research REPORT

Towards the development of a GHG emissions baseline for the agriculture, forestry and other land use (AFOLU) sector in South Africa

environmental affairs

Department:
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Towards the development of a GHG emissions baseline for the agriculture, forestry and other land use (AFOLU) sector in South Africa

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Acknowledgements:

AFOLU Baseline Steering Committee

Barney Kgope – Department of Environmental Affairs (Chair & Project Manager)

Itchell Guiney – Department of Environmental Affairs (Co-chair & Project Manager)

Thapelo Letete – Department of Environmental Affairs

Oscar Mokotedi – Department of Environmental Affairs

Jongikhaya Witi – Department of Environmental Affairs

Mokhele Moeletsi – Agricultural Research Council

Lindeque du Toit – Tshwane University of Technology

Tony Knowles – Cirrus Group

Mark Thompson – GeoTerra Image

Johan Bester – Department of Agriculture, Forestry and Fisheries

All stakeholders

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Foreword

The Agriculture, Forestry and Other Land Use (AFOLU) sector is an important and unique sector globally. It is a sector that services national food requirements and export earnings for many developing countries around the world. Its uniqueness stems from the fact that it is the only sector within which both sources and sinks for greenhouse gases can be found. Despite this, our understanding of the greenhouse gas emissions and the associated carbon stocks has remained poor for a long time as compared to sectors like energy, transport and waste. However, the past decade has seen a significant improvement in our understanding of this sector globally as seen from the series of the Intergovernmental Panel on Climate Change (IPCC) assessment reports.

In recent years, South Africa commissioned a number of studies geared towards improving our understanding of the greenhouse gas emissions and the associated carbon stocks in the AFOLU sector. These studies included the first National Terrestrial Carbon Sinks Assessment (NTCSA), the National Greenhouse Gas Inventory and the Bio-char Study, to mention a few. Taken together, these studies provided a good foundation to develop the very first baseline for emissions for the AFOLU sector of South Africa.

The purpose of this report is to provide the first emissions baseline for the AFOLU sector in South Africa. Due to the complexity of the AFOLU sector, the agriculture and land sub-sector baselines were developed separately but reported as one combined baseline. Furthermore, the study also developed baselines for each province as part of enhancing our understanding of emissions dynamics at a finer scale. Finally, the study has also highlighted areas of improvement prior to the revision of the emissions baseline.

The timing of the current project is impeccable in that it preceded two very significant developments namely: the outcomes of COP 21 in Paris in December 2015 and the imminent carbon offsetting regime in South Africa. This report will improve our international reporting for the AFOLU sector and also provide a benchmark against which emissions abatement can be tracked going forward.

Barney Kgope and Itchell Guiney
Chief Directorate: Climate Change Mitigation
Directorate: Carbon Sinks Mitigation

Report submitted to:

Department of Environmental Affairs

REPORT COMPILED BY:

NORTH-WEST UNIVERSITY

Contributing authors:

Luanne Stevens, Jared Lodder, Roelof Burger, Stuart Piketh

AND

GONDWANA ENVIRONMENTAL SOLUTIONS

Contributing authors:

Martin van Nierop, Anja van Basten, Aidan Henri, Elani van Staden

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Acronyms, abbreviations and units

AFOLU	Agriculture Forestry and Other Land Use
AGB	Above Ground Biomass
BFAP	Bureau for Food and Agricultural Policy
C	Carbon
CARA	Conservation of Agricultural Resources Act
CDM	Clean Development Mechanism
CH_4	Methane
CO_2	Carbon Dioxide
CO_2eq	Carbon Dioxide Equivalent
DAFF	Department of Agriculture, Forestry, and Fisheries
DEA	Department of the Environmental Affairs
DEAT	Department of Environmental Affairs and Tourism
DEROs	Desired Emissions Reductions Outcomes
Dm	Dry Matter
DOM	Dead Organic Matter
EF	Emission Factor
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Statistics Division of FAO
FAPRI	Food and Agricultural Policy Research Institute
Fertasa	Fertilizer Association of SA
GCM	General Circulation Model
GDP	Gross Domestic Product
Gg	Gigagram (1Gg = 1 000 000kg)
GHG	Greenhouse Gas
GIS	Geographic Information System
Gt	Gigatonne (1Gt = 1 000 000Gg)
GTI	GeoTerra Image
Ha	Hectares
IGDP	Integrated Growth and Development Plan
IPCC	Intergovernmental Panel on Climate Change
IMF	International Monetary Fund
Kcal	Kilocalorie (1kcal = 1 000 calories)
LTMS	Long Term Mitigation Scenario
Mha	Million Hectares
MM	Manure Management
MPA	Mitigation Potential Analysis
MS	Managed Soils
Mt	Metric Ton (1Mt = 1 000kg)
N	Nitrogen
NDP	National Development Plan
NEMA	National Environmental Management Act
NEM:AQA	National Environmental Management: Air Quality Act
NEMBA	National Environmental Management: Biodiversity Act
NEMPAA	National Environmental Management: Protected Areas Act
NH3	Ammonia
NO3-	Nitrate ions
NOx	Nitrogen Oxides
N_2O	Nitrous Oxide
NSSD1	National Strategy for Sustainable Development and Action Plan
NTCSA	National Terrestrial Carbon Sinks Assessment
REDD	Reducing Emissions from Deforestation and Forest Degradation
RFI	Residual Feed Intake
SAPA	South African Poultry Association
SDI	Degradation Index for Soil
SPLUMA	Spatial Planning and Land Use Management Act
VCS	Verified Carbon Standard
VDI	Degradation Index for Vegetation
WISDOM	Woodfuel Integrated Supply/Demand Overview Mapping




Executive summary

INTRODUCTION

Global temperatures have been increasing and weather patterns have changed due to an increase in Greenhouse Gases (GHGs) and air pollutants in the atmosphere. Anthropogenic activities have contributed 40% to the increase in carbon dioxide (CO_2) levels since 1750 and, as a result, play a critical role in shaping our future climate. Globally, the Agriculture Forestry and Other Land Use sector (AFOLU) represents 20–24% of total GHG emissions, and is particularly important in developing countries. AFOLU emissions have decreased overall in the last decade, however, the crop and livestock agriculture emissions continue to increase within the sector and are the dominant AFOLU emission sources. The AFOLU sector has shown nearly a 10% decrease over the past decade (FAOSTAT, 2013). South Africa's AFOLU sector is estimated to contribute around 7% of the total national GHG emissions (DEA, 2015).

A number of projects are being undertaken in South Africa to mitigate the emissions of climate change inducing pollutants (e.g. National Terrestrial Carbon Sinks Assessment, Mitigation Potential Analysis, Development of potential verification standards and methodologies for carbon offset projects in the AFOLU sector). However, through these projects, a gap has been identified in that South Africa does not have an emissions baseline (current or projected) for the AFOLU sector against which the mitigation potentials can be measured, or the effectiveness of the implementation of mitigation projects assessed. This means that the AFOLU sector either gets underestimated or excluded from future emissions projections, which gives an incomplete picture of South Africa's mitigation potential. A baseline scenario is defined as the future GHG emission levels in the absence of future, additional mitigation actions. It can also be referred to as the 'business-as-usual' scenario. A well-developed baseline, more specifically a projected baseline, has the advantage of enabling Desired Emissions Reductions Outcomes (DEROs) and Carbon Budgets to be determined for the AFOLU sector. In addition it will allow South Africa to demonstrate its contribution towards the global goal of reducing emissions from the AFOLU sector.

The aim of this project was to develop a robust, transparent and accurate projected GHG emissions baseline for the AFOLU sector that will enable South Africa to project its emissions into the future.

METHODOLOGY

This project includes the emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) from the following sources:

- Enteric fermentation,
- Manure management,
- Land-use conversion,
- Biomass burning,
- Managed soils.

Projections of emissions are calculated as follows:

Agriculture: In the agricultural sector the Bureau for Food and Agricultural Policy (BFAP) has developed a model to project changes in agricultural commodities. This project built on the outputs of the BFAP modelling process, as it is a model which has been previously used and calibrated for South African conditions.

Land: For the land sector there are numerous variables and limited data so a more simplified approach of modified trajectory was applied to this sub-sector, which entailed:

- Projecting the existing curve using a linear extrapolation of historical data.
- Checking for limits of possible values of the variables.
- Modifying the trajectory as follows:
  - Identify key drivers or causes which may cause the trajectory to be modified.
  - Assess the conditions under which the driver is expected to modify the trajectory.
  - Determine the expected future values.
  - Modify the trajectory based on these drivers.

The methodology for calculating the emissions is mainly drawn from the Intergovernmental Panel on Climate Change (IPCC) 2006 guidelines as they are applicable at the national and provincial scale, whereas the Verified Carbon Standard (VCS) and Clean Development Mechanism (CDM) methodologies are more project specific. Adopting the IPCC methodology also makes integration with the GHG inventory easier.

AGRICULTURE

In South Africa, agricultural production practices can be broadly differentiated into a commercially oriented sector that services national food requirements and export earnings, and a small-scale and homestead farming sector that constitutes a high proportion of the (mainly subsistence) farming population that rely largely on traditional agriculture methods. Commercial agricultural activities in South Africa range from the intensive production of vegetables, ornamentals, and other niche products, to large scale production of annual cereals (e.g. wheat and maize), oil seeds, perennial herbaceous crops (e.g. sugarcane), and tropical, subtropical, and temperate fruit crops. Livestock production is a major contributor to national and household food security and to the Gross Domestic Product (GDP), with significant intensive production of cattle, pigs, and poultry. In addition to its monetary value, livestock also plays a socio-cultural role.

Multiple drivers influence the agricultural landscape. Macroeconomic drivers include population, Brent crude oil, foreign exchange rates, GDP per capita, and interest rates. The consumer market has a significant influence on consumption and, therefore, on production patterns within the agriculture sector. There has been a sharp rise in demand for food, especially animal proteins such as chicken.

International policies affect trade of agricultural products, while domestic policies have led to the introduction of tariff barriers. These are policies which influence the economics, while there are also numerous domestic policies, as pointed out in the National Terrestrial Carbon Sinks Assessment (NTCSA) (DEA, 2015), which can influence the agricultural landscape.

Climate change is another important driver of change particularly in the agriculture sector. Rising temperatures, more erratic rainfall and an increased frequency of drought can have far reaching implications for this sector. Droughts lead to lower crop production, which translates to higher feed prices as well as increased food prices. Higher feed costs impact the livestock and feedlot outputs, while the dry conditions lead to increased livestock death. South Africa is currently experiencing the worst drought since 1982 and this could mean a 30% reduction in livestock which is likely to take 5 years to recover (Meissner, Pers. Comm.). Furthermore farmers will slaughter approximately a third more cattle than last year due to the drought. Higher temperatures also have consequences for water demand, the spread of pests and pathogens, as well as farm labourers. Each 1% decline in rainfall is likely to lead to a 1.1% decline in the production of maize and a 0.5% decline in winter wheat (Blignaut et al., 2009).

These impacts on crops will also have an impact on the consumption of fertilizers. Factors driving fertilizer demand include population growth, increased income, diet diversification, biofuel development, arable land availability and improved nutrient efficiencies (Prud'homme et al., 2015).

The emissions baseline discussed in this report is based on the much expanded AFOLU sector that is included in the national GHG inventory. It incorporates the following agricultural components:

- Livestock enteric fermentation,
- Livestock manure management,
- Liming,
- Urea application,
- Direct N_2O emissions from managed soils,
- Indirect N_2O emissions from managed soils,
- Indirect N_2O emissions from manure management.

Other activities relating to cropland areas and changes in cropland, which affect carbon sequestration, are dealt with in the land component of this report.

The SA agricultural emissions activity data is mostly supplied at the national level. A national level emissions model was, therefore, developed first. Thereafter, data from literature was applied to enable the breakdown of the national emissions data into provincial data.

The agricultural baseline increases from 50 568 Gg CO_2eq in 2010 to 69 621 Gg CO_2eq in 2050 (Figure 1). The livestock populations have the largest influence over emissions in this sector (60%) as they contribute to enteric fermentation, manure management and indirect N_2O emissions from manure management. Enteric fermentation and manure management contribute 55.4% and 3% respectively to the total agriculture baseline. Current agricultural emissions (DEA, 2014a) are found right on the baseline (Figure 1) as it basically represents the baseline. At this point the inventory does not reflect all the mitigation options either due to a lack of data, difficulties incorporating information into the equations, or because some actions have not been implemented yet. It is not always possible to include all actions into the inventory, for example, it is difficult to include a change in the timing of fertilizer application. However, as South Africa moves forward, the mitigation options need to be considered during the inventory update process to ensure that carbon reductions are being included.

