA, 2012).

Continued GHG emissions will cause further warming and long-lasting changes in all components of the climate system (IPCC, 2014). The IPCC (2014) recently reported further climate change to be certain in the coming decades regardless of future emissions. Therefore, the world is expected to experience further warming. The UNEP (2007) stated that the major impacts and threats of global warming are widespread. The IPCC (2007) added that, climate change occurs on a global scale, but the ecological impacts are often local and vary from place to place.

Globally, the year 2014 was the warmest year since the record began in 1880, though there were no EL Nino conditions, which would have caused higher temperatures (IPCC, 2014; NOAA, 2015). According to the fifth assessment report of the IPCC (2014), the effects of anthropogenic GHG emissions have been detected throughout the climate system. In 2007, scientists predicted the warming oceans and melting glaciers due to global warming and that climate change could cause sea levels to rise by 18 to 58 (cm) by the year 2100 (IPCC, 2007). Developing countries are the most vulnerable to climate change impacts due to fewer resources available to adapt socially, technologically and financially (IPCC, 2007).

Africa will become more vulnerable, and extreme weather events are expected to be more frequent and severe with increasing risk to health and life (DEA, 2004; Few et al., 2004; Christensen et al., 2007). In addition, Africa will face increasing water scarcity and stress with a subsequent potential increase of water conflicts as almost all of the 50 river basinsins in Africa are transboundary (Ashton 2002; De wit and jacek 2006). Changes in the amount of rainfall will also affect how crops grow leading to some African countries not having enough food, and many people could suffer from hunger (IPCC, 2007). Under climate change much agricultural land will be lost, with shorter growing seasons and lower yields (Fischer et al. 2002). Agricultural production relies mainly on rainfall for irrigation, therefore, it will be severely compromised in many African countries, particularly for subsistence farmers and in Sub-Saharan Africa.

South Africa would generally also get drier and experience more extreme weather conditions due to global warming (DFID, 2004). In addition, climate change will have a wide range of impacts, including more extreme heat events, fires and drought, more extreme storms, heavy rainfall and floods in South Africa (DEAT, 2004). Many official policy documents in South Africa also openly acknowledged that a large number of sectors in the country are extremely vulnerable to the effects and impacts of climate change (DEA, 2010). For example, agriculture has been identified as the most vulnerable, and thus appropriate for special mitigation and adaptation interventions (Blignaut et al., 2009). Atmospheric scientists also concluded that these impacts will continue and in some cases they will lead to significant risks to agricultural sector which is vital to South Africa's economy (Blignaut et al., 2009; Du Toit et al., 2002).
However, despite the international scientific community's consensus on climate change, a small number of critics continue to deny that climate change exists or that humans are causing it (Begley et al., 2007; Oreskes and Conway, 2010). So far, there has been a lot of interventions internationally and nationally through signing treaties and policy making as well as other interventions (IPCC, 2007 and 2014). Worldwide, many measures have been undertaken to address climate change (IPCC, 2014).

2.4 IPCC Methodology for GHG estimation and assessment reports

The Intergovernmental Panel on Climate Change (IPCC) is the leading international body for the assessment of climate change and was formed in 1988 by two United Nations organizations, the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) (IPCC, 2007), to assess the state of scientific knowledge about the human role in climate change. The IPCC provide information for the public and policy makers concerning climate change issues and publish guidelines and good practices references for GHG accounting (IPCC, 2006). The IPCC also prepares at regular intervals comprehensive assessment reports of scientific, technical and socio-economic information relevant for the understanding of human induced climate change, potential impacts of climate change and options for mitigation and adaptation (IPCC, 2014).

The first assessment report (FAR) of the IPCC was completed in 1990 and it served as the basis for negotiating the United Nations Framework Convention on Climate Change (UNFCCC) (IPCC, 1990). The report was issued in three main sections, corresponding to the three working groups of scientists that the IPCC had established. Working group I (Scientific Assessment of Climate Change), working group II (Impacts Assessment of Climate Change), and working group III (The IPCC Response Strategies) (IPCC, 1990). Each section included a summary for policymakers and this format was adopted in subsequent assessment reports (IPCC, 1990).

The second assessment report (SAR) of the IPCC was published in 1996 and it was an assessment of the available scientific and socio-economic information on climate change (IPCC, 1996). However, the second assessment report was superseded by the third assessment report (TAR) in 2001 (IPCC, 2001a). The IPCC third assessment report (TAR) assessed the available scientific and socio-economic information on climate change. It was the third of a series of assessments. However, it was replaced by the IPCC fourth assessment report (AR4), which was released in 2007 (IPCC, 2007). Climate change 2007, the fourth assessment report (AR4), is the fourth in a series of reports which was intended to assess scientific, technical and socio-economic information concerning climate change, its potential effects, and options for adaptation and mitigation (IPCC, 2007).

The fifth assessment report (AR5) was finalized in 2014 and it provided a clear and up to date view of the current state of scientific knowledge relevant to climate change. It consisted of three working group reports and a synthesis report (SYR) which integrated and synthesized material in the working group reports for policymakers (IPCC, 2014). The outline of the AR5 was developed through a scoping process which involved climate change experts from all relevant disciplines and users of IPCC reports; in particular representatives from governments. Governments and organizations involved in the fourth report were asked to submit comments and observations in writing with the submissions analyzed by the panel (IPCC, 2013).

The IPCC Guidelines also provides the methodology for national and sub-national estimation of emissions (IPCC, 1996; 2006). The IPCC uses the tiered approach (tier 1, 2 and 3) to estimate GHG emissions and a choice of a tier depends on the availability of relevant activity data and indigenous emission factors (IPCC 1996 and 2006; NIES, 2006; Kis-Kovacs et al., 2010). Tier 1 is the basic method, where activity data usually aggregates national statistics and the emission factors are default values representing typical process conditions (IPCC, 2006). In addition tier 1 relies on a universal emission factor combined with activity data. The tier 2 method is more accurate than the tier 1 method and is recommended e.g. for estimating CH_4

emissions for countries with large cattle populations. The key challenge of using IPCC tier 2 method lies on data collection. Generally, collecting data for tier 2 requires a high level of effort (IPCC, 2006; Crutzen et al., 2007; Montzka et al., 2011) and tier 2 utilizes a country-specific emission factor. Tier 3 involves direct measurement or modeling approaches. It was realized by the IPCC that when quantifying emissions from the agricultural sector, tier 3 estimates are rarely available and IPCC emission factor database factors are often employed (IPCC, 2006). Higher tier methodologies are more demanding, in terms of complexity and data requirements as they depend on availability of country-specific information (Bader and Bleischwitz, 2009; Kis-Kovacs et al., 2010). In South Africa agricultural emissions are usually estimated using IPCC Tier 1 mostly, while tier 2 and 3 are rarely employed (DEA, 2011).

2.5 Greenhouse gas (GHG) emissions

The anthropogenic GHGs (CO_2, CH_4, N_2O and fluorinated gases) generally originate from various sources of several sectors and the IPCC (1990, 1996, 2001, 2007 and 2014) assessment reports categorized those sectors into energy supply, transport, buildings, industry, solvent and other product use, agriculture, forestry and waste management, and others. The GHG emission sectors are described on table 2.1 below.

Table 2.1 Description of the anthropogenic GHG emission sectors by the IPCC (2014)

SECTORS	**DESCRIPTION OF ACTIVITIES INCLUDED**
ENERGY SUPPLY	Total emission of all GHGs from stationary and mobile energy activities (fuel combustion as well as fugitive fuel emissions).
TRANSPORT	The total GHGs emissions from the combustion of fuel for all transport activities
INDUSTRIAL PROCESSES	Emissions within this sector comprise by-product or fugitive emissions of GHGs from industrial processes. Emissions from fuel combustion in industry should be reported under Energy.
BUILDINGS	Total emissions from residential and commercial (including institutional) buildings, often called the residential and service sectors.
SOLVENT AND OTHER PRODUCT USE	This category pertains mainly to non-methane volatile compounds (NMVOCs) emissions resulting from the use of solvents and other products containing volatile compounds.
AGRICULTURE	Describes all anthropogenic emissions from this sector, except for fuel combustion emissions and sewage emissions, which are covered in Energy and Waste modules.
LAND-USE CHANGE & FORESTRY	Total emissions and removals from forest and land use change activities.
WASTE	Total emissions from waste management.
OTHER	Any other anthropogenic source or sink not referred to above

The energy supply sector comprises activities of the primary energy sources including fossil carbon fuels; geothermal heat; fissionable, fertile and fusionable nuclides (UNEP, 2009; EPA, 2014). However, these must be extracted, collected, concentrated, transformed, transported, distributed and stored (if necessary) using technologies that consume some energy at every step of the supply chain, as a result during all this activities GHGs such as CO_2, CH_4, N_2O fluorinated gases are emitted (Sims et al., 2006; IEA, 2014). This also includes all emissions from the energy sector which are directly associated with electricity or heat production, such as fuel extraction, refining, processing, and transportation (EPA, 2014). In addition, the burning of coal, natural gas, and oil for electricity and heat is the largest from these sector for global GHGs (IEA, 2015).

GHG emissions from the industry sector includes emissions from chemical, metallurgical, and mineral transformation processes not associated with energy consumption and emissions from waste management activities (Boden et al., 2013; EPA, 2012 and EPA, 2014). Industrial processes produce GHGs, including hydrofluorocarbons (HFC-23) from the manufacture of (HCFC-22); perfluorocarbons (PFCs) from aluminium smelting and semiconductor processing; sulfur hexafluoride (SF6) from use in flat panel screens (liquid crystal display) and semi-conductors, magnesium die casting, electrical equipment, aluminium melting, etc., and CH_4 and N_2O from chemical industry sources and food-industry waste streams (Duoba et al., 2005). However, emissions from industrial electricity use are excluded and are instead covered in the electricity and heat Production under energy sector (IPCC, 2007). The industry sector also includes GHG emission sources such as the energy-intensive industries, iron and steel, non-ferrous metals, chemicals and fertilizer, petroleum-refining, cement, pulp and paper.

The direct route by which the transport sector contributes to GHGs emissions is through the combustion of fossil fuels (IPCC, 2007). Fossil fuels contain a substantial amount of carbon, and when these fuels are burned in the presence of oxygen they form CO_2, the most extensive GHG by volume (IPCC, 2007; Duoba et al., 2005). The transport sector also contributes small amounts of CH_4 and N_2O emissions from fuel combustion and F-gases from vehicle air-conditioning. Methane emissions range between 0.1–0.3% of percentage of the total GHG emitted for transport sector, while N_2O ranges between 2.0 and 2.8% (IEA, 2014). GHG emissions from the transportation sector contains emissions from the combustion of fuel for all transport activity (IEA, 2014) and it primarily involves fossil fuels burned for road, rail, air, and marine transportation (Boden et al., 2013). About 95% of the world's transportation energy comes from petroleum-based fuels, largely gasoline and diesel (Moorhead and Nixon, 2014).

GHG emissions from buildings sector arise from onsite energy generation and burning fuels for heat in buildings or cooking in homes. However, the emissions from electricity use in buildings are excluded and are instead covered in the electricity and heat production under energy sector (FAO, 2014). The disposal and treatment of waste from buildings sector can produce emissions of several GHGs (IPCC, 1996; EPA, 2012). The major GHG emissions from the waste sector are landfill CH_4 and, secondarily, wastewater CH_4 and N_2O (IEA, 2013). CH_4 is also released during the breakdown of organic matter in landfills (Bogner et al., 2007). The most significant GHG produced from waste management is CH_4 (IPCC, 1996; EPA, 2012). In addition, the other forms of waste disposal also produce other GHGs but these are mainly in the form of CO_2 (FAO, 2014). Even the recycling of waste produces some emissions (although these are offset by the reduction in fossil fuels that would be required to obtain new raw materials) (Boden et al., 2013). In addition, the waste treatment process that involves the combustion of organic substances contained in waste materials or the incineration of fossil carbon results in less emissions of CO_2 (Ackerman, 2000; IPCC, 2001b).

This building sector addresses the GHG emissions for residential and commercial (including institutional) buildings, often called the residential and service sectors (IPCC, 2001b). CO_2 emissions from fossil fuel energy used directly or as electricity to power equipment and condition the air (including both heating and cooling) within these buildings is by far the largest source of GHG emissions in this sector (IEA, 2013). Other sources include HFCs from the production of foam insulation and for use in residential and commercial refrigeration and air conditioning, and a variety of GHGs produced through combustion of biomass in cook stoves (IPCC, 2001b).

GHG emissions from Agriculture, Forestry, and Other Land Use (AFOLU) sector emerge mostly from agriculture (cultivation of crops and livestock) and deforestation. The AFOLU sector does not include the CO_2 that ecosystems remove from the atmosphere by sequestering carbon in biomass, dead organic matter, and soils (Tubiello et al., 2014). Agriculture, Forestry and Other Land Use activities produce GHG emissions by sources as well as removals by sinks, caused by the oxidation and fixation of organic matter via photosynthesis and complex microbial processes associated to human management and disturbance of ecosystems. They comprise non-CO_2 emissions by sources from agriculture, CO_2, CH_4 and N_2O emissions by sources from Forestry and Other Land Use (FOLU), and CO_2 removals by FOLU sink (Tubiello et al., 2014).

2.5.1 Agricultural GHG emissions

In agriculture, GHGs are emitted from various sources which include various agricultural management practices. The largest source of CH_4 emissions from agriculture sector is enteric fermentation (Bull et al., 2005; Chhabra et al., 2009; Eagle et al., 2012; Smith et al., 2007 and Smith et al., 2008). However, agricultural sources of N_2O have probably been substantially underestimated due to incomplete analysis of increased nitrogen flows in the environment (Tubiello et al., 2013). These sources are poorly understood regarding their magnitude and geographic distribution and quantifying net emissions represents a major undertaking (Nelson, 2009; IPCC, 2006). Agricultural science for GHG emission is complicated because agricultural land acts both as a source and a sink for GHGs (Smith et al., 2007).

The IPCC further divided the agriculture sector with several sub-sectors including cropland management, grazing land management/pasture improvement, management of agricultural organic soils, restoration of degraded lands, livestock management, manure management, and bio energy production (IPCC, 2014). Within the AFOLU sector, the GHG emission sources and sinks are disaggregated into several components such as non-CO_2 emissions including enteric fermentation (CH_4), manure management (CH_4 and N_2O), rice cultivation (CH_4 and N_2O), agricultural soils (N_2O), burning of biomass (N_2O); and CO_2 emissions or emission removals such as carbon stock changes in biomass (above- and below-ground biomass, litter, deadwood, harvested wood products) and carbon stock changes in soil organic carbon (SOC) (IPCC, 2006).

Cropland management comprise of all systems used to produce food, feed and fiber commodities, furthermore the feedstock for bioenergy production are also included (U.S. EPA, 2013). However, croplands are used for the production of crops cultivated (close-grown crops, such as hay, perennial crops e.g., orchards and vineyards, and horticultural crops (CAST, 2004). Wetlands can also be drained for crop production, which again is considered a cropland since it is used for crop production. Croplands also include agroforestry systems that are a mixture of crops and trees (Smith et al., 2008). Grasslands are composed of grasses, grass-like plants, forbs, or shrubs suitable for grazing and browsing, included is both pastures and native rangelands (Smith et al., 2008). Grazing land systems include managed pastures that may require periodic clearing, burning, chaining and chemicals to maintain the grass vegetation and native rangelands that requires limited management to maintain but may be degraded if overused (Smith et al., 2008). However, croplands, livestock and grazing land management practices influences GHG emissions (Smith et al., 2008).

Methane emissions from enteric fermentation

Enteric fermentation is the process in which livestock produce CH_4 through digestion (Smith et al., 2008; Chhabra et al., 2009) by ruminant animals (Smith et al., 2008). Ruminant animals consist of the fore-stomach or rumen, and this is the largest component of the stomach where food is stored temporarily before returning to the mouth for chewing (Chhabra et al., 2009). Rumen is characterized as a large fermentation vat where about 200 species and strains of micro-organisms are present (Chhabra et al., 2009). This micro-organisms ferment the plant material consumed by the animal through a process of enteric fermentation (EPA, 1995). The ruminant then chews the cud and when the food is sufficiently chewed it is swallowed and passed to the reticulum (Figure 2.5).

The microbial fermentation breaks down food into soluble products that can be effectively used by the animal (Smith et al., 2008). However, the products of this process provide the animal with the nutrients it needs to survive which make it possible for ruminant animals to maintain on rough plant material. As a byproduct of enteric fermentation CH_4 is produced and is forced out of the body (Gibbs ET AL., 1999). Most of the CH_4 is emitted through an animal's mouth as burbs and belches, whereas some is also emitted while the animal is chewing its cud and some through the lungs. However, a small amount is also produced in the intestine and emitted through the rectum as a flatulence (Ripple et al., 2014). Examples of ruminant animals include Goats, Sheep, Cattle, Antelopes and Buffalos (Smith et al., 2008). Cattle, sheep, and goats are the primary ruminant livestock found in South Africa (Du Toit et al., 2013a, b).

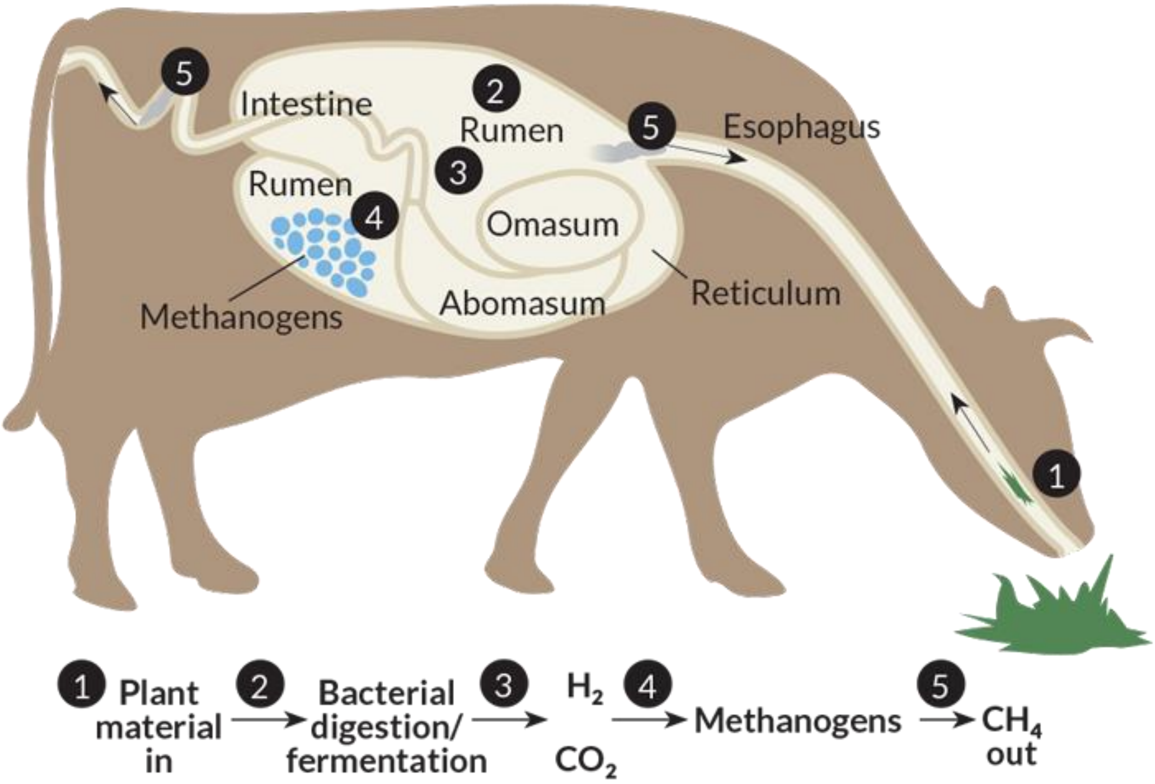

Figure 2.5 The diagram showing the process of enteric fermentation by ruminant animals (adopted from Beil, 2015)

Enteric fermentation is the largest source of CH_4 emissions of agricultural emissions overall in the world (Eagle et al., 2012). Animals with a ruminant digestive system produce more CH_4 per unit of feed consumed than non-ruminant digestive systems for example monogastric, avian, and pseudo-ruminant (Smith et al., 2008). The main difference between ruminants and non-ruminants is that ruminants have a stomach with four chambers that release nutrients from food by fermenting it before digestion, while non-ruminant have a single stomach. Ruminant chew cud and ptyalin is absent in the saliva while non-ruminant do not chew cud and ptyalin is present in their saliva. Most digestion and absorption takes place in the stomach by ruminant animals and ruminants can digest cellulose with the help of cellulase from bacteria while in non-ruminant most digestion and absorption takes place in the ileum and cannot digest cellulose (Chhabra et al., 2009). However, monogastric digestive system has one simple stomach and the stomach secretes acid, resulting in a low pH of 1.5 to 2.5. However, the low pH destroys most bacteria and begins to break down the feed materials. Examples of monogastric animals are hogs, cats, dogs, and humans (Bull et al., 2005).

A pseudo-ruminant is an animal that eats large amounts of roughage but does not have a stomach with several compartments (Boadi et al., 2002). The digestive system does some of the same functions as those of ruminants, for example, in the horse, the cecum ferments forages (Freibauer et al., 2011). Besides horses, examples of pseudo-ruminants are rabbits, guinea pigs, and hamsters (Smith et al., 2008). Pseudo-ruminant 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; IPCC, 2006). Monogastric animals Produce less CH_4 per animal as compared with the ruminants and pseudo-ruminants as less CH_4 producing fermentation takes place in their digestive systems (Bull et al., 2005; IPCC, 2006).

The amount of CH_4 that is released depends upon the type, age and weight of the animal and the quantity and quality of the feed consumed (Reynolds, 2013). The type of digestive system has a significant influence on the rate of CH_4 emission and the livestock fed higher-quality feed produce less CH_4 than those fed low-quality feed (Smith et al., 2008). Feed intake is positively related to animal size, growth rate, and production (e.g., milk production, growth, or pregnancy) (AgDM Newsletter, Aug.2007).

Within livestock, the most prominent source category is enteric fermentation of dairy cows, contributing more than 50 % of the overall agricultural CH_4 emissions in the world (Freibauer et al., 2011). Even if beef cattle represent 50–60% of livestock emissions, this translates roughly into a figure close to 30–35% of all agricultural emissions (UNEP, 2012). The primary reason for high CH_4 emissions is mostly the low quality feed with fibrous contents (De Vries and de Boer, 2010). Heifers emit less CH_4 as compared to non-lactating cows and steers (Boadi and Wittenberg, 2002; Boadi et al., 2002).

Methane emissions from manure management

Methane from animal manure management occurs as a result of manure decomposition under anaerobic conditions through anaerobic digestion (Reynolds, 2013; Smith et al., 2008). Anaerobic digestion occurs when bacteria produce biogas by decomposing organic matter, such as manure without oxygen (Smith et al., 2007). The process consists of four main phases such as hydrolysis, acidogenesis, acetogenesis and methanogenesis involving different microorganism consortia at each step (Figure 2.6) (Gujer and Zehnder, 1983; Demirel, 2005).

Hydrolysis is an extracellular step, while the rest processes are intracellular (biological process) (Batstone et al., 2002). Firstly, the hydrolytic bacteria convert complex particulate matter into dissolved compounds with low molecular weight (Demirel, 2005). In this stage the volatile solids in manure are initially broken down to a series of fatty acids (Ward, 2008). During the hydrolysis process of the polymerized, mostly insoluble organic compounds, such as carbohydrates and proteins, fats are decomposed into soluble monomers and dimers, that is, monosaccharides, amino acids, and fatty acids (Pind et al., 2003; Ward, 2008;Taherzadeh and Karimi, 2008). During solid wastes digestion, only 50% of organic compounds undergo biodegradation (Chandra et al., 2012; Gerardi, 2003). The remaining part of the compounds remains in their primary state because of the lack of enzymes participating in their degradation (Ferrer et al., 2010; Parawira, 2008).

Secondly, the acidongenic or acetogenic bacteria convert the dissolved compounds into organic acids and hydrogen (Gerardi, 2003). Alcohols, for instance ethanol, and volatile fatty acids (VFAs) with more than two carbon atoms are degraded by acetate-forming bacteria with acetate, hydrogen and CO_2 as the main products (Parawira, 2008; Gerardi, 2003). Furthermore, hydrogen and CO_2 are constantly reduced to acetate by homoacetogenic microorganisms (Chandra et al., 2012). The methanogenic bacteria finally consume the acids or hydrogen to generate CH_4 (Parawira, 2008). During this phase, CO_2-reducing and hydrogen-oxidizing methanogens convert hydrogen and CO_2 to producing CH_4, while acetoclastic methanogens utilize acetate to produce CH_4 (De Vrieze et al., 2012). Figure 2.6 depict the four stages of anaerobic digestion of manure (Khanal, 2008).

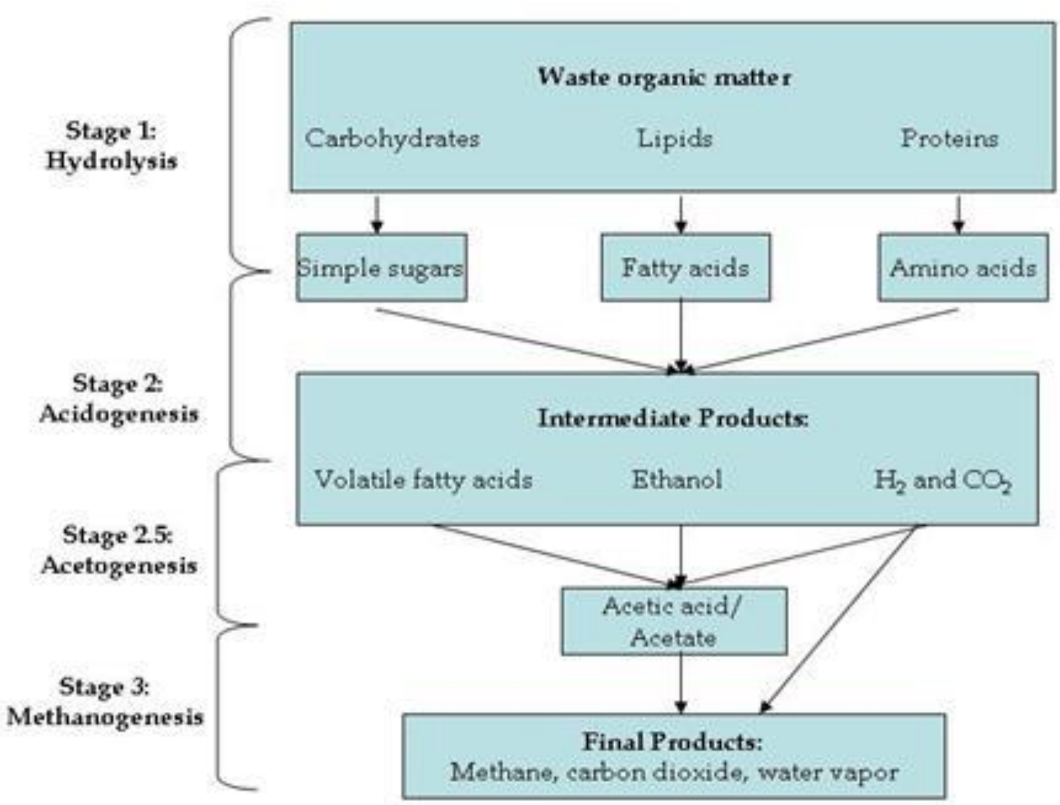

Figure 2.6 Anaerobic digestion of organic matter (adapted from Melanie, 2011)

The CH_4 production potential of manure depends on the specific composition of the manure, which in turn depends on the composition and digestibility of the animal diet (Smith et al., 2007). The management system determines key factors that affect CH_4 production, including contact with oxygen, water content, pH levels, and nutrient availability. The amount of manure produced and the portion of the manure that decomposes anaerobically; also depend on temperature and moisture content (Boadi et al., 2004; Reynolds, 2013). Monteny et al. (2001) indicated that the manure storage temperature and the retention time of the storage has an effect upon CH_4 emissions and this is due to the different types of bacteria which had adapted their activity to different temperature ranges (Sommer et al., 2000). High temperatures preferably between 35°C to 45°C, high moisture level and neutral pH conditions result in high CH_4 production (Boadi et al., 2004; Bull et al., 2005; EPA, 2010). It also depends on the rate of waste production per animal and the number of animals, and the system on how the manure is managed (Eagle et al., 2012). The major problems with the utilisation of manure in the anaerobic digestion process are a high water content (Hamelin et al., 2011) and low biodegradability of animal manure due to a high biofibre content that mainly consists of lignocellulosic material (Knudsen et al., 2004).

Manure stored or treated as a liquid (e.g., in lagoons, ponds, tanks, or pits) decomposes anaerobically and can produce a significant quantity of CH_4 due to moisture content (Jacobson et al., 2000). However, when manure is handled as a solid (e.g., in stacks or piles) or when it is deposited on pastures and rangelands, it tends to decompose under more aerobic conditions and less CH_4 is produced (Monteny et al., 2001).

Nitrous oxide from manure management

N_2O from manure management is produced during the decomposition of nitrogen contained in the livestock waste (IPCC, 2006; USEPA, 1992). N_2O is produced in two ways, directly and indirectly during the storage and treatment of manure (IPCC, 2006; Smith et al., 2008). Direct emissions occur through the processes of nitrification and denitrification while indirect emissions occur through volatilization, leaching and runoff (IPCC, 2006; Bull et al., 2005). Nitrites and nitrates are converted to N_2O and dinitrogen (N_2) during the aerobic processes of nitrification, and the equations below indicate the chemical reactions of the microbial processes for Nitrification and denitrification (IPCC, 2006; Metay et al., 2007; Olander, 2013):

$$Nitrification: NH+\ 4\ +\ O2\ \rightarrow\ H\ +\ +H2O\ +\ NO-\ 2\ NO-\ 2\ +\ O2\ \rightarrow\ NO-\ 3 \quad (2.1)$$

$$Denitrification: NO-\ 3\ \rightarrow\ NO-\ 2\ \rightarrow\ NO\ \rightarrow\ N2O\ \rightarrow\ N2 \quad (2.2)$$

Most of nitrogen in manure is in ammonia (NH_3) form, so nitrification occurs aerobically to converts this ammonia into nitrate (Bremner and Blackmer, 1978; IPCC, 2006), whereas denitrification occurs anaerobically to convert the nitrate to N_2O (Firestone and Davidson, 1989). N_2O production is affected by temperature, pH, biochemical oxygen demand (BOD) which is the amount of dissolved oxygen used by aerobic microorganisms to completely consume the available organic matter, and nitrogen concentration (Sommer et al., 2000). Increasing aeration initiates the nitrification-denitrification reactions, and hence it results to the release of N_2O (Chadwick et al., 2000; Burton and Turner, 2003; Fangueiro et al., 2008; Anon., 2010). Therefore, as fresh dung and slurry is highly anoxic and well-buffered with near neutral pH, N_2O production is expected to increase with increasing aeration (Chadwick et al., 2000; Sherlock et al., 2002; Fangueiro et al., 2008, 2010; Singurindy et al., 2009; Smith et al., 2008). Currently, there is not enough quantitative data to derive a relationship between the degree of aeration and N_2O emissions, and this makes N_2O emissions estimates from this source highly uncertain (Smith et al., 2008).

Volatilization occurs when nitrogen is in the organic form of urea, most commonly from animal manure (Smith et al., 2008). When this happens the nitrogen is changed to ammonia gas (NH_3) and lost into the atmosphere (Smith et al., 2008). This is more likely to take place when soils are warm and moist and the source of urea is near the surface (Chadwick et al., 2000; Sherlock et al., 2002; Fangueiro et al., 2008, 2010; Singurindy et al., 2009). N_2O from manure depends on a large number of variables including organic carbon availability, O_2 partial pressure, soil moisture content, pH, and temperature (Bouwman et al., 1993). High soil pH and high temperatures cause higher rates of volatilization (Engel et al., 2010) since they increase soil concentrations of ammonia dissolved in soil water and warm soil water cannot hold as much ammonia gas (Batstone et al., 2002).

Manure deposited and left on pasture is a major source of N_2O emissions because of its high nitrogen content and N_2O is a by-product generated by the microbial breakdown of nitrogen in soils and manure (Smith et al., 2007). Manure stored for long periods of time generally results in relatively high emissions of N_2O (Moeletsi and Tongwane, 2015). When more nitrogen is added to the soil than is needed, soil bacteria convert the extra nitrogen into N_2O and emit it into the atmosphere (Smith et al., 2007). Lague (2003) noted that there is a needs to be careful management of these systems in order to mitigate N_2O emissions.

Soil nitrous oxide (direct and indirect emissions)

Agricultural soil management practices produce GHGs such as N_2O which as a result contribute to global warming (Omonode et al., 2007). This activities or practices includes application of chemical fertilizers, organic manure and retaining crop residues to soil (Smith et al., 2007). According to the IPCC (2006), emissions of N_2O that result from nitrogen inputs to soils occur through direct and indirect pathways. Direct pathway includes N_2O emission directly from the agricultural managed soils, whereas, N_2O emission through nitrogen leaching and runoff, as well as through volatilization (NH_3, NOx) and subsequent redisposition refer to indirect pathways (Eggleston et al., 2006; Skiba and Smith, 2000; Flechard et al., 2007). N_2O emissions from managed agricultural soils are produced through the microbial processes of nitrification and denitrification after application of nitrogen inputs in soil as shown in Figure 2.7 below.

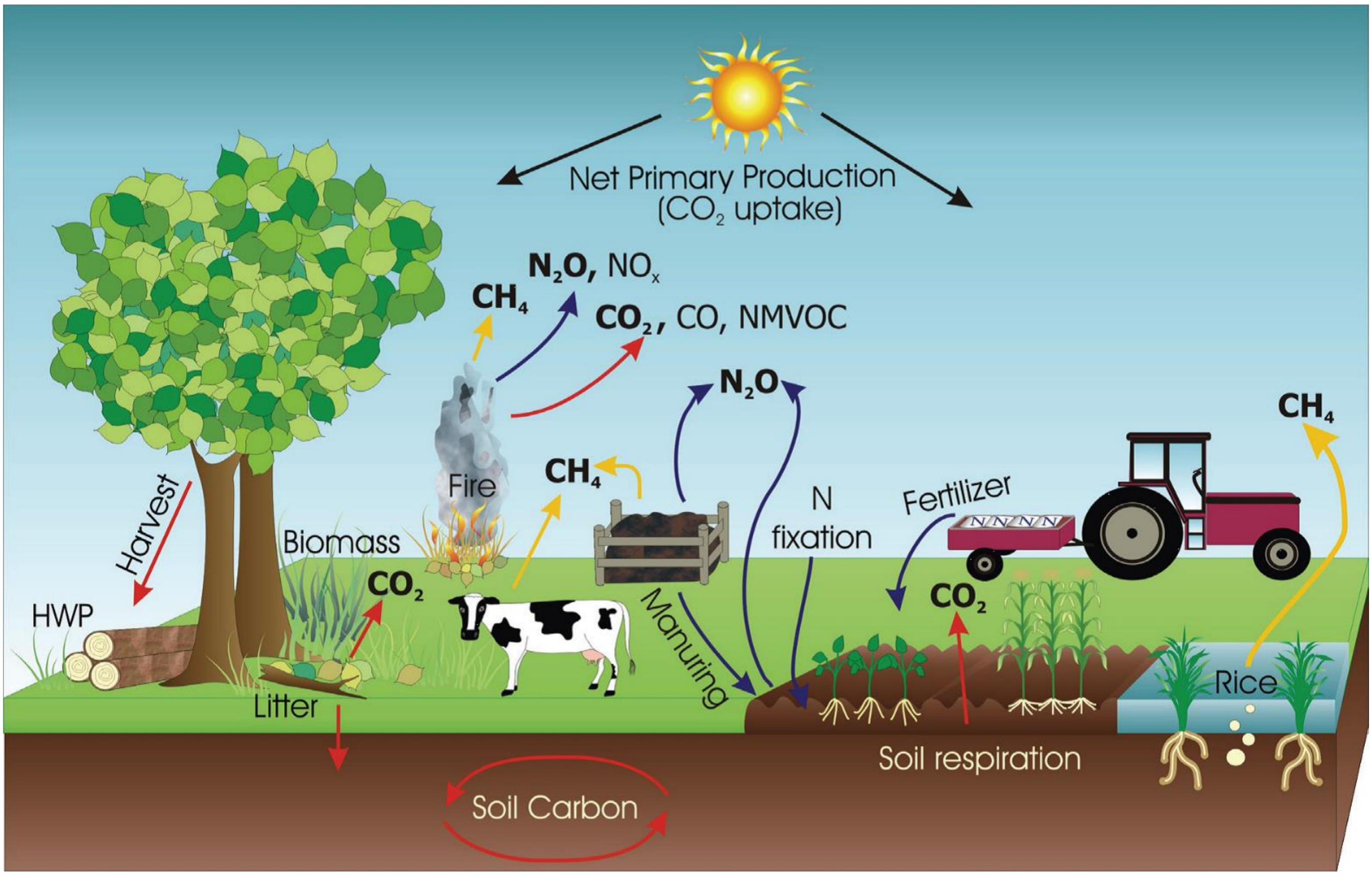

Figure 2.7 The diagram showing the main greenhouse gas emission sources, removals and processes from managed agricultural soil (adapted from IPCC, 2006, page 16)

The microbial reaction as well as the N_2O produced from denitrification is largely influenced by soil properties such as soil temperature, moisture, substrate availability and pH level (FAO, 2001; Velthof et al., 1996). In most agricultural soils, formation of N_2O is enhanced by an increase in available mineral N, which in turn increases nitrification and denitrification rates (Stehfest & Bouwman, 2006). Different processes influencing emissions interact with each other, as well as with the climate and soil making it difficult to predict their overall effect (Baldock, 2012; NRC, 2003; Boehm et al., 2004; FAO, 2011). Moreover, there remains a great deal of scientific doubt about how to control emissions from agriculture, since many factors are at play, such as local climate, soil type, and production practices (FAO, 2011; Batjes, 1992; Batjes and Bridges, 1992). In other words, there is no simple relationship between the quantity of production and emissions (OECD, 2008).

Addition of fertilizer N or manure and wastes containing inorganic or readily mineralizable N, will stimulate N_2O emission, as modified by soil conditions at the time of application (Skiba and Smith, 2000). The large increase in the use of nitrogen fertilizer for the production of high nitrogen consuming crops increases N_2O emissions (Grant et al., 2006; Davidson, 2009; AgDM, 2007; EPA, 2010; Van Groenigen et al., 2010). However, for given soil and climate conditions, N_2O emissions are likely to scale with the nitrogen fertilizer inputs (Soussana et al., 2010).

Residue retention improves soil physical chemical and biological quality (Govaerts et al., 2007; West and Marland, 2002). Retaining crop residue in the soil also improves water use efficiency, decreases soil erosion and temperature, improves soil quality and increases yields (Govaerts et al., 2006, 2007, 2008; Lichter et al., 2008; Lal and Pimentel, 2007). The quantity and quality of residues retained also affect N_2O emissions, legume residues can result in higher N_2O–N losses (Baggs et al., 2000; Huang et al., 2004; Millar et al., 2004) than those from non-legume, low N residues (Aulakh et al., 2001; Millar et al., 2004; Yao et al., 2009). Crop residue decomposition is mainly regulated by climatic conditions, soil nutrient availability and the biochemical composition of the residues, such as lignin and alkaloid contents and C/N ratio (Amado et al., 2003; De Bona et al., 2006).

N_2O production is particularly high in cases where the nitrogen available in soils exceeds that required by plants to grow, which often occurs when nitrogen-rich synthetic fertilizers are applied (Reynolds, 2013). Surplus of nitrogen or excessive rainfall promote nitrogen lost through leaching and surface runoff, producing high N_2O concentrations in the subsurface (Reynolds, 2013). Emissions from leaching and runoff are calculated from leaching-runoff fraction of nitrogen that represents the share of nitrogen losses compared to total applied nitrogen (IPCC, 2006).

The diversity of climate, soil types, and agricultural practices in a particular given farm makes it difficult to define generic scenarios for GHG emissions (Baldock 2012). However, more research has been done during the last few decades to identify and measure the production of GHGs and the changing carbon stocks due to global warming (Shaver et al., 2000; Grace, 2004; and Lal, 2004).

Biomass burning non-CO_2 greenhouse gases

Biomass burning in agriculture comprises the burning of crop and grassland residues and this includes burning of living and dead grasses as well as crop biomass after harvesting (Smith et al., 2007). This also includes the human-initiated burning of vegetation for land-use change as well as natural, lightning-induced fires (Smith et al., 2007). Biomass may also be burned to clear forests for agriculture and grazing, control grass, weeds, and litter, eliminate agricultural waste, and serve as domestic fuels (e.g. wood and dung) (Crutzen and Andreae, 1990; Levine et al., 1995). Biomass burning is a source of GHGs (CO_2, CH_4 and N_2O), and is a source of chemically active gases, including carbon monoxide, non-CH_4 hydrocarbons, and nitric oxide (Levine, 1996). In addition, it releases large amounts of particulates (solid carbon combustion particles) and gases, including GHGs such as CH_4 and N_2O. The IPCC (2006) suggested that only non-CO_2 (CH_4 and N_2O) biomass burning GHGs should be accounted. According to the IPCC guidelines CO_2 emissions from biomass burning for annual crops do not have to be reported, since the carbon released during the combustion process is assumed to be reabsorbed by the vegetation during the next growing season (IPCC, 2007).

Biomass burning has two main phases including flaming and smoldering (Cofer et al., 1990). During the flaming stage, the fuel is well mixed with the surrounding air, and combustion is rapid and more efficient and the products include oxidized gases such as CO_2 and N_2O (Lobert et al., 1991; Laursen, et al., 1992, Ward et al., 1992). Flaming combustion often dominates when grasses burn. Thermal convection and vertical transport can accompany flaming and some smoldering combustion (Hurst et al., 1994). The smoldering stage generally has a lower combustion efficiency and lasts much longer. The products include a larger fraction of reduced gases such as CO, NMHCs, and NH_3 (Lobert et al., 1991; Laursen et al., 1992, Ward et al., 1992) than is the case for flaming combustion. Combustion can also be a combination of the flaming and smouldering phases (Hurst et al., 1994).

Scientists projected that humans are responsible for about 90% of biomass burning with only a small percentage of natural fires contributing to the total amount of vegetation burned (Cole, 1997). The percentage of the agricultural crop residues burnt on-site, which is the mass of fuel available for burning is estimated by taking into account the fractions removed before burning due to animal consumption, decay in the field, and use in other sectors (e.g., biofuel, domestic livestock feed, building materials, etc.) (Smith et al., 2007). The information on the amount of emissions is important for accurate estimates of the environmental impacts of these GHGs (Cole, 1997).