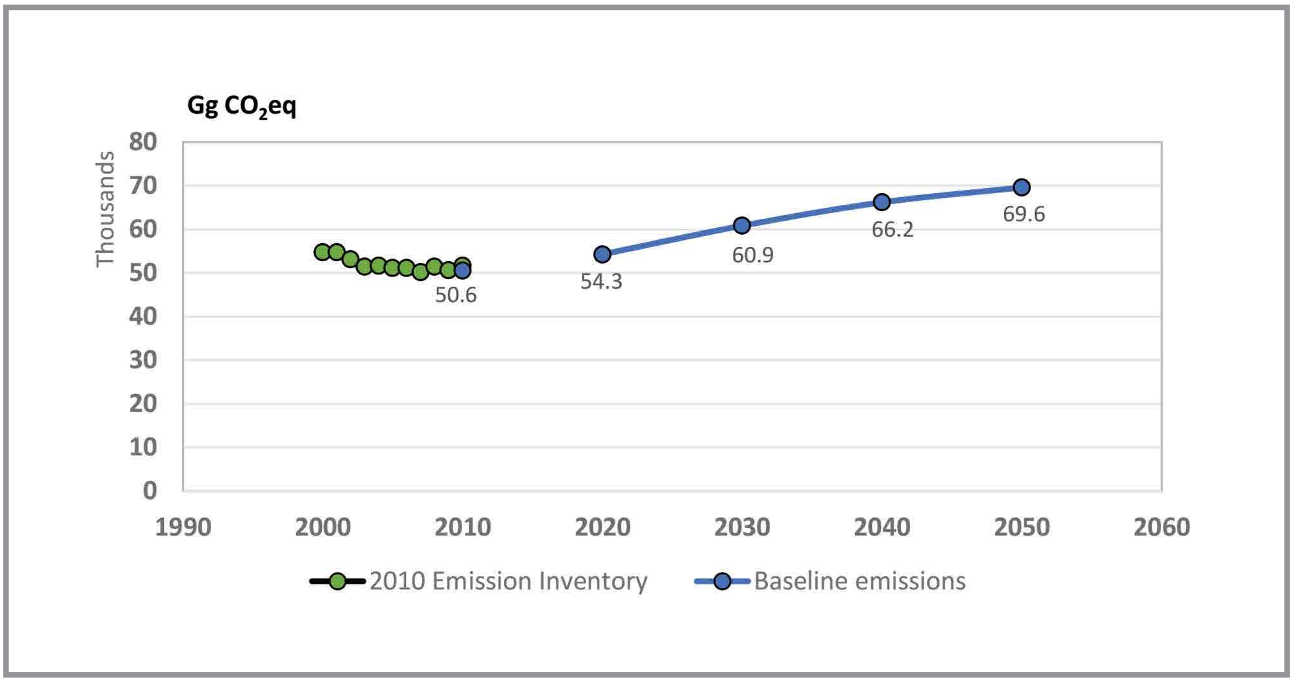

Figure 1: Agricultural baseline and the emissions from the 2010 inventory (Gg CO_2eq). These emissions do not include biomass burning emissions as these are incorporated in the land sector in this report.

LAND

National land cover surveys have been used for many years to determine changes in the South African landscape and the possible drivers behind the changes observed. Fairbanks et al. (2000) in a synopsis of South African land cover characteristics found that cultivation, afforestation and urbanization were the principal activities transforming land cover. In the year 2000 it was estimated that 12.2% of the country was under cultivation. An estimated 26% of grassland had been transformed through direct removal and alien shrub and bush encroachment. The exotic plantation industry, however, was found to be a larger driving force in the transformation of grasslands, particularly over the past 10 years.

Land capability assessments combine the three main natural resource elements of soil, climate and terrain to determine the production potential of specific areas and are based on the country-wide Land Type Survey of natural resources. The land capability analysis shows that approximately 81% of South Africa's surface is under farmland, with only 11% falling under arable land. The remaining area (69%) is suitable for grazing (DEA, 2006).

Land cover projections made during the National Terrestrial Carbon Sinks Assessment (NTCSA) (DEA, 2015) revealed an overall trend of land transformation for South Africa that will continue to the year 2020. The transformation overall has resulted in a loss of indigenous vegetation.

Land cover change has significant impacts on the carbon sink potential of land. Examples of changes in land cover include the conversion of natural vegetation to agricultural crops and forest plantations; changes to natural vegetation through bush encroachment and overgrazing; soil erosion; and accelerating urbanisation. The main drivers of change as identified by the South African Land Cover Change Consortium include: environmental, political, social and economic growth and their associated land use practices (agriculture, forestry and mining).

The Land sector includes carbon changes in:

- Forest land,
- Cropland,
- Grasslands,
- Wetlands,
- Settlements,
- Other land,
- Emissions from biomass burning.

The base year for the projections was 2014 as this was the final date of the national land cover change map. Projections were made based on the land cover in this year.

The land change projections obviously have a huge influence on the baseline projections and the challenge is, therefore, determining the best approach or most appropriate base map for projections. In this project the base change map of 1990–2014 was used and so the calculation outputs must be seen in light of these projections. At the national level the land projections don't show large changes in land area, but the largest changes are around the decrease in grassland, and increase in forest land and bare ground. Since forest land plays such a focal point in carbon estimations this increasing forest land leads to increased carbon sinks.

The lack of data on land change which uses consistent mapping methods and classifications, makes it difficult to validate changes. This is an issue which needs further research in future as it has a significant impact on the future projections and baseline. It highlights the importance of monitoring and research to assist in understanding the change that is occurring. It is also important that land change be monitored more frequently (perhaps every 5 years), with a standardized method, so as to provide some trends to aid in determining which long term changes are actually occurring as opposed to seasonal changes.

The estimated national baseline for the land sector shows an increased sink between 2014 and 2030 (21 105 Gg CO_2eq to 30 683 Gg CO_2eq), after which the sink slows and becomes stable (Table 1). The increasing sink is mainly due to the predicted increase in forest land, but is also combined with the decrease in wood removal from woodlands in the period until 2030. Keeping fuel wood removal constant (i.e. assuming no reduction in wood removals due to electrification) produces a much more constant sink (varying less than 3 000 Gg CO_2eq between 2014 and 2050), but it still shows a slight increase in the sink to 2030 after which it declines to 2050. If the thicket area is increased by 1% then the sink increases by 17% by 2050, which shows the importance of understanding whether the thicket area is increasing, decreasing or remaining constant. Moving towards 2050, there is also a predicted increase in bare ground due to increased erosion and degradation and this leads to loss of carbon causing the carbon sink to stabilize. If the bare ground restriction is increased from 10% to 15% (in Limpopo and North West which were the provinces that were restricted in terms of bare ground) then the sink in 2050 is reduced by a further 13%. This also highlights the need to have a better understanding of the rate of desertification and degradation.

The inclusion of degraded woodlands, soil thicket carbon losses due to degradation, and degraded grassland biomass changes in future, would lead to further decreases in the carbon sink capacity estimated in the baseline. The baseline is also limited in terms of the cropland detail, particularly land use changes within the cropland division, and this is a major limitation of the model which needs to be addressed in the next update. The emphasis on the forest land detail is also the main reason for the forest land components having the largest influence on the outputs at this stage.

Table 1: Estimated National Baseline (Gg CO_2eq) for the Land Sector

	2014	2020	2030	2040	2050
Total Land	-21 104.5	-25 860.4	-31 390.6	-32 223.2	-30 683.2
Land	-22 920.7	-27 663.2	-33 169.9	-33 977.9	-32 407.6
Biomass burning	1 818.5	1 805.0	1 781.5	1 756.8	1 726.6

This is a first attempt at developing a land baseline and it comes with large uncertainties so should be used with caution. A full uncertainty assessment still needs to be conducted on the data, as time limitations do not allow for the completion of this assessment. The data suggests that if the forestland is increased through afforestation and thicket restoration, then the carbon sink would increase. It also indicates that if soil erosion and degradation is prevented, the future decrease in the sink would be alleviated, highlighting the importance of the mitigation actions suggested in the NTCSA (DEA, 2015). Due to the focus on forest land, the provinces that have the largest impact are those which have significant woodland or thicket areas, such as Limpopo, KwaZulu-Natal, Mpumalanga and even Eastern and Western Cape with their thickets.

The overall AFOLU baseline is created by combining the agriculture and land baselines (Table 2). The overall baseline declines *slightly between 2014 and 2020 due to increasing carbon sinks, but thereafter it increases to 39 041 Gg CO_2eq in 2050 due to a declining land sink and an increase in agricultural emissions.*

Table 2: Combined Land and Agriculture Baseline Emissions

Categories	**(Gg CO_2eq)**				
	2014	**2020**	**2030**	**2040**	**2050**
Total AFOLU	30 949.4	28 422.4	29 461.9	33 978.7	38.938.2
Livestock	30 727.6	32 256.5	36 353.5	39 516.6	41 177.5
Aggregate sources and non-CO_2 emissions sources on land	21 326.3	22 026.3	24 499.0	26 685.3	28 443.8
Land	-22 920.7	-27 663.2	-33 169.9	-33 997.9	-32 407.6
Biomass burning	1 818.5	1 805.0	1 781.6	1 756.8	1 726.6

Considering the provincial data it can be seen that the Free State, KwaZulu Natal and North West contribute the most to the overall baseline (Figure 2). The contribution from the Free State is mostly due to livestock (47% - 49%) with land contributing less than 5%. In KwaZulu Natal livestock emissions increase by 38.4% between 2014 and 2050, while the land started as a source in 2014 after which the sink increased. In the North West it is the livestock that dominate (72% - 78%) the emissions. Limpopo is one of the two provinces, the other being the Western Cape, that are a sink for the overall AFOLU sector. In Limpopo the sink declines to become a weak source in 2050 due to increasing degradation and bare ground. The Eastern Cape, KwaZulu Natal, Mpumalanga and Western Cape all showing increasing land sinks between 2014 and 2050 due to increases in the forest land area. Gauteng shows very little change over the period. Western Cape has a small source for the AFOLU baseline in 2040 and 2050 as the agricultural emissions almost balance the land sink.

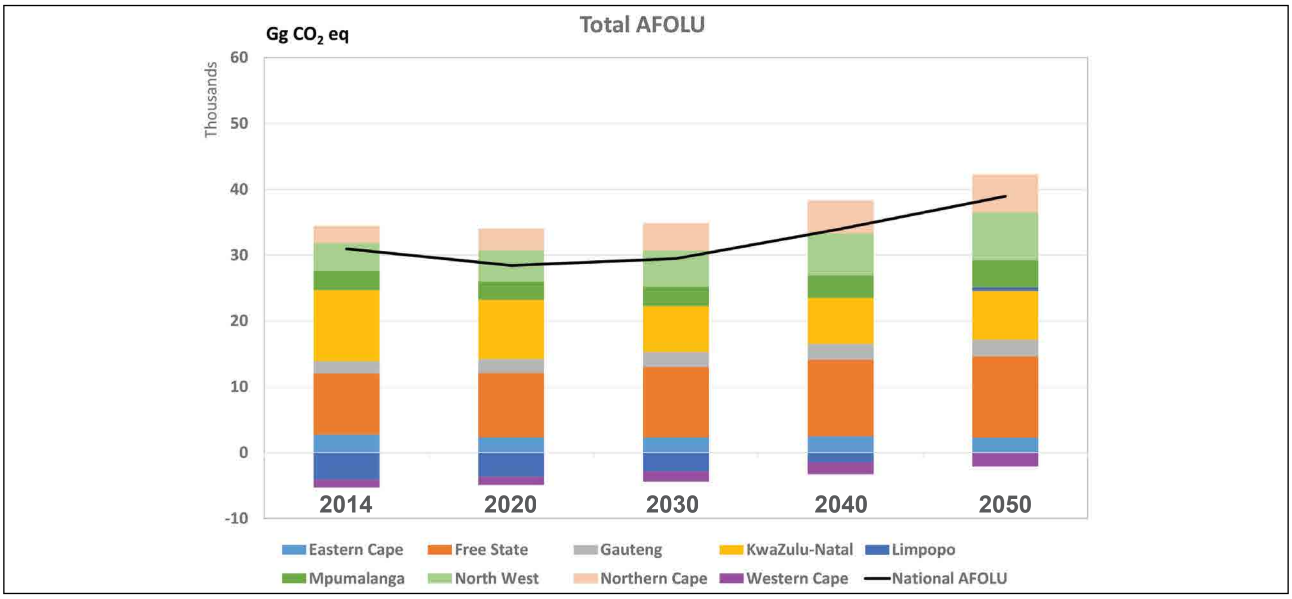

Figure 2: AFOLU Sector Emissions Baseline by Province

RECOMMENDATIONS

This is the first attempt at creating a baseline for the AFOLU sector in South Africa. It is a challenging task given the variability and uncertainty of the available data. However, the process of developing the baseline has provided many lessons. Several recommendations can be made so as to improve the baseline in the future:

- Develop consistency in data sets. This relates to the variability in the data sources and differences in mapping classifications, and applies both to the agricultural and land sector data.
- Issues of scale. The impact of mitigation actions on the emissions are often calculated from the bottom up, by looking at data on the ground and scaling this up to the national level. On the other hand, at present the inventory and baseline are developed from the top down, in that they make use of national scale maps. The different scales of the data present a challenge in finding a way to bring the two sets of numbers together. The incorporation of more detailed country specific data should bring these two sets of data closer together.
- Land cover/change projections. There are enormous challenges in predicting land cover and land use change. The method used in this study relies on historical change data and expert opinion. Land change maps can provide varied outputs depending on when in the year or in which year they were created. As mentioned before, South Africa needs to detect change on a more regular basis, using a consistent methodology, in order to be able to have improved forward projections.
- Incorporation of degradation data. It may not be possible to include all degradation into the inventory or baseline, but it should be decided what level of degradation can be incorporated, and a definition of this degradation should be provided, so that the method and definition can be used consistently in future.
- Incorporate more detailed cropland data.
- Improved livestock population data. In terms of the baseline, it would be useful to develop improved methods for estimating and projecting livestock population numbers. This can possibly be linked with the research of BFAP as they upgrade their supply and demand model every 2 years.
- Research on nitrogen emissions. Research is needed in this area to improve the emission factors, because currently IPCC default emission factors are being used.
- Register of biodigesters and their fuel sources. The information on biodigesters is scattered, therefore, it would be useful to have a central register of this information to assist in estimating and predicting emission savings in terms of the AFOLU sector.
- Fuelwood consumption data. Since there is a lack of information at a national scale as to whether fuelwood removal is declining, it would be important to develop an understanding of the amount of fuelwood consumed at a national scale and to investigate how this is changing over time.

RATIONALE FOR THE AFOLU BASELINE PROJECT

Agriculture, Forestry, and Other Land Use (AFOLU) plays a central role in food security, sustainable development and climate change mitigation and adaptation. Plants take up carbon dioxide (CO_2) from the atmosphere and nitrogen (N) from the soil when they grow, re-distributing it among different pools, including above and below-ground living biomass, dead residues, and soil organic matter. The CO_2 and other non-CO_2 greenhouse gases (GHG), largely methane (CH_4) and nitrous oxide (N_2O), are in turn released to the atmosphere by plant respiration, by decomposition of dead plant biomass and soil organic matter, and by combustion. Anthropogenic land-use activities (e.g. management of croplands, forests, grasslands, wetlands) and changes in land use/cover (e.g. conversion of forest lands and grasslands to cropland and pasture, and afforestation) can cause changes superimposed on these natural stocks and fluxes. AFOLU activities lead to both sources of CO_2 (e.g. deforestation and peatland drainage) and sinks of CO_2 (e.g. afforestation and management for soil carbon sequestration), and to non-CO_2 emissions primarily from agriculture (e.g. CH_4 from livestock and rice cultivation, N_2O from manure storage, agricultural soils and biomass burning). The AFOLU sector is unique compared to all the other sectors (i.e. waste, transport, energy and industry), since the mitigation potential is derived from both an enhancement of removals of greenhouse gases (GHG), as well as a reduction of emissions through management of land and livestock. The AFOLU sector is responsible for just under a quarter (~10–12 Gt CO_2eq/year) of anthropogenic GHG emissions globally (Smith et al., 2014), mainly from deforestation and agricultural emissions from livestock, soil and nutrient management.