Some studies have reported that biomass burning has increased on a global scale over the last 100 years, and computer calculations indicated that a hotter earth resulting from global warming will lead to more frequent and larger fires (Cole, 1997). Increased emissions in the last decades were largely because of increasing rates of deforestation (Houghton, 1991). The burning of grasslands, savannas, and agricultural lands has increased over the last century since the rarely burned ecosystems, such as forests, have been converted to frequently burned ecosystems, such as grasslands, savannas, and agricultural lands (Houghton, 1991; Levine, 1996). The production of gases and particulates from fires varies with the type of ecosystem burned, the fire's characteristics, and the vegetation's moisture content (DeAngelo, 2006).

CO_2 emissions from the usage of agricultural machinery and tractors

The use of agricultural machinery and tractors produce the GHG emissions through the combustion of fuel, generally diesel fuel since is mostly used for tractors in agriculture (FAO, 2015). During the use of the tractor, the internal combustion of diesel will take place in a tractor engine and the name internal combustion also refers to the machinery gas turbines (Zhao, 2010). The diesel engine is an internal combustion engine in which the ignition of the fuel that has been injected into the combustion chamber is caused by the high temperature which a gas attains (i.e. the air) when greatly compressed (adiabatic compression) (Zhao, 2010). Diesel engines by compressing only the air; increase the air temperature inside the cylinder to such a high degree that it then ignites the diesel fuel in the combustion chamber

(Mitsubishi, 2010). The major part of combustion is controlled by fuel air mixing process and mixing is dominated by flow field formed by fuel jet interacting with combustion chamber walls during injection. Highly luminous flame includes the substantial soot formation in the fuel rich zone by pyrolysis, followed by substantial subsequent oxidation and this lead to the production of CO_2 (West and Marland, 2002). The equation below simple illustrate how CO_2 is formed during the diesel combustion by tractor engine:

$$Fuel + O_2 \rightarrow CO_2 + H_2O \qquad (2.3)$$

The fuel and the oxidizer are reactants, i.e., the substances present before the reaction takes place. Combustion takes place when fuel, most commonly a fossil fuel, reacts with the oxygen in air to produce heat. The heat created by the burning of a fossil fuel is used in the operation of equipment such as boilers, furnaces, kilns, and engines. Along with heat, CO_2 and H_2O are created as by-products of the exothermic reaction.

In agriculture, the machinery and tractors generally use diesel fuel during various activities in production of crops (West and Marland, 2002). Those activities include ploughing, disking, planting, spraying fertilizers or lime and crop harvesting (FAO, 2015). It is a common practice worldwide that when using equipment for spraying pesticides or fertilizer and also harvesting diesel engine tractors are required to pull the machine and to provide power (FAO, 2015).

In South Africa, cultivated crops, more especially maize, wheat and drybeans are highly mechanised and thus are reliant on fossil fuel such as diesel (Marland et al., 2003). Energy use efficient has become an emerging issue for crop farming (EIA, 2015). Quantifying the operational energy costs for different crop production systems through the development of an on-farm energy assessment is fundamental in identifying strategies to reduce energy inputs (Grisso et al., 2004). According to the U.S. Energy Information Administration, the agricultural sector consumed about 69% more diesel than the construction sector in 2013 (EIA, 2015). Energy use efficient is an emerging issue for crop farming (EIA, 2015). Machinery and tractor operations during crop growing season on farm uses more fuel, therefore the ability to predict tractor fuel consumption is very useful for farm budgeting and management and also for reducing GHG emissions (Grisso et al., 2004).

2.5.2 Farm GHG emissions

Agricultural practices at farm level are typically more complex than industrial agricultural practices (Henry et al., 2009). Lack of agricultural GHG emission database at farm level is one of the factors contributing to limited availability of data and the variability in agricultural emissions due to the dynamic nature of farm ecosystems (Henry et al., 2009). Colomb et al. (2013) concluded that at farm level detailed data might be available whereas for larger areas, it will be very hard to obtain the accurate statistics required for GHG assessment. However, Olander et al. (2013) argued that the activity data and emission factors at national level are the basis for smaller scale (e.g farm level) applications. To better target interventions aimed at reducing GHG emissions from agricultural systems, there is a need for information on GHG balances and the GHG intensity of agricultural products (e.g. emissions per unit product) at levels where liveliwood and environmental impacts occur and land management decisions are being made (Vermeulen et al., 2012). However, even for smallholder farming systems where decisions are taken in fields and farms that are usually less than one hectare, this decision scale is substantially greater than the scale at which changes in GHG fluxes take place or are measured (Rosenstock et al., 2013). In local government there are no defined protocols to monitor and report agricultural GHG emissions (SEA, 2017). New data are often collected through farmer knowledge or records and field sampling in order to complement data on national level applications FAO (2009).

Huge differences can occur among farms since agricultural emissions depend on specific farm management practices (Rotz et al., 2010). Many farmers are not familiar with provision of detailed activity data concerning the GHG impact of their systems and practices. Though, it is not unusual for farmers to monitor and hold detailed records of the input and output activity data as it is important for managing the whole-farm nutrient balance and maximizing system productivity, as well as being an important exercise for fiscal management (Keller et al., 2011). As a result, there is no field study that can feasible record all of the data needed for a farm specific GHG emission assessment (NRC, 2003). Rotz et al., (2010) argue that, measuring the assimilation and agricultural GHG on farms is difficult. Thus, there is a shortage of a defined and consistent methodology for GHG emissions quantification to enable comparability from different farm systems and management practices (Keller et al., 2011; Branca et al., 2013). Estimation of GHG emissions at farm level is also relevant as agriculture activities are often interdependent within an area (Milne et al., 2012). At farm level, most activity data can be provided by farmers whereas at national level activity data is based on statistics or expert knowledge (Milne et al., 2013).

Complex interactions occur between the processes undertaken for crop and livestock farming which impact more than one GHG. Therefore, estimating only one GHG ignores those interactions (Robertson and Grace 2004; Gregorich et al., 2005; Schils et al., 2005). No baseline data is available for farm level and consequently this leads to challenges and uncertainties for obtaining agricultural emission data (Henry et al., 2009). Moreover, farmers make decisions based on the entire farm because of the subsequent effect that changes in management practices may have on net farm GHG removals (Collas and Liang, 2007; Stewart et al., 2009). A whole system approach is important for evaluating the practices that best reduce GHG emissions at farm level (Stewart et al., 2009). For farmers or farm managers to be motivated to act on reducing GHG emissions, it is important for them to understand the issue of climate change and also the potential opportunities of reducing GHG emissions (Smith et al., 2007). However, quantification of GHG emissions at farm level in SA is scarce (Devarajan et al., 2009).

2.6 Modeling agricultural GHG emissions

According to Denef et al. (2012), accounting tools for GHGs can be divided into three main categories including calculators, protocols and guidelines, and process-based models. Basically, calculators and protocols use models (process-based and/or empirical models) often in combination with IPCC default values as emission factors (Denef et al., 2012). Globally, a variety of models have been developed to model CO_2, CH_4 and N_2O emissions from agriculture, mostly from countries where agriculture is an important contributor of GHG emissions (Crosson et al 2011), and most models are based on the IPCC guidelines which are developed to assist quantification and assessing GHGs (Denef et al., 2012; Colomb et al., 2013).

Models can be used to scale up measurements and fill data gaps on GHG emission trends (Milne et al., 2012). Consequently, several tools that aim to narrow the farm level GHG data gap were developed (e.g. DNDC and DAYCENT), many of which require a strong firm hold of agri-ecosystem processes for effective use, unlike CALM and CFF carbon calculators which adapted national inventory data into tools for farm use in UK (Keller et al., 2011). Many current models for agricultural emissions fail to take into account the differences in farming practices (Keller et al., 2011). Table 2.2 below shows the differences in the tools to calculate the GHG emissions and their similarities.

Table 2.2 The various tools to estimate the greenhouse gas emissions (Legend: + to ++++; from slowest (>1 month) and most difficult (formal training required) to the fastest (<1 day) and easiest to use)

Calculators/ tools	Speed of assessment	Usability	Purpose	The scope	Scale / extension	Method/ approach	Algorithms	GHG emissions	Availability
Agricultural Land Use (ALU)	+	+	Reporting	Developed for LULUCF and Agriculture Sectors	National Sub-national, Project, & Local/Community level)	Accommodates IPCC Tier 1 methods but allows compilers to advance inventory with the Tier 2 method capability	Based on IPCC methods (1996 & 2006 GL and 2000-2003 GPG)	Estimate CO_2, CH_4 and N_2O	Available for free or after registration
USAID AFOLU	++++	++++	Reporting	Developed for Agriculture, Forestry and Other Land Use	National Sub-national, Project, & Local/Community level)	Accommodates IPCC Tier 1 methods but allows compilers to advance inventory with the Tier 2 method capability	Based on IPCC (1996)	Estimate CO_2	Available for free or after registration
Carbon Benefit Project (CBP)	++	++	Project evaluation	Developed for LULUCF and Land Management	National Sub-national, Project, & Local/Community level)	Accommodates IPCC Tier 1 methods but allows compilers to advance inventory with the Tier 2 method capability	Based on IPCC (1996)	Estimate CO_2, CH_4 and N_2O	Available for free or after registration
Ex-Ante Carbon-	++++	++++	Project evaluation	Developed for Agriculture, Forestry,	National Sub-national, Project, &	Accommodates IPCC Tier 1 methods but	Based on IPCC (2006)	Estimate CO_2	Available for free or

balance Tool (EX-ACT)				Fisheries, & Land Management	Local/Community level)	allows compilers to advance inventory with the Tier 2 method capability			after registration
CALM	+++	+++	Reporting	Developed for Agriculture, land use change and forestry	CALM focuses on the farm activities, not on whole life-cycles	Accommodates IPCC Tier 1 methods but allows compilers to advance inventory with the Tier 2 method capability	Based on IPCC (1996 & 2006)	Estimate CO_2, CH_4 and N_2O	Available for free or after registration
CFF carbon calculator	+++	+++	Reporting	Developed for Grassland, livestock, crops and forests		Accommodates IPCC Tier 1 methods but allows compilers to advance inventory with the Tier 2 method capability	Based on IPCC (1996 & 2006)		Available for free or after registration
Holos	++	++	Project evaluation	Developed for temperate crops, livestock, grassland, agroforestry and crop production	National Sub-national, Project, & Local/Community level)	Accommodates IPCC Tier 1 methods but allows compilers to advance inventory with the Tier 2 method capability	Based on IPCC (1996 & 2006)	Estimate CO_2, CH_4 and N_2O	Available for free or after registration
FullCAM	++	++	Reporting	Developed for crop production,	National Sub-national, Project, &	Accommodates IPCC Tier 1 methods but	Based on IPCC (1996 & 2006)	Estimate change in soil and	Available for free or

				grassland and forest	Local/Community level)	allows compilers to advance inventory with the Tier 2 method capability		biomass C stock change for direct LUC and due to tillage residues	after registration
FarmGAS	++	++	Project evaluation	Developed for crop production, grassland, and livestock production.	National Sub-national, Project, & Local/Community level)	Accommodates IPCC Tier 1 methods but allows compilers to advance inventory with the Tier 2 method capability	Based on IPCC (1996 & 2006)	Estimate CO_2, CH_4 and N_2O	Available for free or after registration

Legend for Table 2.2
Speed of assessment - the rate at which the assessment is able to move or operate.
+ to ++++ - (from slowest (>1 month) and (most difficult (formal training required) to the fastest (<1 day) and easiest to use.)
Usability - is the degree to which a tool can be used by specified users to achieve quantified objectives with effectiveness, efficiency, and satisfaction in a quantified context of use.
Purpose - The aim of the tool.
The scope - the extent of the area or subject matter that something deals with or to which it is relevant.
Scale / extension - this is to explain to what extent the software estimates the emissions on a small scale (farm level) or large scale (national).
Method/ approach - Does the software accommodates IPCC Tier 1 methods or allows compilers to advance inventory with the Tier 2 or Tier 3 method capability.
Algorithms - a process or set of rules to be followed in emission calculations by the tool.
GHG emissions - the estimated greenhouse gas emissions by the tool.
Availability - the availability of the tool, whether is purchased or free.

The IPCC method can be used at regional or small scale (Colomb et al., 2013). Presently, the Tier 3 process-based models are only available for a small number of emission sources and are limited to specific regions (Crosson et al 2011). Colomb et al. (2013) assessed eighteen models and found that models were designed for various aims and to be used in different geographical areas and also use slightly different methodologies. However, methods differ in their cost, sophistication and geographic and temporal coverage (Colomb et al., 2013). Due to high costs, quantifying GHGs will likely incorporate modeling for scaling up and for projection (Conant et al., 2010). Models have an essential role to play in a small scale assessments and GHG quantification (IPCC, 2006; Conant et al., 2010). It was noted that most of these GHG emission models are developed for managing activity data and emissions factors other than developing a sustainable GHG estimates (Colomb et al., 2013). However, other tools have been developed for this purpose e.g. the US-EPA inventory management template workbook for developing a national GHG inventory system (US-EPA 2011).

Many models are from the US, Australia and New Zealand (Milne et al., 2013). In developing countries most models are not used, for example, the Agricultural Land Use (ALU), United States Agency for International Development Agriculture Forestry and Other Land Use (USAID AFOLU) carbon calculator, the Carbon Benefit Project (CBP) simple and detailed assessments and the Ex-Ante Carbon-balance Tool (EX-ACT). Most of the models allow the user to input their own management practices data and emission factors (Milne et al., 2013). The EX-ACT tool has been widely used for large scale assessments of two rural development projects in Brazil dominated by smallholder farmers (Branca et al., 2013). EX-ACT allows the user to analyze any mosaic of land as the inputs and outputs are not spatially explicit. The USAID AFOLU carbon calculator carries out the analysis of specific administrative units, although data for a different scale can be entered by the user (Milne et al., 2013). The CBP's tools allow a more spatially explicit approach as the user can divide a landscape into numerous adjacent sub-units and enter detailed land management information for each of these before carrying out an integrated analysis which gives spatially explicit output (Milne et al., 2013).

Most of those models have not been published in peer reviewed Journals (Turner et al., 2007). However, besides the IPCC based models, there are also the Dynamic ecosystem models. These are also known as the processed based models (Turner et al., 2007). The benefit of using processed based models for scaling purposes is their ability to estimate several measurable variables at the same time (Turner et al., 2007). Moreover, they have shown to decrease uncertainties in estimates, compared to estimations made using the IPCC equations (Del Grosso et al., 2010). Debate exists as to whether the focus should be on measurement or modeling. However, both will be needed, and with appropriate coordination the two approaches can be used to inform and enhance the value of each other (Baldock, 2012).

Models which cover developing countries and those that can be applied at a small scale have been developed for a range of purposes and have different strengths and weaknesses (Milne et al., 2012). However, a number of tools have now been developed that aim to narrow this farm level GHG data gap (Hillier et al., 2011). Orlander et al. (2013) noted that there are common challenges for GHG quantification and in order to understand these challenges it is helpful to assess the existing supporting infrastructure and systems for GHGs quantification. Other models combine measurement at the farm-level with an evaluation of management practice to promote GHG saving changes (Keller et al., 2011). However, some models estimate emissions without the need for a data beyond farmer common knowledge of the interactions between management practices (Keller et al., 2011). Component models for predicting all important sources and sinks of CH_4, N_2O, and CO_2 from primary and secondary sources in dairy production were integrated in a software tool called Dairy GHG model (Rotz et al., 2010). Most models require management inputs and they use a year as the unit of time and a hectare as the unit of area (Kitzes et al., 2008). Almost all models estimate emissions from cropland, livestock farming and also grassland (Kitzes et al., 2008). Also, almost all models account for soil N_2O from fertilizers, enteric CH_4 and manure CH_4 as the major sources (Orlander et al., 2013). Mostly, the results are expressed in tons of CO_2 equivalent per year, per unit area or per unit of production and some models use several units to associate the emissions with the production (Rotz et al., 2010).

A comparison of the estimations using various models is limited by differences between the scopes for each model (Conant et al., 2010). It is difficult to give a precise estimates of the time necessary for each model, because models are dependent on the level of accuracy and reliability and availability of the data required (Conant et al., 2010). Validation of most models is not possible because any approach of calculating GHG emissions is just an estimation (Rotz et al., 2010). The measurement, reporting and verification of GHG emissions are important for management and mitigations because it quantifies emission rates and provides the baseline data (Del Grosso et al., 2012). Nevertheless, measurements are an essential element of GHG assessments at any scale (Conant et al., 2010). Developing countries such as South Africa and Chile adapt some of the models and are also developing their own models for some sectors, except the agriculture sector (Winkler et al., 2014). At the farm level, complex models appear to be the best method to quantify the management impacts on emissions because extensive measuring is too expensive and simple models are not reliable at this scale (Del Grosso et al., 2012). But the ability of the models to represent how available land management options interact with environmental conditions to control soil GHG emissions is incomplete (Del Grosso et al., 2012).

Many recent models have been developed to estimate the farm GHG balance (Schils et al., 2007). Most models have used fixed emission factors both for indoor and outdoor emissions e.g. FARM GHG, (Olesen et al., 2006, Lovett et al., 2006). Moreover, as static factors are used rather than dynamic simulations, the environmental dependency of the GHG fluxes is not captured by these models. A dynamic farm-scale model (FarmSim) has been coupled to mechanistic simulation models of grasslands (PASIM, [Riedo et al., 1998; Vuichard et al., 2007]) and croplands (CERES ECC). Therefore, C sequestration by grasslands can be simulated (Soussana et al., 2004) and is included in the farm budget.

Models are available for most activities to be assessed in every part of the world. The accuracy level is still restricted but active research is on going and most model developers are frequently updating their models. There is a lack of homogeneity in methodologies; therefore, it is impossible to do a straight comparison between studies done using different models. Indeed all models refer to IPCC but this does not ensure homogenous approach as IPCC provide a general framework including many methodologies with different levels of details. Only detailed comparative study would enable to evaluate precisely the variability of results depending on the calculator.

CHAPTER 3: MATERIALS AND METHODOLOGY

3.1 Introduction

This chapter explains how the study was conducted, including data collection and analysis. The aim of the study was to estimate GHG emissions resulting from agriculture on selected farms in Tshiame Ward, in Maluti - a - Phofung municipality of the eastern Free State Region of South Africa. The study was the first step towards investigating the potential mitigation options that can reduce GHG emissions at farm level in the region.

3.2 Study area

The study was conducted at different selected farms in the Tshiame Ward of Maluti- a - Phofung municipality (Figure 3.1(a) and (b)). The main agricultural activities undertaken in Tshiame Ward include mixed farming, comprising both livestock and crop farming. Tshiame Ward has high agricultural potential with adequate land and suitable growing conditions for crops such as maize, wheat, and dry bean. Farm boundaries are shown in Figure 3.2. Various soil types were recorded on different farms, including sandy soil, sandy loam soil, loam soil, clay soil, and clay loam soil (ARC, 2014).

3.2.1 The map of the study area

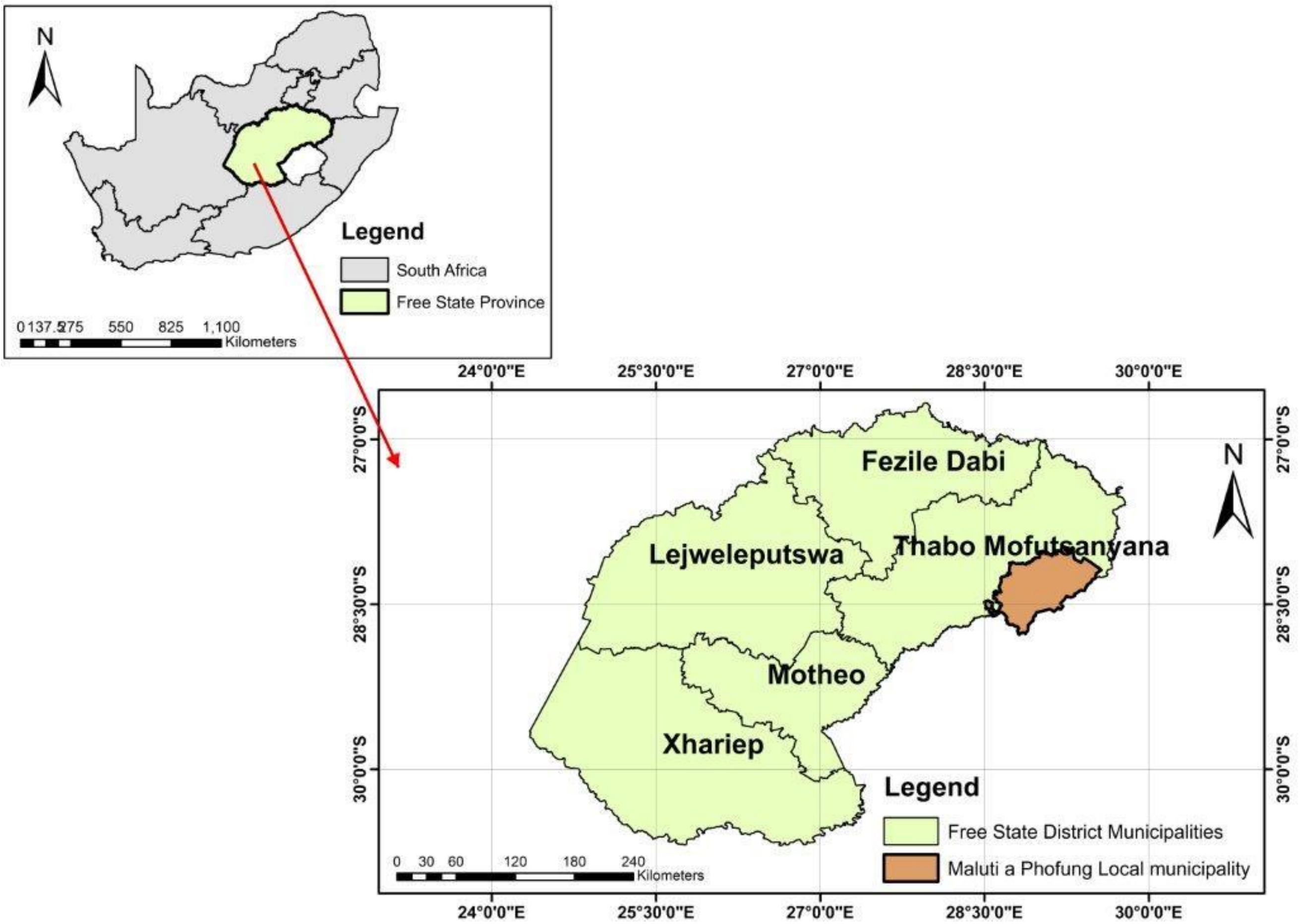

Figure 3.1 (a) The map of the study area

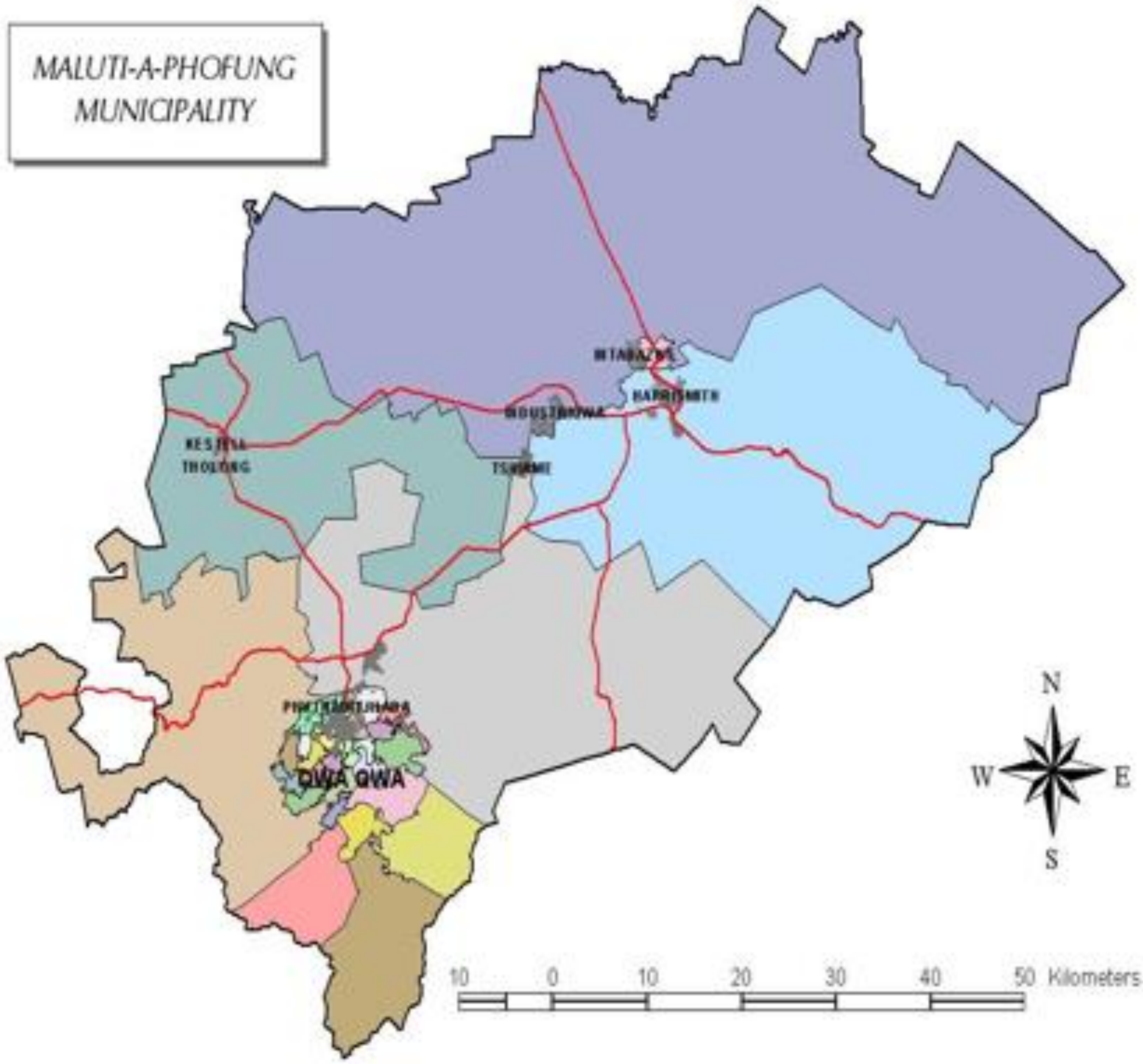

Figure 3.1 (b) The map showing Tshiame in Maluti - A - Phofung municipality

The map below (Figure 3.2) represent the farm boundaries of the sixteen selected farms.

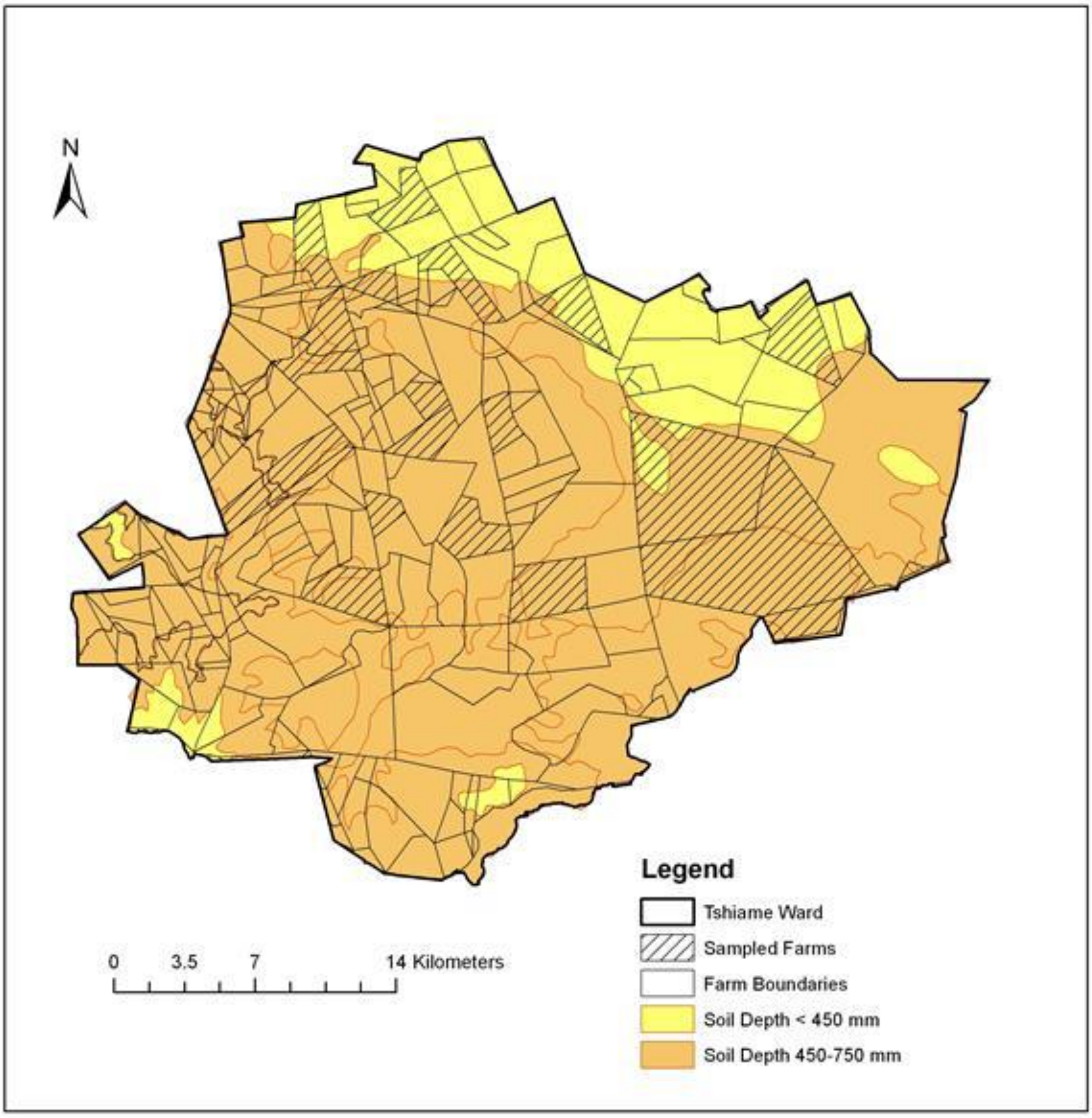

Figure 3.2 The farm boundaries

Tshiame Ward experiences hot weather in summer, but it can also be very cold in winter. Heavy frost and snow are often recorded along mountainous eastern part of the ward (Moeletsi et al., 2016). Tshiame Ward experiences four seasons: Summer (December, January, February), autumn (March, April, May), winter (June, July, August), and spring (Sep, Oct, Nov). Figure 3.3 (a-b) presents a summary of the climatic conditions that prevail in Tshiame Ward. The graphs are based on the data averaged for the period between 1995 and 2014.

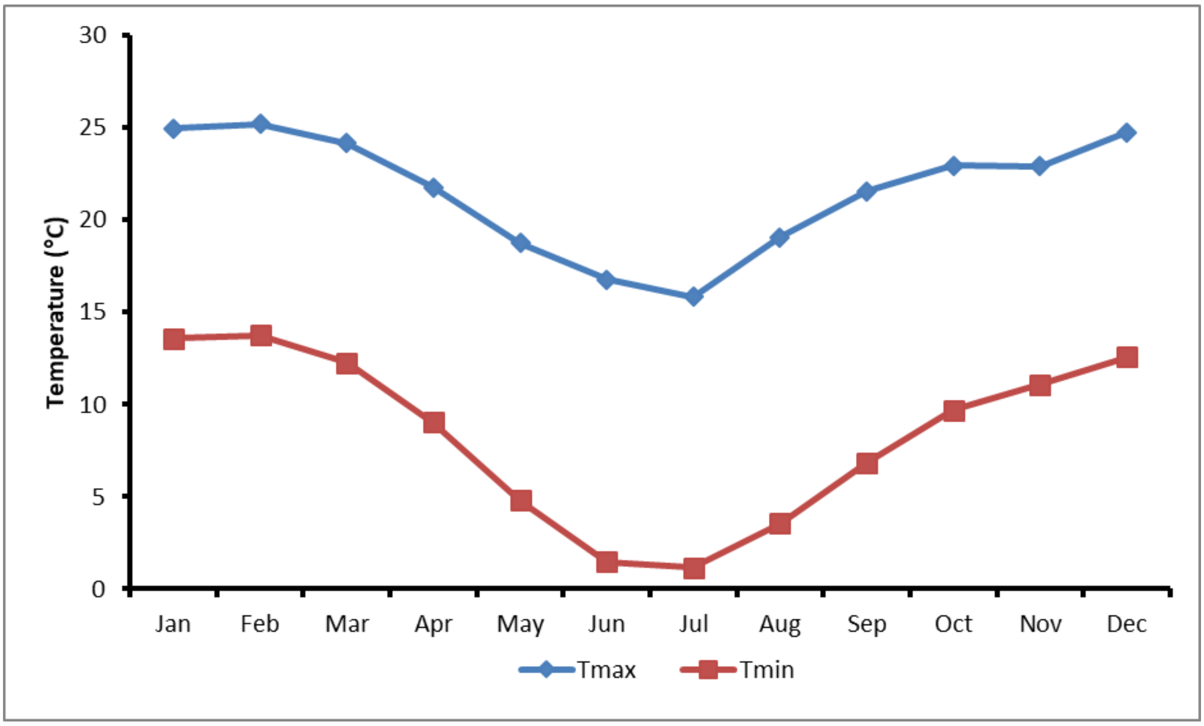

Figure 3.3 (a) Average monthly temperature for Tshiame Ward (blue line) maximum temperature and (red line) minimum temperature for the study area (Data source: ARC, 2014)

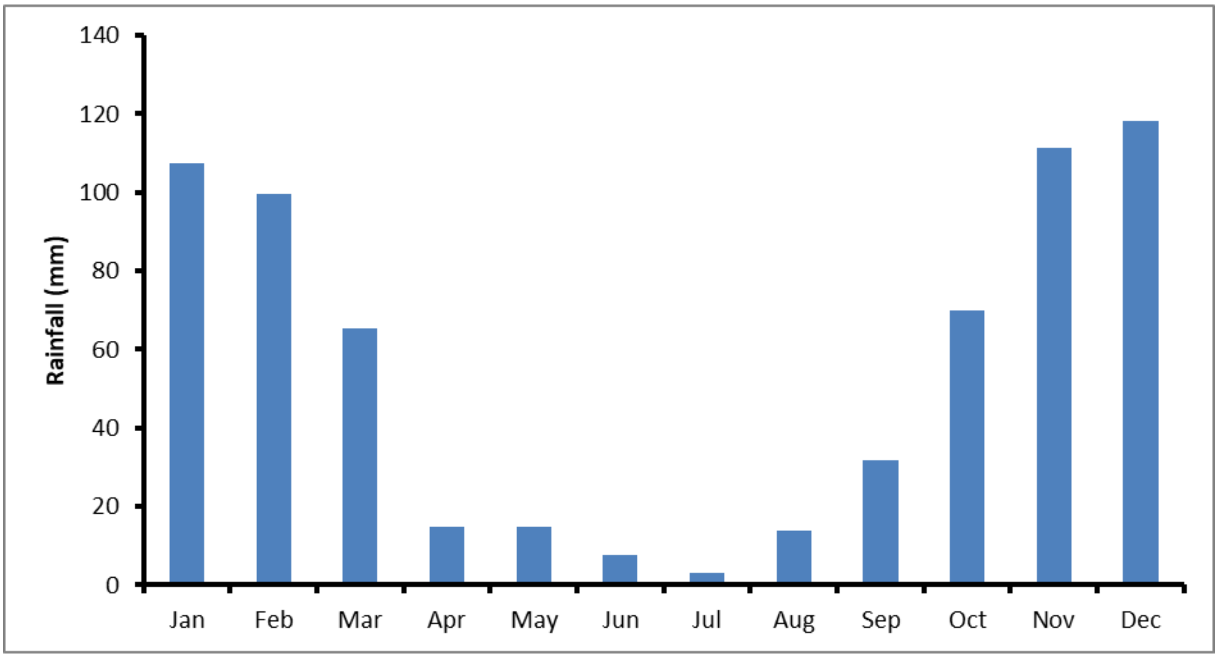

Figure 3.3 (b) Average rainfall (mm) for Tshiame Ward (Data source: ARC, 2014)

The graphs show how temperature and rainfall generally vary from month to month, showing a high degree of seasonality. During the spring season the minimum temperature rises to 14 °C, while the maximum temperature also rises to 25 °C. Figure 3.3(b) shows that the lowest rainfall is received during winter in July (5 mm), while the highest rainfall is received in December (120 mm). This shows that during summer, temperatures, and rainfall are higher than those experienced in winter. The area also experiences many frost days during autumn and winter seasons.

3.2.2 Sampling size for farms selected

Farms were selected using the stratified method on the basis of their production levels. This approach was used to ensure that each category of farmers was represented and to minimise the sample selection bias. Tshiame Ward has 29 farms and their production levels were categorised as commercial or subsistence. The selection ensured that each category of farmers was represented. A total of 8 commercial farms (28 %) and 21 subsistence farms (72 %) exist in Tshiame Ward. Therefore, of all farms that were selected, 50 % of the total selected farms consisted of commercial farms and 50 % subsistence farms. The selected sixteen farms were named and numbered as Farm 1 to Farm 16. The naming and numbering remained consistent throughout the study, so that all results presented for each farm relate to the same farms. The farm data are presented on Table 3.1 below.

Table 3.1 Geographical data of farms used for the study

Farms	**Latitude**	**Longitude**	**Altitude**	**Farm size**	**Production levels**	**Production systems**
Farm 1	-28.4312	28.89669	1746	220	Subsistence	Dairy, beef, sheep, and crop production
Farm 2	-28.473	28.87731	1723	154	Subsistence	Dairy, sheep, pig and crop production
Farm 3	-28.3757	28.93692	1747	429.7	Subsistence	Dairy, beef and crop production
Farm 4	-28.3817	28.92372	1735	386	Commercial	Dairy, beef and crop production
Farm 5	-28.3652	28.87208	1649	150	Subsistence	Dairy and crop production
Farm 6	-28.3027	28.89167	1639	207	Commercial	Dairy, sheep, pig and crop production
Farm 7	-28.3261	28.90947	1660	350	Subsistence	Dairy and beef production
Farm 8	-28.2824	28.87769	1683	480	Subsistence	Dairy, beef and crop production
Farm 9	-28.2765	28.89753	1672	335	Subsistence	Dairy, beef, pig and crop production
Farm 10	-28.2775	28.83475	1634	107	Subsistence	Dairy and crop production
Farm 11	-28.2756	28.52009	1702	310	Commercial	Dairy, beef and crop production
Farm 12	-28.2806	28.52161	1711	386	Commercial	Dairy and crop production
Farm 13	-28.1938	28.54305	1650	209	Commercial	Beef, goat and crop production
Farm 14	-28.2850	28.5301	1767	207	Commercial	Dairy and crop production
Farm 15	-28.1613	28.53101	1678	520	Commercial	Beef, pig and crop production
Farm 16	-28.1531	28.54384	1703	1000	Commercial	Dairy, beef, pig, horse and crop production

3.3 Data collection

The data used in this study emanated from two key source categories, namely livestock and cropland farming, as noted below. Data was collected for each year from 2010 to 2014. Activity data for different years for various sources on Appendix A were collected from farmers through a questionnaire survey (Appendix D). Other sources of activity data included data that were recorded on livestock and crop production. Such data were obtained from agricultural censuses, expert knowledge (e.g. animal scientists and agronomists, researchers, crop grower or livestock associations) and previous surveys. This activity data included animal and crop data such as animal population number, animal weights, feeding situation for animals, cultivated crop types, and all agricultural management practices. The animal weight of all livestock was obtained by weighing each animal using weighing scale at randomly selected farms both in summer and winter. Table 3.4 below shows the dates in which animal weights were recorded from farms.

Table 3.2 The dates in which animal weights were taken from farms

Summer season	**Winter season**
25/03/2014	28/07/2014
26/03/2014	29/07/2014
27/03/2014	30/07/2014
	31/07/2014

Livestock data were categorised in line with Otter et al. (2010) recommendations, as noted in the report "The South African Agricultural GHG Inventory for 2004", as shown in Table 3.3.

Table 3.3 Categorisation of livestock

Livestock category	Livestock sub - categories	Calculation method
Dairy cattle	Mature female cows (< 2 years)	Tier 2
	Heifers (1 – 2 years)	Tier 2
	Calves (> 1 year)	Tier 2
	Bulls	Tier 2
Beef cattle	Mature female cows	Tier 2
	Heifers (1 – 2 years)	Tier 2
	Young oxens (> 1 year)	Tier 2
	Bulls	Tier 2
Sheep	Mature females (ewes)	Tier 2
	Rams	Tier 2
	Heifer	Tier 2
	Lambs	Tier 2
Goats	Mature females	Tier 2
	Rams	Tier 2
	Calves	Tier 2
Pigs	Boars	Tier 1
	Sows	Tier 1
	Growers	Tier 1
Horses	Mature horses	Tier 1

3.3.1 Soil sampling

For soil sampling, the equipment used included sampling tube, an Edelman soil auger, spade and clean plastic bags. A depth of 15 cm was used when collecting soil samples. Four soil samples were collected from each farm and the sample bags were labelled and numbered and the soil samples were collected for physical analysis. This included the determination of nutrient content, composition, as well as acidity or pH level. This was done with the purpose of obtaining the soil texture so as to determine the soil type per farm as required for GHG emission analysis. The various soil types representing various farms of Tshiame Ward were used for analysis.

Table 3.4 Various soil conditions in Tshiame farms (Data source: ARC, 2013)

Farm	Soil type
F1	Loam soil and Sandy Loam soil
F2	Clay soil
F3	Clay soil and Sandy Loam soil
F4	Sandy Loam soil
F5	Clay soil and Sandy soil
F6	Loam soil
F7	Loam soil
F8	Clay soil and Sandy soil
F9	Clay soil and Sandy Loam soil
F10	Sandy Loam soil
F11	Loam soil and Sandy soil
F12	Loam soil
F13	Loam soil
F14	Loam soil and Sandy Loam soil
F15	Sandy Loam soil
F16	Sandy soil

Table 3.5 Description of various soil conditions in Tshiame farms (Data source: ARC, 2013)

Soil Name	Acronym	Description
Sandy Soil	SS	Soil with large particles that drains quickly but holds nutrients poorly
Sandy Loam Soil	SLS	Soil material with 80% or more silt and less than 12% clay
Loam Soil	LS	Soil composed mostly of sand and silt, and a smaller amount of clay
Clay Soil	CS	A fine-grained soil or water-soaked earth or fine grain soil
Clay Loam Soil	CLS	A fine-textured soil that breaks into clods or lumps that are hard when dry

The variability of climate and soil in Maluti-a-Phofung municipality were described and classified according to the requirements of the IPCC guidelines (IPCC, 1996 and 2006).