South Africa is transitioning towards a low carbon economy and mitigation options are being investigated. There are several supply and demand options for mitigation in the AFOLU sector. On the supply side emissions can be reduced from land




use change, land and livestock management, and terrestrial carbon stocks can be enhanced by sequestration in soils and biomass. On the demand side emissions can be reduced through changing consumption patterns. Over the past decade South Africa has improved the quantification of AFOLU emissions and the understanding of the dynamic relationship between sinks and sources through projects such as the 2010 GHG inventory (DEA, 2014a), the Mitigation Potential Analysis (MPA) (DEA, 2014b) and the NTCSA (DEA, 2015). These projects highlight the key mitigation opportunities in the country.

However, through these above mentioned projects, a gap was identified in that South Africa does not have an emissions baseline (current or projected) for the AFOLU sector against which the mitigation potentials can be measured. This means that the AFOLU sector either gets underestimated or excluded from future emissions projections, which gives an incomplete picture of South Africa's mitigation potential. A well-developed baseline, more specifically a projected baseline, has the advantage of enabling Desired Emissions Reductions Outcomes (DEROs) and Carbon Budgets to be determined for the AFOLU sector. In addition it will allow South Africa to demonstrate its contribution towards the global goal of reducing emissions from the AFOLU sector.

The aim of this project is, therefore, to develop a robust, transparent and accurate projected GHG emissions baseline for the AFOLU sector that will enable South Africa to project its emissions into the future. This will involve the following four components:

- The development of an emissions baseline for the agricultural sector.
- The development of an emissions baseline for the land sector.
- A combined AFOLU emission baseline.
- A GHG inventory integration plan.

STRUCTURE OF THE REPORT

The project has two distinct components, namely agriculture and land (i.e. Chapter 2 and 3), and even though there are interactions between the two each has its own drivers and emission methodologies. Therefore, it was decided to divide the report into chapters so as to deal with the concepts separately but then bring them together in the final section. The report is thus structured as follows:

- Chapter 1: Introduction
  - This chapter provides background on important overarching concepts such as AFOLU emissions, baselines, methodologies, projections and mitigation actions in the AFOLU sector.
- Chapter 2: Agricultural emissions baseline
  - The introduction provides a general background to the agricultural sector in South Africa. It also discusses GHG emissions and the possible drivers.
  - This is followed by a detailed methodology for the baseline projections.
  - The agricultural baseline is then presented along with a discussion. Results are discussed at both the national and provincial level.
- Chapter 3: Land emissions baseline
  - As with the agricultural emissions section, the introduction provides a review of the land sector and drivers that may influence emissions going into the future.
  - A detailed methodology section for the estimation of the land sector baseline follows the introduction.
  - The last section in this chapter presents the land baseline results which are also discussed at both the national and provincial level.
- Chapter 4: AFOLU emissions baseline
  - This chapter discusses the overall combined emissions baseline and investigates suggested mitigation potentials in the literature to determine possible future emissions in SA's AFOLU sector.
  - It also discusses the baseline and the GHG inventory.
- Chapter 5: Recommendations and next steps
  - The final section discussed the GHG integration plan and the way forward in terms of the baseline. It also includes a discussion on gaps, baseline updating, and makes recommendations for the way forward.

CHAPTER 1: Introduction

1.1. AFOLU GHG emissions

Global temperatures have been increasing and weather patterns have changed due to an increase in Greenhouse Gases (GHGs) and air pollutants (IPCC, 2014). Emissions of CO_2 from fossil fuel combustion, with contributions from cement manufacture, are responsible for more than 75% of the increase in atmospheric CO_2 concentration since pre-industrial times (IPCC, 2007a). The remainder of the increase comes from land use changes dominated by deforestation (and associated biomass burning) with contributions from changing agricultural practices. The Agriculture, Forestry and Other Land Use (AFOLU) sector is an important sector in that it has both sources and sinks of GHGs and it plays a central role in food security, sustainable development and climate change mitigation and adaptation.

The sources and sinks in the AFOLU sector are:

- *Enteric fermentation* – fermentation that takes place in the digestive system of animals (particularly ruminant animals). Methane (CH_4) is produced in the rumen by bacteria as a by-product of the fermentation process and this CH_4 is expelled by the animal (IPCC, 2006).
- *Manure management* – nitrous oxide (N_2O) is generated by nitrification and denitrification, which occur in soil following the application of manure. Inorganic nitrogen (N) in the form of ammonium it transformed to nitrate via nitrification and this is a source of N_2O and nitrate ions (NO_3-). The NO_3- is a source of N for denitrification and N_2O is further produced as a product of incomplete denitrification (Chadwick et al., 2011). Manure CH_4 is generated during the anaerobic decomposition of organic matter in manure.
- *Land use change* – Plants take up CO_2 from the atmosphere and N from the soil when they grow, re-distributing it among different pools including above and below-ground living biomass, dead residues, and soil organic matter. The CO_2 and other non-CO_2 GHGs, largely CH_4 and N_2O, are in turn released to the atmosphere by plant respiration, by decomposition of dead plant biomass and soil organic matter, and by combustion. The storage of carbon in plants and soils is called carbon sequestration (a GHG sink) (IPCC, 2014a). Land management practices contribute to CO_2 fluxes through changes in standing biomass densities or in soil carbon.
- *Biomass burning* – this not only releases various gases due to the combustion of biomass, but it also removes CO_2 that was being stored in the vegetation.
- *Managed soils* – as mentioned N_2O is formed from nitrification and denitrification, but one of the controlling factors is the availability of source inorganic N in the soils. Emissions from managed soils are, therefore, increased through the addition of fertilizers. Emissions occur through both direct (i.e. directly from the soils), and indirect pathways. The first being through the volatilization of ammonia (NH_3) and nitrogen oxides (NOx) from managed soils, fossil fuel combustion and biomass burning, and the subsequent re-deposition of these gases and their products to the soil (IPCC, 2006). The second pathway is after leaching and runoff of N from managed soils. In addition to N_2O emissions, CO_2 is also emitted from managed soils through the use of lime and urea. Lime is a carbonate and as it dissolves it releases bicarbonate which evolves into CO_2. In the case of urea, it is converted into ammonium, hydroxyl ions and bicarbonate in the presence of water and enzymes. As with lime, the bicarbonate then evolves into CO_2 (IPCC, 2006).

1.2. Global AFOLU emission trends

Globally the AFOLU sector represents 20–24% of total emissions, and is particularly important in developing countries. AFOLU emissions have decreased overall in the last decade, however, the crop and livestock agriculture emissions continue to increase within the sector and are the dominant AFOLU emission sources. Annual GHG emissions (mainly CH_4 and N_2O) from agricultural production in 2000–2010 were estimated at 10–12% of global emissions (5.0–5.8 Gt CO_2eq per year) (IPCC, 2014). Meanwhile, the global annual GHG flux from land use and land-use change activities accounted for 9–11% of total GHG emissions (4.3–5.5 Gt CO_2eq per year) (Tubiello et al., 2014). The AFOLU sector has shown nearly a 10% decrease over the past decade (FAOSTAT, 2013).

Emissions estimates can be divided into their source components which include CO_2 emissions and non-CO_2 emissions comprising of CH_4 and N_2O. Recent estimates indicate that CO_2 levels in the AFOLU sector are declining as a result of increased afforestation and decreased deforestation rates. Net annual baseline CO_2 emissions from AFOLU are projected to decline, with net emissions potentially less than half the 2010 level by 2050, resulting in the possibility of AFOLU sectors becoming a net CO_2 sink before the end of century (IPCC, 2014b, c). On the other hand non-CO_2 emissions are rising largely as a result of agricultural activities.

Global emissions from enteric fermentation grew from 1.4 to 2.1 Gt CO_2eq per year between 1961 and 2010, with average annual growth rates of 0.70% (FAOSTAT, 2013). From 2000 to 2010, cattle contributed the largest share (75% of the total), followed by buffalo, sheep and goats (FAOSTAT, 2013). Global emissions from manure, as either organic fertilizer on cropland or manure deposited on pasture, grew between 1961 and 2010 from 0.57 to 0.99 Gt CO_2eq per year. Emissions grew by 1.1% per year on average. Manure deposited on pasture led to far larger emissions than manure applied to soils as organic fertilizer. Developing countries contribute 80% of emissions from manure left on pastures, with America, Asia and Africa contributing the most (33%, 31% and 25% respectively) between 2000 and 2010 (FAOSTAT, 2013; Herrero et al., 2008). Growth over the same period was most pronounced in Africa, with an average of 2.5% per year (IPCC, 2014).

Emissions from synthetic fertilizers grew at an average rate of 3.9% per year from 1961 to 2010, with absolute values increasing more than 9-fold, from 0.07 to 0.68 Gt CO_2eq per year (Tubiello et al., 2013). Considering current trends, synthetic fertilizers will become a larger source of emissions than manure deposited on pasture in less than 10 years and the second largest of all agricultural emission categories after enteric fermentation. Close to three quarters (70%) of these emissions were from developing countries in 2010. In the decade 2000–2011, the largest emitter was Asia (63%), then the Americas and Europe (Tubiello et al., 2014). Africa only contributed 3% to global synthetic fertilizer emissions over this period, but showed an annual growth rate of 1.8% per year.

1.2.1. Mitigation

The AFOLU sector plays a critical role in food security, sustainable development and carbon sequestration, making mitigation activities in this sector key to decreasing the effects of global climate change. The main mitigation options within AFOLU on the supply side involve prevention of emissions to the atmosphere, sequestration and substitution.

Prevention of atmospheric emissions involves conserving existing carbon pools in soils or vegetation that would otherwise be lost, or by reducing emissions of CH_4 and N_2O. Sequestration involves enhancing the uptake of carbon in terrestrial reservoirs, and thereby removing CO_2 from the atmosphere, while substitution consists of reducing CO_2 emissions by substitution of biological products for fossil fuels or energy-intensive products. Afforestation, sustainable forest management, and reducing deforestation and degradation are all cost effective means to prevent emissions and sequester carbon in the forestry sector. Global forestry mitigation options are estimated to potentially contribute a reduction of 0.2–13.8 Gt CO_2 per year (Smith et al., 2014). In the agricultural sector the most cost effective mitigation mechanisms are cropland management, grazing land management, and restoration of organic soils. In limiting agricultural expansion and the conversion of natural forest/grassland and woodlands into agricultural land one can reduce the environmental impact of livestock and facilitate emissions mitigation processes (Gitz and Ciais, 2004; Steinfeld et al., 2006). Global economic mitigation potentials in agriculture in 2030 are estimated to be 0.5–10.6 Gt CO_2eq per year (Smith et al., 2014).

Mitigation options on the demand side involve lifestyle changes. This includes activities that reduce the loss and waste of food, changes in human diet, and changes in wood consumption. Reducing food losses and waste can reduce GHG emissions by 0.6–6.0 Gt CO_2eq per year. Changes in diet could result in GHG emission savings of 0.7–7.3 Gt CO_2eq per year. A combination of supply and demand side mitigation can reduce emissions of up to 80% by 2030 (Smith et al., 2014).

1.3. South Africa's AFOLU GHG emissions

South Africa's AFOLU sector is estimated to contribute around 7% of the total national GHG emissions (DEA, 2015). The 2010 inventory showed that the AFOLU sector was a source of CO_2 (DEA, 2014a). The source fluctuated between 2000 and 2010, mainly due to the effects of land use change, but overall there appeared to be a decreasing trend. The main cause of this decline was the decreasing emissions from the livestock, and from the aggregated and non-CO_2 emission sub-sectors.

In SA, enteric fermentation is the largest emission in the AFOLU sector, contributing 28 986 Gg CO_2eq in 2010. This declined by 1.1% from 29 307 Gg CO_2eq in 2000 due to a similar decline in livestock numbers. The enteric fermentation emissions are closely linked to the cattle population numbers as these constitute the largest portion of the livestock. Enteric fermentation accounted for an average of 93% of the GHG emissions from livestock, while the rest was from manure management. Manure management emissions showed a 10% increase between 2000 and 2010 (from 1 811 Gg CO_2eq to 2 008 Gg CO_2eq) due to a large increase in the amount of managed poultry manure.

The forest land category was estimated to be a net sink for CO_2 in all years between 2000 and 2010, varying between 32 784 Gg CO_2 and 48 040 Gg CO_2 over the 10 year period (DEA, 2014a). Croplands varied between a weak sink (513 Gg CO_2) and a source (7 529 Gg CO_2) of CO_2. Land converted to grassland was estimated to produce a sink of CO_2, although the value varied over the 10 year period. Carbon changes from settlements and wetlands were negligible and conversions from other land uses were not estimated.

Aggregated and non-CO_2 emission sources on land produced a total of 251 460 Gg CO_2eq between 2000 and 2010. This fluctuated annual with the lowest emissions occurring in 2005 (22 040 Gg CO_2eq) and the highest in 2002 (23 594 Gg CO_2eq). There was a lot of annual variation in emissions from each of the sub-categories in this section, with none of them showing a clear increasing or decreasing trend. Direct N_2O emissions from managed soil were the biggest contributor to this category, producing between 65.6% (2010) and 68.1% (2000) of the total annual aggregated and non-CO_2 emissions. This was followed by indirect N_2O emissions from managed soils (19.6% - 20.1%) and biomass burning (7.9% - 9.2%).

In terms of mitigation the most feasible options for South Africa's AFOLU sector include: restoration of sub-tropical thickets, forests and woodlands; restoration and management of grasslands; afforestation; biomass energy; anaerobic biogas digesters; biochar application to soil; reduced tillage; and REDD+ activities (Reducing Emissions from Deforestation and Forest Degradation) (DEA, 2015). These activities have been estimated to have a mitigation potential of between 14.1 and 16.9 million t CO_2eq, with biogas having the largest potential (26.4%) followed by reforestation (25.1%) and grassland restoration (17.7%). The restoration-related options are considerably cheaper than the energy options. It is suggested that these mitigation activities be rolled out over the next 20 years so the maximum mitigation potential (from these activities) can be achieved by 2035. There are some livestock mitigation options in terms of improving rumen efficiency and increasing livestock productivity (Scholtz et al., 2012), however, these options are seen to have limited potential so are not highlighted in national mitigation option reports (DEA, 2014b).

1.4. Baselines

1.4.1. What is a baseline?

A baseline scenario is defined as the future GHG emission levels in the absence of future, additional mitigation actions. It can also be referred to as the 'business-as-usual' scenario. Baseline scenarios can serve different purposes and therefore can be established at different levels of aggregation (e.g. project-specific, multi-project, sectoral, regional and national) so as to accommodate the various requirements of the specific applications. For example, baselines are developed at a project level to use for monitoring the impact of a particular response measure. They are used in the carbon validation and verification process to determine the carbon credits of a project (e.g. Verified Carbon Standard (VCS) or Clean Development Mechanism (CDM) projects). Baselines are also routinely used to support domestic policy planning as well as to inform national positions in international climate-change negotiations. In recent years national baselines have grown in importance as some developing countries (including South Africa) have defined their mitigation pledges in terms of reductions from their respective baselines. Understanding likely future trends in greenhouse-gas emissions is not only important for international negotiations but can also be used for domestic planning. There is therefore a growing interest to understand and improve approaches to calculating baseline scenarios.

1.4.2. Framework for baseline development

There is currently limited information and guidance available for setting national GHG baselines with significant variability in the approaches and assumptions used by countries globally. In general the methods employed are specific to countries' goals and targets (Clapp and Prag, 2012).




Good practice guidelines on setting emissions baselines have been proposed by Clapp and Prag (2012) and it is suggested that the framework should include: a set timeframe for emissions projections, the scope of emissions sources, key drivers for projections, treatment of domestic climate policy measures, modelling framework and projection methodology, uncertainty and sensitivity analysis, review and updating (Clapp and Prag, 2012). The following section explains in more detail the points made above.

Projection timeframe – baseline projections may be presented over different timeframes to provide input to different policy and planning considerations. Establishing a time series of historic GHG emissions can help inform a smooth transition to emissions projections in the future and to inform national climate change strategies. The guidelines for Annex I countries indicate that countries should report projections to 2020 showing five year intervals of data.

Scope – scope of the baseline involves decisions on which GHGs to include in the projection and which emitting sources to include. Emissions inventories give an indication of the emissions sources at a particular moment in time and are a good starting point for which GHGs to include. Sector definitions need to be clear to allow for comparisons across baselines and models.

Assumptions related to key drivers – all projections are based on assumptions about the future development of drivers of emissions. Analysing the trends in emissions will improve the credibility of a baseline. Important steps in constructing a baseline therefore include identifying the drivers of change for sectors and the assumptions on how drivers will vary over the timeframe of the baseline. The interpretation of landscape drivers is affected by the complexity of interacting factors that make determining the causes of change difficult. In most situations, it is impossible to attribute land-cover changes to a single driver. Changes reflect relationships and feedbacks among many anthropogenic and natural events. Furthermore, natural and human systems interact in ways that may intensify or mitigate effects over time. Important drivers of change affecting landscape indicators include governance capacity, population change, land-tenure regimes, macroeconomic and trade policy, environmental policy, infrastructure, land suitability, domestic and international markets, climate conditions, technology, poverty, cultural beliefs and many others that may be highly specific to localized situations (Allen and Barnes, 1985; Lambin et al., 2003).

Treatment of domestic climate policy measures – many policy measures affect GHG emissions. It is therefore not sensible to completely isolate emissions trends from the impact of existing and expected future policy developments. Guidelines do not provide any examples of which types of policies could be included, leaving the current labelling of scenarios open to much interpretation. A baseline which assumes no new climate action beyond a specific point in time could be the clearest way to treat climate policies for all countries.

Modelling framework or projection methodology – projections can be done through simple extrapolation using historical emissions trends and inventory data, or by more complex modelling. The choice of projection method or model can have significant impact on baselines and resulting mitigation potential. Extrapolation can be done relatively easily using a spreadsheet model to make assumptions on some key variables and emissions drivers to assess the impact on emissions. If there are elements in the projections from key drivers that deviate from past trends, then a more elaborate method is preferable. Complex modelling approaches can be divided into top-down and bottom-up approaches. Multiple modelling approaches may be more preferable depending on the level of detail and timeframe of the baseline. Thus the difficulty faced when considering international guidance on setting baselines is how to allow for a wide variety of approaches specific to national requirements.

Uncertainty and sensitivity – as all projections are descriptions of the future they are unlikely to be accurate. Emissions trajectories are sensitive to drivers, therefore it is important to assess baselines against a number of possible scenarios. The scenarios can reflect a number of views on expected future developments or involve sudden changes in drivers. Multiple scenarios and assumptions will provide information on the sensitivity of key drivers used and a better understanding of the emissions trajectories, in turn providing a transparent means to switch to a different baseline in the future if required.

Updating baseline projection – it is difficult to assess at which point the assumptions made for baseline generation are no longer valid, or when the deviation away from the baseline becomes great enough to warrant selection of different scenarios. Transparent involvement of stakeholders is recommended to increase the credibility and longevity of a baseline. Updates of baselines should use recent data, but should not become too dependent on the effects of current economic cycles especially if baselines are projected over a long period of time. Baselines should be updated though, if measured data on any driver deviates by more than a certain percentage from the value assumed in the original projection. Therefore, the availability of sensitivity analyses around the chosen baseline would be particularly useful to show how changes in key drivers would affect emissions and therefore when a new baseline should be considered based on updated parameters for the key drivers (Clapp and Prag, 2012).

1.4.3. Projection methodology

Projection of activity data can be done using one of three techniques (as described in VMD0019[1], 2012):

- Linear extrapolation – this is the simplest approach and involves the projection of the existing trajectory of change in the value of the variable, based on historical data, into the future. This approach is applicable when it is believed that the drivers, agents and causes leading to change in the variable are likely to remain relatively unchanged in the future;
- Modified trajectory – projection of the future values of the variable based on the existing trajectory (historical data), modified to reflect the expected impacts of changes in one or two relatively independent drivers, agents or causes. This technique is much less complex than the modelled technique, while still integrating the effects of expected changes in the factors influencing the variable.
- Modelled – projection of future values of the variable based on a function or model which integrates the impacts of multiple drivers, agents and causes on the variable. This technique is typically highly data intensive, since the project proponent must have enough data on past changes in the variable and changes in drivers, agents and causes to determine the causal relationships within the system. When this technique is used, the data on past values of the variable is used to develop and 'truth' the model. This technique may be particularly suitable where existing models have been developed and peer reviewed in the scientific literature for forecasting changes in the variable.

1.5. Current baseline for SA's national emissions

The Long Term Mitigation Scenarios (Winkler, 2007) developed the first emission baselines and mitigation scenarios for South Africa. There was a heavy focus on energy as its contribution to emissions is over 80%. A detailed MARKAL model was used to develop the main energy emissions baseline and mitigation scenarios. Non-energy components were included by adding outputs from spreadsheet based models to the main MARKAL model outputs. A component of AFOLU was included through the use of the model developed for the SA Country Study on Climate Change (Scholes et al., 2000). The data from this original study was updated and extended for 50 years using mostly data from agricultural statistics. The AFOLU calculations were based around the following mitigation actions: enteric fermentation, manure management, reduced tillage, biomass burning and savanna thickening (afforestation). This meant that enteric fermentation, direct N_2O from manure, cropland soil carbon, CH_4 and NOx from burning, and carbon from savannas were the components included.

Table 3: Baseline Figures from Long Term Mitigation Scenario (LTMS) and Mitigation Potential Analysis (MPA) (Gg CO_2eq).

	2010	2020	2030	2040	2050
LTMS					
AFOLU sector	23 000	24 163	24 275	24 138	23 900
Enteric fermentation	18 000	18 000	18 000	18 000	18 000
Manure management	1 950	2 000	2 000	2 000	2 000
Tillage	5 050	4 663	4 275	3 888	3 500
Fire control and savanna thickening	-2 000	-500	0	250	400
MPA					
AFOLU sector	54 311	53 268	52 506	52 216	52 159

[1] *This Verified Carbon Standard module provides a step by step approach to assessing the key factors that drive change in the variable in question, and it provides a suite of methods and approaches for projecting future conditions.*

More recently the Mitigation Potential Analysis (MPA) (DEA, 2014b) was completed and that also made some baseline projections. In this study the following mitigation activities from the AFOLU sector were included: management of livestock waste, expanding plantations, urban tree planting, restoration of grasslands, and biochar additions to soils. The MPA provided a baseline without policy measures and a baseline with existing policy measures. For the AFOLU sector the baselines were the same as there were no specific policy measures in place to reduce AFOLU emissions or increase the carbon sequestration. The baseline emissions did not incorporate land-use change activities and so the baseline only reflects the livestock and manure management emissions. The baseline declines slightly due to declining livestock populations.

1.6. Project scope, parameters and overarching methodology

1.6.1. Scope

This project includes the emissions of CO_2, CH_4 and N_2O emissions from the following sources:

- Enteric fermentation
- Manure management
  - CH_4
  - Direct and indirect N_2O
- Land-use conversion
  - Changes in biomass carbon
  - Changes in dead organic matter carbon
  - Changes in soil carbon
- Biomass burning
- Managed soils
  - CO_2 from lime and urea application
  - Direct N_2O from nitrogen additions to soils
  - Indirect N_2O

1.6.2. Projections

The modelled approach would be the most accurate due to the amount of data incorporated into the models. However, this approach is very data intensive and requires the use of models which have already been tested or calibrated for the South African system. In the agricultural sector the Bureau for Food and Agricultural Policy (BFAP) has developed a model to project changes in agricultural commodities. This project built on the outputs of the BFAP modelling process as it is a model which has been previously used and calibrated for South African conditions. For the land sector there are numerous variables and limited data so a more simplified approach of modified trajectory was applied to this sub-sector.

The steps undertaken in this approach (as described in VMD0019 (2012)) are:

- Project the existing curve using a linear extrapolation of historical data.
- Check for conservatism:
  - Based on the analysis of agents, drivers and causes, the project proponent must determine and document whether there are any reasonably possible changes in the status of these factors which might cause the use of the trajectory to be non-conservative. If any such factors are noted then a modified trajectory approach must be applied rather than the linear extrapolation method.
- Check for limits of possible values of the variables:
  - Check whether the values for X, based on the linear extrapolation, reach a limit of the possible values of the variable. If no limit is reached, use the values derived from the historic curve as the projected values of the variable. If an absolute limit is reached, all values of the variable above an upper limit or below a lower limit must default to the limit value, and the revised values are the projected values.

- Modified trajectory:
  - Identify key drivers or causes which may cause the trajectory to be modified.
  - Assess the conditions under which the driver is expected to modify the trajectory.
  - Determine the expected future values:
    - These projected values are derived from documented assessments of related drivers, or are supported by documentation from literature or expert opinion.
    - Future projections are conservative projections.
  - Modify the trajectory based on these drivers.

1.6.3. Emission methodology

The methodology for calculating the emissions is mainly drawn from the IPCC 2006 guidelines (IPCC, 2006) as they are more applicable at the national and provincial scale, whereas the Verified Carbon Standard (VCS) and Clean Development Mechanism (CDM) methodologies are more project specific. Adopting the IPCC methodology also makes integration with the GHG inventory easier. However, during the method development a few of the CDM/VCS methodologies were considered:

- AMS-III.D: Methane recovery in agricultural and agro-industrial activities;
- VM0026: Sustainable grassland management; and the
- CDM tool to estimate emissions associated with the cultivation of land to provide biomass.

A series of spreadsheet-based emission models were developed from the above-mentioned equations. For the agriculture sector a national emission model was set up and then this was divided into provincial spreadsheets, whereas for the land sector files were created for each province and then this was combined to form a national file (details provided in methodology sections 2.2 and 3.2).




CHAPTER 2: Agricultural emissions baseline

2.1. Introduction

2.1.1. Global agriculture

The average amount of cropland and pasture land per capita in 1970 was 0.4 and 0.8 ha and by 2010 had decreased to 0.2 and 0.5 ha per capita, respectively (FAOSTAT, 2013). Changing land-use practices, technological advancement and varietal improvement have enabled world grain harvests to double from 1.2 to 2.5 billion tonnes per year between 1970 and 2010 (FAOSTAT, 2015a & b). Average world cereal yields have increased from 1 600 to 3 030 kg/ha over the same period (FAOSTAT, 2015a) while there has also been a 233% increase in global fertilizer use from 32 to 106 Mt per year, and a 73% increase in the irrigated cropland area (FAOSTAT, 2015). Globally, since 1970, there has been a 1.4-fold increase in the numbers of cattle and buffalo, sheep and goats (which is closely linked to the trend of CH_4 emissions in the sector); and increases of 1.6-fold and 3.7-fold for pigs and poultry respectively (FAOSTAT, 2015a).

If food and agriculture develop according to projections made by the Food and Agriculture Organization of the United Nations (FAO) for the year 2030, global agricultural area is likely to expand by an estimated 280 Mha, increasing deforestation pressure and carbon emissions. Future global trends predict an increase in demand for meat that will be doubled towards the year 2050 (FAO, 2009).