3.4 Calculation of agriculture related GHG emissions

The quantification methodology used to estimate GHG emissions was based on the 1996 and 2006 IPCC guidelines and tier 2 methods were used in categories where data was available and where it permitted such calculations. Tier 1 was applied where the basic data was applicable and potential emissions are projected to be minimal. The Agricultural land use (ALU) software was used to quantify all emissions from various sources that are included in the study. The program is developed based on revised 1996 IPCC guidelines, 2000 IPCC Good Practice Guidance, 2003 IPCC Good Practice Guidance and 2006 IPCC guidelines (Colomb et al., 2013). The ALU calculation process has three steps to complete the farm GHG estimation, including activity data entry, assignment of emission factors and emission calculations. It was Developed in Colorado State University and designed to make the inventory process easier to implement and consistent with guidelines provided by the Intergovernmental Panel on Climate Change. The choice of ALU over other models was due to the fact that, Agriculture and Land Use (ALU) Software guides an inventory compiler through the process of estimating greenhouse gas emissions and removals related to agricultural and forestry activities. The software also has internal checks to ensure data integrity. This software program is designed to support an evaluation of mitigation potentials using the inventory data as a baseline for projecting emission trends associated with management alternatives. ALU version 6.0 (2012) was used, compared to other versions this version can develop an enhanced characterization for livestock, which is the major contributor source of greenhouse gas emissions in agriculture sector. ALU accommodates Tier 1 and 2 methods as defined by the IPCC.

Activity data (AD) was collected and emission factors (EFs) were then calculated in order to estimate emissions. Activity data, according to the Revised 1996 IPCC Guidelines for National GHG Inventories, are defined as data on the magnitude of human activity resulting in emissions or removals taking place during a given period of time. An emission factor is defined as the average emission rate of a given GHG for a given source, relative to units of activity (IPCC 1996 and 2006). In other words this refers to the rate of emission per unit of activity, output or input. Data output from ALU was further analysed using STATISTICA. The GHGs estimated included CH_4, N_2O and CO_2 emanating from various agricultural sources of emissions due to livestock and cropland farming (Table 3.4).

Table 3.6 The various agricultural GHG sources that were estimated from livestock and cropland farming systems

Sources	**Greenhouse gasses (GHGs)**
Livestock	
Enteric fermentation	Methane (CH_4)
Manure management	Methane (CH_4) and Nitrous oxide (N_2O)
Cropland	
Biomass burning non-CO_2 GHG	Methane (CH_4) and Nitrous oxide (N_2O)
Synthetic fertilizer application	Nitrous oxide (N_2O)
Organic fertilizer application	Nitrous oxide (N_2O)
Crop residue retained in the soil	Nitrous oxide (N_2O)
Tractor usage in the fields (ALU was not used for this source, Its methodology is provided on section 3.4.6)	Carbon dioxide (CO_2)

3.4.1 CH_4 from enteric fermentation

Enteric fermentation CH_4 emissions from ruminant animals (dairy cattle, beef cattle and sheep) were calculated using tier 2 approaches. Ruminant animals produce CH_4 emissions through the process of enteric fermentation which is the digestion of food. In some cases expert opinions were used to compensate for lack of agricultural data as farmers did not always have all the data requirements of the tier 2 calculations. The activity data that were estimated by use of expert opinions included the type of feeding system, feed quality, feed intake, diet and feed digestibility. CH_4 emissions from non-ruminant animals (Goats, Pigs, and Horses) were also calculated. The IPCC defaults emission factor values were used for goats (5 kg CH_4/head/day), horses (18 kg/CH_4/head/day) and pigs (1 kg/CH_4/head/day) (IPCC, 1996).

The average daily weight gains (WG) were calculated from heifers, calves and lambs subcategories (See appendix A, Table 1, Table 5 and Table 6), since it was assumed that mature cows or animals don't grow Otter et al. (2010). The WG data for calves and lambs was calculated from average birth weights of all the breeds' type of animal livestock. The average weight for all animal subcategories were obtained from the averages of all the breeds that were weighed in 2013 for two seasons (summer and winter). The collected data included the average weights of the mature female cow, heifers, bulls, and calves, young and mature oxen, ewes, rams and lambs (See appendix A, Table 2, Table 4, Table 6). All other productivity data such as feed intake, and diet data were obtained from each farm through questionnaires (See appendix A, Table 1 and Table 5). However, the sheep diet data, milk productivity data, as well as the fat content were based on literature.

The daily milk production, milk protein content, and fat content for dairy livestock were obtained from the monthly results of the tests made by the local milk company (See Appendix

A, Table 3). The percentage of lactating mature females for both beef and dairy cattle ranged from 90% to 100% at most farms. The swine livestock category were fed on concentrates which are high in energy, low in fiber and consist of < 20% protein. The feeding situations were considerably similar at all farms. In this study dairy cattle were 70% pasture-based and 30% TMR-based for feeding situation, while the beef cattle were 100% pasture-based, and this was employed at all farms. Nevertheless, the quality of the pasture-based feeding system was different from the TMR-based diet. The pasture-based animals had higher EFs than TMR-based feeding system. This is due to the variations in the digestibility energy various feeding system, for pasture-based is higher than the TMR-based. Dairy mature females at all farms were based on the TMR with 30% of the feeding situation.

Methane emission factors

Emission factors for dairy, beef cattle and sheep were determined using Tier 2 approach in ALU software, which is made of the algorithms from the 1996 and 2006 guidelines of the IPCC. The equation below was used:

$$EF = \left(GE * \left(\frac{Ym}{100}\right) * 365 \div 55.65\right) \quad (3.1)$$

Where EF is the average emission rate for a given GHG for a given source relative to activity, GE (MJ day-1) is the gross energy for cattle and sheep, and Y_m is the methane conversion factor. For Tier 2 approach the gross energy (GE) was calculated through ALU (IPCC, 1996 and 2006), and the equation below was used:

$$GE = ((NE_m + NE_a + NE_L + NE_{work} + NE_p \div REM) + (NE_g \div REG)) \div DE\,\%/100 \quad (3.2)$$

Where GE is the gross energy for cattle and sheep, NE_m is the Net energy for maintenance (MJ day^{-1}), NE_a is the net energy for activity (MJ day-1), NE_g is the net energy required for growth (MJ day-1), NE_L is the net energy required for lactation (MJ day-1), NE_{work} is the net energy required for work (MJ day $^{-1}$), NE_p is the net energy required for pregnancy (MJ day^{-1}), REM is the ratio of net energy available in a diet for maintenance to digestible energy consumed (MJ day^{-1}), REG is a net energy available for growth in a diet to digestible energy consumed (MJ day^{-1}), DE is the digestible energy expressed as a percentage of gross energy. IPCC (2006) default values were used for digestibility (DE) percentage. For animals fed with > 90% concentrate diet the digestibility of 75 – 85% was used, for pasture based animals 55 – 75% was used and for animal fed low quality forage 45 – 55% was used (IPCC, 2006). The net energy for maintenance was calculated using:

$$NE_m = Cf_i * (Weight)^{0.75} \quad (3.3)$$

Where NE_m is the Net energy for maintenance (MJ day^{-1}), Cfi is the coefficients for calculating net energy for maintenance and it varies for each animal category (MJ day^{-1} kg^{-1}), weight is the live weight of animal (kg) (IPCC, 1996 and 2006). Net energy for activity (for dairy and beef cattle) was calculated using:

$$NE_a = C_a * NE_m \quad (3.4)$$

Where NE_a is the net energy for activity (MJ day-1), C_a is the coefficient corresponding to animal s feeding situation, NE_m is the net energy required by animal for maintenance (MJ day-$_1$). Net energy for activity (for sheep) was calculated using:

$$NE_a = C_a * (weight) \quad (3.5)$$

Where NE_a is the net energy for activity (MJ day-1), C_a is the coefficient corresponding to animal's feeding situation, weight is the live weight of animal (kg) (IPCC, 2006). Net energy for growth (for dairy and beef cattle) was calculated using:

$$NE_g = 22.02 * \left(\frac{BW}{C} * MW\right)^{0.75} * WG^{1.097} \tag{3.6}$$

Where NE_g is the net energy required for growth (MJ day^{-1}), BW is the average live body weight of the animals in the population (Kg), C is a coefficient with a value of 0.8 for females, 1.0 for castrates and 1.2 for bulls (NRC, 2003), MW is the mature live body weight of an adult female in moderate body condition (kg), WG is the average daily weight gain of the animals in the population (kg day^{-1}). Net energy for growth (for sheep) was calculated using:

$$NE_g = WG_{lamb} * (a + 0.5b\ (BW_i + BW_f)) \div 365 \tag{3.7}$$

Where NE_g is the net energy required for growth (MJ day^{-1}), WG_{lamb} is the average daily weight gain of the animals in the population (kg day^{-1}) (only for lamb), a and b are constants for use in calculating net energy needed for growth for sheep as shown in Appendix A, Table 9. BW_i is the average live body weight of the animals in the population (Kg), BW is the live bodyweight (live – weight) (kg). Net energy for lactation for beef and dairy cattle (lactating mature females only) was calculated using:

$$NE_L = Milk * (1.47 + 0.40 * Fat) \tag{3.8}$$

Where NE_L is the net energy required for lactation (MJ day^{-1}), milk is the amount of milk produced (kg of milk day^{-1}), fat is the fat content of milk (% by weight). Net energy for lactation for sheep (Milk production) was calculated using:

$$NE_L = \left(\frac{5 * WG_{wean}}{365}\right) * EV_{milk} \tag{3.9}$$

Where NE_L is the net energy required for lactation (MJ day^{-1}), WG_{wean} is the weight gain of the lamb between birth and weaning (kg), EV_{milk} is the energy required to produce 1 kg of milk, MJ kg^{-1}. A default value of 4.6 MJ kg^{-1} was used (AFRC, 1993) was used. Net energy for work (for dairy and beef cattle) was calculated using:

$$NE_{work} = 0.10 * NE_m * Hours \quad (3.10)$$

Where NE_{work} is the net energy required for work (MJ day -1), NE_m is the net energy required for maintenance (MJ day^{-1}), hours is the number of hours of work per day. Net energy to produce wool (for sheep) was calculated using:

$$NE_{wool} = (EV_{wool} * Production\ wool \div 365) \quad (3.11)$$

Where NE_{wool} is the net energy required to produce wool (MJ day-1), EV_{wool} is the energy value of each kg of wool produced (weighed after drying but before scoring), MJ kg^{-1} (A default value of 24 MJ kg $^{-1}$ was used) (AFRC, 1993), $Production_{wool}$ is the annual wool production per sheep (kg^{-1}). Net energy for pregnancy (for dairy, beef cattle and sheep) was calculated using:

$$NE_p = C_{pregnancy} * NE_m \quad (3.12)$$

Where NE_p is the net energy required for pregnancy (MJ day^{-1}), $C_{pregnancy}$ is the pregnancy coefficient used for calculating NE_p, and NE_m is the net energy required for maintenance.

Ratio of net energy available in a diet for maintenance (REM) to digestible energy consumed was calculated using the following equation:

$$REM = (1.123 - (4.092 * 10^{-3} * DE\ \%) + (1.126 * 10 - 5 * (DE\ \%)^2) - (25.4/DE\ \%)) \quad (3.13)$$

Where REM is the ratio of net energy available in a diet for maintenance to digestible energy consumed (MJ day^{-1}), DE is the digestible energy expressed as a percentage of gross energy.

Ratio of net energy available for growth (REG) in a diet to digestible energy consumed was calculated using:

$$REG = (1.164 - (5.160 * 10 - 3 * DE\ \%) + (1.308 * 10 - 5 * (DE\ \%)\ 2) - (37.4/DE\ \%)) \quad \textit{(3.14)}$$

Where REG is a net energy available for growth in a diet to digestible energy consumed and DE is the digestible energy expressed as a percentage of gross energy.

Enteric CH_4 emissions for other animal categories

Default CH_4 emission factors from the IPCC 2006 Guidelines were used for all other livestock, since there was a shortage of data and less number for those animal population categories and the following equation was used:

$$Emissions = EF_{(T)} * (N_{(T)}/10^6) \quad (3.15)$$

Where emissions is the CH_4 emissions from enteric fermentation Gg CH_4 yr^{-1}, EF $_{(T)}$ is the CH_4 emission factor for the defined livestock population (kg CH_4 $head^{-1}$ yr^{-1}), $N_{(T)}$ is the number of head of livestock species/ category T, and T is the species/ category of livestock.

3.4.2 Methane from manure management

CH_4 emissions from manure management were calculated from animal population, activity data and manure management system (MMS) data (IPCC, 2006). CH_4 from all livestock manure management was calculated using the tier 2 approach in ALU software.

Activity data and Emission factors

The weights for livestock categories were obtained from the averages of all animals per farm per sub-category. Volatile solids (VS) for cattle were calculated using ALU software, the DE% values were used (IPCC, 2006). The typical value of 0.04 was used for urinary energy (UE) and 0.08 was the ASH value used (IPCC recommended values, IPCC 2006). The Africa default VS values were used for all other livestock categories in ALU software (See Appendix A, Table 13). The methane producing capacity (B_o) values for all livestock categories (See Appendix A, Table 11) were obtained from the default values of the 2006 guidelines. Animal data and MMS data was used to calculate the annual CH_4 emission factor manure management per farm. The CH_4 EFs from manure management were calculated using:

$$EF\ (T) = (VS_T * 365) * (B\ o_{(T)} * 0.67/m^3 * \sum MCF_{S,K}/100 * MS_{(T,S,K)})$$

(3.16)

Where $EF_{(T)}$ is the annual methane emission factor for livestock category T (kg CH_4 animal^{-1} yr^{-1}), VS is the volatile solid excretion per day on a dry organic matter basis (kg VS. day^{-1}), B_o is the maximum methane producing capacity for manure produced by livestock category T (M^3 CH_4 kg^{-1}) of VS excreted, 0.67 is the conversion factor of M^3 CH_4 to kilograms CH_4, $MCF_{(s,k)}$ is the methane conversion factors for each manure management system S by climate region k (%), $MS_{(T,S,k)}$ is the fraction of livestock category TS manure handled using manure management system S in climate region k (dimensionless). Volatile solid excretion rates were calculated using:

$$VS = (GE * (1 - DE\%/100) + (UE * GE)) * ((1 - ASH \div 18.45)) \quad (3.17)$$

Where VS is the volatile solid excretion per day on a dry organic matter basis (kg VS. day^{-1}), GE is the gross energy intake (MJ day^{-1}), DE% is the digestibility of the feed in percent, (UE x GE) is the urinary energy expressed as a fraction of GE, ASH is the ash content of manure calculated as a fraction of the dry matter feed intake and 18.45 is the conversion factor for dietary GE per kg of dry matter (MJ day^{-1}), this value is relatively constant across a wide range of forage and grain-based feeds commonly consumed by livestock. Then the total emissions were estimated using:

$$Lmm = (Pop * (\%MMS/100) * EFe/1000 \qquad (3.18)$$

Where Lmm is the enhanced manure methane emissions (kg CH_4), Pop is the population number (head), %MMS is the percent in manure management system (%), EFe is the enhanced manure CH_4 emission factor (kg CH_4/head/yr).

The default EFs obtained from the IPCC guidelines were used for goats, pigs, and horses (IPCC, 2006) (See Appendix A, Table 14).

3.4.3 N_2O emissions from manure management

N_2O emissions from manure management for cattle were calculated using Tier 2 approach, and N_2O emissions from manure management were calculated for all livestock categories per farm for the period of 2010-2014.

Activity data and Emission factors

N_2O emissions from manure management were estimated from animal population data, activity data and MMS data. Nitrogen excretion rate (N_{rate}), and annual N excretion per head of livestock (N_{ex}) were used for all animal categories (See Appendix A, Table 15) including the values of animal weight. The N_{rate} was obtained from the Africa default values in 2006 IPCC guidelines while the N_{ex} was estimated using ALU based on the guidelines (IPCC, 2006). The defaults N_2O EFs were used for the various manure management systems by ALU (IPCC, 2006).

Direct N_2O emissions due to leaching from manure management

The direct N_2O emissions due to leaching from manure management were estimated using the equation below:

$$N_2O_D\ (mm)\ = ((\sum_S (\sum_T \left(N_{(T)} * N_{ex\ (T)} *\ MS_{(S,T)}\right) *\ EF_3) * 44/28 \qquad (3.19)$$

Where N_2O_D(mm) is the direct N_2O emissions from Manure Management in the farm (kg N_2O yr^{-1}), N(T) is the number of head of livestock species/category T in the farm, $Nex_{(T)}$ is the annual average N excretion per head of species/category T in the farm (kg N animal-1 yr^{-1}), $MS_{(T,S)}$ is the fraction of total annual nitrogen excretion for each livestock species/category T that is managed in manure management system S in the country, dimensionless EF_3(S) is the emission factor for direct N_2O emissions from manure management system S in the country (kg N_2O-N/kg N) in manure management system, S is the manure management system, T is the species/category of livestock 44/28 is the conversion of (N_2O-N)(mm) emissions to N_2O(mm) emissions. Annual N excretion rates were calculated using:

$$N_{ex\ (T)} = N_{intake\ (T)} *\ (1 -\ N_{retention\ (T)}) \qquad (3.20)$$

Where $Nex_{\ (T)}$ is the annual N excretion rates (Kg N $animal^{-1}$ yr^{-1}), $N_{\ intake\ (T)}$ is the annual N intake per head of animal of species/category T (Kg N $animal^{-1}$ yr^{-1}), $N_{retention\ (T)}$ is the fraction of annual N intake that is retained by animal of species/category T (dimensionless). N intake rates for cattle were calculated using:

$$N\_(intake\ (T)) = GE/18.45 * (CP\% / 100 / 6.25) \tag{3.21}$$

Where $N_{intake\ (T)}$ is the annual N intake per head of animal of species/category T (Kg N animal^{-1} yr^{-1}), GE is the gross energy intake of the animal (MJ day^{-1}), 18.45 is the conversion factor for dietary GE per kg of dry matter (MJ day^{-1}), CP% is the percentage of crude protein in a diet, 6.25 is the conversion from Kg of dietary protein to Kg of dietary N, Kg feed protein (Kg N)$^{-1}$. N retained rates for cattle were calculated using:

$$N\_(retention\ (T)) = (Milk * (Milk\ PR\% /100) \div 6.38) + (WG * (268 - (7.03 * NE\ g / WG \div 6.25))) \tag{3.22}$$

Where $N_{retention\ (T)}$ is the fraction of annual N intake that is retained by animal of species/category T (dimensionless), milk is the milk production (Kg animal^{-1})(applicable to dairy and beef mature female (MF) cows only), milk PR% is the percentage of protein in milk, calculated as (1.9+0.4*% fat), where %fat is an input (applicable to dairy MF cows) (see Appendix A, Table 1) and beef MF (see Appendix A, table 5), 6.38 is the conversion from milk protein to milk N, Kg protein (Kg N)$^{-1}$, NE_g is the net energy required for growth (MJ day^{-1}), WG is the average daily weight gain of the animals in the population (kg day^{-1}), 268 and 7.03 are constants (NRC, 2003), 6.25 is the conversion from Kg dietary protein to Kg dietary N, Kg protein (Kg N^{-1}).

Indirect N_2O emissions due to leaching from manure management

The indirect N_2O emissions due to leaching from manure management were estimated using:

$$N_2OL\ (mm) = (N_{leaching} - MMS * EF5) * 44/28$$

(3.23)

Where $N_2O_{L\ (mm)}$ is the indirect N_2O emissions due to leaching and runoff from manure management in the farm (kg N_2O y^{-1}), $N_{leaching\ -\ MMS}$ is the amount of manure nitrogen that leached from manure management system (kg N yr^{-1}), EF_5 is the emission factor for N_2O emissions from nitrogen leaching and runoff (kg N_2O-N/kg N leached and runoff (default value 0.0075 Kg N_2O-N (Kg N leaching/runoff)$^{-1}$. An N loss due to leaching from manure management systems was calculated using:

$$N_{leaching} - MMS \ = \ \sum (\sum ((N_{(T)} * N_{ex\ (T)} * \ MS\ (S,T)) * \ (FracleachMS\ /100)\ (T,S)\ ))$$

(3.24)

Where $N_{leaching\text{-}MMS}$ is the amount of manure nitrogen that leached from MMS (kg N yr^{-1}), $N_{(T)}$ is the number of head of livestock species/category T in the country (kg N $animal^{-1}$ yr^{-1}), $Nex_{(T)}$ is the annual average N excretion per head of species/category T in the country (kg N $animal^{-1}$ yr^{-1}), $MS_{(S,T)}$ is the fraction of total annual nitrogen excretion for each livestock species/category T that is managed in manure MMS S in the farm (dimensionless), $Frac_{leachMS}$ is the percentage of managed manure nitrogen losses for livestock category T due to runoff and leaching during solid and liquid storage of manure (typical range 1-2%). Annual N excretion rates were calculated using equation 3.20, N intake rates for cattle were calculated using equation 3.21 and N retained rates for cattle were calculated using equation 3.22.

3.4.4 N_2O emissions from managed soils

Soil N_2O emissions from managed soils were estimated based on cropland data and this included crop residue retained, synthetic fertilizer and organic amendments data. The data required for N_2O estimation from crop residue retained included the crop type, crop management strategies and the amount of residues retained. Data required for direct soil

N_2O estimation from organic manure included the annual amount of animal manure nitrogen intentionally applied to soils adjusted to account for the amount that volatilises as NH_3 and NO_x, the total amount of animal manure produced, and the fraction of animal manure N that volatilises as NH_3 and NOx (kg NH_3-N and NO_x-N/kg of N excreted). Synthetic fertilizer data included the amount of fertilizer applied to soil, type of synthetic fertilizer applied, and N fertilizer application rate. Direct and indirect N_2O emissions from agricultural managed soils were calculated through ALU and Tier 2 approach.

Activity data and Emission factors

The quantity of crop residues left or retained after harvesting was calculated based on the crop yield through ALU. Estimates for N in crop residues were based on the IPCC equations (IPCC, 2006). The amount and the type of N fertilizers applied and crop types cultivated per farm per hectare were obtained through a questionnaire survey. Default EFs IPCC (2006) in ALU were used for the fraction of manure N for volatilized and leached/ runoff. And it was used for animal manure amendments, animal manure deposited on pastures, rangeland and paddocks.

Direct N_2O emissions from agricultural soils

The direct N_2O emissions from agricultural soils were calculated using the following equation:

$$N_2O_{Direct} - N = \Sigma i\ (((F_{SN} + F_{AM})i * EF_i] + ((F_{BN} + F_{CR}) * EF_1) + (F_{OS} * EF_2))$$
(3.25)

Where N_2O_{Direct} -N is the emission of N_2O in units of Nitrogen that volatilises as NH_3 and NO_x, F_{SN} is the annual amount of synthetic nitrogen fertiliser applied to soils adjusted to account for the amount that volatilises as NH_3 and NOx, F_{AM} is the annual amount of animal manure nitrogen intentionally applied to soils adjusted to account for the amount that volatilises as NH_3 and NOx, F_{BN} is the amount of nitrogen fixed by N-fixing crops cultivated annually, F_{CR} is the amount of nitrogen in crop residues returned to soils annually, EF_i is the emission factors developed for N_2O emissions from synthetic fertiliser and animal manure application under different conditions i, F_{OS} is the area of organic soils cultivated annually, EF_1 is the emission factor for emissions from N inputs (kg N_2O-N/kg N input), EF_2 is the emission factor for emissions from organic soil cultivation (kg N_2O-N/ha-yr), Conversion of N_2O-N emissions to N_2O emissions for reporting purposes is performed by using the following equation:

$$N_2O = N_2O - N * 44/28 \quad (3.26)$$

N_2O emissions from N from synthetic fertiliser application were calculated using the following equation:

$$F_{SN} = N_{FERT} * (1 - Frac_{GASF}) \quad (3.27)$$

Where F_{SN} is the annual amount of synthetic nitrogen fertiliser applied to soils after adjusting to account for the amount that volatilises, N_{FERT} is the total amount of synthetic fertiliser consumed annually, $FRAC_{GASF}$ is the volatilised as NH_3 and NO_x.

N_2O emissions from N from animal manure application were calculated using the following equation:

$$F_{AM} = \Sigma_T(N_{(T)} * Nex_{(T))}\,(1 - Frac_{GASM}) * (1 - (\,Frac_{FUEL-AM}) \quad (3.28)$$

Where F_{AM} is the annual amount of animal manure nitrogen intentionally applied to soils adjusted to account for the amount that volatilises as NH_3 and NO_x, Σ_T ($N_{(T)}$)* $Nex_{(T)}$) is used for the total amount of animal manure produced, $Frac_{GASM}$ is the fraction of animal manure N that volatilises as NH_3 and NOx (kg NH_3-N and NOx-N/kg of N excreted) and $FRAC_{FUEL-AM}$ is the fraction of animal manure used as fuel.

N_2O emissions from Residue returned to soils were calculated using:

$$F\_CR = \Sigma\_i\ [(Crop_{Oi} *\ Res_{Oi}\ / Crop_{Oi} *\ Frac_{DMi} *\ FracNCROi\ ) *$$
$$(1 - FracBURNi - FracFUEL - CRi - FracCNST - CRi - FracFODi\ )] +$$
$$\Sigma j\ [(CropBFj *\ ResBFj\ / CropBFj *\ FracDMj *\ FracNCRBFj\ ) *$$
$$(1 - FracBURNj - FracFUEL - CRj - FracCNST - CRj - FracFODj\ )]$$

(3.29)

Where F_{CR} is the N_2O emissions from Residue returned to soils, $Res_{Oi}/Crop_{Oi}$ and ResBFj/CropBFj is the residue to crop product mass ratio, FracDMi and FracDMj is the dry matter content of the aboveground biomass, FracNCROi and FracNCRBFj is the nitrogen content of the aboveground biomass, FracBURNi and FracBURNj is the fraction of residue burned in the field before and after harvest, FracFUEL-CRi and FracFUEL-CRj is the fraction of residue used as fuel, FracCNST-CRi and FracCNST-CRj is the fraction of residue used for construction, FracFODi and FracFODj is the fraction of residue used as fodder.

Indirect N_2O emissions

The indirect N_2O emissions were calculated using the following equation:

$$N_2Oindirect - N\ =\ N_2O\ (G)\ +\ N_2O(L) \qquad (3.30)$$

Where N_2Oindirect-N is the emissions of N_2O in units of nitrogen (kg N/year), $N_2O(G)$ is the N_2O produced from volatilisation of applied synthetic fertiliser and animal manure N, and its subsequent atmospheric deposition as NOx and NH_4 (kg N/yr), $N_2O(L)$ is the N_2O produced from leaching and runoff of applied fertiliser and animal manure N (kg N/yr), and conversion of N_2O-N emissions to N_2O emissions for reporting purposes was performed by using the following equation:

$$N_2O = N_2O - N * 44/28 \quad (3.31)$$

N_2O from deposited n from leaching/runoff (from synthetic fertilizer and organic manure application) was calculated using:

$$N_2O\ (L) - N = N_{FERT} + \{\Sigma T\ (N(T) * Nex(T)) * [1 - (Frac_{FUEL} - AM)]\} * FracLEACH * EF_5 \quad (3.32)$$

Where N_2O (L) is the N_2O produced from leaching and runoff of applied fertiliser and animal manure N (kg N/yr), N_{FERT} is the total amount of synthetic fertiliser consumed annually, (Σ_T ($N_{(T)}$)* $Nex_{(T)}$) is used for the total amount of animal manure produced, $FRAC_{FUEL-AM}$ is the fraction of animal manure used as fuel, FracLEACH is the fraction of N input that is lost through leaching and runoff and EF_5 is the emission factor for leaching/runoff.

N_2O from atmospheric deposition of N was calculated using:

$$N_2O\ (G) - N = \{(N_{FERT} * Frac_{GASF}) + [\Sigma_T\ (N_{(T)} * Nex_{(T)})] * Frac_{GASM}\} * EF_4$$

(3.33)

Where N_2O (G) is the N_2O produced from atmospheric deposition of N (kg N/yr), N_{FERT} is the total amount of synthetic nitrogen fertiliser applied to soils (kg N/yr), (ΣT(N(T) * $Nex_{(T)}$) is the total amount of animal manure nitrogen excreted in a country, kg N/yr, $Frac_{GASF}$ is the fraction of synthetic N fertiliser that volatilises as NH_3 and NOx, kg NH_3-N and NOx-N/kg of N input,

$Frac_{GASM}$ is the fraction of animal manure N that volatilises as NH_3 and NOx, kg NH_3-N and NOx-N/kg of N excreted and EF_4 is the emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces, kg N_2O-N/kg NH_3-N and NOx-N emitted.

3.4.5 Biomass burning

Non-CO_2 emissions from biomass burning (CH_4 and N_2O) are calculated based on cropland and grassland data. However, this study had calculated only biomass burning from grassland biomass since it is a common practice by farmers to graze or collect crop residues after harvesting. Grassland biomass burning emissions were calculated through ALU. The method used to calculate the biomass burning from grasslands had utilized the amount of area burned per farm per year. Estimated emissions from biomass burning included CH_4 and N_2O (IPCC, 2006).

Activity data and Emission factors

The estimation of GHG emissions for grasslands fire included the percentage of grass residues burnt which is the mass of fuel available for burning, grass type, and management systems. It also required information on area burnt (A), mass of fuel available for combustion, combustion factor and emission factors, the equation used was obtained from ALU. Burnt area (A) was collected from farmers through questionnaires and the results are presented in Table 3.5 below.

Table 3.7 Burned area data

Farms	Annual burned area (ha)				
	2010	2011	2012	2013	2014
F1	80	-	-	120	-
F2	-	-	-	-	-
F3	191	-	13	10	-
F4	30	126	-	-	-
F5	122	-	-	122	-
F6	113	70	90	50	60
F7	-	200	150	-	-
F8	-	-	12	-	-
F9	106	-	-	106	107
F10	281	140	-	-	-
F11	-	50	-	239	20
F12	4	-	-	-	-
F13	89	20	-	25	-
F14	20	-	165	165	-
F15	50	50	50	50	-
F16	261	-	-	-	-
- Represents the unavailability of grassland biomass burning in other farms					

To determine mass of fuel available for combustion for grasslands, biomass data was acquired by using the area burned per farm per year. The combustion factor and EFs were estimated through ALU. The biomass burned were calculated using:

$$BB = A * BD * FB \tag{3.34}$$

Where BB is the biomass burned (tonnes dm), A is the Area burned (ha), BD is the aboveground biomass density (tonnes dm/ha), FB is the fraction actually burned. Biomass CH_4 emissions were calculated using:

$$L\,(CH_4) = ((CRI * ERI\,(CH_4)) + (CRd * ERd\,(CH_4))) * (16/12) \tag{3.35}$$

Where L (CH_4) is the CH_4 emissions (tonnes CH_4), CRI is the carbon released from biomass (tonnes C), ERI (CH_4) is the CH_4 emission ratio for live biomass (tonnes CH_4-C/tonnes C), CRd is the carbon release from dead biomass (tonnes C), and ERd (CH_4) is the CH_4 emission ratio for dead biomass (tonnes CH_4-C/ tonnes C). The N_2O emissions from grassland biomass burning was calculated using:

$$L(N_2O) = \left((CRI\ * ERI\ (N_2O) * NCI) + (CRd\ *\ ERd\ (N_2O) *\ NCd)\right) * (\frac{44}{28}) \qquad (3.36)$$

Where L(N_2O) is the N_2O Emissions (tonnes N_2O), CRl is the carbon Released from Live biomass (tonnes C), ERl(N_2O) is the N_2O emission ratio for live biomass (tonnes N_2O-N/tonnes N), NCl is the N/C ratio of live biomass (tonnes N/tonnes C), CRd is the carbon released from dead biomass (tonnes C), ERd(N_2O) is the N_2O emission ratio for dead biomass (tonnes N_2O-N/tonnes N), NCd is the N/C ratio of dead biomass (tonnes N/tonnes C).

3.4.6 CO_2 emissions emanating from the use of tractors

Estimation of CO_2 emissions resulting from the use of tractors included the activities undertaken, frequency of the activity in the growing season, operation time per hectare, Mean fuel consumption (MFC), and the density of diesel used. To estimate direct energy use and emissions by tractor engines during cultivation activities, the following equations based on Nemecek and Kagi (2007) and FAO (2006) were used per farm per activity per ha:

$$Diesel - use\ (kg/ha)\ =\ frequency\ *\ operation\ time\ *\ MFC\ *\ density\ (diesel)$$

(3.37)

Where Frequency is the frequency of the activity in the growing season, operation time is the time required to complete an activity (hour/ha), MFC is the Mean Fuel Consumption, the characteristic fuel consumption for a specific activity with a tractor (liters/hour), density (diesel) is the density of diesel (kg per liter), and these data was acquired through a questionnaire survey as shown in Table 4.27. The energy use was calculated using the following equation:

$$Energy - use\ (mj/ha)\ =\ Diesel - use\ (kg/ha)\ *\ MJdiesel\ (mj/kg) \quad (3.38)$$

Where MJdiesel is the energy density diesel (mj/kg). The total direct GHG emissions were estimated using:

$$Emissions\ (Kg\ CO_2/ha)\ =\ Energy - use\ (mj/ha)\ *\ CO_2dieselMJ\ (kg\ CO_2/MJ\ diesel) \quad (3.39)$$

Where CO_2dieselMJ is the direct and indirect GHG emissions per MJ of diesel (in g/MJ).

3.5 Conversion factor of emissions to CO_2 equivalent

Estimated GHG emissions (CH_4 and N_2O) were converted to CO_2 equivalent emissions as required by the international panel on climate change guidelines (IPCC, 2006). The 100 years global warming potentials were used to change CH_4 and N_2O emissions into their CO_2 equivalents; 1 for CO_2, 21 for CH_4 and 310 for N_2O as used by Forster et al. (2007); Scheutz et al. (2009). This is also based on the Fourth Assessment Report of the IPCC released in 2007. Carbon dioxide equivalent (CO_2eq) is referred to as a unit of measurement that allows the effects of different GHGs to be compared using CO_2 as a standard unit for reference (IPCC, 2007).

3.6 Calculation of emission intensity

Emission intensity is the average emission rate of a given pollutant from a given source relative to the intensity of a specific activity; for example grams of carbon dioxide released per mega joule of energy produced. In this study the emission intensity was calculated using the following equation:

$$Emission\ intensity\ = \frac{Total\ farm\ emissions\ (kg\ CO_2eq/farm)}{Total\ number\ of\ hectares/farm\ (ha)} \tag{3.40}$$

3.7 Investigation of Potential mitigation options

The evaluation of potential mitigation options was done through ALU software. The methodology used in this study was in agreement with recommendations from literature such as Smith et al. (2014), where it is suggested that GHGs can be reduced by supply-side mitigation options (e.g., by reducing GHG emissions per unit of land/animal, or per unit of product), or by demand-side options (e.g., by changing demand for food and fibre products, reducing waste). However, the fourth assessment report of the IPCC, the forestry chapter Nabuurs et al. (2007) considers some demand-side options, but the agriculture chapter focuses on supply-side options only (Nabuurs et al., 2007; Smith et al., 2007). The IPCC Fourth Assessment Report (2007) concluded that, the options that both reduce GHG emissions and increase productivity should be adopted more than those which only reduce emissions.

The various management practices were analyzed in order to investigate the potential mitigation strategies which were recommended for the study area with the view to reduce the GHG emissions. The sixteen (16) farms, with the same climate of temperate and representing various soil conditions in Tshiame Ward (See Figure 3.3) were used to provide the basis for evaluating mitigation for potential options to reduce GHG emissions from agriculture.

The data on farming methods of the study such as manure management and feeding systems were used in ALU software for evaluation purposes. For each of these farms, the baseline established for active management systems on the farms were compared against the mitigation scenarios or proposed changes. The mitigated emissions were obtained by calculating the difference between the actual and the mitigation results from ALU. All management practice scenarios, regardless of location, were designed with some assumptions to support the same number and type of animal that were used to allow comparisons among the management practices. The recommendations proposed were based on the estimated emissions resulting from various management strategies employed.

The management systems which reduced GHG emissions, which are profitable to farming, and were environmentally friendly, which also promoted sustainability were recommended as the potential management practices for the study.

Table 3.8 various manure management systems and feeding systems that were evaluated for the study

Designation	**Description**
Manure storage	
Aerobic treatment	The biological oxidation of manure collected as a liquid with either forced or natural aeration.
Anaerobic Digester	Animal excreta with or without straw are collected and anaerobically digested in a large containment vessel or covered lagoon.
Anaerobic lagoon	A type of liquid storage system designed and operated to combine waste stabilization and storage.
Burned for fuel	The dung and urine are excreted on fields. The sun dried dung cakes are burned for fuel.
Cattle/swine deep litter < 1 month	As manure accumulates, bedding is continually added to absorb moisture over a production cycle and possibly for less than a month.
Cattle/swine deep litter > 1 month	As manure accumulates, bedding is continually added to absorb moisture over a production cycle and possibly for more than a month.
Compost extensive	Composting in windrows with infrequent turning for mixing and aeration.
Compost intensive	Composting in windrows with regular (at least daily) turning for mixing and aeration.
Daily Spread	Manure is routinely removed from a confinement facility and is applied to cropland or pasture within 24 hours of excretion.
Dry lot	A paved or unpaved open confinement area without any significant vegetative cover where accumulating manure may be removed periodically.
Liquid/slurry	Manure is stored as excreted or with some minimal addition of water in either tanks or earthen ponds outside the animal housing, usually for periods less than one year.
Open pit storage < 1 month	Collection and storage of manure usually with little or no added water typically below a slatted floor in an enclosed animal confinement facility, usually for periods less than one year.
Open pit storage > 1 month	Collection and storage of manure usually with little or no added water typically below a slatted floor in an enclosed animal confinement facility, usually for periods more than one year.
Pasture/Range/Paddock	The manure from pasture and range grazing animals is allowed to lie as deposited, and is not managed.
Solid storage	The storage of manure, typically for a period of several months, in unconfined piles or stacks.
Feeding situation	
Large area grazing	Animals are confined to a small area (i.e. tethered, pen, barn) with the result that they expend very little or no energy to acquire feed.
Pasture	Animals are confined in areas with sufficient forage requiring modest energy expense to acquire feed.
Stall	Animals are confined to a small area (i.e. tethered, pen, barn) with the result that they expend very little or no energy to acquire feed.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Agricultural emissions and emission factors

This chapter presents the GHG emissions emitted by agricultural management practices at farm level in the Tshiame Ward of the eastern Free State, South Africa, over the period of five (5) years (2010 – 2014). Emission factors and emissions are estimated from each agriculture source of GHG emission from the farms and the potential mitigation options are evaluated. Trends of emissions are outlined and comparisons of emissions per farm are made, as well as with existing literature. Uncertainties associated with the emissions are also presented per agricultural source. Emission factors are influenced by farm activity data which contributed to the total farm emissions.

4.1.1 Enteric fermentation

Enteric fermentation CH_4 emission factors

The results of the enteric CH_4 EFs estimates by cattle livestock category are shown in Tables 4.1 and 4.2, respectively. The calculated gross energy intake (GEI) also varied per animal sub-category per farm (See Appendix B, Table 1), and this is the reason for variations in the calculated EFs among the farms. For example, the dairy mature females from Farm 1 had the highest EF, with 105 kg/head/year as compared to other farms, while mature females from Farm 5 and 6 had the lowest EFs of 71 kg/head/year. Dairy mature females at Farms 1 and 2 consumed the highest daily GEI of about 246 and 255 MJ/head and this explains the high EF at Farm 1, while, Farm 6 had the lowest, about 166 MJ/head/day. Dairy mature females consumed the highest GEI compared to other subcategories at all farms and this is due to their requirements for more energy needed for lactating or milk production. The lower EFs for other animal subcategories were influenced by the consumed lower daily GEI (See Appendix B, Table 1).

The EFs for dairy calves were more dispersed than all other animal subcategories with more Coefficient of Variation (CV) as shown in Table 4.1. The large variations by calves might be due to the rapid rate of growth at some farms and also might have been caused by the differences in GEI consumed per animal subcategory. Table 4.1 below represents the enteric CH_4 EFs calculated for all dairy cattle.

Table 4.1 Enteric CH_4 emission factors for dairy cattle

Lvstk categ	Mature female(D)	Heifers(D)	Mature Bulls(D)	Calves(D)	Calves(D)	Young bulls (D)
LvstkSub	Mature Females	Young Females - Age 1-2	Mature Bulls	Young Females - Age 0-1	Young Intact Males - Age 0-1	Young intact males Age 1-2
Units	(kgCH_4/head/year)	(kg CH_4/head/year)	(kg CH_4/head/year)	(kg CH_4/head/year)	(kg CH_4/head/year)	(kg CH_4/head/year)
F1	105	43	87	22	25	55
F2	109	41	71	14	15	51
F3	89	56	70	18	20	60
F4	92	43	63	20	23	-
F5	71	41	70	18	21	43
F6	71	33	70	14	20	-
F7	72	49	96	10	15	51
F8	74	41	91	16	12	45
F9	89	48	68	18	19	-
F10	73	50	70	13	15	-
Standard deviation(SD)	12	6	11	3	4	6
Mean	84	44	76	17	19	51
Coefficient variation(CV)	15	13	14	20	22	11
- Represents the unavailability of other animal sub-categories during certain periods						

The higher enteric CH_4 EFs for beef animal subcategories at Farms were also due to higher GEI consumed (See Appendix B, Table 2). The lower variations in EFs by beef cattle subcategories might be due to the same feeding strategies at all Farms. The higher GEI noted among beef MFs also led to higher EFs. The calculated EFs for dairy and beef animal subcategories have shown a proportional relationship with the consumed GEI per animal subcategory and this shows that the calculated EFs were strongly influenced by the GEI consumed.