The global situation is that overall growth in agricultural production is slowing down, and is expected to continue to do so as a consequence of the slowdown in population growth, in spite of the fact that levels of food consumption are likely to increase. Notwithstanding a slowing in the growth rate of the population, agricultural production will need to increase by 70% (nearly 100% in developing countries) by 2050 to cope with a 40% increase in world population and to raise average food consumption to 3 130 kcal per person per day.

By far the largest proportion of livestock sector growth in recent years is attributable to the poultry sector, which has consistently grown at more than 5% per annum since the 1960s. Its share in world meat production doubled from 15% thirty years ago to 30% in 2000. Growth and an increased share in overall meat consumption have also been seen in pork, but ruminant meat consumption has actually been on the decline (Bruinsma, 2009; Rae and Nayga, 2010).

2.1.2. Agriculture in SA

In South Africa, agricultural production practices can be broadly differentiated into a commercially oriented sector that services national food requirements and export earnings, and a small-scale and homestead farming sector that constitutes a high proportion of the (mainly subsistence) farming population that rely largely on traditional agriculture methods. Commercial agricultural activities in South Africa range from the intensive production of vegetables, ornamentals, and other niche products, to large scale production of annual cereals (e.g. wheat and maize), oil seeds, perennial herbaceous crops (e.g. sugarcane), and tropical, subtropical, and temperate fruit crops. Livestock production is a major contributor to national and household food security and to GDP, with significant intensive production of cattle, pigs, and poultry. In addition to its monetary value, livestock also plays a socio-cultural role.

The livestock industry consists of an estimated 38 500 commercial farms. According to 2010 estimates (DAFF, 2010), which incorporate ruminant and non-ruminant livestock across both the commercial and non-commercial farming sectors, the largest portion of South Africa's national total of livestock numbers is made up of poultry, sheep, and cattle. Historical trends show minimal fluctuations in the cattle, sheep and goat livestock numbers (Meissner et al., 2013) with dairy, beef (rangeland), sheep, and goat numbers actually showing a slight decline even though consumption and demand has increased. Meissner et al. (2013) suggests that cattle, sheep and goats numbers have not changed significantly over the past 10 years.

Future trends indicate that there will be an increased demand for livestock products due to growing populations. An increase in demand is also related to improved income in South Africa. South Africa's middle class population has increased dramatically in the last 10 years with increasing demand for livestock products. Livestock products, on a weight basis, contribute 27% of the consumer food basket (Meissner et al., 2013).

Increasing the area of grazing systems is limited in South Africa (Scollan et al., 2010), particularly since rangelands are shown to be decreasing in size (GTI, 2015). Thus the increase in livestock products in the long term is expected to come from pig and poultry production. However, in SA the demand for pork is low, so the increased demand for meat is projected to come mainly from the poultry industry. Poultry population numbers have, therefore, been increasing sharply (BFAP, 2015). Feedlots are expected to increase to meet rising food demands (DEA, 2013), but this increase is expected to level off after 2030. Climate change can also have an impact on feedlots as the growth of beef feedlots is dependent on the availability of calves and the feed price. Drought causes feed prices to increase, meaning that feedlots may become unviable (Dave Ford, Pers. Comm.).

2.1.3. Drivers of agricultural change

Multiple drivers influence the agricultural landscape. Macroeconomic drivers include population, Brent crude oil, foreign exchange rates, GDP per capita, and interest rates. The SA economy is forecast to expand by a mere 2% in 2015, but the International Monetary Fund (IMF) (2015) projects that growth will accelerate to 2.5% by 2024. The population is expected to expand to over 58 million by 2024. Agriculture has to expand to keep up with the demand of the growing population. In order to keep up with growing demand, South Africa imports a variety of foods and the exchange rates have a significant impact at this level. Depreciation of the exchange rate has a direct effect on the cost of food items. It also influences feed prices which impacts on the livestock sector. Macro-economic drivers dictate that food demand over the next decade will not increase at the same rate, but will slow slightly, and real net farm income is predicted to gradually increase from 2017 to 2024 (BFAP, 2015).

The consumer market has a significant influence on consumption and, therefore, on production patterns within the agriculture sector. Rising income, class mobility, urbanization, age distribution, education levels, unemployment, debt and nutritional status all play a role in determining the consumer market. Over the past decade SA has managed to maintain a positive class mobility rate by reducing the share of the population in the lower income categories significantly, moving them into a higher income bracket. This has resulted in a sharp rise in demand for food, especially animal proteins such as chicken.

International policies affect trade of agricultural products, while domestic policies have led to the introduction of tariff barriers. These are policies which influence the economics, while there are also numerous domestic policies, as pointed out in the NTCSA (DEA, 2015), which can influence the agricultural landscape through:

- promoting small scale agriculture (e.g. New Growth Path, National Development Plan (NDP), The Strategic Plan for South African Agriculture, and the Integrated Growth and Development Plan (IGDP));
- land reform (e.g. the NDP, the IGDP, and the Department of Rural Development and Land Reform: Strategic Plan);
- promotion of sustainable landscapes and associated agricultural production (e.g. the National Climate Change Response White Paper, the National Biodiversity Framework, the Conservation of Agricultural Resources Act (CARA), and the National Strategy for Sustainable Development and Action Plan (NSSD1), the National Environmental Management: Biodiversity Act (NEMBA), and the National Environmental Management: Protected Areas Act (NEMPAA)); and
- promotion of spatial planning (the National Environmental Management Act (NEMA), the National Environmental Management: Air Quality Act (NEM:AQA), and the Spatial Planning and Land Use Management Act (SPLUMA)).

Climate change is another important driver of change particularly in the agriculture sector. Rising temperatures, more erratic rainfall and an increased frequency of drought can have far reaching implications for this sector. Droughts lead to lower crop production, which translates to higher feed prices as well as increased food prices. Higher feed costs impact the livestock and feedlot outputs, while the dry conditions lead to increased livestock death. South Africa is currently experiencing a drought and this could mean a 30% reduction in livestock which is likely to take 5 years to recover. Higher temperatures also have consequences for water demand, the spread of pests and pathogens, as well as farm labourers. Each 1% decline in rainfall is likely to lead to a 1.1% decline in the production of maize and a 0.5% decline in winter wheat (Blignaut et al., 2009).

These impacts on crops will also have an impact on the consumption of fertilizers. Factors driving fertilizer demand include population growth, increased income, diet diversification, biofuel development, arable land availability and improved nutrient efficiencies (Prud'homme et al., 2005).

2.1.4. Activities covered in the agricultural GHG emissions baseline

The emissions baseline discussed in this report is based on the much expanded AFOLU sector that is included in the national GHG inventory. It incorporates the following agricultural components:

- Livestock enteric fermentation,
- Livestock manure management,
- Liming,
- Urea application,
- Direct N_2O emissions from managed soils,
- Indirect N_2O emissions from managed soils,
- Indirect N_2O emissions from manure management.

Other activities relating to cropland areas and changes in cropland, which affect carbon sequestration, are dealt with in the land component of this report.

2.2. Methodology

The SA agricultural emissions activity data is mostly supplied at the national level. A national level emissions model was, therefore, developed first. Thereafter, data from literature was applied to enable the breakdown of the national emissions data into provincial data.

2.2.1. Livestock activity data

2.2.1.1. Livestock population data

Initially, projections were made based, as in previous baselines, on the historical population data. Graphs of the historical population numbers of cattle, goats, pigs, sheep and poultry are presented in Figure 3 and Figure 4. This means that there is an underlying assumption that livestock populations will continue to grow or decline as they did in the past. Historical commercial livestock population data was obtained from the Agricultural Abstracts (DAFF, 2012), while poultry data was supplied by the South African Poultry Association (SAPA; http://www.sapoultry.co.za/). Feedlot cattle need to be separated out from other cattle, as feedlot cattle have a different emission factor (EF). Annual feedlot cattle numbers were obtained from the South African Feedlot Association (SA Feedlot Association, 2013; Ford, Dave, 2013. Pers. Comm.). Data was only available for the years 2008–2012, and an average of 420 000 was used for the years prior to this. Horse and donkey population data in SA is very variable (DAFF, 2012; Simalenga et al., 2002; Du Toit et al., 2013c) and for the purposes of this baseline the FAO Statistics data was selected as it has a more consistent and longer time series. The age, sex and type of livestock (i.e. lactating or dry cow) have different EFs, so the herd composition data from Du Toit et al. (2013a, 2013b, 2013c) was applied to the national dairy, sheep, goat and swine population numbers to obtain the herd composition sub-categories for these livestock. The sub-categories for sheep, goats and swine were obtained by combining some of the more detailed sub-categories given in Du Toit et al. (2013a, 2013b, 2013c) as some of the populations were small and EF's didn't vary significantly. For the baseline it was assumed that herd composition will not change. Discrepancies between the different sources of livestock populations' data, and the difficulty of including communal livestock numbers, are discussed in Box 1.

BOX 1: DISCREPANCIES IN LIVESTOCK POPULATION DATA

Livestock population numbers are the driving activity data for emissions. Changes in population numbers will change both the enteric and the manure emissions. It is therefore important to try to obtain a consistent and accurate data set of livestock population data. Commercial population data is well known, but during the data collection process it became evident that different numbers can be obtained from different sources. The agricultural abstracts (DAFF, 2013) are a long-standing data set which has annual data going back to 1970 in most cases. This is the data set that has been used for developing the inventory due to its time-series consistency. However, when talking to the various livestock organizations, they do not necessarily agree with these numbers. In light of the fact that National Treasury is moving towards a carbon tax system which will require accurate data, it is recommended that a discussion or workshop, led by DAFF and supported by DEA, be held with the various organizations collecting livestock data to discuss the data sets and attempt to understand where and why the inconsistencies are occurring. It is also important to understand what is included in each of the data sets. For example, it is not always apparent as to whether feedlot cattle are included or excluded in cattle numbers. The workshop should also aim to determine a future reporting plan, so that there is one central point where the official data set can be obtained.

There are also uncertainties surrounding data on communal livestock numbers. This is the result of the difficulty in actually collecting the data due to the extensive nature of the communal livestock populations. At the moment the communal numbers have been set at a ratio of the commercial population. It should be evaluated as to whether these ratios are still acceptable, whether they need further adjustment, or whether they should be fluctuating. New ways of monitoring livestock populations, through the use of remote sensing or modelling for example, should be explored in the future so as to reduce uncertainties on livestock data.

The total communal cattle population was determined from Abstracts of Agricultural Statistics (DAFF, 2012). All the communal cattle were assumed to be other cattle. Due to a lack of data the communal population was assumed to have the same herd composition (excluding feedlot cattle) as the commercial population. The total communal population numbers for sheep, goats and swine was obtained by using the ratio of commercial to communal population from the quarterly census numbers which have been recorded by DAFF from 1996 onwards. It is assumed that this ratio does not change going into the future.

Another aspect which has been incorporated into the baseline is emissions from game. It is often debated as to whether game emissions should be included in the inventory, and thus in the baseline, because they are not thought to be managed. Experts in the field, however, indicate that game in privately owned game farms are managed and even provided with specific feed. Furthermore, there is this perception that if you switch to game farming the emissions would be reduced, which is not necessarily the case. Therefore, privately owned game has been included. Du Toit et al. (2013d) provides estimates of the game on privately owned game farms. Emission factors were calculated for 16 species of game and therefore these are the game included in this baseline.

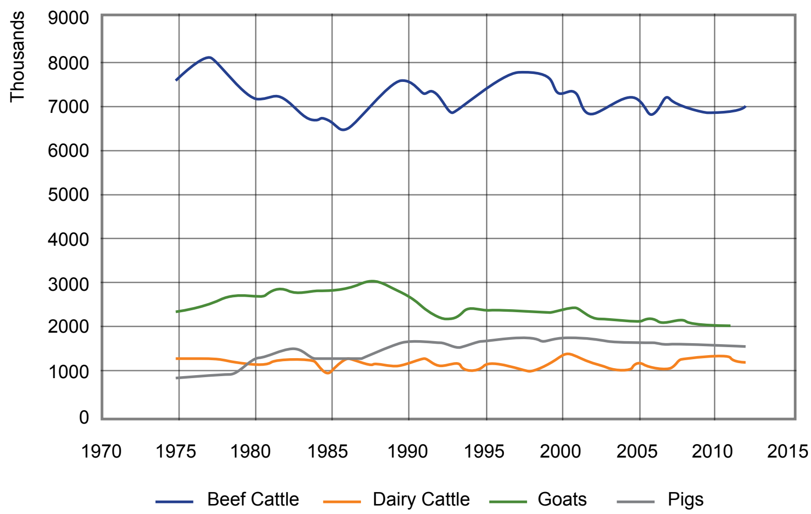

Figure 3: Historical Population Numbers of Cattle, Goats and Pigs (Source: DAFF, 2012; SAPA, Pers. Comm.).

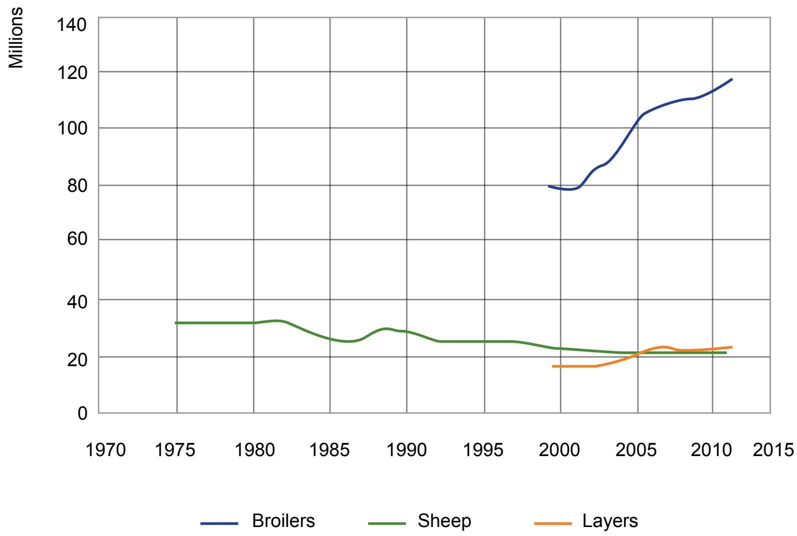

Figure 4: Historical Population Numbers of Sheep and Poultry (Source: DAFF, 2013; SAPA, Pers. Comm.).

2.2.1.2. Livestock population projections

The base year for agricultural emissions was taken as 2010 which was the last year of the inventory. For all livestock a regression was fitted to the historical population data and a logarithmic transformation completed to obtain an average rate of change in order to project the population data into the future. This rate was applied to the decadal intervals between 2010 and 2050, then literature, data and expert opinions were used to make informed adjustments to the projected rates of change.

Growing demand for beef is expected to be met by a growing feedlot population. Feedlot SA shows an increasing number of smaller, privately operated feedlots entering the market. Standing numbers in feedlots have increased by 5.9% since 2008 (SA Feedlot Association, 2013) to make up around 85% of the annual national number of cattle slaughtered. Lower feed grain prices increase the prevalence of feedlots that convert feed to meat more efficiently, but feed prices are expected to increase in the future due to climate change causing an increase in the frequency of drought (Dave Ford, Pers. Comm.). This increase in feedlot cattle was taken into account when determining the herd composition. It was assumed, based on discussions with experts in the field, that feedlots would increase by 5% to 2020 and this increase would decline to 2% in 2050. This follows the same trend assumed by the Mitigation Potential Analysis (DEA, 2014b).

Climate change and droughts will have an impact on livestock in the future (Rust and Rust, 2013). South Africa is currently experiencing a drought which is likely to cause a 30% reduction in livestock population (Meissner, Pers. Comm.). If the drought is broken and weather conditions improve, it could take around 5 to 7 years to recover. These perturbations are not reflected in the baseline as it is an average data set, however the possibility of an increased frequency of drought could lead to a further decline in livestock numbers due to the populations not having sufficient time between droughts to recover. These are aspects which need to be considered going into the future.

Nesamvuni et al. (2012) used the outputs of General Circulation Models (GCMs) to show that the probability of heat stress for livestock is likely to increase in the future. It indicated that in the intermediate future (2046–2065) dairy and feedlot cattle are likely to experience more severe heat stress particularly in the northern areas of Limpopo and the Northern Cape. Archer van Garderen (2011) supported these findings. The Long Term Adaptation Scenario report for Agriculture (DEA, 2013) indicates that tolerance thresholds for feedlot cattle have already been reached in the North West, Northern Cape and Free State. Broiler chickens are vulnerable to heat stress and it is suggested that ventilation will need to be increased in the housing or stocking densities should be reduced. An increase of 2.5–3oC in temperature could lead to substantial mortality in the broiler industry (DEA, 2013). Pigs are less susceptible to the heat stress, however, stocking rates may need to be decreased so as to reduce heat within the housing. Furthermore, increases in temperature will also have an impact on water availability, and thus feed, and the water demand projections for 2025 show that there are likely to be water shortages in at least half of the water management areas (DWA, 2013). It was, therefore, assumed that the rate of increase in pig and particularly poultry would slow over the 2030–2050 period due to the impacts of climate change, reduced forage availability as well as an increase in degradation. Increases were assumed to slow to half the rate between 2030 and 2050 for pigs and decline by a further quarter for poultry by 2050.

The shift in land use from pastoralism to game farming has been identified since the 1980's as a fast growing trend in South Africa (Grossman et al., 1999). There is very little data on game population numbers so it is difficult to establish a trend. It is estimated that there are 20 million head of game in SA currently, and it is expected to rise to 30 million by 2025 (Gert Dry, Wildlife Ranching SA, Pers. Comm; Cloete et al., 2015.). Based on these estimates and limited literature (Joliffe, 2001; Bothma, 2002; Smith and Wilson, 2002) game numbers were assumed to increase by 5% p.a. between 2010 and 2020, but this is projected to decline by 1.5% p.a. between 2040 and 2050 due to limitations of land area and feed availability.

Overall, these historical projections showed a slight decline in dairy cattle, goats and sheep populations, while large increases were seen in the pig and poultry populations. This reflects the changing mobility of the South African population, with the cheaper white meat increasing in demand (BFAP, 2015). Declining cattle numbers means that an increasing productive efficiency is required in order to meet growing demands, which is true for most livestock sectors. This is seen in the increase in feedlots to meet the growing demands. Stock theft and lower demand for sheep and goat meat could cause these populations to decline. However, there is still a good international market for wool (Meissner et al., 2013) which could cause a slowing in the decline of sheep in the future.

As mentioned in the introduction, projections can be made using historical data or from models which are run by drivers. A modelling approach was considered so as to make some comparisons to the historical projections. There is no specific model for livestock populations, but the Bureau for Food and Agricultural Policy (BFAP, 2015) has a model which is calibrated for SA and projects agricultural commodities to 2024 based on supply and demand information. It includes a variety of drivers. The BFAP model is an economic, recursive, partial equilibrium model which incorporates a range of economic, technological, environmental, political, institutional and social factors. All the assumptions are outlined in the BFAP report (BFAP, 2015) but some of the key assumptions are:

- Current international as well as domestic agricultural policies will be maintained throughout the period;
- Macroeconomic conditions are based on a combination of projections developed by the International Monetary Fund (IMF) and the World Bank;
- All commodity markets are generated by the Food and Agricultural Policy Research Institute (FAPRI);
- All macro-economic indicators play out as stated in the model assumptions; and
- Average weather conditions will prevail in South and southern Africa and around the world.

Once the critical assumptions are captured in the BFAP sector model, the outlook for all commodities is simulated within a closed system of equations. This implies that, for example, any shocks in the grain sector are transmitted to the livestock sector and vice versa.

The model is concerned with consumer products so it does not project livestock data but rather consumption of livestock products. It takes into account imports and exports as well. In order to convert the production data into livestock population data, a production per animal was calculated from the production and the historical population data from DAFF (2012). This approach was adopted for the beef, dairy, pig and poultry (layers and broilers) populations as these are the ones that are associated with commodities. Sheep data was difficult to derive, as there are both wool, and meat products, so historical sheep data were maintained.

It should be noted that the model output refers to commercial livestock, therefore, subsistence livestock numbers needed to be estimated and added to this number. These subsistence livestock numbers, together with their herd composition, were determined in the same way as for the historical projection. In addition game population numbers were also added.

BFAP data was used to project to 2024 and then the rate of change between 2010 and 2024 was extrapolated to 2050.

The same climate impact assumptions and restrictions applied to the historical data were applied.

This modelled approach led to a much higher projected beef population, in order to meet the growing meat demand, and slightly higher dairy numbers. The projected poultry numbers were actually lower than that projected with historic data, while swine numbers increased slower in the beginning, but reached a slightly higher value in 2050 to that predicted by the historical data (Table 4).




Table 4: Projected Livestock Population Numbers from Historical and from BFAP (2015) Projections

	2010	2020	2030	2040	2050
Population estimates from historical projections					
Dairy cattle	1 340 000	1 325 333	1 310 826	1 296 478	1 282 287
Other cattle	12 359 999	12 575 953	12 803 484	13 001 705	13 238 119
Sheep	24 492 558	21 707 189	19 238 581	17 050 711	15 111 651
Goats	6 105 170	5 605 636	5 146 976	4 725 843	4 339 168
Horses	300 000	333 333	370 370	411 523	457 247
Mules and asses	166 300	168 632	170 997	173 395	175 827
Swine	1 969 197	2 105 183	2 176 780	2 250 811	2 327 360
Poultry	140 493 251	209 630 904	256 644 377	284 131 240	314 574 355
Game	201 660 047	274 263 072	323 869 583	352 975 008	385 241 185
Population estimates from the Bureau for Food and Agricultural Policy projections					
Dairy cattle	1 340 000	1 329 462	1 369 219	1 402 268	1 418 793
Other cattle	12 359 999	14 043 368	15 778 493	16 958 515	17 313 030
Swine	1 802 151	1 841 390	2 012 780	2 169 490	2 326 200
Poultry	140 493 251	169 522 789	216 736 000	241 744 000	258 416 000

Considering both baselines and consulting with industry experts and stakeholders, it was decided that the numbers based on the BFAP projections would be used in the final baseline as these are derived from more robust modelling methods. These numbers could also be updated in future based on the continued updating of the BFAP baseline.

2.2.2. Livestock emissions modelling

2.2.2.1. Enteric fermentation emissions

Enteric fermentation emissions can be affected by different mitigation actions. Table 5 indicates some of these mitigation actions, and how they have been accounted for in the baseline.

Table 5: Mitigation Actions Which Could Affect Enteric Fermentation Emissions and Related Baseline Assumptions

Mitigation actions considered	Baseline assumptions
• Change in livestock diet • Use of additives • Management of herd composition • Alteration of livestock species	• Livestock diet remains as it is • Current Emission Factor kept constant • Herd composition kept at current ratios • Average Emission Factor used, so no cattle species detail required

Enteric fermentation emissions are a product of the livestock population number and the methane emission factor:

$$\text{Enteric } CH_4 = \sum_i \left[\frac{(EF_i * N_i)}{10^6} \right]$$

Where:
Enteric CH_4 = total methane from enteric fermentation (Gg CH_4 yr^{-1})
i = livestock category or sub-category
EF_i = emission factor for the defined livestock population *i* (kg CH_4 $head^{-1}$ yr^{-1})
N_i = number of head of livestock in category $_i$

Du Toit et al. (2013a, b, c and d) provided emission factors for all the age classes and types of livestock. The calculated emission factor takes into account the environmental conditions and changes in feed quality through the year. The data sources and validation references are provided in Table 6.

Table 6: Data Sources and Validation for the Enteric Fermentation Emissions Calculations

Activity data	Data sources	Validation data sources
Population data	Agricultural Abstracts (DAFF, 2012) BFAP (2015) Meissner et al. (2013) South African Poultry Association (SAPA) LACTO Data (2015) FAO Statistics (http://faostat.fao.org/)	Du Toit et al (2013a,b,c,d) Census (2011) FAO Statistics (http://faostat.fao.org/) Agricultural Abstracts (DAFF, 2012)
Emission factors	Du Toit et al. (2013a,b,c,d) GHG Inventory (2010) (DEA, 2014a)	IPCC 2006 Guidelines (IPCC, 2006) IPCC Emission Factor Database

2.2.2.2. Manure management

Emissions from manure management can be affected by different mitigation actions. Table 7 indicates some of these mitigation actions, and how they have been dealt with in the baseline.

Table 7: Mitigation Actions Which Could Affect Emissions from Manure Management and Related Baseline Assumptions

Mitigation actions considered	Baseline assumptions
• Alteration of livestock diet • Alteration of manure management systems • Use of biodigesters	• Livestock diet remains as it is • Emission Factor kept constant • Manure management systems continue as currently being used • No biodigester usage[2]

Emissions of CH_4 and N_2O (direct) from manure are calculated in the same way as for enteric fermentation, just applying different emission factors:

$$\text{Manure } CH_4 \text{ or } N_2O = \sum_i \left[\frac{(EF_i * N_i)}{10^6} \right]$$

Where:
Manure CH_4 or N_2O = total CH_4 or N_2O from manure (Gg gas yr^{-1})
i = livestock category or sub-category
EF_i = emission factor for the defined livestock population $_i$ (kg gas $head^{-1}$ yr^{-1})
N_i = number of head of livestock in category *i*

Emission factors determined by Du Toit et al. (2013a, b, c and d) incorporate the changing diet and

[2] There are several biodigesters in use in South Africa, however there is no comprehensive list of all the digesters and, therefore, due to time limitations the reduction in emissions due to the use of biodigesters has not been included, but should be included in future.

There is very little data on indirect emissions, but emissions can be calculated from the amount of nitrogen available in the various manure types and IPCC 2006 default emission factors as follows:

$$N_2O_{Indirect} = N_2O_{Volatilization} + N_2O_{leaching}$$

$$N_2O_{Volatilization} = \{\sum[\sum[(N_i * Nex_i * MS_{is}) *(\frac{Frac_{GasMS}}{100}]] * EF_4\} * \frac{44}{28}$$

$$N_2O_{Volatilization} = \{\sum[\sum[(N_i * Nex_i * MS_{is}) *(\frac{Frac_{GasMS}}{100}]] * EF_5\} * \frac{44}{28}$$

Where:
$N_2O_{Volatilization}$ = indirect N_2O emissions due to volatilization of N from manure management (kg N_2O yr^{-1})
$N_2O_{Leaching}$ = indirect N_2O emissions due to leaching and runoff from manure management (kg N_2O yr^{-1})
N_i = number of head of livestock *i*
$N_{ex\ i}$ = annual average N excretion per head of species i (kg N animal-1 yr^{-1})
MSi, s = fraction of total annual nitrogen excretion for each livestock species i that is managed in manure management systems (dimensionless)
$Frac_{GasMS}$ = percent of managed manure nitrogen for livestock category *i* that volatilizes as NH_3 and NOx in the manure management systems
$Frac_{LeachMS}$ = percent of managed manure nitrogen losses for livestock category *i* due to runoff and leaching during solid and liquid storage of manure
EF_4 = emission factor for N_2O emissions from atmospheric deposition of nitrogen on soils and water surfaces (kg N_2O-N (kg NH_3-N + NO_x -N volatilized)$^{-1}$); default = 0.01
EF_5 = emission factor for N_2O emissions from nitrogen leaching and runoff (kg N_2O-N/kg N leached and runoff); default value = 0.0075

Table 8: Data Sources and Validation for the Manure Management Emissions Calculations

Activity data	Data sources	Validation data sources
Population data	Agricultural Abstracts (DAFF, 2012) BFAP (2015) Meissner et al. (2013) SAPA FAO Statistics (http://faostat.fao.org/)	Du Toit et al (2013a,b,c,d) Census (2011) Census (2002) FAO Statistics (http://faostat.fao.org/)
Livestock weights	Du Toit et al. (2013a,b,c,d)	Breeder associations; DAFF (2010)
Manure management data	Du Toit et al. (2013a,b,c,d)	Moeletsi et al. (2015) DAFF (2010)
Emission factors and constants	Du Toit et al. (2013a,b,c,d) IPCC 2006 Guidelines (IPCC 2006)	IPCC 2006 Guidelines IPCC Emission Factor Database

2.2.3. Uncertainty and error propagation

Uncertainty was determined as described in the IPCC guidelines (IPCC, 2006). The uncertainty on each variable was determined where possible, and where no error was provided expert opinion was used. These uncertainties were then combined to provide a higher level uncertainty by using the following two rules:

Rule 1 - where uncertainties are to be combined by addition or subtraction:

$$U_{Total} = \sqrt{U_1^2 + U_2^2 + \dots + U_n^2}$$

Where U_{total} = the absolute combined uncertainty;

U_i = the uncertainties associated with each of the quantities.