The beef cattle subcategories such as mature females and bulls for all farms had higher average EFs compared to the dairy cattle subcategories, while the beef heifers, young bulls and calves had the EFs which are lower than that of dairy (Table 4.1 and 4.2). The higher EFs recorded among beef cattle subcategories are explained by the feed intake, as well as the GEI, which included 100% of pasture-based feeding system. In contrast, dairy cattle were fed 30% total mixed ration (TMR)- based and 70% pasture – based feeding systems at all farms and this might have caused a slightly differences in the calculated EFs between dairy and beef cattle. Therefore, the pasture based production system had higher EFs than TMR-based production system, as shown in Tables 4.1 and 4.2. This can be explained by the lower digestibility of pasture - based diets, as well as the high intakes attained by animals feeding on pasture-based diets. The beef mature females based on 100% pasture feeding system had the highest CH_4 EFs, ranging from 95-109 kg/head/year with the average of 103 kg/head/year, while the dairy mature females based on TMR had the CH_4 EFs ranging from 71-105 kg/head/year per farm with an average of 84 kg/head/year. These results are similar to those from a study by Stewart et al. (2009) where pasture feeding cattle were shown to have higher gross energy intake (GEI) which led to higher EFs as compared to confined cattle. However, this was different from the study by Du Toit et al. (2013a) since cattle production systems based on concentrate feeds (TMR-based) had higher EFs than pasture-based production systems.

The EFs calculated for MF lactating dairy cattle in this study were comparable with the IPCC default values for North America with 128 kg/head/year, Western Europe with 117 kg/head/year and Oceania with 90 Kg/head/year (IPCC, 2006). The calculated enteric CH_4 EFs for MF beef cattle in this study were higher (103 Kg/head/year) than dairy cattle EFs in other developing countries such as Brazil and India, with 62 and 36 Kg/head/year respectively as reported by Chhabra et al., (2009). The IPCC (2006) reported enteric CH_4 emission default factor for Africa as 46 kg/head/year for dairy cattle and this was also lower than the results found in this study. This also differed from the findings by Du Toit et al., (2013a), where enteric CH_4 the EF of 130 Kg/head/year for lactating animals was recorded. Lactating MF CH_4 EFs for South Africa by Du Toit et al., (2013a) were consistent with the results from Tshiame farms since both are higher than the IPCC default EFs and other developing countries. This implies that lactating MF cattle EFs for enteric CH_4 for Tshiame Ward are higher across all cattle sub-categories, when compared with other developing countries. This is due to the use of country-specific activity data with relatively higher productivity and higher weights than values used to derive the default values. In addition, results from research by Du Toit et al. (2013a) and Otter et al. (2010) are comparable with the results from this study, since the mature cows and bulls had the highest CH_4 EFs for enteric fermentation. Table 4.2 represent the EFs for beef cattle per subcategory per farm.

Table 4.2 Methane enteric fermentation emission factors for beef cattle

Lvstk categ	Mature female(B)	Heifers(B)	Mature Bulls(B)	Calves(B)	Calves(B)	Young bulls (B)
LvstkSub	Mature Females	Young Females - Age 1-2	Mature Bulls	Young Females - Age 0-1	Young Intact Males - Age 0-1	Young intact males Age 1-2
Units	($kgCH_4$/head/year)	($kgCH_4$/head/year)	($kgCH_4$/head/year)	($kgCH_4$/head/year)	($kgCH_4$/head/year)	($kgCH_4$/head/year)
F1	109	52	86	17	21	38
F2	-	-	-	-	-	-
F3	95	37	70	17	20	-
F4	102	40	78	17	24	58
F5	-	-	-	-	-	-
F6	101	-	-	-	-	-
F7	107	52	89	13	15	60
F8	-	44	-	8	10	-
F9	-	39	75	-	-	42
F10	-	-	-	-	-	-
Standard deviation(SD)	5	6	7	3	5	10
Mean	103	44	80	15	18	50
Coefficient variation(CV)	5	14	9	24	28	19
- Represents the unavailability of other animal sub-categories during certain periods						

The enteric CH_4 EFs calculated for sheep livestock category varied per animal subcategory and were calculated at Farm 1 only. Ewes recorded the enteric CH_4 EF of 7 kg CH_4/head/year, young females (1-2 years) 0.86 kg CH_4/head/year, rams with about 9 kg CH_4/head/year and lambs had calculated the enteric CH_4 EF of about 0.22 kg CH_4/head/year. However, these were higher than the IPCC default value of 5 kg/head/year for developing countries (IPCC, 1996). Du Toit et al. (2013b) reported that the enteric CH_4 EF for communal sheep was 6.1 kg/head/year which was comparable to the sheep EFs recorded in this study. However, the high EF registered by ewes was due to high daily GEI of 64 MJ/animal/day consumed which was higher than other animal subcategories. The sheep category were based on 100% grazing on hilly pasture feeding system.

Total CH_4 enteric fermentation emissions

The annual total farm CH_4 emissions from enteric fermentation per farm ranged from 7056 to 339801 Kg CO_2eq over a period of 5 years (Table 4.3). The production of CH_4 by enteric fermentation included emissions from ruminant (dairy, beef cattle, and sheep) and non-ruminant animals (pigs, goats, and horses). The results have shown that the ruminant animals in this study emitted more enteric CH_4 emissions than non-ruminant animals per farm and this is due to variations in their digestive systems. The total farm CH_4 emission results show less variability across the years per farm as presented on Table 4.3 below. This might be due to less differences in animal populations and feeding systems within a farm across the years. Higher enteric CH_4 emissions by Farm 11 were due to the higher population of ruminant animals at the farm compared to other farms. The lactating beef and dairy mature female cattle at all farms were responsible for higher enteric CH_4 emissions. Higher CH_4 emissions by lactating beef and dairy mature females were due to higher calculated EFs as shown in Table 4.1 and Table 4.2 above. Table 4.3 below represent the total farm CH_4 emissions from enteric fermentation by ruminant and non-ruminant animals.

Table 4.3 Total Methane enteric emissions per farm from 2010 to 2014

Year	2010	2011	2012	2013	2014	Standard deviation	Mean	Coefficient variation(CV)
Farm	**E(KgCO2-eq)/Year**	**E(KgCO2-eq)/Year**	**E(KgCO2-eq)/Year**	**E(KgCO2-eq)/Year**	**E(KgCO2-eq)/Year**	**E(KgCO2-eq)/Year**	**E(KgCO2-eq)/Year**	**%**
F1	189567	181545	197652	203427	164199	13705	187278	0,07
F2	86919	91665	115731	285642	269094	88517	169810	0,52
F3	88452	143871	175875	59325	68733	45131	107251	0,42
F4	73668	65394	64638	66192	91245	10045	72227	0,14
F5	55104	38451	70434	67662	42798	12816	54890	0,23
F6	31206	35154	25011	33243	37548	4262	32432	0,13
F7	101640	111468	103383	106428	105588	3337	105701	0,03
F8	40488	45549	31458	33117	37086	5091	37540	0,14
F9	139566	100590	43932	288603	68166	86401	128171	0,67
F10	27258	103467	19047	24990	21462	32235	39245	0,82
F11	313404	322224	335748	339801	154560	69934	293147	0,24
F12	48069	38724	21609	21672	16212	12081	29257	0,41
F13	73605	115899	129276	180243	211596	48636	142124	0,34
F14	144207	138642	49140	76251	75726	37778	96793	0,39
F15	19299	22155	7056	31563	23982	7987	20811	0,38
F16	161427	93744	73668	111741	151893	33545	118495	0,28

Enteric CH_4 emissions from the sheep livestock category was the second highest emitter after the cattle livestock category, and this sequence was the same at all farms (See Appendix B, Table 6). The total enteric CH_4 emissions from goats and horses were produced from Farm 13 and Farm 16 respectively, and they were less than those of other livestock categories (See Appendix B, Table 7). The swine livestock category also produced enteric CH_4 emissions (See Appendix B, Table 8).

CH_4 emissions by ruminant animals were significantly higher than those produced by non-ruminant animals and this was the case for all farms in Tshiame Ward. Dairy cattle at all farms were the largest emitters in all years with about 60-67% of total farm enteric CH_4 emissions. Beef cattle were the second largest emitter with about 30-39% of the total farm enteric CH_4 produced over the period of five years at all farms. The sheep category was the third emitter with 1-3% of the total farm enteric CH_4, while the non-ruminant animals emitted the least (less than 1 percent) at all farms. Just like the results from the study by Du Toit et al. (2013a), the high amount of emissions from enteric fermentation were from ruminants' animals such as dairy and beef cattle at all farms in this study. In studies undertaken by Du Toit et al. (2013a) and O' mara (2011), enteric CH_4 emissions were closely related to ruminant numbers. This has been confirmed by the results of this study. The lower amount of enteric CH_4 produced by non-ruminant livestock is due to the lower animal populations per farm. This is similar to findings from most studies, for example, in a study by Stevens and Hume, (1995), and another by Wang and Huang, (2005), it was found that ruminant animals contribute higher CH_4 emissions than non-ruminant animals. It was also emphasized in the study by Du Toit et al. (2013a) that the non-ruminant sector is a minor GHG contributor compared with ruminant CH_4 emissions.

Uncertainty analysis

The uncertainty analysis was done for the estimated CH_4 emissions from enteric fermentation. The quantitative analysis for this source category and the subsequent categories was done using the ALU software. The analysis was carried out at 95% confidence interval as recommended by IPCC (IPCC, 1996). 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 at animal annual population data up to the determination of emission factors. The results showed the uncertainty ranging from 8.44 to 18.82% below and above estimated values and this varied per farm per year as shown in Tables 4.4, 4.5 and in Appendix C, Table 1- Table 8.

Table 4.4 Uncertainty for CH_4 emissions by non-dairy cattle

Farms	2010 estimate	Uncertainty range and percentage		
	(Kg CO2eq)	Lower bound	Upper bound	Uncertainty percentage
Farm 1	47443	43438	51447	8.44
Farm 2	18374	15683	21066	14.65
Farm 3	87244	76129	98359	12.74
Farm 4	57880	49256	66504	14.9
Farm 5	34997	29005	40988	17.12
Farm 6	15684	13930	17437	11.18
Farm 7	77420	68447	86393	11.59
Farm 8	12338	10518	14158	14.75
Farm 9	44317	36614	52019	17.38
Farm 10	9582	8251	10913	13.89
Farm 11	191320	166123	216517	13.17
Farm 12	14864	13146	16582	11.56
Farm 13	89918	76763	103073	14.63
Farm 14	37179	32558	41800	12.43
Farm 15	20853	16929	24778	18.82
Farm 16	45051	40415	49686	10.29

Table 4.5 Uncertainty for CH_4 emissions by dairy cows

Farms	2010 estimate	Uncertainty range and percentage		
	(Kg CO2eq)	Lower bound	Upper bound	Uncertainty percentage
Farm 1	105518	85998	125039	18.50
Farm 2	45707	37224	54190	18.56
Farm 3	-	-	-	-
Farm 4	23244	19011	27476	18.21
Farm 5	17843	14397	21288	19.31
Farm 6	14841	11955	17728	19.45
Farm 7	37551	30191	44911	19.60
Farm 8	29526	23653	35398	19.89
Farm 9	108897	88054	129740	19.14
Farm 10	15308	12381	18235	19.12
Farm 11	83449	68053	98845	18.45
Farm 12	37652	31790	43515	15.57
Farm 13	-	-	-	-
Farm 14	118271	95586	140955	19.18
Farm 15	-	-	-	-
Farm 16	134086	108958	159213	18.74
- Represents the unavailability of other animal sub-categories during certain periods				

Quality control and quality assurance

Quality control of activity data was done while populating the Agriculture and Land Use (ALU) software. Various checks like consistency were done to ensure that data was correct and there were no errors. Quality assurance of the activity data was done by the supervisor. The main quality control measures were centred on the activity data and emission factors obtained. Activity data checks included:

- Animal population data was discussed with the supervisor and the checks that the data was entered correctly was performed by the supervisor.
- All activity was quality controlled through the utilization of ALU QA/QC functionality. This function was operated after populating the database.

Emission factors and emissions QC included the following activities:

- Emission factors obtained in all the animal sub-categories were checked against the IPCC recommended default emission factors and their corresponding activity data and reasons for disparity had to be documented.
- Emission factors were also compared with emission factors obtained from the literature for consistencies and the explanations for any deviations were also documented.
- The utilization of updated global warming potentials from the fifth assessment report for different GHG emissions was performed outside ALU software.

4.1.2 Manure management systems

Methane emissions from animal manure depended on the manure management system (MMS) applied as well as the conditions and the manner in which the system operates. Manure management systems employed in the study included cattle/swine deep litter >1 month (CSDL), manure left on pasture during grazing, manure stored in an open pit, dry lot spread and feeding anaerobic digester. As a result, the employed MMS remained the same at all farms for the period of 5 years as shown in Tables 4.6, 4.7, 4.8, and 4.9.

Table 4.6 Manure management systems for different animal categories in percentages (applicable for all farms except farm 1, 2 and 14)

Livestock category	Sub-category	Cattle/Swine Deep Litter < 1 Month (CSDL) (%)	Pasture (%)	Anaerobic digester (%)
Dairy cattle	Lactating cows	75	20	5
	Non-lactating dairy cattle	80	20	0
Beef cattle	All Beef	80	20	0
Sheep	All sheep	80	20	0
Goats	All goats	80	20	0
Horses	All horses	80	20	0
Pigs	All pigs	80	20	0

Table 4.7 Manure management system for different animal categories in percentages (applicable for farm 1 only)

Livestock category	**Sub-category**	**Cattle/Swine Deep Litter < 1 Month (CSDL) (%)**	**Drylot spread (%)**	**Pasture (%)**
Dairy cattle	Lactating cows	75	5	20
	Non-lactating dairy cattle	75	5	20
Beef cattle	All Beef	75	5	20
Sheep	All sheep	75	5	20

Table 4.8 Manure management system for different animal categories in percentages (applicable for farm 2 only)

Livestock category	**Sub-category**	**Cattle/Swine Deep Litter < 1 Month (CSDL) (%)**	**Pasture (%)**	**Anaerobic digester (%)**	**Composting - static pile (%)**
Dairy cattle	Lactating cows	30	60	10	
	Non-lactating dairy cattle	0	100	0	
Sheep	All sheep	0	80	0	20
Pigs	All pigs	80	0	20	

Table 4.9 Manure management system for different animal categories in percentages (applicable for farm 14 only)

Livestock category	Sub-category	Cattle/Swine Deep Litter < 1 Month (CSDL) (%)	Pasture (%)	Open pit storage (%)
Dairy cattle	Lactating cows	75	20	5
	Non-lactating dairy cattle	80	20	0
Beef cattle	All Beef	80	20	0
	All sheep	80	20	0

Manure Methane

Manure Methane emission factors

Manure CH_4 EFs were dependent on the methane conversion factor (MCF) which also differed for each MMS per livestock category and the livestock differed for each animal subcategory per farm. The MCF values applied were those of the IPCC default with pasture (0.015), CSDL (0.45), dry lot spread (0.015), open pit storage > 1 month (0.45) and anaerobic digester (1). The EFs for MMSs varied per animal subcategories. In summary, manure CH_4 EFs for beef category were consistent with the dairy category at all animal subcategories as shown in Table 4.10 and 4.11 below. The CV per animal subcategories across the farms were less due to similar MMS used within the farms.

Table 4.10 Emission factors for manure management systems per farm (Dairy cattle)

Lvstk categ	Mature Females(D)	Heifers(D)	Bulls(D)	Calves(D)	Calves(D)	Bulls (D)
LvstkSub	Mature Females	Young Females - Age 1-2	Mature Bulls	Young Females - Age 0-1	Young Intact Males - Age 0-1	Young bulls
Units	Kg CH_4/animal/year	Kg CH_4/animal/year	Kg CH_4/animal/year	Kg CH_4/animal/year	Kg CH_4/animal/year	Kg CH_4/animal/year
F1	0.8	0.6	1	0.3	0.4	0.6
F2	2.2	1	-	0.5	0.5	0.8
F3	-	-	1	-	-	0.8
F4	1.1	0.6	0.9	0.3	0.3	-
F5	0.8	0.6	1	0.2	0.3	0.8
F6	0.8	0.5	1	0.3	0.3	-
F7	0.8	0.7	1	0.2	0.2	-
F8	0.9	0.6	1	0.1	0.2	0.9
F9	1.1	0.7	0.9	0.2	0.3	-
F10	0.9	0.7	1	0.2	-	-
F11	1.2	0.6	0.9	0.2	0.2	-
F12	1.1	0.6	1	0.2	0.3	-
F13	-	-	-	-	-	-
F14	1.0	0.6	1	0.1	0.2	-
F15	-	-	-	-	-	-
F16	1.0	0.7	1	0.2	0.2	-
Standard deviation(SD)	0.3	0.2	0.1	0.1	0.1	0.1
Mean	1.0	0.7	1.0	0.2	0.3	0.8
Coefficient variation(CV)	33	26	13	33	30	14
- Represents the unavailability of other animal sub-categories during certain periods						

Table 4.11 Emission factors for manure management systems per farm (Beef cattle)

Lvstk categ	Mature Females(B)	Heifers(B)	Bulls(B)	Calves(B)	Calves(B)	Mature Oxen (B)	Bulls (B)
LvstkSub	Mature Females	Young Females - Age 1-2	Mature Bulls	Young Females - Age 0-1	Young Intact Males - Age 0-1	Mature oxen	Young bulls
Units	Kg CH_4/animal/year	Kg CH_4/animal/year	Kg CH_4/animal/year	Kg CH_4/animal/year	Kg CH_4/animal/year	Kg CH_4/animal/year	Kg CH_4/animal/year
F1	1.5	0.7	1.2	0.2	0.3	-	-
F2	-	-	-	-	-	-	0.5
F3	1.3	0.2	1.0	0.2	0.3	-	-
F4	1.4	-	1.1	0.2	0.3	-	-
F5	-	-	-	-	-	-	1.1
F6	-	-	-	-	-	0.7	-
F7	1.5	0.7	1.2	0.2	0.2	-	-
F8	-	0.6	-	0.1	-	-	0.8
F9	-	0.5	1.2	-	-	-	-
F10	-	-	-	-	-	-	0.6
F11	1.2	0.5	0.9	0.2	0.2	-	-
F12	-	-	-	-	-	-	-
F13	1.4	0.7	1.2	0.2	0.2	-	-
F14	-	-	-	-	-	-	-
F15	1.4	-	-	-	-	-	-
F16	1.4	-	-	0.1	0.1	-	-
Standard deviation(SD)	0.10	0.16	0.12	0.05	0.06	0	0.22
Mean	1.4	0.6	1.1	0.2	0.2	0.7	0.8
Coefficient variation(CV)	7	27	11	25	26	0	29
- Represents the unavailability of other animal sub-categories during certain periods							

The lactating mature females had the highest manure CH_4 EFs across all farms in this study. Similarly, lactating animals had the highest manure CH_4 EFs due to different diets and MMS as compared to other animal sub-categories (Du Toit, 2013a). In addition, the study shows relatively lower manure CH_4 EFs for mature female dairy cow as compared to the results found by Moeletsi and Tongwane (2015) with about 40.98 kg/year. This difference might be due to the different MMSs employed. However, the results are consistent with the IPCC (2006) manure CH_4 EFs. The IPCC (2006) reported manure CH_4 emission default factors for Africa to be around 1 kg/head/year.

Manure CH_4 EFs by sheep differed per MMS per farm and this included manure left on pasture/range/paddock and composting - static pile. Ewes had calculated the manure CH_4 EFs of about 0.29 and 0.44 kg/animal/day for manure left on pasture/range/paddock and composting - static pile respectively. The manure CH_4 EFs for heifers were between 0.01 and 0.016, rams between 0.16 and 0.26, and female lambs (0.16 and 0.24), male lambs (0.15 and 0.23).

The manure CH_4 EFs were dependent on the volatile solid (VS), the biodegradability of manure (Bo), the methane conversion factors (MCFs) and the MMS % per farm. The VS for dairy mature females ranged from 2.05 (by Farm 5) to 4.62 kg dry solid/head/day (by Farm 15). Dairy heifers had the VS ranging from 1.01 (Farm 16 and Farm 4 each) to 4.26 kg dry solid/head/day (Farm 10). Dairy bulls ranged from 1.27 to 3.85 kg dry solid/head/day, with Farm 4 as the lowest and Farm 1 the highest. Dairy calves ranged from 0.82 to 2.35 kg dry solid/head/day, with Farm 12 as the lowest and Farm 2 as the highest. However, the beef mature females had the VS ranging from 2.71 to 7.36 kg dry solid/head/day with Farm 16 as the lowest and Farm 9 as the highest. Farm 16 had the lowest VS of about 0.64 and Farm 3 had 2.58 kg dry solid/head/day VS for heifers. Farm 13 had the lowest VS (about 1.19) and Farm 3 had the highest (3.46 kg dry solid/head/day). The young bulls had 1-2 kg dry solid/head/day, while the calves had the lowest VS of 0.64 and Farm 1 had the highest of 1.19 kg dry solid/head/day.

Manure methane emissions

Over the five year period, the farm total manure CH_4 emissions ranged from 1890 to 446040 kg CO_2eq/year at all farms (Table 4.12). The CV across the years per farm were less due to similar MMS used within the farms across the years. This might also be due to similar farm animal populations feeding systems.

Table 4.12 Annual farm manure methane emissions

Year	2010	2011	2012	2013	2014	Standard deviation	Mean	Coefficient variation(CV)
Farms	E(KgCO_2-eq)/Year	E(KgCO_2-eq)/Year	E(KgCO_2-eq)/Year	E(KgCO_2-eq)/Year	E(KgCO_2-eq)/Year	E(KgCO_2-eq)/Year	E(KgCO_2-eq)/Year	%
F1	22260	56490	65520	67410	33810	17965	49098	0,37
F2	8820	9030	14280	63210	31920	20681	25452	0,81
F3	51030	84420	446040	21420	24990	161811	125580	1,29
F4	38010	32970	39690	33810	49980	6087	38892	0,16
F5	26040	12810	24570	15960	15120	5351	18900	0,28
F6	13860	10710	8820	11760	13860	1927	11802	0,16
F7	49560	53340	50400	55440	95760	17556	60900	0,29
F8	17430	16380	11130	12810	15330	2322	14616	0,16
F9	59850	36330	15960	122220	25830	38005	52038	0,73
F10	12600	37800	6510	9030	7140	11784	14616	0,81
F11	165690	158760	158970	32797	52290	58480	113701	0,51
F12	20580	13860	7560	7560	5250	5598	10962	0,51
F13	35490	67830	75810	105630	123690	30654	81690	0,38
F14	61320	5670	1890	2730	2730	23261	14868	1,56
F15	11130	13020	4200	18690	14280	4738	12264	0,39
F16	68250	38010	28770	44730	40530	13179	44058	0,30

The CSDL MMS had contributed the highest to the total farm manure CH_4 emissions compared to the other MMSs followed by the CH_4 from manure left on pasture during grazing and this resulted at all farms. High amount of manure were stored as cattle/Swine Deep Litter < 1 Month system at all farms in the study. Although the open pit storage and dry lot MMSs were not a usual practice in Tshiame farms, manure stored in an open pit contributed to fewer emissions from Farm 14, with 1% of the total manure CH_4 emissions during the year 2010 and 2011. The amount of manure treated as dry lot spread and anaerobic digester were less. Dairy manure contributed the highest followed by beef manure. Manure CH_4 by swine livestock category were produced from Farm 2, 6, 7, 9, 13, 15, and 16 and this increased the total farm manure CH_4 emissions in those farms. Manure from swine livestock category were managed as cattle/Swine Deep Litter < 1 Month and by its nature it contribute to the production of CH_4 emissions. Goat livestock category produced less manure CH_4 emissions to the total farm at Farm 13 only and the horse subcategory also produced less to the total farm manure CH_4 emissions at farm 16 only.

The results of this study, show that the liquid manure produced high CH_4 emissions and this was due to the nature of liquid manure management which influenced more CH_4 emissions (Du Toit, 2013a; Moeletsi and Tongwane, 2015). In addition, the MMS which are based on slurry, and CSDL are sensitive to temperature variations and have higher MCFs which lead to high EFs to produce more CH_4 emissions (Monteny et al., 2001; Smith et al., 2007 and 2008; Du Toit, 2013a; Moeletsi and Tongwane, 2015). Cattle owners grazed their livestock on pastureland. However, the cattle were confined overnight in a cattle pen (kraal) and it is known that more manure is produced during the night. The results show that most of the manure produced on farms in Tshiame Ward are left in the kraal and managed as CSDL, and this contributes the most with approximately 98% of the farm totals of manure CH_4 emissions in 2010, 2011 and 2014 and 99% in the year 2012 and 2013. This observation is consistent with the findings in a study by Sappo (2011), where it was found that a high percentage of manure in South Africa was managed as liquid, contributing to 93.5 % of CH_4 emissions.

Manure nitrous oxide

Manure nitrous oxide emission factors

Manure N_2O EFs for livestock varied per MMS and were the same at all farms and this included the IPCC default value of 0.01 kg /head/year for manure managed as CSDL and for manure managed as dry lot and pasture (0.02 kg/head/year). However, manure used for feeding anaerobic digester, as well as the manure stored in an open pit contributed to the N_2O EF of 0.001 kg/head/year.

The default EFs used in this study were consistent with the manure EFs used by Tubiello et al., (2013). Contrary to findings from this study, Amon et al. (2001) found that N_2O EFs for manure deposited directly on pasture were greater than that for manure kept in storage and this was due to the aeration in pasture-deposited manure. In a study by Zhang and Han (2008), N_2O EFs for manure deposited on pasture in China was 0.35% while EF for pasture for Netherlands was 0.17 (Schils et al., 2008). In another study by IPCC (2006) the New Zealand country had the specific EF values for urine and dung of 0.01 and 0.0025, respectively to estimate direct N_2O emissions from manure. This was different from results of this study since the EF values for urine and excreta used were combined. However, the N_2O EFs for this study were similar with the EFs in the study by IPCC (2006), wherein the EFs were the same for farms located at medium and high slope. The EF for pasture in Neitherlands was 0.29% (Schils et al., 2008), whereas, the EF for pasture in the Amozon in Brazil was 2.80% (Neli et al., 2005). The less N_2O EFs from manure in this study might be due to the lower quality of feeding. Jungbluth et al. (2001) cited results from Amon et al. (2001) which, when recalculated using IPCC defaults for Nex, suggest an emissions factor of 0.14 percent.

Manure nitrous oxide emissions

The total farm N_2O emissions from manure management ranged from 1240 to 65100 kg CO_2eq/year, as shown in Table 4.13. The CV in manure CH_4 emissions were less across the years per farm and the less variability were due to similar MMS used at per farm in all years. This might also be due to the comparable farm animal populations and feeding systems across the years.

Table 4.13 Total manure nitrous oxide emissions per farm

Year	2010	2011	2012	2013	2014	Standard deviation	Mean	Coefficient variation(CV)
Farm	**E($KgCO_{2}$-eq)/Year**	**E($KgCO_{2}$-eq)/Year**	**E($KgCO_{2}$-eq)/Year**	**E($KgCO_{2}$-eq)/Year**	**E($KgCO_{2}$-eq)/Year**	**E($KgCO_{2}$-eq)/Year**	**E($KgCO_{2}$-eq)/Year**	**%**
F1	9610	31310	33170	32860	20150	9250	25420	0,36
F2	3720	4960	8680	18600	50220	17300	17236	1,00
F3	14880	23250	32240	12400	47740	12866	26102	0,49
F4	15190	14260	11780	22630	53320	15374	23436	0,66
F5	11780	11470	26040	13950	18290	5443	16306	0,33
F6	8370	10540	8370	11160	15810	2724	10850	0,25
F7	25730	25110	22940	24490	34410	4045	26536	0,15
F8	12090	14880	14880	10850	12710	1586	13082	0,12
F9	35960	30690	13020	16740	21390	8566	23560	0,36
F10	6820	6510	6510	7750	9300	1063	7378	0,14
F11	56110	56110	65100		32860	11943	52545	0,23
F12	12400	10540	6200	6200	4340	3022	7936	0,38
F13	14880	20460	22630	31620	40920	9163	26102	0,35
F14	32860	33170	10850	17050	17050	9120	22196	0,41
F15	3100	4030	1240	6200	6200	1897	4154	0,46
F16	45880	28520	23250	31620	31620	7503	32178	0,23

Cattle/swine deep litter > 1 month system contributed the highest with 80% of the total N_2O emissions in all years while dry lot and manure left on pasture contributed minimally to the total farm N_2O emissions with 20 percent only from cattle livestock. Manure N_2O emissions from the non- ruminants' animals did not have any effect on total farm N_2O production due to the lower quantity of the manure owing to the lower population number of animals. Manure stored in an open pit and anaerobic digester MMSs did not contribute to N_2O emissions also due to less amount of manure.

High manure N_2O emissions resulted from the CSDL MMS and followed by manure left on pasture at all farms. Manure left on pasture did not have much effect on N_2O emissions since most of the manure were managed as CSDL at all farms. This was different from other studies since manure stored in solid form usually produces more N_2O emissions than manure stored in liquid form (Chadwick et al., 2000; Sherlock et al., 2002; Fangueiro et al., 2008, 2010; Singurindy et al., 2009; Smith et al., 2008).

N_2O emissions from manure management were related to cattle population data; including nitrogen excretion rate and annual N excretion per head of cattle. The N_{rate} was 60 for dairy mature females and 40 for all other dairy subcategories and all beef cattle (IPCC, 2006). N_2O is produced by nitrification and denitrification and the rate of both these processes increases with increasing temperature (Sommer, 2000). N_2O emissions from slurry systems were assumed to be zero as a result of the anaerobic conditions (Monteny et al., 2001).

Uncertainty analysis

To estimate the uncertainty analysis for N_2O and CH_4 emissions from manure management, the level of uncertainty was determined at 95% confidence interval for each of the activity data and where possible expert opinion on observed variation was utilized for qualitative data such as MMSs. This was done in accordance with the IPCC recommendations (IPCC, 2006). The process was done for all the activity data and ALU already had predefined uncertainty ranges for all the default IPCC values imbedded in the software. The uncertainty results produced were ranging from 18.22% to 35.72% for CH_4 and 33.77% to 92.61% for N_2O from manure management respectively. High uncertainties for CH_4 manure management is attributed to high error estimate attached to MMSs and utilization of default values which carries uncertainties exceeding 50%. In estimating N_2O, most of the data utilized for estimating EFs were obtained from the IPCC default values hence the extremely high error estimate. The uncertainty results are shown in Tables 4.14, 4.15 and also in the Appendix C, Table 9 – Table 26.

Table 4.14 Uncertainty for manure CH_4 emissions by non-dairy

Farms	2010 estimate	Uncertainty range and percentage		
	(Kg CO_2eq)	Lower bound	Upper bound	Uncertainty percentage
Farm 1	672	528	815	21.34
Farm 2	538	434	642	19.35
Farm 3	1759	1394	2124	20.75
Farm 4	801	655	947	18.22
Farm 5	484	388	581	20
Farm 6	217	169	265	22.03
Farm 7	1130	897	1364	20.67
Farm 8	171	136	206	20.65
Farm 9	614	491	736	20
Farm 10	133	107	158	19.36
Farm 11	2649	2013	3284	23.98
Farm 12	206	157	254	23.58
Farm 13	1245	923	1567	25.87
Farm 14	515	390	640	24.25
Farm 15	289	227	350	21.36
Farm 16	783	611	956	22.05

Table 4.15 Uncertainty for N_2O emissions from manure management by non-dairy for 2010

Farms	2010 estimate	Uncertainty range and percentage		
	(Kg CO_2eq)	Lower bound	Upper bound	Uncertainty percentage
Farm 1	64839	40913	88765	36.9
Farm 2	309	113	505	63.42
Farm 3	17095	7356	26834	56.97
Farm 4	15575	5484	25666	64.79
Farm 5	9417	2784	16051	70.44
Farm 6	4220	2185	6256	48.23
Farm 7	21672	10596	32749	51.11
Farm 8	6640	2471	10809	62.79
Farm 9	11925	3983	19868	66.6
Farm 10	2579	1024	4133	60.29
Farm 11	51483	20465	82502	60.25
Farm 12	4000	1905	6094	52.36
Farm 13	24196	8733	39660	63.91
Farm 14	10005	4451	15558	55.51
Farm 15	9085	1279	16891	85.92
Farm 16	15226	8458	21994	44.45

Quality control and quality assurance

To ensure that collected data on manure management was understood, training of the data collection was done most specifically by the supervisors to gain knowledge on the differences between the livestock MMSs. Understanding of these systems had ensured that when asking farmers, they probe intelligently. MMSs collected were then compared with the previous findings and where possible individual farmers were also contacted to verify their choice of MMSs. The data from the survey was complemented by reports from the experts with different animal commodities. Quality control and quality assurance on activity data outlined in the previous section (Enteric CH_4) also apply to this source.

4.1.3 Non-CO_2 biomass burning emissions

Biomass burning emission factors and emissions

Biomass burning in agriculture at farms comprises the burning of grassland residues, including the burning of both living and dead grasses (Smith et al., 2007). Between 2010 and 2014, CH_4 emission ratio for both life and dead biomass at all farms resulted into a similar factor value of 0.004 (tonnes CH_4-C/tonnes) which is equivalent to 4 kg^{-1} dry fuel. However, the N_2O emission ratio for both live and dead biomass were also similar by 0.007 (tonnes N_2O-N/tonnes) in all years at all farms which is corresponding to 7 kg^{-1} dry fuel. A default combustion factor (C_f) value of 1 was used in this study. The amount of CH_4 and N_2O EFs from biomass burning were influenced by grassland data. This data included the percentage of grassland burnt on site which is the mass of fuel available for burning, grass type, and management systems (Smith et al., 2007). This also depended on the aboveground biomass density and the fraction actually burned (Crutzen and Andreae, 1990; Levine et al., 1995; Smith et al., 2007).

Methane and N_2O EFs in this study were similar to the EFs noted in other studies in literature (Christian et al., 2004; Bertchi et al., 2003; Keene et al., 2006; Yokelson et al., 2007). The fuel consumption used in the study by Christian et al., (2004) was 5% with the calculated CH_4 EF ranging from 1.21 to 17.6 Kg^{-1} dry fuel. However, the N_2O EF estimated in the study by Bertchi et al. (2003) was 0.49 Kg^{-1} dry fuel. The CH_4 estimated EF by Keene et al. (2006) was 11.0 Kg^{-1} dry fuel, whereas, Yokelson et al. (2007) estimated CH_4 EF which were ranging from 1.50 to 15.7 Kg^{-1} dry fuel. Bertschi et al. (2003) estimated the average CH_4 EF of 17.1 Kg^{-1} dry fuel.

The farm total CH_4 emissions from biomass burning ranged from 945 to 66339 kg CO_2eq/year, when all farms were taken into consideration. The results of CH_4 emissions from biomass burning are presented in Table 4.16 below. Taking all farms into consideration, the total farm N_2O emissions from grassland biomass burning ranged from 310 to 12090 kg CO_2eq as shown in Table 4.17. Emissions depended on the amount of biomass burned and the area burned (ha). The CV across the years within the farm were less and the less variability in CH_4 and N_2O emissions were due to slightly the same annual area burned (ha).

During some years there were no grassland burning, at some farms while at Farm 2 there were no occurrence of fires in all years. It was found that grassland burning in Tshiame Ward is caused by either natural or unintended man-made fires. The percentage of grassland burnt differed per farm. Much of the large expanses of grassland fires were caused by periodic fires initiated by hunting and the sizes of the broadcast fires were often uncontrolled. The higher contributions of CH_4 and N_2O emissions from fires were from farms which does not implement fire mitigation strategies. In contrast, the lowest emissions occurred at farms where fire was controlled, for example through fire belts or fire breaks. Fire patterns at some farms were managed by human actions such as controlled burning, back-burning and firebreaks, as reported by Yokelson et al. (2007).

Table 4.16 Total methane emissions from biomass burning

Year	**2010**	**2011**	**2012**	**2013**	**2014**	**Standard deviation**	**Mean**	**Coefficient variation(CV)**
Farm	**E(KgCO_{2-}eq)/Year**	**E(KgCO_{2-}eq)/Year**	**E(KgCO_{2-}eq)/Year**	**E(KgCO_{2-}eq)/Year**	**E(KgCO_{2-}eq)/Year**	**E(KgCO_{2-}eq)/Year**	**E(KgCO_{2-}eq)/Year**	**%**
F1	18879	-	-	28329	-	4725	23604	0,2
F2	-	-	-	-	-	-	-	-
F3	45087		3066	2352	-	19979	16835	1,2
F4	7077	29757	-	-	-	11340	18417	0,6
F5	-	-	-	28812	-	0	28812	0
F6	26670	16527	21252	11802	12180	5652	17686	0,3
F7	-	47208	-	47208	-	0	47208	0
F8	-		2835	-	-	0	2835	0
F9	25032	-	-	25032	25074	20	25046	0
F10	66339	33054	-	-	-	16643	49697	0,3
F11	-	-	-	-	4725	0	4725	0
F12	945	-	-	-	-	0	945	0
F13	21021	4725	-	5901	-	7420	10549	0,7
F14	4725	-	38955	-	-	17115	21840	0,8
F15	11802	11802	11802	11802	-	0	11802	0
F16	11802	-	-	-	-	0	11802	0
- Represents the unavailability of grassland residue burning during certain periods								

Table 4.17 Total nitrous oxide emissions from biomass burning

Year	**2010**	**2011**	**2012**	**2013**	**2014**	**Standard deviation**	**Mean**	**Coefficient variation(CV)**
Farm	**E(kgCO2-eq)/Year**	**E(kgCO2-eq)/Year**	**E(kgCO2-eq)/Year**	**E(kgCO2-eq)/Year**	**E(kgCO2-eq)/Year**	**E(kgCO2-eq)/Year**	**E(kgCO2-eq)/Year**	**%**
F1	3410	-	-	5270	-	930	4340	0,2
F2	-	-	-	-	-	-	-	-
F3	8370	-	620	310		3729	3100	1,2
F4	1240	5580	-	-	-	2170	3410	0,6
F5	-	-	-	5270	-	-	5270	0,0
F6	4960	3100	4030	2170	2790	980	3410	0,3
F7	-	8680	-	8680	-	-	8680	0,0
F8	-	-	620	-	-	-	620	0,0
F9	4650	-	-	4650	5890	585	5063	0,1
F10	12090	5890	-	-	-	3100	8990	0,3
F11	-	-	-	-	930	-	930	0,0
F12	310	-	-	-	-	-	310	0,0
F13	3720	930	-	930	-	1315	1860	0,7
F14	930	-	7130	-	-	3100	4030	0,8
F15	2170	2170	2170	2170	-	-	2170	0,0
F16	2170	-	-	-	-	-	2170	0,0
- Represents the unavailability of grassland residue burning during certain periods								

Uncertainty analysis

The causes of uncertainty from grassland biomass burning emissions arise from many sources such as the use of global or national average rates of conversion and coarse estimates of land areas converted to grassland, estimation of the area converted that is burnt as part of a management practice, mass of available fuel and combustion factors. The large uncertainty in the input data required for the calculations increased the uncertainties in the CH_4 and N_2O emission estimates as shown in Tables 4.18 and 4.19 below. The uncertainty results for 2011-2014 are presented in the Appendix C, Table 27 – Table 34.

Table 4.18 Uncertainty for grassland biomass burning CH_4 emissions

Farms	2010 estimate	Uncertainty range and percentage		
	(Kg CO_2/animal/year)	Lower bound	Upper bound	Uncertainty percentage
Farm 1	18879	7387	30371	60.87
Farm 2	-	-	-	-
Farm 3	45087	17643	72531	60.87
Farm 4	7077	2769	11385	60.87
Farm 5	-	-	-	-
Farm 6	26670	10436	42904	60.87
Farm 7	-	-	-	-
Farm 8	-	-	-	-
Farm 9	25032	9795	40269	60.87
Farm 10	66339	25958	106720	60.87
Farm 11	-	-	-	-
Farm 12	945	370	1520	60.87
Farm 13	21021	8226	33816	60.87
Farm 14	4725	1849	7601	60.87
Farm 15	11802	4618	18986	60.87
Farm 16	11802	4618	18986	60.87
- Represents the unavailability of grassland biomass burning during certain periods				

Table 4.19 Uncertainty for grassland biomass burning N_2O emissions

Farms	2010 estimate	Uncertainty range and percentage		
	Kg CO_2eq	Lower bound	Upper bound	Uncertainty percentage
Farm 1	3410	1423	5397	58.26
Farm 2	-	-	-	-
Farm 3	8370	3494	13246	58.26
Farm 4	1240	518	1962	58.26
Farm 5	-	-	-	-
Farm 6	4960	2070	7850	58.26
Farm 7	-	-	-	-
Farm 8	-	-	-	-
Farm 9	4650	1941	7359	58.26
Farm 10	12090	5046	19134	58.26
Farm 11	-	-	-	-
Farm 12	310	129	491	58.26
Farm 13	3720	1553	5887	58.26
Farm 14	930	388	1472	58.26
Farm 15	2170	906	3434	58.26
Farm 16	2170	906	3434	58.26
- Represents the unavailability of grassland biomass burning during certain periods				

Quality control and quality assurance

The quality of ALU in estimating CH_4 and N_2O emissions from grassland biomass burning often depend on the quality of data input. Data on the annual total area burnt per farm and the mass of available fuel used were collected from farmers. The combustion factors used were from the IPCC (2006).

4.1.4 Agricultural soil management N_2O emissions

Direct soil N_2O from manure N in pasture

The IPCC default (2006) 0.02 (kg N_2O-N/kg N) was used for N_2O EFs by cattle manure left on pasture. The sheep animal category had the manure CH_4 EFs of about 0.29 kg/head/year for ewes, 0.01 kg/head/year for young females (1-2 years), 0.16 kg/head/year for rams and 0.16 kg/head/year for lambs. However, ewes manure had the Nex rate of about 9 kg N/animal/year which was higher than all other sheep categories which had 5 kg N/animal/year each and this explained higher EFs associated with this animal category.

The direct soil N_2O emissions from manure left on pasture were reliant on the annual amount of animal manure nitrogen applied to soils adjusted to account for the amount that volatilises as ammonia (NH_3) and nitrogen oxide (NO_x). This is the fraction of animal manure N that volatilises as NH_3 and NOx (kg NH_3-N and NOx-N/kg of N excreted). The farm direct soil N_2O emissions from the applied manure N on pasture ranged from 930 to 29450 kg CO_2eq in all years at all farms. The CV across the years within the farms were less and the less variability in CH_4 and N_2O emissions were due to slightly the same amount of manure left on pasture as shown in Table 4.20.