Rule 2 – where uncertainties are to be combined by multiplication or division:

$$\frac{U_{Total}}{Z} = \sqrt{\left(\left(\frac{U_1}{Z_1}\right)^2 + \left(\frac{U_2}{Z_2}\right)^2 + \dots + \left(\frac{U_n}{Z_n}\right)^2\right)}$$

Where Utotal = the combined uncertainty;
Z = the overall expected value;
Ui = the uncertainties associated with each of the quantities;
Z_i = the expected value.

The uncertainties for enteric fermentation vary between 8.9% and 18.8% for the different livestock categories for the year 2010. For manure management CH_4 emissions, the uncertainties are slightly higher (11.6%–19.5%) and even higher for N_2O emissions (up to 137%) due to high uncertainties associated with the N_2O emission factors. Indirect N_2O emission factors also have similarly high uncertainties but these uncertainties are not uncommon for the N_2O emissions (Moeletsi et al., 2015). Uncertainties also increase in the future years as the uncertainty on the livestock population increases with time.

2.2.4. Managed soils N_2O activity data

2.2.4.1. Synthetic fertilizers

Synthetic fertilizer application data was obtained from the Fertilizer Association of SA (Fertasa). Data was available for the years 1955–2012 (Figure 5). There was a sharp increase between 1955 and 1980, then a decline the following year, after which there was a slow increase in consumption. Historical data from 1983 was extrapolated to 2050. Fertilizer consumption is related to area planted per crop that uses fertilizers and the amount of fertilizer applied. Grains, oilseeds and sugar cane are the biggest users of fertilizers in SA (GrainSA, 2011; FAO, 2005; Prud'homme et al., 2005), with maize consuming 62.2% of nitrogen fertilizer and sugar cane accounting for 8.9% in 2012. Considering that the production of maize has been declining over the last two decades, and with maize being the biggest consumer of nitrogen fertilizer, it could be expected that the fertilizer consumption rate might have slowed. However this has not been the case. In a report by FAO (2005) it was discussed that a reduction in cropped area and more intensive production in the remaining areas were likely to lead to a stable or slow growing fertilizer demand in the foreseeable future. The slow growth (0.7%) of the historical fertilizer consumption data was therefore assumed to be reasonable.

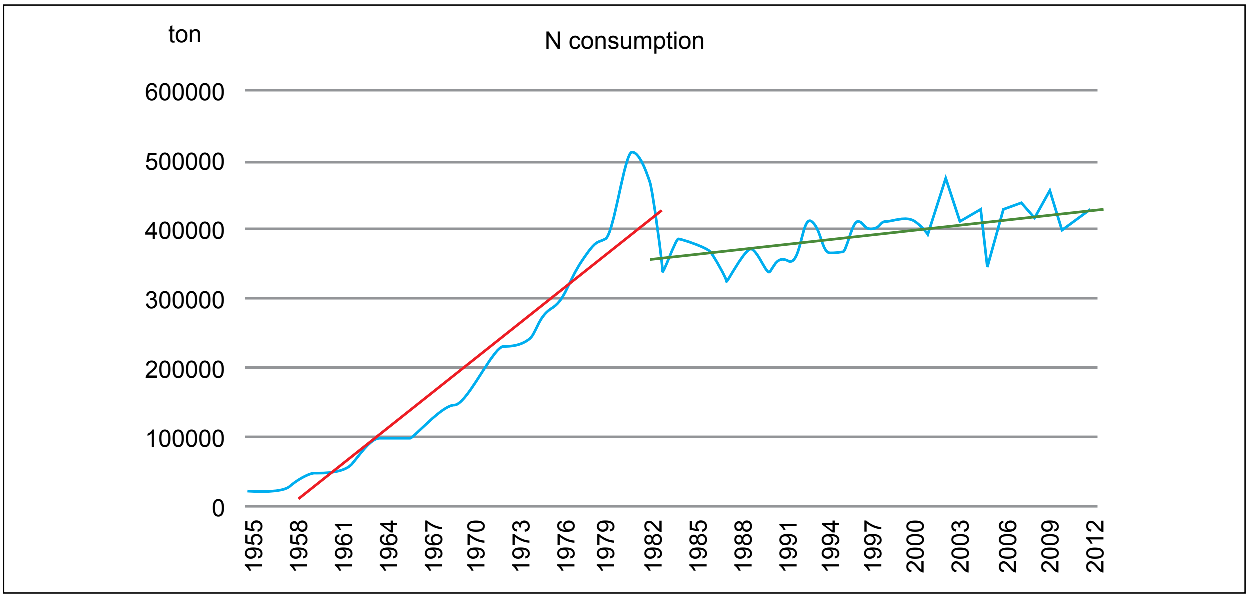

Figure 5: Fertilizer Consumption (Fertilizer Association of South Africa; GrainSA, 2011)

2.2.4.2. Nitrogen from manure application and deposition of urine and dung

Nitrogen from animal manure that is applied to fields is calculated from the livestock and manure data provided in sections 2.2.1 and 2.2.2 as it is dependent on the amount of manure produced. Similarly, urine and dung N application in pastures is also dependent on the amount of manure produced, but this also takes into account manure management practices. Projections were based on the livestock numbers.

2.2.4.3. Nitrogen from crop residues

The amount of crop residue available for application was determined by obtaining the yield data for each crop (FAOStat, 2013) and multiplying this with a residue to yield ratio (Moeletsi et al., 2015). This was then multiplied by the percentage residue retained (Moeletsi et al., 2015). Finally the N content of the residue applied to the field was determined by multiplying the residue retained by a dry matter fraction and a carbon fraction to nitrogen content ratio (Moeletsi et al., 2015). BFAP (2015) reported projected crop area and yield estimates for the major crops to 2024, therefore, crop residues could be calculated for this period. These numbers were then extrapolated to 2050. For the crops where there was no projected data, historical trends were extended.

2.2.5. Emissions modelling for managed soils N_2O

Emissions of N_2O from soils, through the process of nitrification and denitrification, are dependent on the amount of N available in the soil. Emissions are, therefore, determined by multiplying the nitrogen consumption by an N_2O emission factor. Nitrogen is added to the soils in various ways: synthetic fertilizers, compost or crop residues, manure application to the field or from manure and urine deposited on the soil by grazing livestock. Table 9 shows the possible mitigation actions and assumptions used in the calculation of the baseline. All data and validation sources are provided in Table 10.

Table 9: Mitigation Actions Which Could Affect N_2O Emissions and Related Baseline Assumptions

Mitigation actions considered	Baseline assumptions
• Reduction, or improvement of efficiency of use, of synthetic fertilizers • Use of animal and crop residues in biodigesters	• Fertilizer consumption continues at the current rate • Fraction of livestock population in fields remains constant • Manure management systems remain as they are currently • Amount of manure used for feed, fuel, construction remains constant • Ratio of crop residues retained remain at current levels • Emission factors kept constant

Direct N_2O emissions were calculated as follows:

$$N_2O_{Direct} - N = N_2O - N_{N\ Inputs} + N_2O - N_{PRP}$$

$$N_2O - N_{N\ Inputs} = \Sigma\,(F_{SN} + F_{ON})_i * EF_{1,i} + (F_{CR} + F_{SOM}) * EF_1$$

$$N_2O - N_{PRP} = [\,(F_{PRP,CPP} * EF_{3PRP,CPP}) + (F_{PRP,SO} * EF_{3PRP,SO})]$$

Where:
N_2O_{Direct}-N = annual direct N_2O-N emissions produced from managed soils (kg N_2O-N yr^{-1});
N_2O-$N_{N\ inputs}$ = annual direct N_2O-N emissions from N inputs to managed soils (kg N_2O-N yr^{-1});
N_2O-N_{PRP} = annual direct N_2O-N emissions from urine and dung inputs to grazed soils (kg N_2O-N yr^{-1});
F_{SN} = annual amount of synthetic fertilizer N applied to soils (kg N yr^{-1});
F_{ON} = annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils (kg N yr^{-1});
F_{CR} = annual amount of N in crop residues, including N-fixing crops, and from forage/pasture renewal, returned to soils (kg N yr^{-1});
F_{SOM} = annual amount of N in mineral soils that is mineralized in association with loss of soil C from soil organic matter as a result of changes in land use (kg N yr^{-1})
F_{PRP} = annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock (kg N yr^{-1})
CPP = Cattle, Poultry and Pigs
SO = Sheep and Other
EF_1 = emission factor for N_2O emissions from N inputs (kg N_2O-N (kg N input)$^{-1}$);
EF_{3PRP} = emission factor for N_2O emissions from urine and dung N deposited on pasture, range and paddock by grazing animals (kg N_2O-N (kg N input)$^{-1}$), CPP = Cattle, Poultry and Pigs, SO = Sheep and Other.

N_2O can also be emitted indirectly from atmospheric deposition of N volatilized from managed soils:

$$N_2O_{ATD} - N = [(F_{SN} * Frac_{GASF}) + ((F_{ON} + F_{PRP}) * Frac_{GASM})] * EF_4$$

Or from N leaching/runoff from managed soils in regions where leaching/runoff occurs:

$$N_2O_{LR} - N = (F_{SN} + F_{ON} + F_{PRP} + F_{CR} + F_{SOM}) * Frac_{Leach-H} * EF_5$$

Where:
N_2O_{AT}D-N = annual amount of N_2O-N produced from atmospheric deposition of N volatilised from managed soils (kg N_2O-N yr^{-1})
N_2O_{LR}-N = annual amount of N_2O-N produced from leaching and runoff of N additions to managed soils in regions where leaching/runoff occurs (kg N_2O-N yr^{-1})
$Frac_{GASF}$ = fraction of synthetic fertilizer N that volatilizes as NH_3 and NO_x (kg N volatilised (kg N applied)$^{-1}$)
$Frac_{GASM}$ = fraction of applied organic N fertilizer materials (F_{ON}) and of urine and dung N deposited by grazing animals

(F_{PRP}) that volatilizes as NH_3 and NO_x (kg N volatilized (kg of N applied or deposited)$^{-1}$)
$Frac_{Leach-H}$ = fraction of all N added to/mineralized in managed soils in regions where leaching/runoff occurs that is lost through leaching and runoff (kg N (kg N additions)$^{-1}$)
EF_4 = emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces (kg N-N_2O (kg NH_3-N + NO_x-N volatilised)$^{-1}$)
EF_5 = emission factor for N_2O emissions from N leaching and runoff (kg N_2O-N (kg N leached and runoff)$^{-1}$)

Table 10: Data Sources and Validation for the Managed Soils Emissions Calculations

Activity data	Data sources	Validation
Synthetic fertilizer consumption	Fertasa (http://www.fssa.org.za/) FAO (2005a)	FAO Statistics (http://faostat.fao.org/)
Compost and sewage sludge	DEA (2014a)	DAFF (2010)
Crop harvested area, yield and production data	FAO Statistics (http://faostat.fao.org/) BFAP (2015) Crop Estimates Committee GTI (2015)	Moeletsi, et al. (2015) GrainSA (2011) DAFF (2012)
Crop residue retained	Moeletsi et al. (2015)	IPCC 2006 Guidelines (IPCC 2006)
C fraction to N content	Moeletsi et al. (2015)	
Livestock data	As discussed in section 2.2.1.	
Emission factors and constants	IPCC 2006 guidelines (IPCC 2006)	

2.2.6. Uncertainties

The uncertainty on N_2O emissions from managed soils is high due to large uncertainties on both activity and emission factor data. Much of the uncertainty in this section is due to emission factor uncertainty. The uncertainty ranges for EF_1, $EF_{3PRP,CPP}$ and $EF_{3PRP,SO}$ are 0.003 to 0.03, 0.007 to 0.06, and 0.003 to 0.03, respectively (IPCC 2006 Guidelines, Table 11.1).

2.2.7. Managed soils: Lime and urea activity data

Data on limestone and dolomite consumption between 1980 and 2008 was obtained from Fertasa. There was a sharp increase in 1981 of both (to the highest levels ever recorded) and then a very sharp decline from 1981–1983. These points were excluded as they were skewing the data, and a trend was developed from 1984. Lime application is very variable but the overall trend shows a slow increase in limestone and dolomite use. Statistics SA supplied the urea data, but data was only available for 2004 to 2014. Data is variable but shows an overall 3.9% annual increase which was projected to 2050.

2.2.8. Emission modelling for lime and urea application

Table 11 shows the baseline assumptions for estimating the lime and urea application emissions, with the data and validation sources provided in Table 12.