Table 4.20 Soil nitrous oxide from Manure N in pasture

Year	2010	2011	2012	2013	2014	Standard deviation	Mean	Coefficient variation(CV)
Farm	**E(KgCO_{2}-eq)/Year**	**E(KgCO_{2}-eq)/Year**	**E(KgCO_{2}-eq)/Year**	**E(KgCO_{2}-eq)/Year**	**E(KgCO_{2}-eq)/Year**	**E(KgCO_{2}-eq)/Year**	**E(KgCO_{2}-eq)/Year**	**%**
F1	29450	31310	32550	32550	32550	1215	31682	0,04
F2	12090	15190	24800	32860	48360	13089	26660	0,49
F3	3720	5890	8370	3410	3720	1895	5022	0,38
F4	3410	3410	2480	5580	5580	1262	4092	0,31
F5	4960	2790	6200	3720	3410	1218	4216	0,29
F6	2480	2480	1860	2790	3100	411	2542	0,16
F7	6200	6200	5580	5890	8680	1109	6510	0,17
F8	2790	3720	2480	2170	2480	533	2728	0,20
F9	8990	7750	3100	4340	4960	2196	5828	0,38
F10	1550	6820	1550	1860	1550	2080	2666	0,78
F11	14570	14570	17050	37200	8990	9727	18476	0,53
F12	3410	2480	1240	16430	1240	5793	4960	1,17
F13	4340	5270	5890	8060	10540	2227	6820	0,33
F14	8060	8990	3410	4650	4340	2209	5890	0,38
F15	930	930	310	1550	1550	464	1054	0,44
F16	11780	7130	5580	7440	8060	2060	7998	0,26

Direct soil N_2O from application of organic fertilizers

The organic fertilizers that were applied on the farms were estimated for the period of 5 years taking into account only the N_2O from manure amendments and this was employed only on Farm 1. The IPCC default N_2O EF of 0.01 kg N_2O-N/kg N from manure amendment was used. The results are presented in Table 4.21 below.

Table 4.21 Soil nitrous oxide from Manure amendments

Year	2010	2011	2012	2013	2014	**Standard deviation**	**Mean**	**Coefficient variation(CV)**
Farm	**E(KgCO$_{2}$-eq)/Year**	**E(KgCO$_{2}$-eq)/Year**	**E(KgCO$_{2}$-eq)/Year**	**E(KgCO$_{2}$-eq)/Year**	**E(KgCO$_{2}$-eq)/Year**	**E(KgCO$_{2}$-eq)/Year**	**E(KgCO$_{2}$-eq)/Year**	**%**
F1	1550	1581	1674	1674	1612	50	1618	0,03

The direct soil N_2O from organic fertilizers were reliant on the total annual amount of animal manure nitrogen intentionally applied to soils adjusted to account for the amount that volatilises as NH_3 and NO_x, the total amount of animal manure produced, and the fraction of animal manure N that volatilises as NH_3 and NOx (kg NH_3-N and NOx-N/kg of N excreted) and the EF. Variations in total annual emissions across the years were less and there was an annual average N_2O emissions of 1618 kgCO_2eq/ha from organic fertilizers. N_2O emissions from manure amendments depended on the amount of nitrogen manure (NM) applied, population number of animals, Nex and Nadj. The animal live weights differed per animal subcategories at all farms. The nitrogen excretion rate (Nex) also varied for animal subcategories per MMS at all farms.

Direct soil N_2O from synthetic fertilizers

The estimation of soil N_2O from synthetic fertilizers was based on the annual amount of synthetic fertiliser N applied to soils after adjusting to account for the amount that volatilises, the total amount of synthetic fertiliser applied to soil annually, the volatilised as NH_3 and NO_X, and also the calculated N_2O fertilised EF per farm. The direct soil N_2O default EF of 0.01 (kg N_2O-N/kg N) for synthetic fertilizers was used. The CV across the years were less per farm and the less variability in N_2O emissions were due to similar amount of fertilizers applied annually. The annual amount of synthetic fertiliser nitrogen applied to soils varied per farm, per crop, per kg, as well as per hectare. The amount of nitrogen in synthetic fertilizer applied varied per fertilizer type per farm. Taking all farms into consideration, the amount of nitrogen from the synthetic fertilizer applied in percentages ranged from 6% to 22% for all years. Concisely, the total farm N_2O emissions from the fertilizer application per hectare were consistent with the amount of nitrogen fertilizers applied per farm per hectare. However, the total nitrogen per kg per hectare per farm were less at all farms and this explains the less N_2O produced at all farms. The results of N_2O from synthetic fertilizer applied are presented in Table 4.22 below.

Table 4.22 Soil nitrous oxide from application of synthetic N fertilizers

Year	**2010**	**2011**	**2012**	**2013**	**2014**	**Standard deviation**	**Mean**	**Coefficient variation(CV)**
Farm	**E(KgCO$_{2}$-eq)/Year**	**E(KgCO$_{2}$-eq)/Year**	**E(KgCO$_{2}$-eq)/Year**	**E(KgCO$_{2}$-eq)/Year**	**E(KgCO$_{2}$-eq)/Year**	**E(KgCO$_{2}$-eq)/Year**	**E(KgCO$_{2}$-eq)/Year**	**%**
F1	3410	1550	1550	1550	13640	4705	4340	1,08
F2	8370	8370	8370	8370	8370	0	8370	0
F3	1860	4030	5270	3410	5270	1277	3968	0,32
F4	2790		930	1550	2480	739	1938	0,38
F5	0	1860	1860	19530	39060	15083	12462	1,21
F6	620		620	620	39060	16645	10230	1,63
F7	11160	8370			8370	1315	9300	0,14
F8	1550	1550	1550	1550	1550	0	1550	0
F9	1550	1550	1550	1550		0	1550	0
F10	3410	3410	3410	3410	15190	4712	5766	0,82
F11	4030	4030	4030	4030	2790	496	3782	0,13
F12	930	1550	1860	4030		1168	2093	0,56
F13	15190	15190	15190	15190	15190	0	15190	0
F14	3410	1550	1550	1550	1550	744	1922	0,39
F15	6200	6200	6200	4340	6200	744	5828	0,13
F16	23250	23250	3410	4960	4960	9231	11966	0,77
- Represents the unavailability of grassland biomass burning during certain periods								

Direct soil N_2O from returned crop residues

The direct N_2O default EF for crop residues retained was used (0.01 tonnes N_2O-N/tonnes) 10 kg N_2O-N/kg) in all years at all farms. The N_2O emissions from retained crop residues are presented in Table 4.23. There is a less variability across the years per farm and this could be due to less quantities of crop residues retained annually. The total farm N_2O emissions from residue returned to soil depended on the amount of residues returned in the field, residue to crop product mass ratio, the dry matter content of the aboveground biomass, and the nitrogen content of the aboveground biomass. This also depended on the crop residue N (Ncr) and Ncr was determined using the amount of residues retained, dry matter fraction of residue (DMF), carbon fraction (CF), and N/C ratio - crop residue and the crop type.

Gomes et al (2009) observed that the biochemical composition of plant residues added to the soil was responsible for higher or lower N_2O emissions from retained residues. Similarly, Liu et al. (2011) reported that wheat straw incorporation increased N_2O emissions in the subsequent maize season, while the incorporation of maize straw did not influence the emissions. Results from this study are unique, since residues from maize contributed higher emissions and this is due to higher amount of maize residues retained than other crop residues. Toma & Hatano (2007) observed greater N_2O emissions in plots receiving low C/N ratio residues, possibly because these residues are easily decomposable. In a no-till crop system, in southern Brazil, soil N_2O emissions were lower for maize (higher C/N ratio) than for soybean (lower C/N ratio) (Escobar et al., 2010). Siqueira Neto et al. (2009) measured greater N_2O emissions in areas cultivated with corn-wheat than in areas cultivated with soybean-wheat. They explained this by the high amount of N applied to the corn field, in contrast to the biological N (via microorganism fixation) used as N source by the soybean crop. Therefore, the total farm N_2O emissions from retained residues depend on the amount of residues returned in the field and residue to crop product mass ratio as indicated in this study. Jantalia et al. (2008) reported that by using N-fixing in legume crops, N_2O emissions were not altered in subsequent crops. In agreement with such findings, Siqueira Neto et al. (2009)

suggested that legume crops could be used as a N source in agricultural systems, with the advantage of decreasing N_2O emissions, in comparison to N-fertilizers. An interaction between straw C/N ratio and mineral N-fertilizer addition may occur, increasing nitrification and denitrification rates and, therefore, increasing the N_2O production and emission in agricultural soils.

Table 4.23 Nitrous oxide from retained crop residues

Year	**2010**	**2011**	**2012**	**2013**	**2014**	**Standard deviation**	**Mean**	**Coefficient variation(CV)**
Farm	**E(KgCO2-eq)/Year**	**E(KgCO2-eq)/Year**	**E(KgCO2-eq)/Year**	**E(KgCO2-eq)/Year**	**E(KgCO2-eq)/Year**	**E(KgCO2-eq)/Year**	**E(KgCO2-eq)/Year**	**%**
Farm 1	-	-	310	-	310	-	310	0
Farm 2	930	-	-	-	-	-	930	0
Farm 3	1550	310	-	-	-	620	930	0,67
Farm 4	-	-	-	-	-	-	-	-
Farm 5	-	-	-	-	-	-	-	-
Farm 6	310	310	-	-	-	-	310	0
Farm 7	5890	5270	6510	620	-	2324	4573	0,51
Farm 8	-	-	-	-	-	-	-	-
Farm 9	310		310	310	310		310	0
Farm 10	620	620	1240	620	310	304	682	0,45
Farm 11	310				310		310	0
Farm 12	-	930	6510		310	2788	2583	1,08
Farm 13	1240	620	1240	2480	620	679	1240	0,55
Farm 14	-	620	-	-	-	-	620	0
Farm 15	-	-	-	-	-	-	-	-
Farm 16	46810	25110		2170	2170	18555	19065	0,97
- Represents the unavailability of crop residue retained during certain periods								

Indirect soil N_2O emissions from organic and synthetic fertilizer

The indirect N_2O emissions from atmospheric N deposition depended on the total fertilizer nitrogen (N), the fraction of fertilizer volatilized (FNv), and indirect emission factor for volatilized N (EFv). The fraction of fertilizer volatilized and the indirect default emission factor for volatilized N were 0.1 (kg N volatilized) and 0.01 (kg N_2O-N/kg N), respectively regardless of farm. However, the total fertilizer N varied slightly per farm. The indirect N_2O emissions from leaching/runoff depended on the total fertilizer N, the fraction of fertilizer N leached/runoff (FNlr), the indirect emission factor for N leached/runoff (EFlr). The fraction of fertilizer N leached/runoff and indirect emission factor for N leached/runoff were 0.3 (kg N leached and runoff) and 0.007 (kg N_2O-N/KG N leached), respectively. The study resulted in higher indirect N_2O emissions through leaching and runoff than indirect N_2O emissions through atmospheric deposition N_2O emissions and this occurred at all farms. For the whole 5 year period of study, the total farm indirect soil N_2O emissions ranged from 310 to 12710 kg CO_2eq at all farms. The CV across the years were less per farm and this was due to slightly the same amount of leaching and runoff of the applied organic and synthetic fertilizers annually as shown in Table 4.24.

Table 4.24 Indirect N_2O emissions by Atmospheric deposition, leaching and runoff

Year	**2010**	**2011**	**2012**	**2013**	**2014**	**Standard deviation**	**Mean**	**Coefficient variation(CV)**
Farms	**Kg CO2eq**	**Kg CO2eq**	**Kg CO2eq**	**Kg CO2eq**	**Kg CO2eq**	**Kg CO2eq**	**Kg CO2eq**	**%**
F1	8680	7750	8370	8060	11160	1218	8804	0,14
F2	4650	5890	7750	9610	12400	2745	8060	0,34
F3	1240	1860	3410	1550	2480	769	2108	0,36
F4	1550	0	310	930	1860	707	930	0,76
F5	310	620	1860	6510	12710	4711	4402	1,07
F6	0	620	620	620	620	248	496	0,50
F7	4960	4030	1240	1240	4030	1556	3100	0,50
F8	930	930	930	930	930	0	930	0,00
F9	1860	1550	930	930	930	392	1240	0,32
F10	930	930	930	930	4650	1488	1674	0,89
F11	3720	3720	4030	3720	2170	662	3472	0,19
F12	930	930	620	310	310	277	620	0,45
F13	5270	5270	5270	5890	6510	496	5642	0,09
F14	2170	2170	930	930	930	607	1426	0,43
F15	1860	1860	1860	1550	2170	196	1860	0,11
F16	9300	8060	2170	3410	2790	2938	5146	0,57

Uncertainty analysis

Uncertainties associated with emissions of N_2O from managed soils were higher as compared to other sources of emissions. This is 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 et al. (2010) and Monni et al. (2007). High uncertainty of the emissions result from 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 et al., 2014). N_2O emissions from agricultural soils are highly uncertain because they depend very much on both the exact conditions of the soil, the application of fertilizers and meteorological condition. The uncertainties from this source were higher and are presented in Table 4.25. The uncertainty results for 2011-2014 are presented in the Appendix C, Table 35 – Table 38.

Table 4.25 Uncertainty for soil nitrous oxide emissions

Farms	2010 estimate	Uncertainty range and percentage		
	Kg CO_2eq	Lower bound	Upper bound	Uncertainty percentage
Farm 1	43090	-8338	94518	119.35
Farm 2	26040	-12377	64457	147.53
Farm 3	9920	-1025	20865	110.33
Farm 4	7750	-2713	18213	135.00
Farm 5	5270	-1850	12390	135.11
Farm 6	3410	-885	7705	125.96
Farm 7	28210	-15039	71459	153.31
Farm 8	5270	-5477	16017	203.93
Farm 9	12710	-5362	30782	142.19
Farm 10	6510	-2292	15312	135.20
Farm 11	22630	-2109	47369	109.32
Farm 12	5270	-3215	13755	161.01
Farm 13	26040	-9143	61223	135.11
Farm 14	13640	-2555	29835	118.73
Farm 15	8990	-1130	19110	112.57
Farm 16	91140	-23104	205384	125.35

Quality control and quality assurance

The amount of the applied fertilizers that was obtained from farmers was checked against other farms and were generally seen as similar. The data on manure management that was obtained from the survey was compared with limited available information from the literature and expert opinions within agricultural research council (ARC) was sought. Cropland management data that was collected from the farmers was compared against average practices and values according to the literature to remove the outliers. Data quality of the cropland areas and other management practices was checked by crop type against various statistics including official reports, published data and expert judgement where information was lacking.

4.1.5 CO_2 from diesel-tractor emissions

CO_2 EFs from diesel- tractor resulted to be the same at all farms with 0.073 Kg CO_2e/L of diesel. The EFs from the use of agricultural diesel machines or tractors in this study was lower (0.073 kg CO_2 MJfuel $^{-1}$) as compared to EFs in other studies. Rajaniemi et al. (2011) recorded the EF of 98.48 g CO_2 MJfuel^{-1} which is equivalent to 0.09848 kg CO_2 MJfuel $^{-1}$ with the energy content of 36.3 MJ^{-1}. This study has used the energy density of 42.8 MJ/ha (Bridges and Smith, 1979) which is higher compared to that by Rajaniemi et al. (2011). In addition the EF for heavy-duty diesel vehicles was recorded as 2730 g CO_2/L which is equivalent to 2.73 kg CO_2/L which is also higher than the EF used in this study. The variations in the calculated EFs were due to differences in the type of tractor engine used and the the density of diesel (kg/liter). In this study the type of tractor engine used was neglected since the equation used did not include the type of engine tractor used, and the same amount of 0.84 density of diesel (kg/liter) was used at all farms. Agricultural tractor emission (Revised March 2004) reported the EFs of 0.41886 and 0.5856 Kg/Mj for two categories of tractor engines and which was also higher than the EF used in this study. However, this implies that, the EFs depend mostly on the type of the engine used as well as the density of diesel.

The total farm CO_2 emissions from diesel tractor-engine used for crop production ranged from 596 to 87884 kg CO_2eq at all farms for the year 2010 to 2014. Higher total farm CO_2 emissions from this sub source were due to high area of hectares planted per farm as it required more energy for crop production and this also led to less variations of emissions across the years per farm as shown by less CV in Table 4.26.

Table 4.26 CO_2 from diesel-tractor emissions

Year	2010	2011	2012	2013	2014	Standard deviation	Mean	Coefficient variation (CV)
Farm	**E(Kg CO_2eq/farm/ year)**	**E(Kg CO_2eq/farm/ year)**	**E(Kg CO_2eq/farm/ year)**	**E(Kg CO_2eq/farm/ year)**	**E(Kg CO_2eq/farm/ year)**	**E(Kg CO_2eq/farm/ year)**	**E(Kg CO_2eq/farm/ year)**	**%**
F1	14330	12220	18707	18057	15080	2407	15679	0,15
F2	8005	7795	8005	7406	7795	219	7801	0,03
F3	3438	2299	1354	861	5795	1759	2749	0,64
F4	3701	4317	6168	6168	12577	3153	6586	0,48
F5	3128	2976	2661	1850	2661	442	2655	0,17
F6	882	903	1129	596	4514	1465	1605	0,91
F7	20471	22571	21495	25904	28741	3057	23836	0,13
F8	14802	14802	14802	7598	4724	4330	11346	0,38
F9	2997	2871	2997	3163	3107	101	3027	0,03
F10	7401	6141	6141	6141	6960	528	6557	0,08
F11	23043	26318	20755	22597	14435	3931	21430	0,18
F12	2047	10236	1024	3330	8608	3681	5049	0,73
F13	28366	28366	30234	30234	24938	1935	28427	0,07
F14	5984	3464	6394	5748	5427	1019	5403	0,19
F15	12729	12729	12729	12939	8635	1661	11952	0,14
F16	50015	45858	60804	87884	12708	24287	51454	0,47

A previous study by Stajnko et al (2009) showed that, higher CO_2 emissions were recorded from conventional tillage system followed by the minimum tillage system. All crop production activities were undertaken the same way at all farms and this included activities such as disc ploughing, harrowing, fertilizer spraying, planting and harvesting. The total amount of diesel, operation time and energy used per year varied per activity as shown in Table 4.27 below.

Table 4.27 The total amount of diesel, operation time and energy used per year per activity

Activity	Diesel used (L/ha)	Operation Time (T/hrs)	Energy used (MJ/ha/farm)
1 Disc ploughing	8	0.50	287
2 Harrowing	4	0.25	143
3 Spraying	2	0.12	71
4 Planting	10	0.67	359
5 Harvesting	13	0.92	467

The farm total energy used for crop production varied per farm depending on the crops produced per growing season. The farm total energy consumed for crop production ranged from 15460 to 5253388 MJ when all farms were considered. In 2010 Farm 16 had consumed the highest farm total energy for production of crops with about 4008804 MJ and farm 6 used the lowest total farm energy of about 24736 MJ. In 2011 Farm 16 reduced its farm total energy use. However, it remained the highest with 3466802 MJ, whereas, Farm 6 remained constant with energy use of about 24736 MJ becoming the lowest as compared to other farms. In 2012 Farm 16 continued to use the most energy (2514720 MJ) though it decreased its farm total energy used. Farm 12 had utilized the smallest energy of about 14020 MJ in the same period. In 2013 Farm 16 increased its total farm energy and it remained the highest with 5253388 MJ, while Farm 6 had utilized less energy (15460 MJ) as compared to other farms. In 2014 Farm 16 remained the highest in energy consumption with 1480440 MJ and Farm 5 utilized the least energy of 36452 MJ. The high amount of energy used at Farm 16 in all years were due to more hectares planted than at other farms. However, at farms where more hectares of dry bean and soybean were planted more energy was used as these crops need to be planted on cleaner soil than other crops. This crops require thoroughly soil preparations and seed-bed of a depth of six to eight inches, loose soil which allows beans roots to stretch rapidly and take in water and oxygen easily. However, the full tillage system was used for production of soya and dry beans which required more energy of about 1690 MJ/ha/crop at all farms and this included disc ploughing X2, harrowing X1, fertilizer spraying X2, planting X1 and harvesting X1.

The results have shown that the production of crops such as maize, maize silage, sunflower, wheat and barley consumed the energy of about 1402 MJ/crop/ha. A full tillage system was also employed and this included disc ploughing X1, harrowing X1, fertilizer spraying X2, planting X1 and harvesting X1. Crops such as rhubarb, oats, teff grass and Lucerne hay required lesser energy (1186 MJ/crop/ha) than other crops. A minimum tillage system was employed and this included activities such as disc ploughing X1, fertilizer spraying X1, planting X1 and harvesting X1. Farm 16 and Farm 7 had applied the full tillage system the most while Farm 6, Farm 12 and Farm 5 had applied the minimum tillage system more regularly.

The fertilization and planting activities in this study required more energy than other activities with about 10 L/ha and this was consistent with the energy used in other studies (Maraseni et al., 2009). The fuel consumption for spraying in all crops in this study were almost the same as that which was reported in a study by Maraseni et al (2009). Harvesting fuel consumption in this study are consistent with harvesting fuel consumption under irrigated land as found in a study by Maraseni et al (2009). The fuel consumption for harvesting by Maraseni et al (2009) were lower than the fuel consumption in this study. Among all the farming activities, harvesting energy use was found to be the highest and accounted for 52% of total energy used per farm. Energy use for planting was also significant, accounting for approximately 24% of the overall direct energy use.

Farmers in the study area used minimum tillage for fodder crops whereas conventional tillage was applied on crops such as maize, drybean, soybean, wheat and barley. However, conventional tillage required more energy than minimum tillage system. At some farms harvesting was done using diesel operated machines and the harvesting of other crops utilized several units of work involving mechanical harvesting of crops such as drybeans. However, this implies that where they practiced minimum tillage there was a potential saving of the overall fuel use on the farm unlike where conventional tillage was applied.

For all farms growing maize, the diesel used was around 39 Liters/ha, broadly consistent with that reported in literature and from the experiences for other farmers (Gholani et al., 2013). From the results, it can be seen that the (direct) fuel use for spraying is significantly lower than that used for other activities. In a study by Gholani et al (2013), it was found that emissions of specific tractor engine depended mainly on engine speed. It was also found in the study by Gholani et al (2013) that emissions increased as the engine oil temperature increased. Results from this study differ since engine type and speed were not considered due to lack of data. The highest fuel consumption was recorded for conventional tillage with 82 L/ha and 68.38 L ha-1 at two different areas of the Eastern Slovenia, as reported in a study by Stajnko et al., (2009), showing higher emissions, as compared to those reported in this study. The minimum tillage system diesel consumption level were 35.09 L/ha and 38.93 L/ha, respectively, lower than the conventional tillage in the Eastern Slovenia. However, the lowest diesel oil consumption of all tillage systems were recorded with the direct seeding after Gliphosat spraying (DS-G system) on both location with 16.11 L/ha and 14.76 L/ha respectively (Stajnko et al., 2009).

Uncertainty analysis

In general, use of the fuel-based methods produces less uncertainty than use of the distance based methods (IPCC, 2006c). However, this study used the fuel - based methods to reduce uncertainties and the use of locally estimated data at farm level reduced uncertainties as recommended by the IPCC (IPCC, 2006). The less uncertainty for CO_2 emission factors from this source was also due to the uncertainty in the diesel fuel composition as shown in Table 4.28 below. The uncertainty results for 2011-2014 are presented in the Appendix C, Table 39 - Table 42.

Table 4.28 The uncertainty for CO_2 emissions from diesel tractor

Farms	2010 estimate	Uncertainty range and percentage		
	Kg CO_2eq	Lower bound	Upper bound	Uncertainty percentage
Farm 1	14329.75	12410	16250	13.4
Farm 2	8004.713	6932	9077	13.4
Farm 3	3438.09	2977	3899	13.4
Farm 4	3700.539	3205	4196	13.4
Farm 5	3128.399	2709	3548	13.4
Farm 6	881.8307	764	1000	13.4
Farm 7	20471.07	17728	23214	13.4
Farm 8	14802.16	12819	16786	13.4
Farm 9	2997.174	2596	3399	13.4
Farm 10	7401.079	6409	8393	13.4
Farm 11	23043.07	19955	26131	13.4
Farm 12	2047.107	1773	2321	13.4
Farm 13	28365.55	24565	32167	13.4
Farm 14	5983.851	5182	6786	13.4
Farm 15	12728.81	11023	14434	13.4
Farm 16	50015.02	43313	56717	13.4

Quality control and quality assurance

The activity data such as the frequency of the activity in the growing season and the time required to complete an activity (hour/ha) were collected from farmers. However, this data was compared with data from literature. The Mean Fuel Consumption was calculated based on the data collected from farmers and was compared with the values from literature. The characteristic fuel consumption for a specific activity with a tractor (litres/hour) and the density of diesel (kg per litre) used was derived from the IPCC (2006).

4.2 Total farm emissions

The total farm emission results are presented in the Appendix B, Table 4. The total emission results for each farm were directly correlated with total farm inputs. For example, in 2010, Farm 11 contributed the highest total amount of farm emissions with 580877 kg CO_2eq. Farm 16 was the second emitter with 430684 kg CO_2eq, while Farm 9 was the third contributor. All the remaining farms emitted less, whereas Farm 15 emitted the lowest with 69220 kg CO_2eq. Therefore, the total farm GHG emissions produced depend on the farm total inputs.

The highest total farm GHG emissions at some farms such as Farm 11 were due to higher inputs, especially livestock and cropland farming inputs. Livestock inputs included the stock rate which were higher at Farm 11 as compared to other farms. Meanwhile, this led to high demand of energy for production at farm level, including the feeding situations, as well as the intensive livestock management strategies for higher amount of manure. Higher stocking rates also affected Farm 2, Farm 13 and Farm 1 where farm inputs were high in all years. Furthermore, cropland production also required a high energy use for intensive farming management systems but emissions were also high due to use of high amount of synthetic fertilizers. Conversely, the lowest total farm GHG emissions at some farms as described above were due to lower amount of farm inputs used for livestock and cropland farming.

4.3 Emission intensity

The sizes of the farms included in this study ranged from about 107 to 1000 hectares. The sizes of the farms remained the same for all the sixteen farms from 2010 to 2014. Farm 16 with 1000 hectares was the largest farm covering more than 9 times the area of the smallest farm, which is Farm 10, with 107 hectares. Farm 16 as the largest farm should have required more inputs, and therefore contributed the highest GHG emissions, compared to the other 15 farms. However, this was not the case since farmers did not utilize all the available land. The area under cropping (e.g. the total area sown for grain or hay production, not including fallow or pasture area) fluctuated between 2010 and 2014 for all of the farms, except for Farm 15 where the area under cropping remained the same. On the other hand the area under cropping on Farms 4, 7, 9, and 13 increased during the same period.

Table 5 (Appendix B) indicates the annual emissions per hectare per farm for the 5 year period (2010-2014) which varied per year. The average annual emissions per hectare for each farm ranged from 133 to 1832 kg CO_2eq/year/ha/farm. Farm 2 had emitted the highest average annual emissions per hectare with 1832 kg CO_2eq/year/ha. Farm 11 was the second highest with 1633 kg CO_2eq/year/ha, Farm 1 the third (1524 kg CO_2eq), and Farm 13 fourth (1506 kg CO_2eq/year/ha). Farm 15 emitted the lowest amount with 133 kg CO_2eq/year/ha, compared to all other farms. The farm total emissions was not related to the total farm size, since the largest farm did not produce the higher emissions, neither did the smaller farm emit the least. Emissions varied according to activities undertaken on the farm. However, emission intensities varied widely across the farms. The farming practices that contributed the lowest emission intensity were from crop farming, while livestock related activities contributed the highest emission intensity in all years at all farms and this included enteric fermentation and manure management practices.

Compared to commercial farming, in 2010, 2011 and 2014 commercial farming contributed the most to GHG emissions with 57, 52 and 51% respectively. However, in 2012 and 2013 subsistence farming contributed the most with 52 and 53% in that order. However, emissions compared per unit area of land (ha) had shown that commercial farming contributed higher than subsistence farming. This might be due to that, commercial farms use the intensive systems contrasting to smallholder farms, which generally implement the extensive systems. There were differences in emission intensity between producers. For ruminant products especially, but also for crop management systems, emission intensities vary greatly among producers (Figure 4.1).

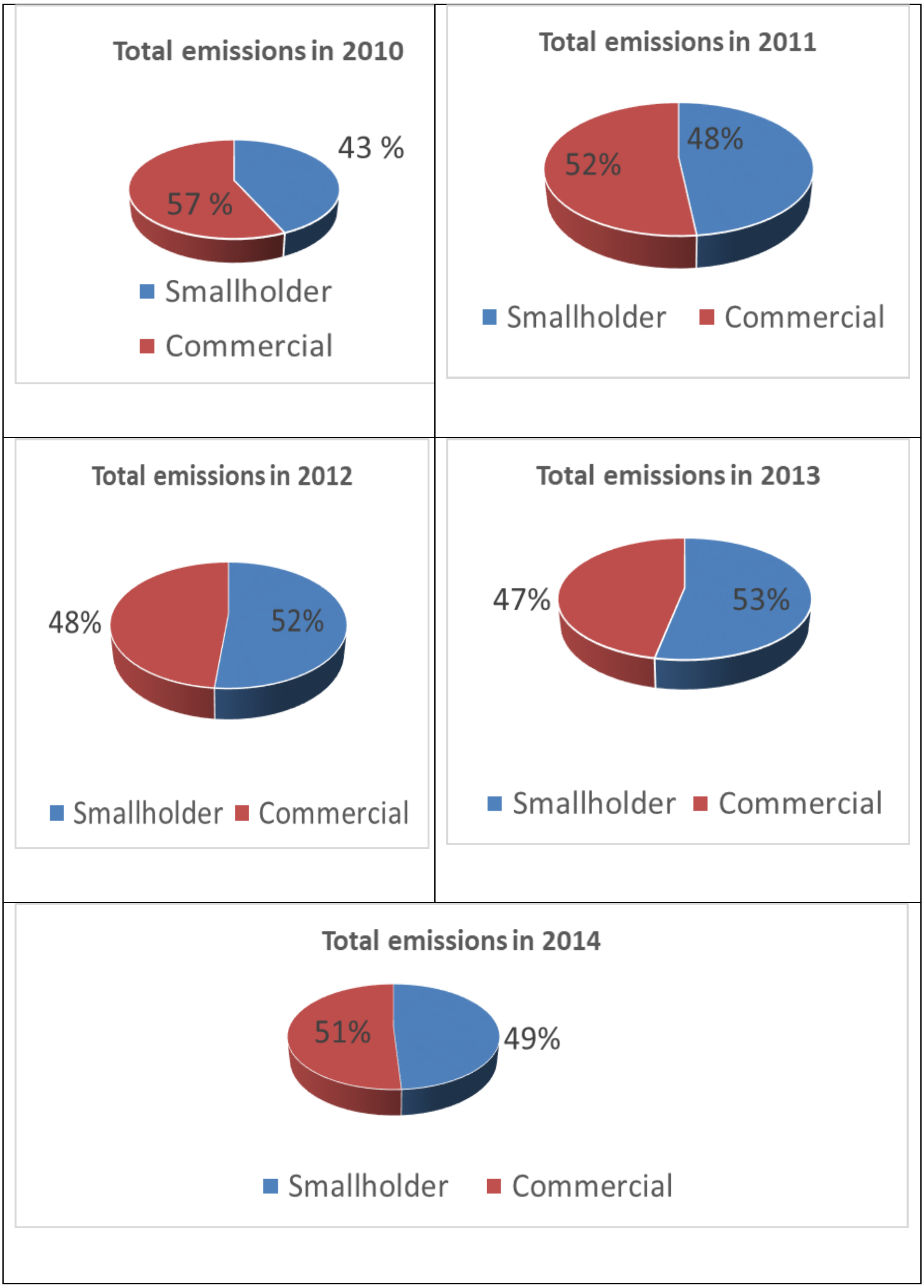

Figure 4.1 The commercial VS subsistence farming scale

Difference agro-ecological conditions and farming practices explain this heterogeneity, observed both within and across production systems. It is within this variability between producers with highest emission intensity and those with lowest emission intensity.

4.4 Potential Mitigation options

The mitigation analysis focused on mitigation measures that have the greatest capacity to reduce CH_4 and N_2O from enteric fermentation and manure management since livestock related activities contributed the most to the farm total GHG emissions in all years at all farms. The potential mitigation management practices used in the study are presented in Table 4.29 below. The results show that the potential management practices were the same at all farms though the mitigated emissions varied per farm, depending on the size of the farm. The potential mitigation options were chosen based on their ability to reduce GHG emissions, profitability to farming, and were environmentally friendly, and they promoted sustainability.

Table 4.29 Potential management practices for the study

Designation	**Description and input**
Mitigation 1: Solid storage manure management system	Changing manure management system (From cattle/swine deep litter>1 month to solid storage)
Mitigation 2: Anaerobic digester manure management system	Changing manure management system (From cattle/swine deep litter>1 month to anaerobic digester)
Mitigation 3: Pasture manure management system	Changing manure management system (From cattle/swine deep litter>1 month to pasture)
Mitigation 4: Drylot manure management system	Changing manure management system (From cattle/swine deep litter>1 month to drylot)
Mitigation 5: Feeding situation	Decreasing pasture and Increasing supplements (TMR) to 50% pasture and 50% supplements (TMR), from approximately 80% pasture and 20% supplements (TMR).
Mitigation 6: Feeding situation	100% Supplements (TMR)

4.4.1 Mitigation 1: Solid storage manure management system

As a routine, farmers at the study area managed manure through the following systems: cattle/swine deep litter for greater than 1 month, manure left on pasture during grazing, manure stored in an open pit, dry lot spread and lastly manure feeding on anaerobic digester. However, cattle/swine deep litter >1 month has contributed more CH_4 and N_2O emissions from all farms and in all years of the study compared with the other active manure management. Therefore, mitigation of manure CH_4 and N_2O emissions was done with more focus on reducing emissions from the system that contributed the most. Hence, when famers practice solid manure storage instead of treating manure as cattle/swine deep litter for greater than one (1) month, total CH_4 emission was reduced, while N_2O emission increased. However, the total farm manure emissions (kgCO_2eq) were reduced by 21% to 75% in all years at all farms. In 2010, Farm 3 had reduced more than other farms by 60% of the total manure emissions and in the year 2011, Farm 3 reduced more by 64% of the emitted manure emissions. In 2012 the farm manure emissions were reduced by 75% (Farm 3) which was more than at other farms. In 2013, Farm 11 reduced more by 69% of farm manure emissions and in the year 2014, farm 3 reduced its manure emissions by 70% and it was the highest. In view of that, solid storage reduced emissions as compared to that of cattle/swine deep litter for greater than 1 month and this indicated that solid storage can be considered instead of cattle/swine deep litter >1 month. The higher reductions at farms were due to the nature of solid manure management which influence less emissions (kgCO_2eq) than liquid manure management. The results on manure emission reduction on mitigation 1 are presented in Table 4.30.

Table 4.30 Reduction of emissions by mitigation 1

Year	2010	2011	2012	2013	2014
Farms	Kg CO2eq	Kg CO2eq	Kg CO2eq	Kg CO2eq	Kg CO2eq
F1	-14672	-41031	-51387	-51433	-23687
F2	-5269	-5005	-8756	-43106	-41892
F3	-39720	-68424	-357673	-10489	-51010
F4	-22603	-22149	-27480	-19488	-28120
F5	-18785	-5398	-12595	-9416	-13146
F6	-8519	-10220	-4368	-5352	-8748
F7	-33513	-38384	-34831	-38886	-53336
F8	-6117	-6609	-12738	-6051	-7361
F9	-40498	-19858	-8490	-70991	-16003
F10	-8891	-25539	-3328	-5518	-6083
F11	-108089	-111490	-117900	-22647	-30081
F12	-12194	-8628	-4900	-4040	-3117
F13	-21721	-52139	-58280	-65094	-96162
F14	-38579	-18004	-7519	-9426	-8906
F15	-7468	-8976	-2756	-11019	-10063
F16	-44599	-21252	-12328	-24185	-17512

4.4.2 Mitigation 2: Anaerobic digester manure management system

When all farmers were advised to use biogas digester instead of managing manure as cattle/swine deep litter for greater than one (1) month, total emissions reduction amount ranged from 9% to 24% in all years. This manure mitigation option showed less potential in reducing farm total manure emissions compared to mitigation 1. In 2010 Farms 1, 2 and 11 reduced their total farm manure emissions by 22% which was more than other farms. In 2011 Farm 14 reduced their manure emissions by 24% per farm and in 2012 Farms 1 and 8 reduced the highest of 23 percent. In 2013 Farm 8 reduced the highest by 24% and in 2014 there were more reduction of manure emissions from Farm 7 by 24%. The results on manure emission reduction on mitigation 2 are presented in Table 4.31.

Table 4.31 Reduction of emissions by mitigation 2

Year	2010	2011	2012	2013	2014
Farms	Kg CO_2eq	Kg CO_2eq	Kg CO2eq	Kg CO2eq	Kg CO2eq
F1	-6891	-21280	-22330	-21259	-11499
F2	-2788	-3410	-3018	-14625	-7959
F3	-7900	-19869	-56870	-6399	-12800
F4	-9780	-10470	-8630	-12720	-18078
F5	-7129	-2279	-10480	-6210	-3990
F6	-2109	-2872	-2644	-2660	-4190
F7	-13549	-10210	-9700	-13900	-31710
F8	-4679	-5000	-5909	-5729	-4779
F9	-8570	-13600	-4300	-18880	-9990
F10	-2159	-6978	-2239	-3674	-2506
F11	-49479	-49429	-44550	-5147	-10526
F12	-7425	-4678	-2906	-2130	-1068
F13	-10800	-11269	-14269	-31588	-24289
F14	-8968	-9450	-2980	-2859	-2239
F15	-1910	-2516	-1120	-4560	-3820
F16	-13308	-15489	-11350	-12840	-7530

4.4.3 Mitigation 3: Pasture - based manure management system

Replacing manure management of cattle/swine deep litter for greater than one (1) month with pasture/range/paddock resulted in emission reduction ranging 20% – 75 percent. The total CH_4 emission was reduced, while N_2O emission increased and the sequence was similar to that of mitigation 1. In the year 2010, the highest mitigated farm manure emissions were from Farm 3 by 61 percent. However, in the year 2011 Farm 10 reduced more by 71 percent and in the year 2012 farm 3 had reduced more of its manure emissions by 75% of the total emitted manure emissions. In the year 2013 Farm 10 had reduced the highest manure emissions by 74% and in 2014 Farm 11 had reduced more (69%) of its total manure emissions as compared to other farms. The results for pasture manure management as a mitigation option are presented in table 4.32 below.

Table 4.32 Reduction of emissions by mitigation 3

Year	2010	2011	2012	2013	2014
Farms	Kg CO2eq	Kg CO2eq	Kg CO2eq	Kg CO2eq	Kg CO2eq
F1	-14158	-35590	-44745	-45080	-21889
F2	-6504	-7348	-7881	-33559	-39878
F3	-40389	-58076	-359060	-11680	-37300
F4	-23463	-21500	-26868	-17979	58232
F5	-17010	-4880	-16120	-10680	-14150
F6	-9349	-4999	-5100	-5909	-15030
F7	-26000	-24480	-27448	-39140	-67439
F8	-11999	-15229	-12852	-4766	-6809
F9	-44012	-16940	-13072	-98708	-10022
F10	-6701	-31490	-3438	-12392	-5848
F11	-122569	-108730	-100130	-23954	-58607
F12	-10490	-5066	-3478	-4525	-3016
F13	-21350	-49848	-41765	-72959	-97648
F14	-31515	-19712	-3440	-8791	-5718
F15	-8359	-9355	-2205	-14409	-11099
F16	-35723	-19091	-10678	-25940	-19557

4.4.4 Mitigation 4: Drylot spread manure management system

Drylot spread manure management system is rarely used in the study area since it is practiced by only one farmer (Farm 1). However, changing manure management from cattle/swine deep litter for greater than one (1) month to drylot spread manure management system resulted in the emission reduction ranging from 20 to 74% in all years. The total CH_4 emission was reduced, while N_2O emission increased. In 2010, Farm 11 reduced more by 64%, while in 2011 Farm 3 had reduced about 61% of their farm total manure emissions. In 2012, the highest reduction was recorded from Farm 4 by 68% and in 2013, Farm 11 had reduced higher than other farms by 74 percent. In 2014, Farm 3 reduced 60% of farm manure emissions and it was the highest. The results on manure emission reduction on mitigation 4 are presented in Table 4.33.

Table 4.33 Reduction of emissions by mitigation 4

Year	2010	2011	2012	2013	2014
Farms	Kg CO2eq	Kg CO2eq	Kg CO2eq	Kg CO2eq	Kg CO2eq
F1	-15968	-26730	-37300	-46322	-12470
F2	-5898	-6269	-8208	-48912	-39278
F3	-32920	-65199	-306180	-8679	-43403
F4	-23530	-16480	-35110	-18065	-58403
F5	-12895	-14219	-30400	-6828	-13450
F6	-5259	-5831	-6308	-11180	-14800
F7	-33641	-35370	-34448	-41830	-50070
F8	-7389	-8730	-15229	-4709	-6089
F9	-32710	-15860	-6670	-87630	-11330
F10	-7999	-25568	-2989	-5497	-5870
F11	-141628	-122052	-90320	-24367	-36225
F12	-10870	-6458	-4206	-3889	-2339
F13	-19590	-50357	-56364	-78885	-85299
F14	-42347	-17120	-5120	-6819	-7590
F15	-6980	-7386	-2210	-13080	-8250
F16	-37040	-22744	-17378	-23495	-22110

4.4.5 Mitigation 5: Feeding system (50% Pasture and 50% supplements (TMR)

When farmers were advised to decrease pasture and increase supplements in a feeding situation (50 % pasture and 50 % supplements), there was a decrease in enteric CH_4 emissions for all years compared with the baseline data. There was a CH_4 reduction of approximately 27% - 45% in all years at all farms. Consequently, complementary of supplements and grazing pastures led to reduction of enteric CH_4 emissions as compared to the high percent of livestock grazing on pastures as practiced in Tshiame farms. The results on reduced CH_4 emissions by mitigation 5 are presented in Table 4.34 below.

Table 4.34 Reduction of emissions by mitigation 5 (50% pasture 50% supplements)

Year	2010	2011	2012	2013	2014
Farm	Kg CO2eq	Kg CO2eq	Kg CO2eq	Kg CO2eq	Kg CO2eq
F1	-69799	-82812	-88143	-67033	-74788
F2	-26672	-33673	-69399	-132008	-105756
F3	-27211	-45935	-79153	-22183	-24011
F4	-23425	-23956	-32891	-30771	-46693
F5	-19896	-13800	-37369	-28290	-16018
F6	-11522	-22767	-15120	-11449	-13440
F7	-28251	-38566	-38821	-41060	-44763
F8	-18944	-20035	-10887	-10996	-12584
F9	-49773	-119651	-24580	-31843	-33616
F10	-10935	-5789	-7672	-8300	-10141
F11	-110954	-110177	-122611	-132133	-53620
F12	-21640	-16622	-11059	-7805	-9460
F13	-32397	-52393	-47663	-87481	-110097
F14	-54184	-73925	-21766	-32882	-30471
F15	-9074	-10364	-2676	-11895	-10864
F16	-77208	-48333	-33142	-42635	-56487

4.4.6 Mitigation 6: feeding system (TMR based 100%)

This feeding system had reduced more CH_4 emissions from enteric fermentation by 81 to 92% than the previous mitigation option and the results are shown in Table 4.35. More reduction in CH_4 enteric emission was due to the higher digestibility of TMR-based diets as well as the higher intakes attained by animals feeding on confined based diets.

Table 4.35 Reduction of emissions by mitigation 6 (100% TMR)

Year	2010	2011	2012	2013	2014
Farm	Kg CO2eq	Kg CO2eq	Kg CO2eq	Kg CO2eq	Kg CO2eq
F1	-146770	-149845	-144710	-139102	-122416
F2	-77233	-95038	-211284	-226809	-215085
F3	-79705	-109870	-118983	-45226	-65471
F4	-74380	-73743	-69252	-186500	-113695
F5	-46106	-35203	-76837	-51793	-52645
F6	-27353	-49992	-27634	-33661	-38814
F7	-98852	-109213	-79294	-107874	-114847
F8	-33771	-44250	-29043	-29763	-33789
F9	-143023	-108078	-44949	-66061	-74481
F10	-22295	-11618	-18811	-22788	-22307
F11	-223464	-222377	-225111	-296639	-109614
F12	-44144	-39936	-22464	-22042	-11622
F13	-87400	-159286	-115325	-120962	-227810
F14	-130629	-110434	-54363	-82964	-77150
F15	-18139	-20618	-6753	-33789	-33869
F16	-146425	-109122	-85031	-110276	-113062

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The GHG EFs and emissions were calculated for sixteen (16) farms in the Ward, for the period of 2010 to 2014. The study used the Agricultural Land Use (ALU) software, which is developed based on revised 1996 IPCC guidelines, 2000 IPCC Good Practice Guidance, 2003 IPCC Good Practice Guidance and 2006 IPCC guidelines to estimate EFs and emissions.

Emissions produced from all sources were estimated per year and per farm. The annual farm total emissions for all sixteen (16) farms ranged between 36270 to 676245 Kg CO_2eq. The total livestock emissions were higher than cropland total emissions in all years. The livestock emissions ranged from 76 to 83 % while cropland emissions ranged from 17 to 24 % per year at all farms. Enteric fermentation contributed the highest to GHG emissions while manure amendments contributed the lowest and this was the case in all years at all farms. In all years, emissions from enteric fermentation remained the highest, ranging from 7499 to 983776 Kg CO_2/year/farm and were directly related to stocking rate on the farms. However, the manure CH_4 emissions remained the second highest for all years, and it ranged from 230 to 46181 Kg CO_2/year/farm, while manure N_2O emissions remained the third highest at all farms ranging from 2018 to 77790 Kg CO_2/year. As a result CH_4 and N_2O manure emissions were directly related to the number of animals and the manure management systems practiced at the farms.

The CH_4 emissions from grassland biomass burning were the fourth highest, ranging from 945 to 66339 Kg CO_2/year. These emissions were directly related to the number of hectares burned per farm. The next highest were CO_2 emissions from the engine tractor usage which ranged from 596 to 87884 Kg CO_2/year/farm. However, the emissions were related to the amount of diesel used per activity per hectare per farm. The sixth highest were the N_2O emissions from N pasture, which ranged from 310 to 48360 Kg CO_2/year/farm. These emissions were related to the amount of N manure left on pasture per year per farm. In the seventh place were the N_2O emissions from the synthetic fertilizer application, ranging from 620 to 39060 Kg CO_2/year/farm. The N_2O emissions were related to the amount of N fertilizers applied per hectare per year per farm. N_2O emissions from synthetic fertilizer and manure left on pasture were the highest contributors to the total soil N_2O emissions. During the period between 2010 and 2012, the higher contributions of emissions were from synthetic fertilizers. Synthetic fertilizer emissions were the highest, followed by N derived from pasture, and N from manure amendments emissions unlike in 2013 and 2014 when emissions from manure left on pasture were the highest, followed by those from synthetic fertilizer and manure amendments, which contributed the least to the total of N_2O emissions.

Indirect soil N_2O emissions were ranked the eight, ranging from 310 to 12710 Kg CO_2/year/farm. These emissions were produced from the crop residue retained, synthetic and organic fertilizer application, as well as from the manure N pasture. N_2O emissions from crop residue management ranged from 310 to 46810 Kg CO_2eq. N_2O emissions from grassland biomass burning ranged between 310 and 12090 Kg CO_2eq. Both the CH_4 and N_2O emissions from grassland biomass burning were related to the total number of hectares of grassland burned annually at all farms. N_2O emissions from manure amendments ranged from 1550 to 1674 Kg CO_2-eq, making them the lowest among all sources. In this study much higher emissions were generally found on Farm 11 and the total emissions from this farm were directly related to the higher inputs. The lowest emitter was by Farm 15, whose emissions were directly related to the lower inputs as compared to other farms.

In conclusion, the livestock emission factors assessed in this study were higher than the emission factors assessed in most previous studies and this might be due to the lower quality of the feeding situation used in the study area. However, the cropland emission factors were consistent with those cited in literature from most of the studies. There is a need for the development of emission factors at farm level or on a small scale. Each farm should have its own emission factors per GHG source, depending on the farm management practices. However, the results of this study have shown that, the activity data can be improved by replacing actual data collected with the assumptions as a way of evaluating the mitigation strategies. The mitigation analysis focused on mitigation measures that have the greatest capacity to reduce CH_4 and N_2O from enteric fermentation and manure management. Emissions from livestock related activities contributed the most to the farm total GHG emissions in all years at all farms. In this study, the mitigation options were analysed and evaluated, and as a result, six (6) mitigation options were regarded as the potential mitigation options for Tshiame farms. The six (6) potential mitigation options met the requirements of sustainability, environmental friendliness as well as profitability to farmers.

5.2 Recommendations

The conclusions of this research suggest five recommendations. First, farmers should be advised to adopt application of both synthetic (50%) and organic fertilizers (50%). Since farmers in Tshiame Ward only use synthetic fertilizers, it is highly recommended that farmers should adopt the strategy of applying both synthetic (50%) and organic fertilizers (50%).

Manure which accumulates throughout the year in a kraal can be spread on the fields during the dry season to avoid the run-off of Nitrogen manure. Inorganic fertilizers provides nutrients or minerals for crop production without adding any organic matter to the soil. However, in comparison, waste typically contains half as much organic matter, and minerals are concentrated within the waste. There are many benefits of adding organic matter to the soil with manure application, if organic matter is depleted in the soil. Thus, effluent can be as good of a crop fertilizer as the original manure, depending on soil properties of the land.

Secondly, it is suggested that farmers should move from conventional tillage to minimum and/ no tillage for a potential saving of energy and also for reduction of CO_2 emissions from diesel-tractor. No-tillage is recommended as a strategy to improve soil organic carbon content and reduce erosion, minimize agricultural energy use, and decrease CO_2 emission to the atmosphere.

The third recommendation is related to preparation for accidental fires, farmers should be advised to prepare for these fires. In Tshiame Ward, since in most cases fires are accidentally started by human beings, farmers should be advised to adopt strategies that reduce chances of their fields or grasslands catching fire, including the creation of fire belts. Therefore if all farmers can adapt to those strategies, there will be a huge decrease in CH_4 and N_2O emissions from this source.

The fourth recommendation is on complementary use of supplements. Farmers should be advised to use complementary supplements (TMR) and grazing pasture feeding situations for their animals. The complementary of supplements (TMR) and grazing pasture feeding situations have proved to meet the requirements of sustainability, environmental friendliness, as well as profitability to farmers. This feeding situation has the potential to reduce the GHG emissions from pastures only.

The fifth recommendation relates to the storage and treatment of manure. Farmers should be advised to store or treat the manure as solid. The solid storage of manure leads to a reduction of CH_4 manure emissions and also to a reduction of N_2O emissions. The manure stored as solid has a potential to be environmental friendly. It also promotes sustainability and the methods involved are cheap, as compared to storing the manure as liquid. Anaerobic digester also reduced the CH_4 emissions from manure.

REFERENCES

Ackerman, F. (2000). Waste management and climate change. *Local Environment*, *5*(2), pp.223-229.

AgDM (Ag Decision Maker) Newsletter. (2007). Global warming-agriculture‘s impact on greenhouse gas emissions: published in April 2008.

AFRC. (1993). Technical Committee on Responses to Nutrients. Energy and Protein Requirements of Ruminants. 24-159, CAB International, Wallingford, U.K.

Aldy, J.E. (2006). Per capita carbon dioxide emissions: convergence or divergence? *Environmental and Resource Economics*, *33*(4), pp.533-555.

Alexandratos, N. and Bruinsma, J. (2012). World agriculture towards 2030/2050: the 2012 revision. ESA Working paper No. 12-03. Rome, FAO, [On line] available: http://www.fao.org/fileadmin/templates/esa/Global_persepctives/ world_ag_2030_50_2012_rev.pdf/ [accessed on 10 May 2015]

Amado, T.J.C., Santi, A. and Acosta, J.A.A. (2003). Adubação nitrogenada na aveia preta. II-Influência na decomposição de resíduos, liberação de nitrogênio e rendimento de milho sob sistema plantio direto. *Bras. Ci. Solo*, *27*, pp.1085-1096.

Amon, B., Amon, T., Boxberger, J., Alt, C., Freibauer, A., (2001). Emissions of NH3, N_2O and CH_4 from dairy cows housed in a solid manure tying stall (housing, manure storage, manure spreading). Nutr. Cycling Agroecosyst. 60, 103–113.

Anon, (2010). Ruminant nutrition regimes to reduce methane and nitrogen emissions. Final Report for Defra Project AC0209. [On line] available: http://randd.defra.gov.uk/Document.aspx?Document5AC0209_ 10114_FRP.pdf [accessed October 20 2016]

ARC (Agricultural research council). (2014). Soil databank. 600 belvedere, Pretoria, South Africa.

Ashton, P.J. (2002). Avoiding conflicts over Africa's water resources. *AMBIO: A Journal of the Human Environment*, *31*(3), pp.236-242.

Aulakh, M.S., Khera, T.S., Doran, J.W. and Bronson, K.F. (2001). Denitrification, N_2O and CO_2 fluxes in rice-wheat cropping system as affected by crop residues, fertilizer N and legume green manure. *Biology and Fertility of Soils*, *34*(6), pp.375-389.

Bader, N. and Bleischwitz, R. (2009). Study Report Comparative Analysis of Local GHG Inventory Tools, Institut Veolia Environnement, College of Europe, Brugge.

Baggs, E.M., Rees, R.M., Smith, K.A. and Vinten, A.J.A. (2000). Nitrous oxide emission from soils after incorporating crop residues. *Soil use and management*, *16*(2), pp.82-87.

Baldock, J.A., Wheeler, I., McKenzie, N. and McBrateny, A. (2012). Soils and climate change: potential impacts on carbon stocks and greenhouse gas emissions, and future research for Australian agriculture. *Crop and Pasture Science*, *63*(3), pp.269-283.

Batjes, N.H. (1992). Nitrous oxide. *A Review of Soil Factors and Processes that Control Fluxes of Heat, Moisture and Greenhouse Gases. ISRIC, Technical Paper*, *23*, pp.67-96.

Batjes, N.H. and Bridges, E.M. (1992). August. World inventory of soil emission potentials. In *Proceedings of an international workshop organised in the framework of the Dutch National Research Programme on Global Air Pollution and Climate Change* (pp. 11-79).

Batstone, D.J., Keller, J., Angelidaki, I., Kalyuzhnyi, S.V., Pavlostathis, S.G., Rozzi, A., Sanders, W.T.M., Siegrist, H. and Vavilin, V.A. (2002). The IWA anaerobic digestion model no 1 (ADM1). *Water Science and Technology*, *45*(10), pp.65-73.

Begley, S., Conant, E., Stein, S., Clift, E. and Philips, M. (2007). The truth about denial. *Newsweek*, *150*(7), pp.20-29.

Bertschi, I. T., Yokelson, R. J., Ward, D. E., Babbitt, R. E., Susott, R. A., Goode, J. G. and Hao, W. M. (2003). Trace gas and particle emissions from fires in large diameter and belowground biomass fuels, *J. Geophys. Res., 108*(D13), 8472, doi:10.1029/2002JD002100.

Blignaut, J., Ueckermann, L. and Aronson, J. (2009). Agriculture production's sensitivity to changes in climate in South Africa. *South African Journal of Science*, *105*(1-2), pp.61-68.

Boadi, D.A. and Wittenberg, K.M. (2002). Methane production from dairy and beef heifers fed forages differing in nutrient density using the sulphur hexafluoride (SF6) tracer gas technique. *Canadian Journal of Animal Science*, *82*(2), pp.201-206.

Boadi, D.A., Wittenberg, K.M. and Kennedy, A.D. (2002). Validation of the sulphur hexafluoride (SF6) tracer gas technique for measurement of methane and carbon dioxide production by cattle. *Canadian Journal of Animal Science*, *82*(2), pp.125-131.

Boadi, D., Benchaar, C., Chiquette, J. and Massé, D. (2004). Mitigation strategies to reduce enteric methane emissions from dairy cows: update review. *Canadian Journal of Animal Science*, *84*(3), pp.319-335.

Boden, T. A., Marland, G. and Andres, R. J. (2013). Global, Regional, and National Fossil-Fuel CO_2 Emissions in 2 Trends. (Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of 3 Energy, http://cdiac.ornl.gov/, Oak Ridge, Tenn., U.S.A).

Boehm, M., Junkins, B., Desjardins, R., Kulshreshtha, S. and Lindwall, W. (2004). Sink potential of Canadian agricultural soils. *Climatic Change*, *65*(3), pp.297-314.

Bogner, J., Ahmed, M.A., Diaz, C., Faaij, A., Gao, Q., Hashimoto, S., Mareckova, K., Pipatti, R. and Zhang, T. (2007). Waste Management, in Climate Change 2007: Mitigation, Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Bouwman, A.F., Fung, I., Matthews, E. and John, J. (1993). Global analysis of the potential for N_2O production in natural soils. *Global Biogeochemical Cycles*, *7*(3), pp.557-597.

Branca, G., Lipper, L., McCarthy, N. and Jolejole, M.C. (2013). Food security, climate change, and sustainable land management. A review. *Agronomy for sustainable development*, *33*(4), pp.635-650.

Bremner, J.M. and Blackmer, A.M. (1978). Nitrous oxide emission from soils during nitrification of fertilizer nitrogen. *Science*, *199*(4326), pp.295-296.

Bridges, T. C. and Smith E. M. (1979). A method of determining the total energy input for agricultural practices. *Transactions of the ASAE*: 781 – 784.

Bull, P., McMillan, C. and Yamamoto, A. (2005). Michigan Greenhouse Gas Inventory 1990 and 2002. Centre for Sustainable Systems, University of Michigan, Report No. CSS05-07.

Burton, C.H. and Turner, C. (2003). *Manure management: Treatment strategies for sustainable agriculture*. Editions Quae.

CDP. (2011). Norske Skog, Carbon Disclosure Project Report. Investor CDP 2011 information request. Group five structured ingenuity.

Cartwright, A., Oelofse, G., Parnell, S. and Ward, S. (2012). Climate at the city scale: the Cape Town climate think tank. *Cartwright A., Parnell S. Oelofse G. and Ward S. (eds.), Climate Change at the City Scale: Impacts, Mitigation and Adaptation in Cape Town, Routledge, Abingdon, UK*.

Chadwick, D.R., Pain, B.F. and Brookman, S.K.E. (2000). Nitrous oxide and methane emissions following application of animal manures to grassland. *Journal of Environmental Quality*, *29*(1), pp.277-287.

Chandra, R., Takeuchi, H. and Hasegawa, T. (2012). Hydrothermal pretreatment of rice straw biomass: a potential and promising method for enhanced methane production. *Applied Energy*, *94*, pp.129-140.

Chianese, D. S. C. A., Rotz, C., A and Richard, T.L. (2009). Whole farm greenhouse gas emissions: A review with application tee a Pennsylvania dairy farm. *AppI. Eng. Agrie.* 25:431 442.

Chhabra, A., Manjunath, K.R., Panigrahy, S. and Parihar, J.S. (2009). Spatial pattern of methane emissions from Indian livestock. *Current Science*, *96*(5), pp.683-689.

Christensen, J.H., Carter, T.R., Rummukainen, M. and Amanatidis, G. (2007). Evaluating the performance and utility of regional climate models: the PRUDENCE project. *Climatic Change*, *81*, pp.1-6.

Christian, T. J., Kleiss, B., Yokelson, R. J., Holzinger, R., Crutzen, P. J., Hao, W. M., Shirai, T. and Blake, D. R. (2004). Comprehensive laboratory measurements of biomass-burning emissions: 2, First intercomparison of open path FTIR, PTR-MS, GC-MS/FID/ECD, *J. Geophys. Res*., 109, D02311, doi:10.1029/2003JD003874.

City of Cape Town. (2007). Integrated Development Plan 2007/8 – 2011/12, City of Cape Town Integrated Development Planning, Performance, and Participation Unit. [On line] Available: http://www.capetown.gov.za/en/PublicParticipation/Pages/default.asp/ [Accessed 07 August 2015]

City of Cape Town. (2012). Information and Guideline Document on the Implementation of Green Procurement in the City of Cape Town. Cape Town: City of Cape Town.

Cofer, W.R., Levine, J.S., Winstead, E.L. and Stocks, B.J. (1990). Gaseous emissions from Canadian boreal forest fires. *Atmospheric Environment. Part A. General Topics*, *24*(7), pp.1653-1659.

Cole, C.V., Duxbury, J., Freney, J., Heinemeyer, O., Minami, K., Mosier, A., Paustian, K., Rosenberg, N., Sampson, Sauerbeck, D. and Zhao, Q. (1997). Global estimates of potential mitigation of greenhouse gas emissions by agriculture. *Nutrient Cycling Agroecosyst*. 49:221-228.

Collas, P. and Liang, C. (2007). Agriculture. In National Inventory Report – Greenhouse Gas Sources and Sinks in Canada 1990–2005, pp. 154–176. Gatineau, Quebec: Greenhouse Gas Division, Environment Canada.

Collins, N.E., Kemble, L.J. and Williams, T.H. (2012). Energy requirements for tillage on coastal plains soils. *Agriculture and energy*, p.233.

Colomb, V., Touchemoulin, O., Bockel, L., Chotte, J. L., Martin, S., Tinlot, M. and Bernoux, M. (2013). Selection of appropriate calculators for landscape-scale greenhouse gas assessment for agriculture and forestry Environ. Res. Lett.

Council for Agricultural Science and Technology. (2004). Climate Change and Greenhouse Gas Mitigation: Challenges and Opportunities for Agriculture. Ames, IA: Council for Agricultural Science and Technology.

Cowan, N. J., Famulari, D., Levy, P. E., Anderson, M., Bell, M. J., Rees, R. M., Reay, D. S. and Skiba, U. M. (2014). An improved method for measuring soil N_2O fluxes using a quantum cascade laser with a dynamic chamber, *Eur. J. Soil Sci*., 65, 643–652.

Crosson, P., Shalloo, L., O'Brien, D., Lanigan, G.J., Foley, P.A., Boland, T.M. and Kenny, D.A., (2011). A review of whole farm systems models of greenhouse gas emissions from beef and dairy cattle production systems. *Animal Feed Science and Technology*, *166*, pp.29-45.

Crutzen, P.J. and Andreae, M.O. (1990). Biomass burning in the tropics: Impact on atmospheric chemistry and biogeochemical cycles. *Science*, *250*(4988), pp.1669-1679.

Crutzen, P.J., Mosier, A.R., Smith, K.A. and Winiwarter, W. (2007). N_2O release from agrobiofuel production negates global warming reduction by replacing fossil fuels. *Atmos. Chem. Phys. Discuss*. 7, 11191–11205.

DAFF. (2010). Quarterly economic review of the agriculture sector. Pretoria: DAFF.

Dave S. Reay, Eric A. Davidson, Keith A. Smith, Pete Smith, Jerry M. Melillo, Frank Dentener and Paul J. Crutzen . (2012). Nature Climate Change 2,410–416doi, [on line] Available: http://www.10.1038/nclimate1458 [accessed 04 February 2015]

Davidson, E.A. (2009). The contribution of manure and fertilizer nitrogen to atmospheric nitrous oxide since 1860. *Nature Geoscience*, *2*(9), pp.659-662.

DeAngelo, B.J., De la Chesnaye, F.C., Beach, R.H., Sommer, A. and Murray, B.C. (2006). Methane and nitrous oxide mitigation in agriculture. *The Energy Journal*, pp.89-108.

De Bona, F.D., Bayer, C., Bergamaschi, H. and Dieckow, J. (2006). Carbono orgânico no solo em sistemas irrigados por aspersão sob plantio direto e preparo convencional. *Revista Brasileira de Ciência do Solo*, *30*(5), pp.911-919.

DEA. (2004). South Africa: Initial National Communication under the United Nations Framework Convention on Climate Change. Submitted at COP-9, Pretoria. [On line] Available: http://www. unfccc.int/resource/docs/natc/zafnc01.pdf/ [Accessed 07 August 2015]

DEA. (2010). National climate change response green paper; prepared Pretoria.

DEA. (2011). Defining South Africa’s desired greenhouse gas mitigation outcomes. Presentation to Parliamentary Portfolio Committee for Water and Environmental

Affairs, 29 March 2011, Cape Town. [On line] Available: http://www.pmg.co.za/ [accessed 09 June 2016]

DEA. (2014) GHG Inventory for South Africa: 2000–2010, Department of Environmental Affairs, Pretoria, South Africa.

DEA. (2015) 'Analyzing the 2030 emissions gap'. Energistyrelsen. [On line] Available: http://www.ens.dk/en/info/facts-figures/scenarios-analyses-models/models/compare/analyzing- 2030-emissions-gap/ [accessed on 10 November 2015]

DEAT. (2004). A national climate change response strategy for South Africa, September 2004.

DEAT. (2008). People–Planet –Prosperity: A National Framework for Sustainable Development in South Africa. July 2008. Pretoria. [On line] Available: http://www.environment.gov. za. [Accessed on 21 July 2016]

DEAT. (2011). Eastern Cape Climate Change Response Strategy [on line] Available: http://www.dedea.gov.za/Policies/Draft%20EC%20Climate%20Change%20Response%20Strategy.pdf/ [accessed on 02 September 2014]

Demirel, B., Yenigun, O. and Onay, T. (2005). Anaerobic treatment of dairy wastewaters. A review. *Proc. Biochem*., 40, 2583– 2595.

Denef, K., Paustian, K., Archibeque, S., Biggar, S. and Pape, D. (2012). Report of greenhouse gas accounting tools for agriculture and forestry sectors. *Interim report to USDA under Contract No. GS23F8182H*, pp.1-135.

Del Grosso, S.J., Ogle, S.M., Parton, W.J. and Breidt, F.J. (2010). Estimating uncertainty in N_2O emissions from US cropland soils. *Global Biogeochemical Cycles*, *24*(1).

Del Grosso, S.J., Parton, W.J., Adler, P.R., Davis, S.C., Keough, C. and Marx, E. (2012). DayCent model simulations for estimating soil carbon dynamics and greenhouse gas fluxes from agricultural production systems. *Managing agricultural greenhouse gases: coordinated agricultural research through GRACEnet to address our changing climate. Elsevier, San Diego*, pp.241-250.

Denman, K.L., G. Brasseur, A. Chidthaisong, P. Ciais, P.M. Cox, R.E. Dickinson, D. Hauglustaine, C. Heinze, E. Holland, D. Jacob, U. Lohmann, S Ramachandran, P.L. da Silva Dias, S.C. Wofsy and X. Zhang, .(2007). Couplings between Changes in the Climate System and Biogeochemistry. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Devarajan, S. Go, D.S. Robinson, S. and Thierfelder, K. (2009). Tax Policy to Reduce Carbon Emissions in South Africa World Bank.

De Vries, M. and de Boer, I.J. (2010). Comparing environmental impacts for livestock products: A review of life cycle assessments. *Livestock science*, *128*(1), pp.1-11.

De Vrieze, J., Hennebel, T., Boon, N. and Verstraete, W. (2012). Methanosarcina: the rediscovered methanogen for heavy duty biomethanation. *Bioresour. Technol*. 112, 1–9.

De Wit, M. and Stankiewicz, J. (2006). Changes in surface water supply across Africa with predicted climate change. *Science*, *311*(5769), pp.1917-1921.

DFID. (2004). Department for International Development “Working Paper for the Renewable Natural Resources and Agriculture Team, DFID Policy Division. September 2004.

DOE. (2011). integrated resource plan for electricity: 2010–2030 (revision 2 final report). Department of Energy, Government of the Republic of South Africa: Pretoria, South Africa.

Duoba, M., Lohse-Busch, H. and Bohn, T. (2005) Investigating Vehicle Fuel Economy Robustness of Conventional and Hybrid Electric Vehicles, in: Proceedings of the 21st Worldwide Battery, Hybrid and Fuell-Cell Electric Vehiche Symposium and Exposition (EVS-21).

Du Plooy, P. and Jooste, M. (2011). Trade and Climate Change: Policy and Economic Implications for South Africa. Trade and Industrial Policy Strategies, Pretoria.

Du Toit, A. S, M. A. Prinsloo, W. Durand, and G. Kiker. (2002). Vulnerability of maize production to climate change and adaptation assessment in South Africa. Combined Congress: South African Society of Crop Protection and South African Society of Horticulture Science; Pietermaritzburg, South Africa.

Du Toit, C.J.L., Meissner, H.H. & Van Niekerk, W.A. (2013a). Direct methane and nitrous oxide emissions of South African dairy and beef cattle. *S. Afr. J. Anim. Sci*. 43, 320-339.

Du Toit, C.J.L., Van Niekerk, W.A. & Meissner, H.H. (2013b). Direct greenhouse gas emissions of South African small stock sectors. *S. Afr. J. Anim*. Sci. 43, 340-361.

Eagle, AJ. and Olander, L.P. (2012). Greenhouse gas mitigation with agricultural land management activities in the United States—a side-by-side comparison of biophysical potential. *Advances in Agronomy*, 115, 79–179.

Engel, R., Liang, D.L., Wallander, R. and Bembenek, A. (2010). Influence of urea fertilizer placement on nitrous oxide production from a silt loam soil. *Journal of environmental quality*, *39*(1), pp.115-125.

EIA, U. (2015). *Emissions of Greenhouse Gases in the US*. Tech. rep., US Energy Information Administration.

Environmental Protection Agency. (1992). US Sewage Sludge Regulations 40 CFR Rule 503, Washington D.C.

EPA. (1995). Air Emissions from Municipal Solid Waste Landfills- Background Information for Final Standards and Guidelines, Emission Standards Division, (US EPA-453/R-94-021). Office of Air and Radiation, Office of Air Quality Planning and Standards, United States Environmental Protection Agency.

EPA. (2006). Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks. (EPA publication no. EPA 530-R-06-004.) Washington, DC: U.S. Environmental Protection Agency, Office of Solid Waste.

EPA. (2008). Inventory of U.S. Greenhouse (,'as Emissions and Sinks: 9911 2006. EPA 430-11-0s 005. l.S. Environmental Protection Agency. Washington. DC. [On line] Available: http://www.svww.epa.guuv/el'eunate'elmauege/eiuuissieeuus/(lov,'iilu)acls/O8.A.nemex 6.1)df/ [Accessed 26 April 2014]

EPA. (2010). Inventory of U.S. greenhouse gas emissions and sinks: 1990 –2008. EPA 430-R-10-006. US EPA, Office of Atmospheric Programs, Washington, DC. [On line] Available: http://www.epa.gov/climatechange/emissions/usinventory report.html/ [accessed 02 August 2016]

EPA. (2011). Emission Facts: Average Carbon Dioxide Emissions Resulting from Gasoline and Diesel Fuel. US EPA, Washington, DC, USA. [On line] Available: http://www.epa.gov/oms/ climate/420f05001.htm [accessed 08 July 2015]

EPA. (2012). Emissions and Generation Resource Integrated Database (eGRID2012), Tech. Rep., the Environmental Protection Agency (EPA), http://www.epa.gov/cleanenergy/egrid/index.htm. Accessed 12 December 2013 EPA (2014) EPA fuel economy datafile. Environmental Protection Agency. [On line] Available: http://www.fueleconomy.gov/feg/epadata/14data.zip [accessed 21 February 2014]

EPA. (2013). Office of the Inspector General). 2013. "EPA Needs to Improve Air Emissions Data for the Oil and Natural Gas Production Sector." February 20, 2013, Report No. 13- P-0161. [On line] Available: http://www.epa.gov/oig/reports/2013/20130220-13-P-0161.pdf. [Accessed 26 June 2015]

EPA. (2014). Inventory of U.S. greenhouse gas emissions and sinks: 1990–2012. [On line] Available: http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2014-Main-Text.pdf and http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2014-Annexes.pdf [accessed 11 April 2015]

Eggleston, S., Buendia, L., Miwa, K., Ngara, T. and Tanabe, K. (2006). IPCC Guidelines for National Greenhouse Gas Inventories. Vol. 5 Waste. IPCC National Greenhouse Gas Inventories Programme, Institute for Global Environmental Strategies, Hayama, Kanagawa, Japan. [On line] Available: http://www.ipcc-nggip.iges.or.jp/public/2006gl/ [Accessed 17 March 2016]

Escobar, L. F., Carneiro Amado, T. J., Bayer, C., Chavez, L. F., Acordi Zanatta, J., Ernani Fiorin, J. (2010) Postharvest nitrous oxide emissions from a subtropical oxisol as influenced by summer crop residues and their management. Revista Brasileira de Ciência do Solo, Viçosa, v. 34, n. 2, p. 507-516, 2010. Available: http://www.redalyc.org/articulo.oa?id=180214231023 [Accessed 17 March 2016]

Food and Agriculture Organization. (2001). Soil carbon sequestration for improved land management. World Soil Resources Reports No. 96. FAO, Rome, 58 pp.

Food and Agriculture Organization. (2006). Livestock's long shadow – Environmental issues and options, by H. Steinfeld, P. J. Gerber, T. Wassenaar, V. Castel, M. Rosales & C. de Haan. Rome

FAO. (2009). Datasets on agriculture, land use and forestry for use together with the IPCC Guidelines, IPCC – FAO – IFAD Expert Meeting held in Rome, Italy, 20-22 October, 2009.

FAO. (2011). Commission on genetic Resources for food and Agriculture: Draft guidelines on phenotypic characterization of animal genetic resources. Rome, 18-22 July 2011.

FAO. (2012). The Ex Ante Carbon-balance Tool—EX-ACT Version 3.4. [On line] Available: http://www.fao.org/tc/exact, accessed: 06.04.14/ [Accessed 20 June 2015]

FAO. (2014). FAOSTAT: Emissions—land use. [On line] Available: http://faostat3.fao.org/faostat-gateway/go/to/download/G2/*/E/ [Accessed 22 Feb 2015]

FAO. (2015). Global Forest Resource Assessment 2015, Rome. [On line] Available: http.www.fao.org/forest-resources-assessment/en/ [Accessed 30 November 2015]

FAOSTAT. (2014). FAOSTAT online database. [On line] Available: http://faostat3.fao.org/faostat-gateway/go/to/browse/G1/*/E/ [accessed 10 July 2014]

FAOSTAT. (2015): Food and Agriculture Organization of the United Nations Statistics division. [On line] Available: http://faostat3.fao.org/ [Accessed 6 December 2015]

Ferrer, I., Vázquez, F. and Font, X. (2010). Long term operation of a thermophilic anaerobic reactor: process stability and efficiency at decreasing sludge retention time. *Bioresource technology*, *101*(9), pp.2972-2980.

Few, R., Ahern, M., Matthies, F. and Kovats, S. (2004). *Floods, health and climate change: a strategic review*. Norwich: Tyndall Centre for Climate Change Research.

Firestone, M.K. and Davidson, E.A. (1989). Microbiological basis of NO and N2O production and consumption in soil. *Exchange of trace gases between terrestrial ecosystems and the atmosphere*, *47*, pp.7-21.

Fischer, G., Mahendra, S. & van Velthuizen, H. (2002). Climate Change and Agricultural Variability. A special report on Climate Change and Agricultural Vulnerability, Contribution to the World Summit on Sustainable Development. Johannesburg 2002.

Flechard, C.R., Ambus, P., Skiba, U., Rees, R.M., Hensen, A., Van Amstel, A., Van Den Pol-Van Dasselaar, A., Soussana, J.F., Jones, M., Clifton-Brown, J. and Raschi, A. (2007). Effects of climate and management intensity on nitrous oxide emissions in grassland systems across Europe. *Agriculture, Ecosystems & Environment*, *121*(1), pp.135-152.

Forster, P., Ramaswamy, V., Artaxo, P., Berntsen, T., Betts, R., Fahey, D.W., Haywood, J., Lean, J., Lowe, D.C., Myhre, G. and Nganga, J. (2007). Changes in atmospheric constituents and in radiative forcing. Chapter 2. In *Climate Change 2007. The Physical Science Basis*.

Freibauer, A., Mathijs, E., Brunori, G., Damianova, Z., Faroult, E., Girona, J., Gomis, I. and O'Brien, L., Treyer, S. (2011). Sustainable Food Consumption and Production in a Resource-constrained World, Euroepean Commission e Standing Committee on Agricultural Research (SCAR). The Third SCAR Foresight Exercise.

GDARD. (2011). Gauteng Climate Change Response Strategy. Gauteng Department of Agriculture and Rural Development: Johannesburg.

GDED. (2011). Green strategic programme for Gauteng. Gauteng Department of Economic Development.

Gerardi, M.H. (2003). *The microbiology of anaerobic digesters*. John Wiley & Sons.

Gholami, M., Khakvar, R., Aliasgarzad, N. (2013). Application of endophytic bacteria for controlling anthracnose disease (Colletotrichum lindemuthianum) on bean plants.

Archives of Phytopathology and Plant Protection, Berlin, v. 46, n. 15, p. 1831- 1838, 2013.

Gibbs, M.J., Jun, P. and Gaffney, K. (1999). N_2O and CH_4 emissions from livestock manure. Background paper for IPCC expert meeting on Good Practice in Inventory Preparation: Agricultural Sources of Methane and Nitrous Oxide, 24-26 February 1999, Wageningen, The Netherlands.

Godfray H. C .J., Beddington, J .R., Crute, I .R., Haddad, L., Lawrence, L., Muir, J .F., Pretty, J., Robinson, S., Thomas, S .M. and Toulmin, C .Q. (2010). Food security: the challenge of feeding 9 billion people. Science 327.

Gomes, J., Bayer, C., Costa, F.S., Piccolo, M.C., Zanatta, J.A., Vieira, F.C.B., Six, J. (2009). Soil nitrous oxide emissions in long-term cover crops-based rotations under subtropical climate. Soil & Tillage Research, Amsterdam, v. 106, n. 1, p. 36- 44, 2009.

Govaerts, B., Sayre, K.D. and Deckers, J. (2006). A minimum data set for soil quality assessment of wheat and maize cropping in the highlands of Mexico. *Soil and Tillage Research*, *87*(2), pp.163-174.

Govaerts, B., Sayre, K.D., Lichter, K., Dendooven, L. and Deckers, J. (2007). Influence of permanent raised bed planting and residue management on physical and chemical soil quality in rain fed maize/wheat systems. *Plant and Soil*, *291*(1-2), pp.39-54.

Govaerts, B., Barrera-Franco, M.G., Limón-Ortega, A., Muñoz-Jiménez, P., Sayre, K.D. and Deckers, J. (2008). Clasificación y evaluación edafológicas de tres sitios experimentales en el altiplano central de México. *Tropicultura*, *26*(1), pp.2-9.

Grace, J. (2004). Understanding and managing the global carbon cycle J. Ecol. 92 189–202

Grant, R.F., Pattey, E., Goddard, T.W., Kryzanowski, L.M. and Puurveen, H. (2006). Modeling the effects of fertilizer application rate on nitrous oxide emissions. *Soil Science Society of America Journal*, *70*(1), pp.235-248.

Gregorich, E.G., Rochette, P., VandenBygaart, A.J. and Angers, D.A. (2005). Greenhouse gas contributions of agricultural soils and potential mitigation practices in Eastern Canada. *Soil and Tillage Research*, *83*(1), pp.53-72.

Grisso, R., M. F. Kocher, and D. H. Vaughan. (2004). Predicting Tractor Fuel Consumption. *Appl. Eng. Agric*. 20:553.–561.

Gujer, W. and Zehnder, A.J. (1983). Conversion processes in anaerobic digestion. *Water Science and Technology*, *15*(8-9), pp.127-167.

Hamelin, L., Wesnæs, M., Wenzel, H. and Petersen, B.M. (2011). Environmental consequences of future biogas technologies based on separated slurry. *Environmental science & technology*, *45*(13), pp.5869-5877.

Hansen, J., Sato, M. and Ruedy, R. (2012). Perception of climate change. *Proc. Natl. Acad. Sci*., 109, 14726-14727, E2415-E2423, doi:10.1073/pnas.1205276109.

Henry, M., Tittonell, P., Manlay, R. J., Bernoux, M., Albrecht, A. and Vanlauwe, B. (2009). Biodiversity, carbon stocks and sequestration potential in aboveground biomass in smallholder farming systems of western Kenya Agric. *Ecosyst. Environ.* 129 238–52.

Hillier, J., Walter, C. Malin, D., Garcia-Suarez, T., Mila-i-Canals, L. and Smith, P. A. (2011).farm-focused calculator for emissions from crop and livestock production. Environmental

Modelling & Software (Accepted for publication), (2011). [On line] Available: http://www.lenntech.com/greenhouse-effect/kyoto-emission-reductions-overview.htm [Accessed 07 September 2015]

Houghton, R.A. (1991). Tropical deforestation and atmospheric carbon dioxide. In *Tropical Forests and Climate* (pp. 99-118). Springer Netherlands.

Houghton, R. A., G. R. van der Werf, R. S. DeFries, M. C. Hansen, J. I. House, C. Le Quéré, J. Pongratz, and N. Ramankutty. (2012). Chapter G2 Carbon emissions from land use and land-cover change, Biogeosciences Discuss, 9, 835–878.

Hovi J. and Holtsmark B. (2006). Cap-and-trade or carbon taxes? The feasibility of enforcement and the effects of non-compliance. International Environmental Agreements Journal. Volume 6. Pp 137-155.

Huang, G.F., Wong, J.W.C., Wu, Q.T. and Nagar, B.B. (2004). Effect of C/N on composting of pig manure with sawdust. *Waste management*, *24*(8), pp.805-813.

Huber, M., and R. Knutti, 2012: Anthropogenic and natural warming inferred from changes in Earth's energy balance. Nature Geoscience, 5, 31-36, doi:10.1038/ngeo1327. [On line] Available: http://www.nature.com/ngeo/journal/v5/n1/pdf/ngeo1327.pdf] [Accessed 03 January 2014]

Huffman, W. E. (2010). Measuring Public Agricultural Research Capital and Its Contribution to State Agricultural Productivity. Iowa State University Department of Economics Working Paper #09022.

Hurst, D.F., Griffith, D.W. and Cook, G.D. (1994). Trace gas emissions from biomass burning in tropical Australian savannas. *Journal of Geophysical Research: Atmospheres*, *99*(D8), pp.16441-16456.

IEA. (2011). World Energy Outlook 2011 (Paris: IEA).

IEA. (2013). World Energy Outlook 2013 Special Report: Redrawing the Energy– Climate Map. Paris: International Energy Agency/ Organisation for Economic Co-operation and Development.

IEA. (2014). World Energy Investment Outlook. (International Energy Agency, Paris, 2014)

IEA. (2015). Emissions Database. IEA/OECD, Paris, France. [On line] Available: http://data.iea.org/ [Accessed 30 March]

IPCC. (1990). Intergovernmental Panel on Climate Change by Working Group I J.T. Houghton, G.J. Jenkins and J.J. Ephraums (eds.). Cambridge University Press, Cambridge, Great Britain, New York, NY, USA and Melbourne, Australia 410 pp.

IPCC. (1996). – Edited by Houghton, J.T. Meira Filho, L.G. Lim, B. Treanton, K Mamaty, I. Bonduki, Y. Griggs, D.J. and Callender B.A. (Eds) IPCC/OECD/IEA. UK Meteorological Office,Bracknell.

IPCC. (2001a). Climate Change 2001- The Scientific Basis. Contribution of Working Group I to the third Assessment Report of the intergovernmental panel on climate change. Cambridge University Press. Cambridge, UK.

IPCC. (2001b). Climate Change 2001 - Mitigation. The Third Assessment Report of the Intergovernmental Panel on Climate Change. B. Metz, O. Davidson, R. Swart, and J. Pan (eds.). Cambridge University Press, Cambridge, UK.

IPCC. (2006). “IPCC Guidelines for National Greenhouse Gas Inventories", prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). (IGES: Japan, 2006), 16.

IPCC. (2007). Climate change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor & H.L. Miller, eds.]. Cambridge, UK, Cambridge University Press.

IPCC. (2012). “Summary for Policymakers.” In Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation, 1–19. Cambridge and New York: Cambridge University Press.

IPCC. (2013). Climate Change 2013: “The Physical Science Basis, Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change”. (Eds.T.F. Stocker, D. Qin,G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley). (Cambridge University Press, Cambridge, United Kingdom and New York, USA). pp. 1535.

IPCC. (2014). Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S.

Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jacobson, M.C., Hansson, H.C., Noone, K.J. and Charlson, R.J. (2000). Organic atmospheric aerosols: Review and state of the science. *Reviews of Geophysics*, *38*(2), pp.267-294.

Jenkinson D. (2010). Climate change. Rothamsted Research Harpenden UK. [On line] Available: http://www.rothamsted.bbsrc.ac.uk/aen/reviews/Climate_Change_Draft_B03.pdf [Accessed 2August 2014]

Jantalia C. P., Santos H. P., Urquiaga S., Boddey R.M., Alves B.J.R. (2008). Fluxes of nitrous oxide from soil under different crop rotations and tillage systems in the south of Brazil. *Nutrient Cycling in Agroecosystems*, Dordrecht, v. 82, n. 2, p. 161-173, 2008.

Janzen, H.H. (1999). The health of our air: toward sustainable agriculture in Canada, Publication (Canada. Agriculture and Agri-Food Canada). Ottawa: Agriculture and Agri-Food Canada, Research Branch. [On line] Available: http://www.agric.gov.ab.ca/sustain/compost/ghg.html/ [Accessed 05 October 2015]

Janzen, H.H. (2004). Carbon cycling in earth systems - a soil science perspective. *Agriculture, Ecosystems and Environment*, 104, pp. 399-417.

Keene, W. C., Lobert, J. M., Crutzen, P. J., Maben, J. R., Scharffe, D. H., Landmann, T., Hely, C. and Brain, C. (2006). Emissions of ma- ´ jor gaseous and particulate species during experimental burns of southern African biomass, *J. Geophys. Res*., 111, D04301, doi:10.1029/2005JD006319, 2006.

Keller, C. A., D. Brunner, S. Henne, M. K. Vollmer, S. O'Doherty, and S. Reimann, (2011). Evidence for under-reported western European emissions of the potent greenhouse gas HFC-23. *Geophys. Res. Lett*., 38, L15808.

Kitzes, J., Wackernagel, M., Loh, J., Peller, A., Goldfinger, S., Cheng, D. and Tea, K. (2008). Shrink and share: humanity's present and future Ecological Footprint. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1491), pp.467-475.

Knudsen, M.T. Hauggard-Nielsen, H. and Jensen, E.S. (2004). Cereal-grain legume intercrops in organic arming – Danish survey. In: European Agriculture in global context: Proceedings of VIII ESA Congress, 11-15 July 2004, Copenhagen, Denmark.

Laguë, C. (2003). Management practices to reduce greenhouse gas emissions from swine production systems. In *Advances in pork production: proceedings of the... Banff Pork Seminar*.

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. *Science*, *304*(5677), pp.1623-1627.

Lal, R. (2007). Carbon management in agricultural soils. *Mitigation and adaptation strategies for global change*, *12*(2), pp.303-322.

Laursen, K.K., Ferek, R.J., Hobbs, P.V. and Rasmussen, R.A. (1992). Emission factors for particles, elemental carbon, and trace gases from the Kuwait oil fires. *Journal of Geophysical Research: Atmospheres*, *97*(D13), pp.14491-14497.

Lobert, J.M., Scharffe, D.H., Hao, W., Kuhlbusch, T.A., Seuwen, R., Warneck, P. and Crutzen, P.J. (1991). Experimental evaluation of biomass burning emissions: Nitrogen and carbon containing compounds. In *Global biomass burning. Atmospheric, climatic, and biospheric implications*.

Lockwood, M. (2009). "Solar Change and Climate: an update in the light of the current exceptional solar minimum," Proceedings of the Royal Society A, 2 December 2009, doi 10.1098/rspa.2009.0519.

Lokupitiya, E. and K. Paustian. (2006). Agricultural soil greenhouse gas emissions: A review of national inventory method. Journal of Environmental Quality 35:1413-1427.

Lovett, D.K., Shalloo, L., Dillon, P. and O'Mara, F.P. (2006). A systems approach to quantify greenhouse gas fluxes from pastoral dairy production as affected by management regime. *Agricultural Systems*, *88*(2), pp.156-179.

Le Treut, H., Somerville, R., Cubasch, U., Ding, Y., Mauritzen, C., Mokssit, A., Peterson, T. and Prather, M., (2007). Historical overview of climate change. In: SOLOMON, S.; QIN, D. et al. (Eds.). Climate change 2007: the physical science basis. Cambridge: Cambridge University Press, 2007. p. 93-127.

Levine, J. S., Cofer, W. R., Cahoon, D. R. and Winstead, E. L. (1995). 'Biomass Burning: A Driver for Global Change', Env. Sci. Tech. 29 (3), 120–125.

Levine, J.S. (1996). *Biomass Burning and Global Change: Remote sensing, modeling and inventory development, and biomass burning in Africa* (Vol. 1). MIT Press.

Lichter, K., Govaerts, B., Six, J., Sayre, K.D., Deckers, J. and Dendooven, L. (2008). Aggregation and C and N contents of soil organic matter fractions in a permanent raised-bed planting system in the Highlands of Central Mexico. *Plant and Soil*, *305*(1-2), pp.237-252.

Liu C., Wang K., Meng S., Zheng X., Zhou Z., Han S., Chen D., Yang Z. (2011). Effects of irrigation, fertilization and crop straw management on nitrous oxide and nitric oxide emissions from a wheat–maize rotation field in northern China. Agriculture, Ecosystems and Environment, 140(1–2), 226-233.

Maraseni, T. N., Mushtaq, S. & Maroulis J. (2009). Greenhouse gas emissions from rice farming inputs: a cross country assessment. *Journal of Agricultural Science*, Cambridge 147, 117–126.

Massey, R., and A. Ulmer. (2010). "Agriculture and Greenhouse Gas Emissions." University of Missouri Extension. Available: http://extension.missouri.edu/p/G310 [Accessed 20 October 2015].

Melanie S. (2011). Anaerobic Processes for Waste Treatment and Energy Generation, Integrated Waste Management - Volume II, Mr. Sunil Kumar (Ed.), ISBN: 978-953-307-447-4, InTech. [Available from: http://www.intechopen.com/books/integrated-waste-management-volume-ii/anaerobic-processes-for-wastetreatment-and-energy-generation [Accessed October 2015].

Metay, A., Moreira, J.A.A., Bernoux, M., Boyer, T., Douzet, J.M., Feigl, B., Feller, C., Maraux, F., Oliver, R. and Scopel, E. (2007). Storage and forms of organic carbon in a no-tillage under cover crops system on clayey Oxisol in dryland rice production (Cerrados, Brazil). *Soil and Tillage Research*, *94*(1), pp.122-132.

Metz, B, Davidson, O., de Coninck, H. C., Loos, M., and Meyer, L. A. (eds.). (2005). *IPCC Special Report on Carbon Dioxide Capture and Storage*. Prepared by Working Group III of the Intergovernmental Panel on Climate Change Cambridge and New York: Cambridge University Press.

McMichael, A.J., Powles, J.W., Butler, C.D. and Uauy, R. (2007). Food, livestock production, energy, climate change, and health. *The Lancet*, 370(9594): 1253–1263.

Milne, E., Neufeldt, H., Smalligan, M., Rosenstock, T., Malin, D., Easter, M., Bernoux, M., Ogle, S., Casarim, F., Pearson, T., Bird, N., Steglich, E., Ostwald, M., Deneuf, K. and Paustian, K. (2012) Overview Paper: Methods for the quantification of net emissions at the landscape level for developing countries in smallholder contexts. White paper for CCAFS.

Milne, E., Neufeldt, H., Rosenstock, T., Smalligan, M., Cerri, C.E., Malin, D., Easter, M., Bernoux, M., Ogle, S., Casarim, F. and Pearson, T. (2013). Methods for the quantification of GHG emissions at the landscape level for developing countries in smallholder contexts. *Environmental Research Letters*, *8*(1), p.015019.

Millar, N., Ndufa, J.K., Cadisch, G. and Baggs, E.M. (2004). Nitrous oxide emissions following incorporation of improved-fallow residues in the humid tropics. *Global Biogeochemical Cycles*, *18*(1).

Mitsubishi. (2010) MiEV Specification Overview. 15. Drive, Mitsubishi reveals pricing for electric car. 2010.

Moeletsi, M.E. and Tongwane, M.I. (2015). 2004 Methane and Nitrous Oxide Emissions from Manure Management in South Africa. *Animals*, *5*(2), pp.193-205.

Moeletsi, M.E., Tongwane, M. and Tsubo, M. (2016). The Study of Frost Occurrence in Free State Province of South Africa. *Advances in Meteorology*, *2016*.

Monteny, G.J., Groenestein, C.M. and Hilhorst, M.A. (2001). Interactions and coupling between emissions of methane and nitrous oxide from animal husbandry. *Nutrient Cycling in Agroecosystems*, *60*(1), pp.123-132.

Monni, S., Perälä, P. and Regina, K. (2007). Uncertainty in Agricultural CH_4 and N_2O Emissions from Finland. Possibilities to Increase Accuracy in Emission Estimates. *Mitigation and Adaptation Strategies for Global Change* 12(4): 545-571.

Montzka, S.A., Dlugokencky, E.J. and Butler, J.H. (2011). Non-CO_2 greenhouse gases and climate change. *Nature*, *476*(7358), pp.43-50.

Moorhead, J. and Nixon, T. (2014). "Global 500 Greenhouse Gases performance 2010-2013: 2014 Report on Trends". A Thomson Reuters Financial and Risk White Paper.

Mukheibir, P. and Ziervogel, G. (2007). Developing a Municipal Adaptation Plan (MAP) for climate change: the city of Cape Town. *Environment and Urbanization*, *19*(1), pp.143-158.

Nabuurs, G.-J., K. Masera, K. Andrasko, P. Benitez-Ponce, R. Boer, M. Dutschke, E. Elsiddig, J. Ford-Robertson, P. Frumhoff, T. Karjalainen, O. Krankina, W. A. Kurz, M. Matsumoto, W. Oyhantcabal, N. H. Ravindranath, M. J. Sanz Sanchez and X. Zhang (2007). Forestry. Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. [B. Metz, O. R.

Davidson, P. R. Bosch, R. Dave, L. A. Meyer (eds)], Cambridge, Cambridge University Press: 541-584.

NOAA. (2012). Global Gas Flaring Estimates through 2011. Pers. comm., 15 April 2012.

NOAA. (2007). IMPD: The International Multiproxy Paleofire Database. [On line] Available: http://www.ncdc.noaa.gov/paleo/impd/ [Accessed 10 August 2014]

NOAA. (2015). Physical Sciences Division of the National Oceanic and Atmospheric Administration/Earth System Research Laboratory (NOAA/ESRL). [On line] Available: http://www.esrl.noaa.gov/ [Accessed 06 December 2015]

NRC. (2001). *Nutrient requirements of dairy cattle: 2001*. National Academies Press.

NRC. (2003). *Air emissions from animal feeding operations: Current knowledge, future needs*. National Academies Press.

Nelson, R.G., Hellwinckel, C.M., Brandt, C.C., West, T.O., De La Torre Ugarte, D.G. and Marland, G. (2009). Energy use and carbon dioxide emissions from cropland production in the United States, 1990–2004. *Journal of Environmental Quality*, *38*(2), pp.418-425.

Nemecek, T. and Kagi, T. (2007). Life cycle inventories of agricultural systems. *EcoInvent* Report 15.

NIES. (2006). Greenhouse gas inventory developments in Asia – Experiences from workshops on greenhouse gas inventories in Asia, [Umemiya, C. (ed)], National Institute for Environmental Studies, Ibaraki.

OECD. (2011). Towards Green Growth. Paris: OECD. [On line] Available: http://www.oecd.org/dataoecd/37/34/48224539.pdf [Accessed 7 August 2014]

Olander, L.., Wollenberg, E., Tubiello, F. and Herold, M. (2013). Advancing agricultural greenhouse gas quantification. *Environ. Res. Lett*. 8 011002.

Oreskes, N., & Conway, E. M. (2010). Merchants of doubt. New York, NY: Bloomsbury.

Otter, L., Moeletsi, M., Swanepoel, C., Tswai, R. and Kidson, M. (2010). The South African agricultural GHG inventory for 2004. Department of Agriculture. *Forestry and Fisheries, South Africa*.

OECD. (2008). OECD Environmental Outlook to 2030, OECD, Paris.

Oenema, O. Wrage, N. Velthof, G.L. van Groenigen, J.W. Dolfing, J. Kuikman, P.J. (2005). Trends in global nitrous oxide emissions from animal production systems. *Nutr. Cycl. Agroecosyst*. 72, 51–65.

Olander, L. P., Haugen-Kozyra, K., Del Grosso, S., Izaurralde, C., Malin, D., Paustian, K. and Salas, W. (2011). Using Biogeochemical Process Models to Quantify Greenhouse Gas Mitigation from Agricultural Management Projects (Durham, NC: Nicholas Institute for Environmental Policy Solutions, Duke University). [On line] Available: http://nicholasinstitute.duke.edu/ ecosystem/t-agg/using-biogeochemical-process/ [Accessed 08 November 2014]

Olander, L., Wollenberg, E., Tubiello, F. and Herold, M. (2013). Advancing agricultural greenhouse gas quantification. *Environ. Res. Lett*. 8 011002

Olesen, J.E., Schelde, K., Weiske, A., Weisbjerg, M.R., Asman, W.A. and Djurhuus, J. (2006). Modelling greenhouse gas emissions from European conventional and organic dairy farms. *Agriculture, Ecosystems & Environment*, *112*(2), pp.207-220.

Omonode, R.A., Vyn, T.J., Smith, D.R., Hegymegi, P. and Gál, A. (2007). Soil carbon dioxide and methane fluxes from long-term tillage systems in continuous corn and corn–soybean rotations. *Soil and Tillage Research*, *95*(1), pp.182-195.

Parawira, W., Read, J.S., Mattiasson, B. and Björnsson, L. (2008). Energy production from agricultural residues: high methane yields in pilot-scale two-stage anaerobic digestion. *Biomass and Bioenergy*, *32*(1), pp.44-50.

Parry M.L., Canziani O.F., Palutikof J.P., van der Linden P.J. and Hanson C.E. (2007). Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change Eds. Cambridge University Press, Cambridge, UK, 976 pp.

Paustian, K., and Babcock, B.A. (2004). Climate change and greenhouse gas mitigation: challenges and opportunities for agriculture. Task Force Report number 141. CAST [Council for Agricultural Science and Technology], Ames, Iowa, USA.

Paustian, K. (2013). Bridging the data gap: engaging developing country farmers in greenhouse gas accounting. *Environ. Res. Lett*. 8 021001.

Pind, P.F., Angelidaki, I. and Ahring, B.K. (2003). Dynamics of the anaerobic process: effects of volatile fatty acids. *Biotechnology and bioengineering*, *82*(7), pp.791-801.

Rajaniemi, M., Mikkola, H. and Ahokas, J. (2011). Greenhouse gas emissions from oats, barley, wheat and rye production Agron. Res., 1 (2011), pp. 189-195.

Ramaswamy, V., O. Boucher, J. Haigh, D. Hauglustaine, J. Haywood, G. Myhre, T. Nakajima, G. Y. Shi, and S. Solomon. (2001). Radiative forcing of climate change in Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, edited by Houghton, J. T., Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, X. Dai, et al., pp. 349-416, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2001.

Reynolds, L. (2013). Agriculture and Livestock Remain Major Sources of Greenhouse Gas Emissions. World watch institute, accessed 12 April 2016. [On line] Available: http://www.worldwatch.org/agriculture-and-livestock-remain-major-sources-gr/ [Accessed 8 July 2014]

Riedo, M., Grub, A., Rosset, M. and Fuhrer, J. (1998). A pasture simulation model for dry matter production, and fluxes of carbon, nitrogen, water and energy. *Ecological Modelling*, *105*(2), pp.141-183.

Ripple, W.J., Smith, P., Haberl, H., Montzka, S.A., Mcalpine, C. and Boucher,D.H. (2014). Ruminants, climate change andclimate policy. Nature Climate change Vol 4 January 2014 pp.2-5.

Robertson, G. P. & GRACE, P. R. (2004). Greenhouse gas fluxes in tropical and temperate agriculture: the need for a full-cost accounting of global warming potentials. Environment, Development and Sustainability 6, 51–63.

Rosenstock, T.S., Rufino, M.C., Butterbach-Bahl, K., Wollenberg, E., Richards, M. (2016). Methods for Measuring Greenhouse Gas Balances and Evaluating Mitigation Options in Smallholder Agriculture. SpringerNature.

Rotz, C. A., F. Montes, and D. S. Chianese. (2010). The carbon footprint of dairy production systems through partial life cycle assessment. *J. Dairy Sci*. 93:1266–1282.

SAPPO. (2011). Report to authors on pig numbers in South Africa and production data. South African Pork Producers Organisation, Pretoria, South Africa.

SEA. (2017). Sustainable energy solutions for South African local government: a practical guide (Cape Town: Sustainable Energy Africa). Design and layout: dotted line design [On line] Available: http://www.dottedlinedesign.co.za/ [Accessed 8 July 2014]

Seebauer, M. (2014). Whole farm quantification of GHG emissions within smallholder farms in developing countries. *Environ. Res. Lett*. 9, 35006.

Scheutz, C., Kjeldsen, P. and Gentil, E. (2009). Greenhouse gases, radiative forcing, global warming potential and waste management – an introduction, *Waste management and Research*, Vol. 27, pp. 716-723.

Schils, R.L., Verhagen, A., Aarts, H.F. and Šebek, L.B. (2005). A farm level approach to define successful mitigation strategies for GHG emissions from ruminant livestock systems. *Nutrient Cycling in Agroecosystems*, *71*(2), pp.163-175.

Schils, R.L.M. Olesen, J.E. del Prado, A. and Soussana, J.F. (2007). A review of farm level modelling approaches for mitigating greenhouse gas emissions from ruminant livestock systems *Livest. Sci*., 112 (2007), pp. 240–251.

Schils R.L.M., Van Groenigen J.W, Velthof G.L, Kuikman P.J. (2008). Nitrous oxide emissions from multiple combined applications of fertilizer and cattle slurry to grassland. *Plant and Soil, Dordrecht*, v. 310, n. 1-2, p. 89-101, 2008.

Schils R.L.M., Van Groenigen J.W, Velthof G.L, Kuikman P.J. (2008) Nitrous oxide emissions from multiple combined applications of fertiliser and cattle slurry to grassland. Plant Soil 310:89–101

Scialabba, N. E. and Muller-Lindenlauf, M. (2010). Organic agriculture and climate change. Natural Management and Environment Department, Food and Agriculture Organization of the United Nations (FAO), Viale delle Terme di Caracalla, 00153 Rome, Italy. Renewable Agriculture and Food Systems, vol. 25 (2), pp.158–169 nadia.scialabba@fao.org.

Shaver, G.R., Canadell, J., Chapin, F.S III., Gurevitch, J., Harte, J., Henry, G., Ineson I., Jonasson S., Melillo J., Pitelka L. and Rustad L. (2000). Global warming and terrestrial ecosystems: a conceptual framework for analysis. *Bioscience.* 50: 871–82.

Sherlock, R.R., Sommer, S.G., Khan, R.Z., Wood, C., Guertal, E.A., Freney, J.R., Dawson, C.O. and Cameron, K.C. (2002). Ammonia, methane, and nitrous oxide emission from pig slurry applied to a pasture in New Zealand. *Journal of Environmental Quality*, *31*(5), pp.1491-1501.

Singurindy, O., Molodovskaya, M., Richards, B.K. and Steenhuis, T.S. (2009). Nitrous oxide emission at low temperatures from manure-amended soils under corn (Zea mays L.). *Agriculture, ecosystems & environment*, *132*(1), pp.74-81.

Sims, R.E., Hastings, A., Schlamadinger, B., Taylor, G. and Smith, P. (2006). Energy crops: current status and future prospects. *Global change biology*, *12*(11), pp.2054-2076.

Siqueira neto, M., Venzke filho, S. P., Piccolo, M. C.; Cerri, C. E. P.; Cerri, C. C. (2009). Rotação de culturas no sistema de plantio direto em Tibagi (PR): I - Sequestro de carbono no solo. Revista Brasileira de Ciência do Solo, Viçosa, v. 33, n. 4, p. 1013-1022, 2009.

Skiba, U. and Smith, K.A. (2000). The control of nitrous oxide emissions from agricultural and natural soils. *Chemosphere-Global Change Science*, *2*(3), pp.379-386.

Smith, P. (2004). Engineered biological sinks on land. In The Global Carbon Cycle. Integrating humans, climate, and the natural world, C.B. Field and M.R. Raupach (eds.). SCOPE 62, Island Press, Washington D.C., pp. 479-491.

Smith, K.A. & Conen, F. (2004). Impacts of land management on fluxes of trace greenhouse gases. *Soil Use and Management*, 20, pp. 255-263.

Smith, P., D. Martino, Z. Cai, D. Gwary, H. Janzen, P. Kumar, B. McCarl, S. Ogle, F. O'Mara, C. Rice, B. Scholes, O. Sirotenko (2007). Agriculture. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C. and Scholes, B. (2008). Greenhouse gas mitigation in agriculture. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1492), pp.789-813.

Smith, D. M., R. Eade, N. J. Dunstone, D. Fereday, J. M. Murphy, H. Pohlmann, and A. A. Scaife. (2010). Skilful multi-year predictions of Atlantic hurricane frequency. Nature Geosci., 3, 846–849.

Smith, P., Bustamante, M., Ahammad, H., Clark, H., Dong, H., Elsiddig, E.A., Haberl, H., Harper, R., House, J., Jafari, M., Masera, O., Mbow, C., Ravindranath, N.H., Rice, C.W., Robledo Abad, C., Romanovskaya, A., Sperling, F. and Tubiello, F. (2014): Agriculture, Forestry and Other Land Use (AFOLU). In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Sommer, S.G. and Møller, H.B. (2000). Emission of greenhouse gases during composting of deep litter from pig production–effect of straw content. *The Journal of Agricultural Science*, *134*(03), pp.327-335.

Soussana, J.F., Loiseau, P., Vuichard, N., Ceschia, E., Balesdent, J., Chevallier, T. and Arrouays, D. (2004). Carbon cycling and sequestration opportunities in temperate grasslands. *Soil use and management*, *20*(2), pp.219-230.

Soussana, J.F., Tallec, T. and Blanfort, V. (2010). Mitigating the Greenhouse Gas Balance of Ruminant Production Systems through Carbon Sequestration in Grassland. *Animal*, 4, 334-350.

Stajnko, D., M. Lakota, F. Vučajnk, and R. Bernik. (2009). Effects of different tillage systems on fuel savings and reduction of CO2 emissions in production of silage corn in Eastern Slovenia. *Polish J. Environ*. Stud., 4: 711-716.

Stehfest, E. and Bouwman, L. (2006). N_2O and NO emission from agricultural fields and soils under natural vegetation: summarizing available measurement data and modeling of global annual emissions. *Nutrient Cycling in Agroecosystems*, *74*(3), pp.207-228.

Stern, N. (2006). Stern Review Report on the Economics of Climate Change. London: HM Treasury; 2006

Stevens, C. E. and Hume, I. D. (1995).Comparative Physiology of the Vertebrate Digestive System. 2nd ed. New York: Cambridge University Press.

Stewart, S.M. Little, K.H. Ominski, K.M. Wittenberg, H.H. Janzen. (2009). Evaluating greenhouse gas mitigation practices in livestock systems: an illustration of a whole-farm approach J. Agr. Sci., 147 (2009), pp. 367–382

Taherzadeh, M.J. and Karimi, K. (2008). Pretreatment of lignocellulosic wastes to improve ethanol and biogas production: a review. *International journal of molecular sciences*, *9*(9), pp.1621-1651.

Taylor, C.M. (2001). Feedbacks between the land surface and the atmosphere in the Sahel. *Aridlands Newsletter*, No 49, May/June 2001.

Tubiello, F. et al. (2012). The FAOSTAT GHG Database. *Env. Res. Letters*, 8: 015009.

Tubiello F.N., Salvatore M., Rossi S., Ferrara A., Fitton N. and Smith P. (2013). The FAOSTAT database of greenhouse gas emissions from agriculture, *Environ. Res. Lett*. 8 doi: 10.1088/1748-9326/8/1/015009.

Tubiello F.N., Salvatore M., Cóndor Golec R.D., Ferrara A., Rossi S., Biancalani R., Federici S., Jacobs H., Flammini A., Sanz Sanchez M.J., Smith P., House J. and Srivastava N. (2014). The Contribution of Agriculture, Forestry and other Land Use activities to Global Warming, 1990-2010: Not as high as in the past. Food and Agriculture Organization of the United Nations Rome, 2014. ESS Working Paper No. 2, Mar 2014. [On line] Available: http:// http://www.fao.org/3/a-i3671e.pdf/ [Accessed 02 August 2014]

Tubiello F.N., Salvatore M., Ferrara A.F., House J., Federici S., Rossi S., Biancalani R., Condor Golec R.D., Jacobs H., Flammini A., Prosperi P., Cardenas-Galindo P., Schmidhuber J., Sanz Sanchez M.J., Srivastava N., Smith P. (2015). The contribution of agriculture, forestry and other land use activities to global warming, 1990–2012 Glob. Change Biol. (2015). [On line] Available: http://dx.doi.org/10.1111/gcb.12865/ [Accessed 02 August 2014]

Turner, B. L., E. F. Lambin, and A. Reenberg. (2007). The emergence of land change science for global environmental change and sustainability. *Proceedings of the National Academy of Sciences* 104, 20666–20671. doi: 10.1073/pnas.0704119104.

UNEP. (2007). Buildings and Climate Change: Status, Challenges and Opportunities, UNEP, DTIE, Paris.

UNEP. (2009). Biofuels Working Group and United Nations Environment Programme. International Panel for Sustainable Resource Management, 2009. *Towards sustainable production and use of resources: assessing biofuels*. UNEP/Earthprint.

UNEP. (2012). The Emissions Gap Report 2012. A UNEP Synthesis Report. United Nations Environment Programme (UNEP).

UNFCCC, C.C.S. (2005). Greenhouse Gas Emissions Data for 1990–2003 submitted to the United Nations Framework Convention on Climate Change. In *Key GHG data. United Nations Framework Convention on Climate Change, Bonn*.

UNFCCC. (2007). Report on the Second Workshop on Reducing Emissions from Deforestation in Developing Countries, , <http://unfccc.int/resource/docs/2007/sbsta/eng/03.pd/>

UNFCCC. (2012). GHG Database. [Online] Available: http://www.unfccc.int/ [Accessed 02 August 2015]

USGS. (2013). Cement Statistics and Information, and other commodities. [On line] Available: http://minerals.usgs.gov/minerals/pubs/ commodity/ [Accessed 02 August 2015]

USGS. (2011). Mineral commodity summaries 2011: U.S. Geological Survey, 198 p. ISBN 978–1–4113–3083–2. [On line] Available: http:// http://www.eesi.org/files/usgs_commodities_2011.pdf/ [Accessed 02 August 2015]

USGS. (2012). Mineral commodity summaries 2012: U.S. Geological Survey, 198 p. ISBN 978–1–4113–3349–9. [On line] Available: https://minerals.usgs.gov/minerals/pubs/mcs/2012/mcs2012.pdf [Accessed 02 August 2015]

Van der Werf, G., Morton, D. C., DeFries, R. S., Olivier, J. G. J., Kasibhatla, P. S., Jackson, R. B., Collatz, G. and Randerson, J. (2009). CO_2 emissions from forest loss. *Nature Geosci*. 2 737–8.

Van Groenigen, J.W., Velthof, G.L., Oenema, O., Van Groenigen, K.J. and Van Kessel, C. (2010). Towards an agronomic assessment of N2O emissions: a case study for arable crops. *European Journal of Soil Science*, *61*(6), pp.903-913.

Velthof, G.L., Brader, A.B. and Oenema, O. (1996). Seasonal variations in nitrous oxide losses from managed grasslands in The Netherlands. *Plant and Soil*, *181*(2), pp.263-274.

Vermeulen, S.J., Campbell, B. and Ingram, J. (2012). Climate change and food systems. *Annual Review of Environment and Resources*, 37, 195-222.

Vuichard, N., Ciais, P., Viovy, N. and Soussana, J.F. (2007). Simulating the greenhouse gas budget of European grasslands within a process-driven approach: spatial and temporal patterns of radiative forcing. *Global Biogeochem. Cycles*, *21*.

Wang, S. and Huang, D. (2005). Assessment of greenhouse gas emissions from poultry enteric fermentation. *Asian-Aust. J. Anim. Sci*. 18, 873-878.

Ward, D.E., Susott, R.A., Kauffman, J.B., Babbitt, R.E., Cummings, D.L., Dias, B., Holben, B.N., Kaufman, Y.J., Rasmussen, R.A. and Setzer, A.W. (1992). Smoke and fire characteristics for cerrado and deforestation burns in Brazil: BASE-B experiment. *Journal of Geophysical Research: Atmospheres*, *97*(D13), pp.14601-14619.

Ward, J. (2008). VISION 2008 User's Guide. Vehicle Technologies Program. US Department of Energy, Energy Efficiency and Renewable Energy.

Watson, R.T., Zinyoera, M.C. and Moss, R.H. (1997). The regional impacts of climate change: An assessment of vulnerability. A special report of the IPCC Working Group II. Cambridge: Cambridge University Press. Guidelines for National Greenhouse Gas Inventories.

West, T.O. and Marland, G. (2002). A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: comparing tillage practices in the United States. *Agriculture, Ecosystems & Environment*, *91*(1), pp.217-232.

Winkler, H, Delgado, R, Palma - Behnke, R, Pereira, A, Vásquez Baos, T, Moyo, A, Wills, W & Salazar, A. (2014). Information for a developmental approach to mitigation: Linking sectoral and economy - wide models for Brazil, Chile, Colombia, Peru and South Africa Cape Town. MAPS.

Yao, Z., Zheng, X., Xie, B., Mei, B., Wang, R., Butterbach-Bahl, K., Zhu, J. and Yin, R. (2009). Tillage and crop residue management significantly affects N-trace gas emissions during the non-rice season of a subtropical rice-wheat rotation. *Soil Biology and Biochemistry*, *41*(10), pp.2131-2140.

Yokelson, R. J., Urbanski, S. P., Atlas, E. L., Toohey, D. W., Alvarado, E. C., Crounse, J. D., Wennberg, P. O., Fisher, M. E., Wold, C. E., Campos, T. L., Adachi, K., Buseck, P. R. and Hao, W. M. (2007). Emissions from forest fires near Mexico City, *Atmos. Chem. Phys*., 7, 5569–5584, doi:10.5194/acp-7-5569-2007, 2007.

Zhao, Hua. (2010). *Advanced Direct Injection Combustion Engine Technologies and Development: Diesel Engines*. Woodhead Publishing Limited. p. 8.ISBN 9781845697457.

Zoz, F. M., and R.D. Grisso. (2003). Traction and tractor performance. ASAE Distinguished lecture #27, Agricultural equipment Technology conference, 9-11 february 2003. Louisville, Kentucky.USA.

APPENDICES

Appendix A: Inputs data

Table A.1 Productivity for dairy cattle for 2010-2014

Farms	Fat content (%)	Average daily weight gain (kg day-1)	
	Mature females	Calves	Heifers
F1	4	0.0714	0.0714
F2	4	0.0714	0.0714
F3	3.9	0.0308	0.0308
F4	3	0.0487	0.0487
F5	3	0.052	0.052
F6	3.1	0.052	0.052
F7	3	0.0551	0.0551
F8	3	0.0308	0.0308
F9	3.2	0.0238	0.0238
F10	3.1	0.0975	0.0975
F11	3.6	0.065	0.065
F12	3.2	0.0238	0.0238
F13	n/a	n/a	n/a
F14	3.8	0.0157	0.0157
F15	n/a	n/a	n/a
F16	3	0.0157	0.0157
Standard deviation(SD)	0.4	0.021	0.020
Mean	3	0.052	0.035
Coefficient variation(CV)	12	41	56

Table A.2 Average animal weight (kg) for dairy cattle

Farms	Mature females (< 2 yrs)	Heifers (1-2 yrs)	Mature Bulls	Male Calves (0-1 yrs)	Female calves (0-1 yrs)	Young bulls (1-2 yrs)
F1	558	316	728	134	132	274
F2	400	297	-	76	74	171
F3	546	469	540	102	100	228
F4	472	327	500	62	62	307
F5	465	301	546	103	99	332
F6	459	243	546	102	102	-
F7	494	382	631	70	70	238
F8	502	314	772	48	48	314
F9	428	386	521	96	89	-
F10	460	375	540	93	90	-
Standard deviation(SD)	46	60	92	24	23	53
Mean	478	341	592	89	87	266
Coefficient variation(CV)	10	18	15	27	26	20
- Represents the unavailability of the weights of other animal sub-categories						

Table A.3 Annual milk production for dairy cattle for 2010-2014

Farms	Annual milk production per cow (kg year-1)a				
	2010	2011	2012	2013	2014
F1	4500	4500	4500	4500	4500
F2	6000	6000	6000	6000	6000
F3	3213	3213	3213	3213	3213
F4	4500	4500	4500	4500	4500
F5	1500	1500	1500	1500	1500
F6	1800	1800	1800	1800	1800
F7	2100	2100	2100	2100	2100
F8	2400	2400	2400	2400	2400
F9	4500	4500	4500	4500	4500
F10	2400	2400	2400	2400	2400
F11	5400	5400	5400	5400	5400
F12	4200	4200	4200	4200	4200
F13	-	-	-	-	-
F14	6000	6000	6000	6000	6000
F15	-	-	-	-	-
F16	3600	3600	3600	3600	3600
Standard deviation(SD)	1535	1535	1535	1535	1535
Mean	3609	3609	3609	3609	3609
Coefficient variation(CV)	43	43	43	43	43
- Represents the unavailability of the mature females animal sub-category in other farms					

Table A.4 Average animal weight (kg) for beef cattle

Farms	Mature females	Heifers	Bulls	Male Calve	Fem calve	Young bull
F1	534	430	713	108	100	244
F2	-	-	-	-	-	-
F3	409	446	540	99	99	-
F4	475	304	632	129	100	318
F5	-	-	-	-	-	-
F6	425	243	420	106	106	-
F7	523	414	753	67	67	238
F8	438	314	632	38	38	-
F9	341	274	500	91	91	276
F10	461	385	705	82	82	-
Standard deviation(SD)	59	72	108	26	21	32
Mean	451	351	612	90	85	269
Coefficient variation(CV)	13	21	18	29	25	12
- Represents the unavailability of the weights of other animal sub-categories						

Table A.5 Productivity data for beef cattle for 2010-2014

Farms	Fat content	Annual milk production (kg year-1)	Average daily weight gain (kg day-1)	
			Calves	Heifers
F1	3	500	0.04	0.07
F2	3	500	0.032	0.0317
F3	3	500	0.01	0.041
F4	3	500	0.036	0.0234
F5	3	500	0.0247	0.03
F6	3	500	0.02	0.0813
F7	3	500	0.031	0.052
F8	3	500	0.064	0.062
F9	3	500	0.012	0.028
F10	3	500	0.054	0.065
F11	3	500	0.0243	0.055
F12	3	500	0.039	0.049
F13	3	500	0.055	0.077
F14	3	500	0.047	0.029
F15	3	500	0.015	0.0561
F16	3	500	0.07	0.081
Standard deviation(SD)	0	0	0	0
Mean	3	500	0	0
Coefficient variation(CV)	0	0	45	35

Table A.6 Average weight for sheep sub-categories

Farms	Livestock category	Average weight (kg)			Average daily gain (kg)
	Mature sheep (Ewes)	Rams	Heifers	Lambs	Lambs
F1	80	102	48	36	0.09
F2	76	84	55	22	0.07
F5	69	67	60	28	0.06
F6	80	102	48	36	0.01
F7	65	70	55	24	0.06
F9	73	70	49	31	0.02
F11	58	80	56	20	0.05
F13	80	102	48	36	0.036
Standard deviation(SD)	8	14	4	6	0
Mean	73	85	52	29	0
Coefficient variation(CV)	10	17	8	21	50

Table A.7 Coefficients for calculating energy for maintenance (NEm)

Animal category	Cfi (MJ day^{-1} kg^{-1})	Comments
Cattle (non-lactating cows)	0.322	
Cattle (Lactating cows)	0.386	This value is 20% higher for maintenance during lactation
Cattle (bulls)	0.370	This value is 15% higher for maintenance of intact males
Sheep (Lamb to 1 year)	0.236	This value can be increased by 15% for intact males
Sheep (Older than 1 year)	0.217	This value can be increased by 15% for intact males

Table A.8 Activity coefficients corresponding to animal s feeding situation

Situation	Defination	Ca
Cattle (unit for Ca is dimensionless)		
Stall	Animals are confined to a small area with the result that they expend very little or no energy to acquire feed	0.00
Pasture	Animals are confined in areas with sufficient forage requiring modest energy expense to acquire feed	0.17
Sheep (unit for Ca = MJ^{-1} kg^{-1})		
Housed ewes	Animals are confined due to pregnancy in final trimester (50 days)	0.0090
Grazing flat pasture	Animals walk up to 1000 meters per day and expend very little energy to acquire feed	0.0107
Housed fattening lambs	Animals are housed for fattening	0.0067

Table A.9 Constants for use in calculating net energy needed for growth (NEg) for sheep

Animal species/category	a (MJ kg^{-1})	b (MJ kg^{-2})
Intact males	2.5	0.35
Castrates	4.4	0.32
Females	2.1	0.45

Table A.10 Constants for use in calculating net energy required for pregnancy (NEp)

Animal category	$C_{pregnancy}$
Cattle	0.10
Sheep	
Single birth	0.077
Double birth (twins)	0.126
Triplets birth or more (Triplets)	0.150

Table A.11 The Africa default VS values for livestock categories

Animal	VS (kg VS day^{-1})
Pigs	0.50
Goats	0.35
Horses	1.72

Table A.12 The Bo values for all livestock categories

Animal	Sub-category	B_o (m^3 CH_4 kg^{-1} of VS excreted)
Dairy cattle	Mature females	0.17
	Heifers	0.17
	Bulls	0.17
	Calves	0.17
	Young oxen	0.17
	Mature Oxen	0.17
Beef cattle	Mature cow	0.10
	Heifers	0.10
	Bulls	0.10
	Calves	0.10
	Young oxen	0.10
	Mature oxen	0.10
Sheep		0.13
Pigs		0.45
Goats		0.13
Horses		0.26

Table A.13 Cattle and sheep CH_4 conversion factors (Ym)

Livestock category	Ym[b]
Dairy cows and their young	6.5%
Other cattle that are primarily fed low quality crop residues and by-product	6.5%
Other cattle grazing	6.5%
Lambs (< 1 year old)	4.5%
Mature sheep	6.5%

Table A.14 The EF default used for goats, pigs and horses

Livestock	Emission Factors (EF)	Live weight
Goats	5	40 kg
Horses	18	550 kg
Swine	1	-

Table A.15 Data required for calculating N_2O emissions from manure management

Animal	Sub-category	Nrate	Nex
		(kg N (1000 kg animal mass)-1 d-1)	(kg N animal-1 yr-1)
Dairy cattle	Mature females	0.6	109.06
	Heifers	0.6	77.75
	Bulls	0.63	228.34
	Calves	0.63	28.51
	Young oxen	0.63	106.24
	Mature Oxen	0.63	126.47
Beef cattle	Mature cow	0.63	84.85
	Heifers	0.63	48.98
	Bulls	0.63	134.52
	Calves	0.63	19.55
	Young oxen	0.63	68.99
	Mature oxen	0.63	92.21
Sheep		1.17	17.08
Pigs		0.55	43.76
Goats		1.37	18
Horses		0.46	99.9

Table A.16 Feeding systems for different animal categories in percentages (applicable to all farms)

Livestock category	Sub-category	Pasture-based	TMR-based
Dairy cattle	Mixed-Lactating cows	70	30
	Non-lactating dairy cattle	70	30
Beef cattle	All Beef	100	0
Sheep	All sheep	100	0
Goats	All goats	100	0
Horses	All horses	100	0

Appendix B: Gross energy intake and emission results per livestock category

Table B.1 Gross energy intake by dairy cattle

LvsCategory	Mature female(D)	Bulls(D)	Heifers(D)	Calves(D)	Calves(D)
LvstkSub	Mature Females	Mature Bulls	Young Females - Age 1-2	Young Females - Age 0-1	Young Intact Males - Age 0-1
Units	MJ/head/day	MJ/head/day	MJ/head/day	MJ/head/day	MJ/head/day
F1	246	177	122	155	153
F2	226	-	-	108	106
F3	141	117	175	44	43
F4	199	128	102	49	49
F5	151	117	108	45	44
F6	122	109	94	49	48
F7	155	159	196	38	37
F8	157	159	82	53	52
F9	163	138	110	64	64
F10	152	116	196	44	44
F11	222	150	142	55	54
F12	185	121	116	32	31
F13	-	-	-	-	-
F14	232	105	102	40	40
F15	160	-	-	-	-
F16	158	120	-	-	-
SD	37	22	38	33	32
Mean	179	133	129	60	59
CV	21	17	29	55	55
- Represents the unavailability of other animal sub-categories in other farms during certain periods					

Table B.2 Gross energy intake by beef cattle

LvsCategory	Mature females(B)	Bulls(B)	Heifers(B)	Calves(B)	Calves(B)
LvstkSub	Mature Females	Mature Bulls	Young Females - Age 1-2	Young Females - Age 0-1	Young Intact Males - Age 0-1
Units	MJ/head/day	MJ/head/day	MJ/head/day	MJ/head/day	MJ/head/day
F1	261	166	131	51	51
F2	-	-	-	-	40
F3	232	142	118	73	71
F4	212	128	119	46	46
F5	-	-	-	-	-
F6	-	-	-	-	-
F7	107	159	119	32	31
F8	-	-	-	-	38
F9	-	102	90	71	72
F10	-	-	-	-	-
F11	234	128	123	73	72
F12	-	-	-	-	-
F13	195	111	109	-	37
F14	-	-	-	-	-
F15	193	-	118	32	-
F16	179	-	107	26	25
SD	46	22	11	17	16
Mean	205	134	116	54	51
CV	22	16	10	32	31
- Represents the unavailability of other animal sub-categories in other farms during certain periods					

Table B.3 Gross energy intake by sheep livestock category

LvstkSub	Ewes	Heifers	Rams	Lambs
Farms	MJ/animal/day	MJ/animal/day	MJ/animal/day	MJ/animal/day
F1	64	39	47	30
F2	64	39	47	30
F5	64	39	47	30
F6	64	39	47	30
F7	64	39	47	30
F9	64	39	47	30
F11	64	39	47	30

Table B.4 Total emissions per farm

Emissions	kg CO2eq/year	kg CO2eq/year	kg CO2eq/year	kg CO2eq/year	kg CO2eq/year
Farms	2010	2011	2012	2013	2014
F1	313868	338582	374875	415740	289719
F2	152580	173436	202610	446945	430693
F3	219627	265930	676245	105038	127728
F4	146636	155688	125996	136860	217042
F5	98683	68264	131616	161952	130192
F6	87540	97414	71712	74761	126382
F7	225921	292320	211728	276021	282536
F8	90080	97811	80685	69025	71710
F9	280765	181761	81799	467538	134049
F10	139018	204642	45338	54731	66562
F11	581295	585732	605683	440144	274342
F12	89621	79250	46623	59532	36270
F13	203122	264560	285540	386178	434004
F14	263666	194276	120249	108909	107753
F15	69220	74896	47567	90804	63017
F16	430684	269682	197652	293955	254731

Table B.5 Emission intensity

Total emissions per farm per hectare					
Farms	Kg CO_2eq/farm/ha	Kg CO_2eq/farm/ha	Kg CO_2eq/farm/ha	Kg CO_2eq/farm/ha	Kg CO_2eq/farm/ha
	2010	2011	2012	2013	2014
F1	2266	1242	1358	1477	1284
F2	858	1103	2000	2898	2711
F3	399	465	697	176	246
F4	316	373	275	725	546
F5	500	432	785	940	854
F6	362	441	344	326	560
F7	555	724	416	693	706
F8	158	176	139	111	130
F9	725	502	227	382	427
F10	1149	767	375	460	571
F11	1263	1246	1406	1540	726
F12	189	189	114	145	89
F13	931	5170	1130	1537	1872
F14	1057	1075	645	615	587
F15	128	160	86	165	136
F16	380	238	184	288	202

Appendix C: Uncertainty results

Table C.1 Uncertainty for CH_4 emissions from enteric fermentation by non-dairy for 2011

Farms	2011 estimate	Uncertainty range and percentage		
	(Kg CO_2eq)	Lower bound	Upper bound	Uncertainty percentage
Farm 1	43451	39840	47062	8.31
Farm 2	17775	15787	19762	11.18
Farm 3	119553	100293	138813	16.11
Farm 4	62668	54371	70965	13.24
Farm 5	29970	24731	35209	17.48
Farm 6	12731	11221	14241	11.86
Farm 7	85956	75238	96675	12.47
Farm 8	10496	9075	11918	13.54
Farm 9	18164	15548	20780	14.4
Farm 10	3941	3477	4404	11.76
Farm 11	161688	142479	180897	11.88
Farm 12	16239	13351	19126	17.78
Farm 13	983776	842801	1124751	14.33
Farm 14	30588	25626	35549	16.22
Farm 15	23551	19608	27493	16.74
Farm 16	27169	23192	31147	14.64

Table C.2 Uncertainty for CH_4 emissions from enteric fermentation by non-dairy for 2012

Farms	2012 estimate	Uncertainty range and percentage		
	(Kg CO_2eq)	Lower bound	Upper bound	Uncertainty percentage
Farm 1	51282	46564	56000	9.2
Farm 2	120636	100056	141217	17.06
Farm 3	157782	137523	178041	12.84
Farm 4	60630	51445	69816	15.15
Farm 5	13746	12042	15449	12.39
Farm 6	13118	11442	14795	12.78
Farm 7	54970	48698	61242	11.41
Farm 8	3981	3516	4446	11.68
Farm 9	13776	11806	15746	14.3
Farm 10	5209	4598	5821	11.74
Farm 11	179085	157612	200557	11.99
Farm 12	11571	10127	13015	12.48
Farm 13	139045	119537	158553	14.03
Farm 14	16826	14900	18753	11.45
Farm 15	7499	6478	8519	13.61
Farm 16	18225	16307	20142	10.52

Table C.3 Uncertainty for CH_4 emissions from enteric fermentation by non-dairy 2013

Farms	2013 estimate	Uncertainty range and percentage		
	(Kg CO_2eq)	Lower bound	Upper bound	Uncertainty percentage
Farm 1	43844	40433	47255	7.78
Farm 2	147396	123223	171569	16.4
Farm 3	22598	19721	25474	12.73
Farm 4	217197	187028	247366	13.89
Farm 5	43074	35019	51128	18.7
Farm 6	13158	11805	14510	10.28
Farm 7	96711	84438	108983	12.69
Farm 8	6721	6124	7318	8.88
Farm 9	26508	23545	29472	11.18
Farm 10	12484	11182	13786	10.43
Farm 11	200462	174923	226000	12.74
Farm 12	7207	6352	8062	11.86
Farm 13	196778	166828	226727	15.22
Farm 14	28938	24366	33510	15.8
Farm 15	40292	32874	47710	18.41
Farm 16	69966	62648	77284	10.46

Table C.4 Uncertainty for CH_4 emissions from enteric fermentation by non-dairy 2014

Farms	2014 estimate	Uncertainty range and percentage		
	(Kg CO_2eq)	Lower bound	Upper bound	Uncertainty percentage
Farm 1	68337	63212	73462	7.5
Farm 2	45121	40392	49849	10.48
Farm 3	16803	14800	18806	11.92
Farm 4	133821	117093	150548	12.5
Farm 5	21305	18097	24514	15.06
Farm 6	11374	9945	12802	12.56
Farm 7	138554	127054	150054	8.3
Farm 8	18523	15810	21237	14.65
Farm 9	30985	27413	34558	11.53
Farm 10	9642	8401	10884	12.88
Farm 11	29358	24191	34525	17.6
Farm 12	6388	5389	7387	15.64
Farm 13	259889	220646	299132	15.1
Farm 14	22565	18857	26272	16.43
Farm 15	40858	33438	48278	18.16
Farm 16	51648	45352	57943	12.19

Table C.5 Uncertainty for CH_4 emissions from enteric fermentation by dairy cows for 2011

Farms	2011 estimate	Uncertainty range and percentage		
	(Kg CO_2eq)	Lower bound	Upper bound	Uncertainty percentage
Farm 1	114312	93164	135459	18.50
Farm 2	63989	53988	73991	15.63
Farm 3	-	-	-	-
Farm 4	19370	15701	23038	18.94
Farm 5	14869	11998	17740	19.31
Farm 6	23746	19128	28365	19.45
Farm 7	33045	26568	39522	19.60
Farm 8	40404	32367	48440	19.89
Farm 9	108897	88054	129740	19.14
Farm 10	16839	13619	20058	19.12
Farm 11	108484	88468	128499	18.45
Farm 12	30122	24549	35694	18.50
Farm 13	-	-	-	-
Farm 14	135166	109241	161091	19.18
Farm 15	-	-	-	-
Farm 16	91178	74091	108265	18.74
- Represents the unavailability of the animal sub-category at farms				

Table C.6 Uncertainty for CH_4 emissions from enteric fermentation by dairy cows 2012

Farms	2012 estimate	Uncertainty range and percentage		
	(Kg CO_2eq)	Lower bound	Upper bound	Uncertainty percentage
Farm 1	114312	93164	135459	18.50
Farm 2	109696	89337	130056	18.56
Farm 3	26104	21210	30999	18.75
Farm 4	15496	12559	18432	18.95
Farm 5	72859	58790	86928	19.31
Farm 6	20778	16737	24819	19.45
Farm 7	33045	26568	39522	19.60
Farm 8	31080	24898	37262	19.89
Farm 9	41306	33400	49212	19.14
Farm 10	16839	13619	20058	19.12
Farm 11	133518	108884	158153	18.45
Farm 12	15061	12275	17847	18.50
Farm 13	-	-	-	-
Farm 14	43446	35113	51779	19.18
Farm 15	-	-	-	-
Farm 16	73300	59564	87037	18.74
- Represents the unavailability of the animal sub-category at farms				

Table C.7 Uncertainty for CH_4 emissions from enteric fermentation by dairy cows 2013

Farms	2013 estimate	Uncertainty range and percentage		
	(Kg CO_2eq)	Lower bound	Upper bound	Uncertainty percentage
Farm 1	118708	100237	137179	15.56
Farm 2	165698	134961	196435	18.55
Farm 3	28877	23283	34470	19.37
Farm 4	13559	10989	16128	18.95
Farm 5	17843	14397	21288	19.31
Farm 6	26714	21518	31910	19.45
Farm 7	22531	18115	26947	19.60
Farm 8	26418	21163	31672	19.89
Farm 9	45061	36436	53685	19.14
Farm 10	16839	14096	19582	16.29
Farm 11	127260	103780	150739	18.45
Farm 12	18826	15343	22309	18.50
Farm 13	-	-	-	-
Farm 14	62756	50719	74792	19.18
Farm 15	-	-	-	-
Farm 16	73300	59564	87037	18.74
- Represents the unavailability of the animal sub-category at farms				

Table C.8 Uncertainty for CH_4 emissions from enteric fermentation by dairy cows for 2014

Farms	2014 estimate	Uncertainty range and percentage		
	(Kg CO_2eq)	Lower bound	Upper bound	Uncertainty percentage
Farm 1	101122	82414	119829	18.50
Farm 2	235389	191701	279078	18.56
Farm 3	55851	45167	66535	19.13
Farm 4	13559	11016	16101	18.75
Farm 5	35686	28795	42577	19.31
Farm 6	32651	26300	39002	19.45
Farm 7	15021	12077	17965	19.60
Farm 8	23310	18674	27946	19.89
Farm 9	52571	42509	62633	19.14
Farm 10	15308	12381	18235	19.12
Farm 11	127260	103780	150739	18.45
Farm 12	13178	10740	15616	18.50
Farm 13	-	-	-	-
Farm 14	65170	52670	77669	19.18
Farm 15	-	-	-	-
Farm 16	85815	69733	101896	18.74
- Represents the unavailability of the animal sub-category at farms				

Table C.9 Uncertainty for CH_4 emissions from manure management by non-dairy for 2011

Farms	2011 estimate	Uncertainty range and percentage		
	Kg CO_2eq	Lower bound	Upper bound	Uncertainty percentage
Farm 1	615	484	746	21.34
Farm 2	238	192	285	19.35
Farm 3	1655	1179	2131	28.77
Farm 4	-	-	-	-
Farm 5	415	332	498	20.00
Farm 6	175	136	213	22.03
Farm 7	1213	943	1484	22.32
Farm 8	145	115	175	20.65
Farm 9	251	201	302	20.00
Farm 10	36	29	43	19.36
Farm 11	2238	1755	2721	21.58
Farm 12	225	172	278	23.58
Farm 13	1776	1314	2237	25.99
Farm 14	423	321	526	24.25
Farm 15	326	256	396	21.36
Farm 16	376	293	459	22.05
- Represents the unavailability of the animal category at farms				

Table C.10 Uncertainty for CH_4 emissions from manure management by non-dairy for 2012

Farms	2012 estimate	Uncertainty range and percentage		
	Kg CO_2eq	Lower bound	Upper bound	Uncertainty percentage
Farm 1	726	558	894	23.17
Farm 2	3315	2486	4145	25.01
Farm 3	45871	35344	56399	22.95
Farm 4	839	686	992	18.22
Farm 5	190	152	228	20.00
Farm 6	182	142	222	22.03
Farm 7	761	591	931	22.32
Farm 8	55	44	66	20.65
Farm 9	191	153	229	20.00
Farm 10	72	58	86	19.36
Farm 11	2487	1945	3029	21.8
Farm 12	160	122	198	23.58
Farm 13	1925	1448	2402	24.79
Farm 14	233	176	289	24.25
Farm 15	104	82	126	21.36
Farm 16	247	192	301	22.05

Table C.11 Uncertainty for CH_4 emissions from manure management by non-dairy for 2013

Farms	2013 estimate	Uncertainty range and percentage		
	Kg CO_2eq	Lower bound	Upper bound	Uncertainty percentage
Farm 1	429	329	528	23.17
Farm 2	2219	1664	2774	25.01
Farm 3	313	241	385	22.95
Farm 4	162	132	191	18.22
Farm 5	1935	1548	2321	20.00
Farm 6	182	142	222	22.03
Farm 7	108	84	132	22.32
Farm 8	1361	1080	1642	20.65
Farm 9	255	204	306	20.00
Farm 10	321	259	383	19.36
Farm 11	586	450	722	23.17
Farm 12	2289	1749	2828	23.58
Farm 13	-	-	-	-
Farm 14	3125	2367	3883	24.25
Farm 15	-	-	-	-
Farm 16	1146	893	1398	22.05
- Represents the unavailability of the animal category at farms				

Table C.12 Uncertainty for CH_4 emissions from manure management by non-dairy for 2014

Farms	2014 estimate	Uncertainty range and percentage		
	Kg CO_2eq	Lower bound	Upper bound	Uncertainty percentage
Farm 1	532	371	692	30.19
Farm 2	1149	862	1437	25.01
Farm 3	235	181	289	22.95
Farm 4	31	14	48	55.05
Farm 5	2277	1821	2732	20.00
Farm 6	157	123	192	22.03
Farm 7	45	11	79	76.25
Farm 8	2194	1741	2647	20.65
Farm 9	435	348	522	20.00
Farm 10	307	248	367	19.36
Farm 11	406	312	501	23.17
Farm 12	88	68	109	23.58
Farm 13	-	-	-	-
Farm 14	3910	2962	4859	24.25
Farm 15	-	-	-	-
Farm 16	785	612	958	22.05
- Represents the unavailability of the animal category at farms				

Table C.13 Uncertainty for CH_4 emissions from manure management by dairy cows for 2010

Farms	2010 estimate	Uncertainty range and percentage		
	Kg CO_2eq	Lower bound	Upper bound	Uncertainty percentage
Farm 1	1138	750	1526	34.12
Farm 2	1084	786	1383	27.53
Farm 3	-	-	-	-
Farm 4	276	219	332	20.52
Farm 5	212	164	259	22.33
Farm 6	176	137	215	22.00
Farm 7	405	302	508	25.43
Farm 8	350	255	445	27.11
Farm 9	1292	830	1753	35.72
Farm 10	182	143	220	21.25
Farm 11	990	750	1230	24.21
Farm 12	447	354	539	20.65
Farm 13	-	-	-	-
Farm 14	1403	1035	1771	26.23
Farm 15	-	-	-	-
Farm 16	1591	1251	1930	21.36
- Represents the unavailability of the animal category at farms				

Table C.14 Uncertainty for CH_4 emissions from manure management by dairy cows for 2011

Farms	2011 estimate	Uncertainty range and percentage		
	Kg CO_2eq	Lower bound	Upper bound	Uncertainty percentage
Farm 1	1387	948	1826	31.67
Farm 2	759	550	968	27.53
Farm 3	-	-	-	-
Farm 4	230	183	277	20.52
Farm 5	176	137	216	22.33
Farm 6	282	220	344	22.00
Farm 7	392	292	492	25.43
Farm 8	479	349	609	27.11
Farm 9	1292	830	1753	35.72
Farm 10	200	157	242	21.25
Farm 11	1287	975	1598	24.21
Farm 12	357	284	431	20.65
Farm 13	-	-	-	-
Farm 14	1603	1183	2024	26.23
Farm 15	-	-	-	-
Farm 16	1082	851	1313	21.36
- Represents the unavailability of the animal category at farms				

Table C.15 Uncertainty for CH_4 emissions from manure management by dairy cows for 2012

Farms	2012 estimate	Uncertainty range and percentage		
	Kg CO_2eq	Lower bound	Upper bound	Uncertainty percentage
Farm 1	1387	948	1826	31.67
Farm 2	2602	1886	3319	27.53
Farm 3	310	228	392	26.44
Farm 4	184	146	222	20.52
Farm 5	864	671	1057	22.33
Farm 6	246	192	301	22.00
Farm 7	392	292	492	25.43
Farm 8	369	269	469	27.11
Farm 9	490	315	665	35.72
Farm 10	200	157	242	21.25
Farm 11	1584	1200	1967	24.21
Farm 12	179	142	216	20.65
Farm 13	-	-	-	-
Farm 14	515	380	651	26.23
Farm 15	-	-	-	-
Farm 16	869	684	1055	21.36
- Represents the unavailability of the animal category at farms				

Table C.16 Uncertainty for CH_4 emissions from manure management by dairy cows for 2013

Farms	2013 estimate	Uncertainty range and percentage		
	Kg CO_2eq	Lower bound	Upper bound	Uncertainty percentage
Farm 1	1408	962	1854	31.67
Farm 2	1965	1424	2507	27.53
Farm 3	343	252	433	26.44
Farm 4	161	128	194	20.52
Farm 5	212	164	259	22.33
Farm 6	317	247	387	22.00
Farm 7	267	199	335	25.43
Farm 8	313	228	398	27.11
Farm 9	535	344	725	35.72
Farm 10	200	157	242	21.25
Farm 11	1510	1144	1875	24.21
Farm 12	223	177	269	20.65
Farm 13	-	-	-	-
Farm 14	744	549	940	26.23
Farm 15	-	-	-	-
Farm 16	869	684	1055	21.36
- Represents the unavailability of the animal category at farms				

Table C.17 Uncertainty for CH_4 emissions from manure management by dairy cows for 2014

Farms	2014 estimate	Uncertainty range and percentage		
	Kg CO_2eq	Lower bound	Upper bound	Uncertainty percentage
Farm 1	1227	838	1615	31.67
Farm 2	2792	2023	3561	27.53
Farm 3	662	487	838	26.44
Farm 4	161	128	194	20.52
Farm 5	423	329	518	22.33
Farm 6	387	302	473	22.00
Farm 7	178	133	223	25.43
Farm 8	276	202	351	27.11
Farm 9	624	401	846	35.72
Farm 10	182	143	220	21.25
Farm 11	1510	1144	1875	24.21
Farm 12	156	124	189	20.65
Farm 13	-	-	-	-
Farm 14	773	570	976	26.23
Farm 15	-	-	-	-
Farm 16	1018	800	1235	21.36
- Represents the unavailability of the animal category at farms				

Table C.18 Uncertainty for N_2O emissions from manure management by non-dairy 2011

Farms	2011 estimate	Uncertainty range and percentage		
	(Kg CO_2eq)	Lower bound	Upper bound	Uncertainty percentage
Farm 1	9585	6348	12822	33.77
Farm 2	11198	5208	17188	53.49
Farm 3	64342	17951	110733	72.1
Farm 4	15085	6051	24119	59.89
Farm 5	8065	2266	13863	71.9
Farm 6	3599	1811	5388	49.68
Farm 7	24269	11222	37316	53.76
Farm 8	2825	1134	4515	59.85
Farm 9	4888	2160	7616	55.81
Farm 10	1060	506	1615	52.33
Farm 11	43509	19936	67083	54.18
Farm 12	4370	931	7808	78.69
Farm 13	34518	12033	57004	65.14
Farm 14	8231	2324	14137	71.76
Farm 15	6337	1504	11171	76.27
Farm 16	7311	2429	12193	66.78

Table C.19 Uncertainty for N_2O emissions from manure management by non-dairy for 2012

Farms	2012 estimate	Uncertainty range and percentage		
	(Kg CO_2eq)	Lower bound	Upper bound	Uncertainty percentage
Farm 1	11654	7351	15956	36.92
Farm 2	14820	4713	24928	68.2
Farm 3	42458	18083	66833	57.41
Farm 4	16315	4994	27636	69.39
Farm 5	3699	1794	5603	51.49
Farm 6	3530	1480	5580	58.07
Farm 7	14792	7211	22373	51.25
Farm 8	1071	543	1600	49.34
Farm 9	3707	1662	5752	55.17
Farm 10	1402	672	2132	52.08
Farm 11	48191	21806	74575	54.75
Farm 12	3114	1393	4834	55.26
Farm 13	37416	14506	60326	61.23
Farm 14	4528	2239	6817	50.56
Farm 15	2018	552	3484	72.64
Farm 16	4796	2520	7072	47.45

Table C.20 Uncertainty for N_2O emissions from manure management by non-dairy for 2013

Farms	2013 estimate	Uncertainty range and percentage		
	(Kg CO_2eq)	Lower bound	Upper bound	Uncertainty percentage
Farm 1	6725	4029	9420	40.08
Farm 2	42208	14574	69842	65.47
Farm 3	6081	2617	9545	56.97
Farm 4	3144	1170	5118	62.8
Farm 5	37602	8690	66515	76.89
Farm 6	3541	1934	5148	45.39
Farm 7	2094	877	3311	58.13
Farm 8	26458	16332	36583	38.27
Farm 9	4951	2660	7242	46.27
Farm 10	6244	3215	9272	48.51
Farm 11	11394	4763	18026	58.2
Farm 12	44488	21141	67836	52.48
Farm 13	-	-	-	-
Farm 14	60739	18367	103110	69.76
Farm 15	-	-	-	-
Farm 16	22534	12153	32916	46.07
- Represents the unavailability of the animal category at farms				

Table C.21 Uncertainty for N_2O emissions from manure management by non-dairy for 2014

Farms	2014 estimate	Uncertainty range and percentage		
	(Kg CO_2eq)	Lower bound	Upper bound	Uncertainty percentage
Farm 1	4333	2242	6425	48.27
Farm 2	12234	6520	17949	46.71
Farm 3	4556	2108	7004	53.74
Farm 4	602	44	1159	92.61
Farm 5	41416	13630	69202	67.09
Farm 6	3061	1364	4757	55.42
Farm 7	867	-151	1885	117.48
Farm 8	42749	14890	70609	65.17
Farm 9	4806	2501	7110	47.95
Farm 10	7689	3601	11777	53.17
Farm 11	7900	2387	13413	69.78
Farm 12	1719	529	2909	69.22
Farm 13	-	-	-	-
Farm 14	76007	20856	131157	72.56
Farm 15	-	-	-	-
Farm 16	15260	6824	23696	55.28
- Represents the unavailability of the animal category at farms				

Table C.22 Uncertainty for N_2O emissions from manure management by dairy cows for 2010

Farms	2010 estimate	Uncertainty range and percentage		
	(Kg CO_2eq)	Lower bound	Upper bound	Uncertainty percentage
Farm 1	173013	22717	323309	86.87
Farm 2	3212	428	5996	86.68
Farm 3	-	-	-	-
Farm 4	4356	576	8135	86.77
Farm 5	3344	440	6247	86.85
Farm 6	2781	356	5206	87.20
Farm 7	7037	1773	12301	74.81
Farm 8	6509	857	12162	86.84
Farm 9	20406	2692	38120	86.81
Farm 10	2869	378	5359	86.81
Farm 11	15637	2086	29189	86.66
Farm 12	7056	1676	12435	76.24
Farm 13	-	-	-	-
Farm 14	26074	3476	48671	86.67
Farm 15	-	-	-	-
Farm 16	25126	3337	46915	86.72
- Represents the unavailability of the animal category at farms				

Table C.23 Uncertainty for N_2O emissions from manure management by dairy cows for 2011

Farms	2011 estimate	Uncertainty range and percentage		
	(Kg CO_2eq)	Lower bound	Upper bound	Uncertainty percentage
Farm 1	20082	4589	35575	77.15
Farm 2	11991	1684	22298	85.96
Farm 3	-	-	-	-
Farm 4	3630	480	6779	86.77
Farm 5	2786	366	5206	86.85
Farm 6	4450	570	8330	87.20
Farm 7	6192	811	11574	86.91
Farm 8	8907	1172	16642	86.84
Farm 9	20406	2692	38120	86.81
Farm 10	3155	416	5895	86.81
Farm 11	20329	2712	37945	86.66
Farm 12	5644	752	10536	86.67
Farm 13	-	-	-	-
Farm 14	29798	3972	55624	86.67
Farm 15	17086	2278	31894	86.67
Farm 16	-	-	-	-
- Represents the unavailability of the animal category at farms				

Table C.24 Uncertainty for N_2O emissions from manure management by dairy cows for 2012

Farms	2012 estimate	Uncertainty range and percentage		
	(Kg CO_2eq)	Lower bound	Upper bound	Uncertainty percentage
Farm 1	20082	4589	35575	77.15
Farm 2	7708	1038	14379	86.54
Farm 3	4892	656	9127	86.58
Farm 4	2904	384	5423	86.77
Farm 5	13653	1795	25510	86.85
Farm 6	3894	498	7289	87.20
Farm 7	6192	811	11574	86.91
Farm 8	6852	902	12802	86.84
Farm 9	7740	1021	14459	86.81
Farm 10	3155	416	5895	86.81
Farm 11	25020	3338	46702	86.66
Farm 12	2822	376	5268	86.67
Farm 13	-	-	-	-
Farm 14	9578	1277	17879	86.67
Farm 15	-	-	-	-
Farm 16	13736	1824	25647	86.72
- Represents the unavailability of the animal category at farms				

Table C.25 Uncertainty for N_2O emissions from manure management by dairy cows for 2013

Farms	2013 estimate	Uncertainty range and percentage		
	(Kg CO_2eq)	Lower bound	Upper bound	Uncertainty percentage
Farm 1	22244	3112	41377	86.01
Farm 2	31050	7222	54877	76.74
Farm 3	5411	664	10158	87.72
Farm 4	2541	336	4745	86.77
Farm 5	3344	440	6247	86.85
Farm 6	5006	641	9371	87.20
Farm 7	4222	553	7891	86.91
Farm 8	5824	766	10882	86.84
Farm 9	8444	1114	15774	86.81
Farm 10	3155	745	5566	76.39
Farm 11	23847	3181	44513	86.66
Farm 12	3528	470	6585	86.67
Farm 13	-	-	-	-
Farm 14	13835	1844	25826	86.67
Farm 15	-	-	-	-
Farm 16	13736	1824	25647	86.72
- Represents the unavailability of the animal category at farms				

Table C.26 Uncertainty for N_2O emissions from manure management by dairy cows for 2014

Farms	2014 estimate	Uncertainty range and percentage		
	(Kg CO_2eq)	Lower bound	Upper bound	Uncertainty percentage
Farm 1	17765	4059	31470	77.15
Farm 2	44109	5937	82281	86.54
Farm 3	10466	1396	19536	86.66
Farm 4	2541	336	4745	86.77
Farm 5	6687	879	12495	86.85
Farm 6	6118	783	11454	87.20
Farm 7	2815	368	5261	86.91
Farm 8	5139	676	9601	86.84
Farm 9	9851	1299	18403	86.81
Farm 10	2869	378	5359	86.81
Farm 11	23847	5361	42333	77.52
Farm 12	2469	329	4610	86.67
Farm 13	-	-	-	-
Farm 14	14367	1915	26819	86.67
Farm 15	-	-	-	-
Farm 16	16081	2136	30026	86.72
- Represents the unavailability of the animal category at farms				

Table C.27 Uncertainty for CH_4 emissions from biomass burning for 2011

Farms	2011 estimate	Uncertainty range and percentage		
	Kg CO_2eq	Lower bound	Upper bound	Uncertainty percentage
Farm 1	-	-	-	-
Farm 2	-	-	-	-
Farm 3	-	-	-	-
Farm 4	29757	11644	47870	60.87
Farm 5	-	-	-	-
Farm 6	16527	6467	26587	60.87
Farm 7	47208	18472	75944	60.87
Farm 8	-	-	-	-
Farm 9	-	-	-	-
Farm 10	33054	12934	53174	60.87
Farm 11	-	-	-	-
Farm 12	-	-	-	-
Farm 13	4725	1849	7601	60.87
Farm 14	-	-	-	-
Farm 15	11802	4618	18986	60.87
Farm 16	-	-	-	-
- Represents the unavailability of fire at farms				

Table C.28 Uncertainty for CH_4 emissions from biomass burning for 2012

Farms	2012 estimate	Uncertainty range and percentage		
	Kg CO_2eq	Lower bound	Upper bound	Uncertainty percentage
Farm 1	-	-	-	-
Farm 2	-	-	-	-
Farm 3	3066	1200	4932	60.87
Farm 4	-	-	-	-
Farm 5	-	-	-	-
Farm 6	21252	8316	34188	60.87
Farm 7	-	-	-	-
Farm 8	2835	1109	4561	60.87
Farm 9	-	-	-	-
Farm 10	-	-	-	-
Farm 11	-	-	-	-
Farm 12	-	-	-	-
Farm 13	-	-	-	-
Farm 14	38955	15243	62667	60.87
Farm 15	11802	4618	18986	60.87
Farm 16	-	-	-	-
- Represents the unavailability of fire at farms				

Table C.29 Uncertainty for CH_4 emissions from biomass burning for 2013

Farms	2013 estimate	Uncertainty range and percentage		
	Kg CO_2eq	Lower bound	Upper bound	Uncertainty percentage
Farm 1	28329	11085	45573	60.87
Farm 2	-	-	-	-
Farm 3	2352	920	3784	60.87
Farm 4	-	-	-	-
Farm 5	28812	11274	46350	60.87
Farm 6	11802	4618	18986	60.87
Farm 7	47208	18472	75944	60.87
Farm 8	-	-	-	-
Farm 9	25032	9795	40269	60.87
Farm 10	-	-	-	-
Farm 11	-	-	-	-
Farm 12	-	-	-	-
Farm 13	5901	2309	9493	60.87
Farm 14	-	-	-	-
Farm 15	11802	4618	18986	60.87
Farm 16	-	-	-	-
- Represents the unavailability of fire at farms				

Table C.30 Uncertainty for CH_4 emissions from biomass burning for 2014

Farms	2014 estimate	Uncertainty range and percentage		
	Kg CO_2eq	Lower bound	Upper bound	Uncertainty percentage
Farm 1	-	-	-	-
Farm 2	-	-	-	-
Farm 3	-	-	-	-
Farm 4	-	-	-	-
Farm 5	-	-	-	-
Farm 6	12180	4766	19594	60.87
Farm 7	-	-	-	-
Farm 8	-	-	-	-
Farm 9	25074	9811	40337	60.87
Farm 10	-	-	-	-
Farm 11	4725	1849	7601	60.87
Farm 12	-	-	-	-
Farm 13	-	-	-	-
Farm 14	-	-	-	-
Farm 15	-	-	-	-
Farm 16	-	-	-	-
- Represents the unavailability of fire at farms				

Table C.31 Uncertainty for N_2O emissions from biomass burning for 2011

Farms	2011 estimate	Uncertainty range and percentage		
	Kg CO_2eq	Lower bound	Upper bound	Uncertainty percentage
Farm 1	-	-	-	-
Farm 2	-	-	-	-
Farm 3	-	-	-	-
Farm 4	5580	2329	8831	58.26
Farm 5	-	-	-	-
Farm 6	3100	1294	4906	58.26
Farm 7	8680	3623	13737	58.26
Farm 8	-	-	-	-
Farm 9	-	-	-	-
Farm 10	5890	2458	9322	58.26
Farm 11	-	-	-	-
Farm 12	-	-	-	-
Farm 13	930	388	1472	58.26
Farm 14	-	-	-	-
Farm 15	2170	906	3434	58.26
Farm 16	-	-	-	-
- Represents the unavailability of fire at farms				

Table C.32 Uncertainty for N_2O emissions from biomass burning 2012

Farms	2012 estimate	Uncertainty range and percentage		
	Kg CO_2eq	Lower bound	Upper bound	Uncertainty percentage
Farm 1	-	-	-	-
Farm 2	-	-	-	-
Farm 3	620	259	981	58.26
Farm 4	-	-	-	-
Farm 5	-	-	-	-
Farm 6	4030	1682	6378	58.26
Farm 7	-	-	-	-
Farm 8	620	259	981	58.26
Farm 9	-	-	-	-
Farm 10	-	-	-	-
Farm 11	-	-	-	-
Farm 12	-	-	-	-
Farm 13	-	-	-	-
Farm 14	7130	2976	11284	58.26
Farm 15	2170	906	3434	58.26
Farm 16	-	-	-	-
- Represents the unavailability of fire at farms				

Table C.33 Uncertainty for N_2O emissions from biomass burning for 2013

Farms	2013 estimate	Uncertainty range and percentage		
	Kg CO_2eq	Lower bound	Upper bound	Uncertainty percentage
Farm 1	5270	2200	8340	58.26
Farm 2	-	-	-	-
Farm 3	310	129	491	58.26
Farm 4	-	-	-	-
Farm 5	5270	2200	8340	58.26
Farm 6	2170	906	3434	58.26
Farm 7	8680	3623	13737	58.26
Farm 8	-	-	-	-
Farm 9	4650	1941	7359	58.26
Farm 10	-	-	-	-
Farm 11	-	-	-	-
Farm 12	-	-	-	-
Farm 13	930	388	1472	58.26
Farm 14	-	-	-	-
Farm 15	2170	906	3434	58.26
Farm 16	-	-	-	-
- Represents the unavailability of fire at farms				

Table C.34 Uncertainty for N_2O emissions from biomass burning for 2014

Farms	2014 estimate	Uncertainty range and percentage		
	Kg CO_2eq	Lower bound	Upper bound	Uncertainty percentage
Farm 1	-	-	-	-
Farm 2	-	-	-	-
Farm 3	-	-	-	-
Farm 4	-	-	-	-
Farm 5	-	-	-	-
Farm 6	2790	1165	4415	58.26
Farm 7	-	-	-	-
Farm 8	-	-	-	-
Farm 9	5890	2458	9322	58.26
Farm 10	-	-	-	-
Farm 11	930	388	1472	58.26
Farm 12	-	-	-	-
Farm 13	-	-	-	-
Farm 14	-	-	-	-
Farm 15	-	-	-	-
Farm 16	-	-	-	-
- Represents the unavailability of fire at farms				

Table C.35 Uncertainty for N_2O emissions from agricultural managed soils for 2011

Farms	2011 estimate	Uncertainty range and percentage		
	Kg CO_2eq	Lower bound	Upper bound	Uncertainty percentage
Farm 1	42191	-8164	92546	119.35
Farm 2	29450	-13998	72898	147.53
Farm 3	13671	-1412	28754	110.33
Farm 4	3410	-1194	8014	135.00
Farm 5	5270	-1850	12390	135.11
Farm 6	3410	-885	7705	125.96
Farm 7	23870	-12725	60465	153.31
Farm 8	6200	-6444	18844	203.93
Farm 9	10850	-4578	26278	142.19
Farm 10	11780	-4147	27707	135.2
Farm 11	22320	-2080	46720	109.32
Farm 12	5890	-3593	15373	161.01
Farm 13	26350	-9251	61951	135.11
Farm 14	13330	-2497	29157	118.73
Farm 15	8990	-1130	19110	112.57
Farm 16	63550	-16110	143210	125.35

Table C.36 Uncertainty for N_2O emissions from agricultural managed soils for 2012

Farms	2012 estimate	Uncertainty range and percentage		
	Kg CO_2eq	Lower bound	Upper bound	Uncertainty percentage
Farm 1	44454	-8602	97510	119.35
Farm 2	40920	-19449	101289	147.53
Farm 3	18724	-1934	39382	110.33
Farm 4	3720	-1302	8742	135.00
Farm 5	9920	-3483	23323	135.11
Farm 6	3100	-805	7005	125.96
Farm 7	13330	-7106	33766	153.31
Farm 8	4960	-5155	15075	203.93
Farm 9	5890	-2485	14265	142.19
Farm 10	7130	-2510	16770	135.2
Farm 11	25110	-2340	52560	109.32
Farm 12	10230	-6241	26701	161.01
Farm 13	27590	-9687	64867	135.11
Farm 14	5890	-1103	12883	118.73
Farm 15	8370	-1052	17792	112.57
Farm 16	11160	-2829	25149	125.35

Table C.37 Uncertainty for N_2O emissions from agricultural managed soils for 2013

Farms	2013 estimate	Uncertainty range and percentage		
	Kg CO_2eq	Lower bound	Upper bound	Uncertainty percentage
Farm 1	43834	-8482	96150	119.35
Farm 2	50840	-24164	125844	147.53
Farm 3	10044	-1038	21126	110.33
Farm 4	8060	-2821	18941	135.00
Farm 5	29760	-10449	69969	135.11
Farm 6	4030	-1046	9106	125.96
Farm 7	7750	-4132	19632	153.31
Farm 8	4650	-4833	14133	203.93
Farm 9	7130	-3008	17268	142.19
Farm 10	6820	-2401	16041	135.2
Farm 11	44950	-4189	94089	109.32
Farm 12	20770	-12672	54212	161.01
Farm 13	31620	-11102	74342	135.11
Farm 14	7130	-1335	15595	118.73
Farm 15	7440	-935	15815	112.57
Farm 16	17980	-4558	40518	125.35

Table C.38 Uncertainty for N_2O emissions from agricultural managed soils for 2014

Farms	2014 estimate	Uncertainty range and percentage		
	Kg CO_2eq	Lower bound	Upper bound	Uncertainty percentage
Farm 1	59272	-11469	130013	119.35
Farm 2	69130	-32857	171117	147.53
Farm 3	13082	-1351	27515	110.33
Farm 4	9920	-3472	23312	135.00
Farm 5	55180	-19374	129734	135.11
Farm 6	42780	-11106	96666	125.96
Farm 7	21080	-11238	53398	153.31
Farm 8	4960	-5155	15075	203.93
Farm 9	6200	-2616	15016	142.19
Farm 10	21700	-7638	51038	135.2
Farm 11	14260	-1329	29849	109.32
Farm 12	1860	-1135	4855	161.01
Farm 13	32860	-11537	77257	135.11
Farm 14	6820	-1277	14917	118.73
Farm 15	9920	-1247	21087	112.57
Farm 16	17980	-4558	40518	125.35

Table C.39 Uncertainty for CO_2 from diesel tractor for 2011

Farms	2011 estimate	Uncertainty range and percentage		
	Kg CO_2eq	Lower bound	Upper bound	Uncertainty percentage
Farm 1	12220	10582	13857	13.4
Farm 2	7795	6750	8839	13.4
Farm 3	2299	1991	2607	13.4
Farm 4	4317	3739	4896	13.4
Farm 5	2976	2577	3375	13.4
Farm 6	903	782	1024	13.4
Farm 7	22571	19546	25595	13.4
Farm 8	14802	12819	16786	13.4
Farm 9	2871	2486	3256	13.4
Farm 10	6141	5318	6964	13.4
Farm 11	26318	22792	29845	13.4
Farm 12	10236	8864	11607	13.4
Farm 13	28366	24565	32167	13.4
Farm 14	3464	3000	3929	13.4
Farm 15	12729	11023	14434	13.4
Farm 16	45858	39713	52003	13.4

Table C.40 Uncertainty for CO_2 from diesel tractor for 2012

Farms	2012 estimate	Uncertainty range and percentage		
	Kg CO_2eq	Lower bound	Upper bound	Uncertainty percentage
Farm 1	18707	16201	21214	13.4
Farm 2	8005	6932	9077	13.4
Farm 3	1354	1173	1536	13.4
Farm 4	6168	5341	6994	13.4
Farm 5	2661	2305	3018	13.4
Farm 6	1129	977	1280	13.4
Farm 7	21495	18614	24375	13.4
Farm 8	14802	12819	16786	13.4
Farm 9	2997	2596	3399	13.4
Farm 10	6141	5318	6964	13.4
Farm 11	20755	17973	23536	13.4
Farm 12	1024	886	1161	13.4
Farm 13	30234	26183	34286	13.4
Farm 14	6394	5537	7251	13.4
Farm 15	12729	11023	14434	13.4
Farm 16	60804	52657	68952	13.4

Table C.41 Uncertainty for CO_2 from diesel tractor for 2013

Farms	2013 estimate	Uncertainty range and percentage		
	Kg CO2eq	Lower bound	Upper bound	Uncertainty percentage
Farm 1	18057	15637	20476	13.4
Farm 2	7406	6414	8399	13.4
Farm 3	861	745	976	13.4
Farm 4	6168	5341	6994	13.4
Farm 5	1850	1602	2098	13.4
Farm 6	596	516	676	13.4
Farm 7	25904	22433	29375	13.4
Farm 8	7598	6580	8616	13.4
Farm 9	3163	2739	3586	13.4
Farm 10	6141	5318	6964	13.4
Farm 11	22597	19569	25625	13.4
Farm 12	3330	2884	3777	13.4
Farm 13	30234	26183	34286	13.4
Farm 14	5748	4977	6518	13.4
Farm 15	12939	11205	14673	13.4
Farm 16	87884	76107	99660	13.4

Table C.42 Uncertainty for CO_2 from diesel tractor for 2014

Farms	2014 estimate	Uncertainty range and percentage		
	Kg CO_2eq	Lower bound	Upper bound	Uncertainty percentage
Farm 1	15080	13060	17101	13.4
Farm 2	7795	6750	8839	13.4
Farm 3	5795	5018	6571	13.4
Farm 4	12577	10891	14262	13.4
Farm 5	2661	2305	3018	13.4
Farm 6	4514	3909	5119	13.4
Farm 7	28741	24890	32592	13.4
Farm 8	4724	4091	5357	13.4
Farm 9	3107	2691	3524	13.4
Farm 10	6960	6028	7893	13.4
Farm 11	14435	12500	16369	13.4
Farm 12	8608	7455	9762	13.4
Farm 13	24938	21596	28280	13.4
Farm 14	5427	4700	6155	13.4
Farm 15	8635	7478	9792	13.4
Farm 16	12708	11005	14411	13.4

Appendix D: Questionnaire survey

The purpose of this questionnaire survey is to assess the livestock and crop farming management practices in the eastern Free State. The results of the survey will assist in estimating GHG emissions and also evaluating the potential mitigation strategies that can reduce the GHG emissions from livestock and crop production. Any information provided by the farmers will be used for research purposes only and will be treated confidentially. When completing the questionnaire indicate your response by filling the blank spaces provided.

Background on Interviewee

Farm no:

Geographical co-ordinates:

Farmer 's Name:

Contact:

Date:

Land use categories

Land use category	Area (ha)	Percent (%)
Cropland		
Grassland		
Settlements		

Farm soil type

Soil name	**Acronym**	**Organic**	**Description**

Area burned

Year	Burned Area (ha)	Percentage (%)	Annual Area burned (ha)	Burn Frequency
2010				
2011				
2012				
2013				
2014				

SECTION A: LIVESTOCK DATA

Year:

Feeding situation

Category	Sub-categories	Population data	Feeding situation per sub-category			Live weights
			Confined %	Grazing %	Pasture %	
Dairy cattle	Mature female cows					
	Heifers					
	Calves					
	Bulls					
Beef cattle	Feedlot					
	Mature cows					
	Heifers					
	Young oxens					
	Mature oxens					
	Bulls					
	Calves					
Sheep						

	Ewes					
	Ewe - lamb					
	Lambs					
Goats						
Pigs	**Boar**					
	Sows					
	Growers					

Milk production

Year:

Category	Sub-categories	Population data	Mature females only		Milk production	
			% of females pregnant	% of females lactating	Average daily production (kg day-1)	Total annual production
Dairy cattle	Mature female cows					
Beef cattle	Mature female cows					
Sheep	Ewes					

Manure management system usage (%)

Year:

Category	**Sub-categories**	**Population data**	**Manure management system usage (%)**				
			Lagoon	**Drylot**	**Daily spread**	**Compost**	**Pasture**
Dairy cattle	**Mature female cows**						
	Heifers						
	Calves						
	Bulls						
Beef cattle	**Feedlot**						
	Mature cows						
	Heifers						
	Young oxens						
	Mature oxens						
	Bulls						
	Calves						
Sheep	**Ewes**						
	Heifers						
	Lambs						
Goats							

Pigs	**Boar**						
	Sows						
	Growers						

SECTION B: CROPLAND DATA

Management practices

Year:

Crop types	Area planted(ha)	Production (kilo tonnes)	Management practices						
			Tillage practices			Mineral fertilizer	Organic amendments	Lime application	Irrigation practices
			Full till	Minimum till	No till				
1.									
2.									
3.									

Residues management

Year:

Crop types	Area planted(ha)	Production (kilo tonnes)	Residues management				Fertilizer application (kg/ha)
			Retained (%)	Burned (%)	Collected (%)	Grazed (%)	
1.							
2.							
3.							
4.							

Cropping systems

Year:

Crop types	Area planted(ha)	Production (kilo tonnes)	Cropping systems		Cropping systems combination		
			Continous	Rotation	Single	Double	Inter-crop
1.							
2.							
3.							
4.							
5.							