Table 11: Mitigation Actions Which Could Affect Lime and Urea Application Emissions and Related Baseline Assumptions

Mitigation actions considered	Baseline assumptions
• Reduced or more efficient use of lime • Reduced or more efficient use of urea	• Rate of lime consumption continues at current level • Rate of urea consumption continues at current level • EF kept constant

Lime and urea application lead to the production of CO_2 which is calculated by:

$$CO_2 \text{ - C Emissions} = CE_{LIMESTONE} + CE_{Dolomite} + CE_{Urea}$$

$$CE_{LIMESTONE} = M_{LIMESTONE} * EF_{LIMESTONE}$$

$$CE_{DOLOMITE} = M_{DOLOMITE} * EF_{DOLOMITE}$$

$$CE_{UREA} = M_{UREA} * EF_{UREA}$$

Where:
CO_2-C Emissions = annual C emissions from lime and urea application (t C yr^{-1})
CE = annual C emissions from the application of each component (t C yr^{-1})
M = annual amount of calcic limestone, dolomite or urea applied (t yr^{-1})
EF = emission factor (t C (t limestone, dolomite or urea)$^{-1}$)

Table 12: Data Sources and Validation for the Lime and Urea Application Emissions Calculations

Activity data	Data sources	Validation
Urea consumption	StatsSA	FAO Statistics (http://faostat.fao.org/)
Lime consumption	Fertasa (http://www.fssa.org.za/)	FAO Statistics (http://faostat.fao.org/)
Emission factors	IPCC 2006 Guidelines (IPCC 2006)	
Nitrogen application rates	Fertasa (http://www.fssa.org.za/)	Moeletsi et al. (2015)
Crop area data	FAO Statistics (http://faostat.fao.org/) Crop estimates committee GTI (2015)	DAFF (2012)

2.2.9. Uncertainties

There is uncertainty in the activity data (amount of lime and urea applied); nevertheless emission factor uncertainty is likely to dominate. For urea it is assumed that all urea available for application (imports minus exports) is applied to the field. This approach may over- or under-estimate emissions in individual years, but in the long term the bias should be negligible (IPCC, 2006). Emission factors have a ±50% uncertainty for both urea and lime. The uncertainty ranges on EF4 and EF5 are 0.002 to 0.05, and 0.0005 to 0.025, respectively. For FracGASF, FracGASM and FracLEACH-(H), the uncertainty ranges are 0.03 to 0.3, 0.05 to 0.5 and 0.1 to 0.8, respectively (IPCC 2006 Guidelines).

2.3. Results and discussion

The agricultural baseline emissions are shown to increase from 50 568 Gg CO_2eq in 2010 to 69 621 Gg CO_2eq in 2050 (Table 13). This is a 37.7% increase. The livestock populations have the largest influence over emissions in this sector (60%) as they contribute to enteric fermentation, manure management and indirect N_2O emissions from manure management. Enteric fermentation and manure management contribute 55.4% and 3% respectively to the total agriculture baseline. The relative contribution from enteric fermentation doesn't increase, whereas from manure management it increases by 0.8%. Livestock numbers increase by 38.7% between 2010 and 2050 as feedlot cattle, pigs, poultry and game populations increase. The contribution from game to enteric fermentation increases from 48.1 Gg CO_2eq (3.9% of total enteric fermentation emissions) in 2010 to 190 Gg CO_2eq (11.3%) in 2050. Emissions from aggregated and non-CO_2 emission sources increases by 36.4% between 2010 and 2050. Direct N_2O emissions from managed soils are the largest contributor to this category, contributing 30.3% in 2010. This declines to a contribution of 27.0% in 2050, as the contribution from fertilizer application increases (Table 13). In the Long Term Mitigation Scenario report (Winkler, 2007), livestock were estimated to contribute a constant 20 000 Gg CO_2eq (see Table 3), whereas in this study the contribution from livestock is approximately 10 000 Gg CO_2eq higher in 2010 and this increases to almost double the original LTMS study projection




by 2050 (see Table 13). This is partly due to the addition of game, but also due to estimated increases in beef and feedlot livestock. The overall agriculture baseline numbers are in a similar range to those reported in the MPA study (DEA, 2014b) (which included enteric fermentation, manure management and direct N_2O), although a slight decline in emissions was reported.

Current agricultural emissions (DEA, 2014a) are found right on the baseline (Figure 6) as it basically represents the baseline. At this point the inventory does not reflect all the mitigation options either due to a lack of data, difficulties incorporating information into the equations, or because some actions have not been implemented yet. It is not always possible to include all actions into the inventory, for example, it is difficult to include a change in the timing of fertilizer application. However, as South Africa moves forward, the mitigation options need to be considered during the inventory update process to ensure that carbon reductions are being included.

Table 13: Agricultural Baseline Projections (Gg CO_2eq) Showing the Contribution from Livestock and Aggregated and Non-CO_2 Emission Sources on Land

	2010	2020	2030	2040	2050
Total for agriculture	50 568.01	54 282.82	60 852.48	66 201.91	69 621.35
Livestock	29 708.32	32 256.49	36 353.45	39 516.62	41 177.52
Enteric fermentation	28 139.89	30 457.99	34 187.25	37 103.13	38 550.78
Manure management	1 568.44	1 798.50	2 166.20	2 413.49	2 626.74
Aggregated and non-CO_2 emission sources	20 859.69	22 026.32	24 499.04	26 685.29	28 443.83
Liming	585.54	577.13	594.85	640.87	718.76
Urea application	478.69	724.41	1 096.26	1 658.97	2 510.54
Direct N_2O emissions from managed soils	15 097.01	15 749.39	17 218.19	18 316.03	18 813.55
Indirect N_2O emissions from managed soils	4 212.69	4 332.67	4 759.90	5 104.78	5 317.29
Indirect N_2O emissions from managed soils	485.76	642.73	829.84	964.64	1 083.70

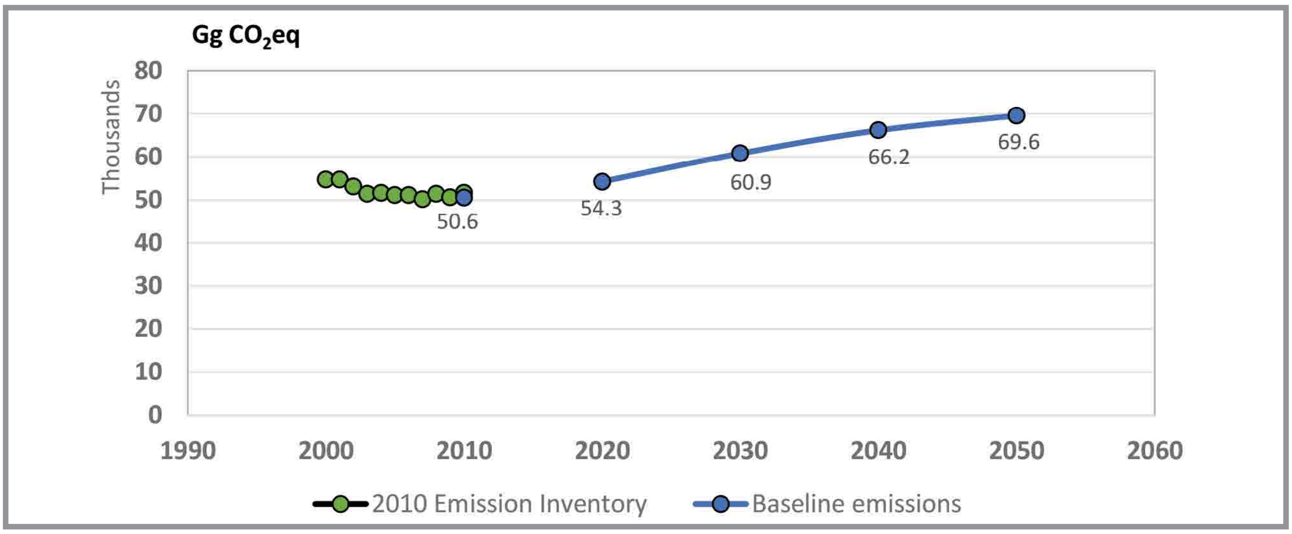

Figure 6: Agricultural Baseline and the Agricultural Emissions from the 2010 GHG Inventory (Gg CO_2eq). These emissions Do Not Include Biomass Burning Emissions as these are Incorporated in the Land Sector in This Report.

Enteric fermentation is the largest contributor, accounting for roughly 56% of the agricultural emissions (Figure 7). This is not unexpected as it is consistent with the current GHG inventory trends that enteric fermentation is a key category. The contribution to the total does decline slightly from 57.4% in 1990 to 55.6% in 2050. Enteric fermentation shows an increase of 37% between 2010 and 2050. The largest increase (424%) comes from emissions from urea application, however, the urea consumption data is highly variable and comes with high uncertainties. Urea consumption is determined from import and export data, and it is assumed that all urea is being applied to the field. It is, therefore, recommended that more detailed data be collected for urea consumption. One limitation of this model is that not all fertilizer types are included, and this can be another aspect which could be improved in the future. Indirect N_2O emissions from manure management increase by 123% between 2010 and 2050, while manure management emissions increase by 67%. Manure management emissions increase due to increasing feedlot cattle, piggeries and poultry. The mitigation option of biodigesters would assist in reducing these emissions due to the reduction in emissions from stored manure. Biodigesters are an important mitigation option as they have several co-benefits and provide emission reductions for more than one sector. Biodigesters can be used to produce electricity which reduces the dependence on the grid, reduces household waste and also contributes to a reduction in fuelwood use. The NTCSA (DEA, 2015) estimates that farm level biodigesters can contribute to a 4.37 million ton CO_2eq emission reductions over 20 years. It is not clear if these calculations include the savings due to reduced manure storage, so the mitigation potential could even be greater than suggested. Also these estimates do not include household biodigesters.

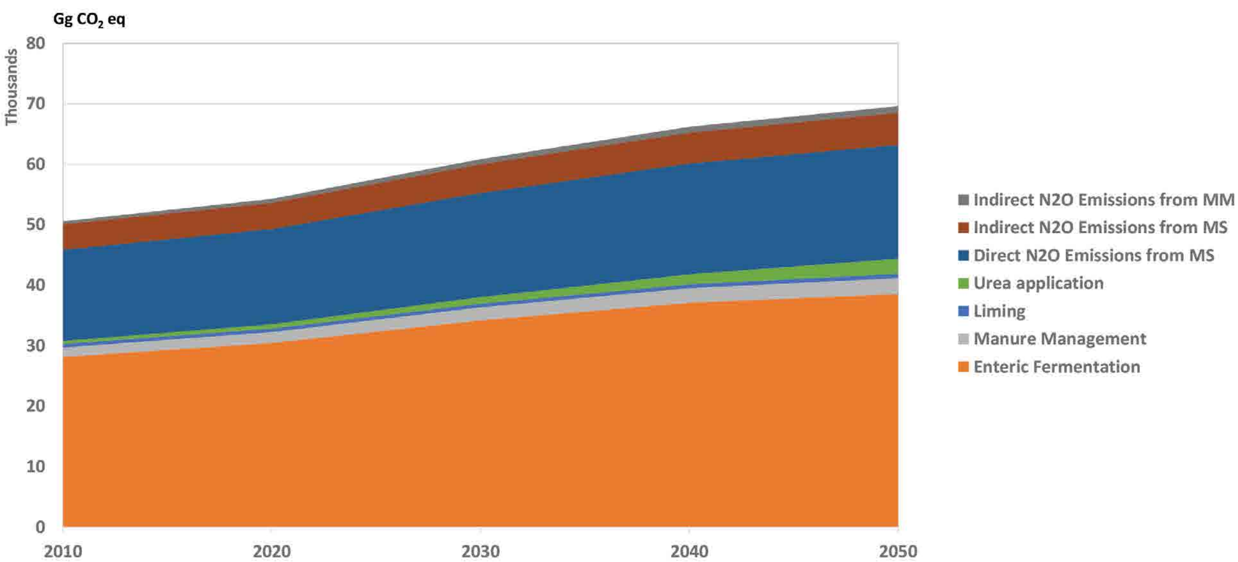

Figure 7: Contribution of the various categories to the agricultural baseline.

(MM = manure management; MS = managed soils).

Another aspect that has been included in this baseline, which hasn't been considered previously, is the game from private farms. These are included as private reserves and are considered to be managed, as farmers often farm intensively and provide feed to their game. This has shown to be increasing markedly and, therefore, is an aspect which needs to be monitored. The data in terms of population numbers is very uncertain due to there not being any central data collection point for this information. Data needs to be obtained from individual reserves, and hence the numbers in this model have been based on estimates determined from carrying capacities (Du Toit et al., 2013d). At this stage N_2O emissions from game deposits in the field are not included due to a lack of data and emission factors, and this could push the estimates even higher.

Mitigation options for the agriculture sector are not often highlighted in terms of the AFOLU sector as they are seen to have limited potential. This does not, however, mean that these options shouldn't be considered, especially since enteric fermentation is a key category in South Africa's GHG inventory. In terms of enteric fermentation there are two options for reducing emissions; namely, increase rumen efficiency and increase livestock productivity. The efficiency of the rumen to produce methane depends on diversity, size and activity of microbial population which are largely determined by diet. Methane emissions from livestock depend on the average daily feed intake and the percentage of this feed energy which is converted to methane. Options to increase rumen efficiency include: hexose partitioning, propionate precursors and genetic engineering. Increasing livestock productivity is a more viable option. It should be noted that a reduction in emissions would only result if total production remained constant and the advantages gained from increased productivity were realized by reducing livestock numbers. The options for improving livestock productivity include improving fitness performance in terms of reproductive rate and longevity (Scholtz et al., 2012); crossbreeding (which can increase weaning weight); breed selection for low residual feed intake (RFI) livestock (Nkrumah et al., 2006); manipulation of nutrition to reduce methane production; and breeding of new forage and pasture cultivars with lower CH_4 emissions. Research related to these activities should be supported going into the future.

In terms of reducing non-CO_2 emissions from managed soils (the CO_2 components are included under the land sector), there are a few options that can be implemented, such as improved fertilizer usage and an increase in legumes. However, as noted in the Draft Mitigation and Adaptation Strategy for DAFF (DAFF, 2015a), it is harder to reduce CH_4 and N_2O emissions than it is to increase carbon sequestration, and hence the focus in the NTCSA (DEA, 2015) on options that will impact soil organic carbon. The Draft DAFF Strategy also correctly states that even though the mitigation potential of the various options (for reducing CH_4 and N_2O) are low, the combined effect still can make a contribution to reducing agricultural emissions.

Finally, the agricultural emissions were split into provincial data to give a first broad estimation of which emissions would be important in the different provinces. All details are provided in Appendix A. The largest contributors to the overall agricultural emissions appear to be the Eastern Cape, Free State and KwaZulu-Natal; while Gauteng and the Northern and Western Cape are seen to be the smallest contributors. In all provinces enteric fermentation is estimated to be the largest contributor, although in Gauteng and the Western Cape the enteric fermentation is half of the overall emissions. Emissions from urea and lime application are highest in the Free State due to the increasing croplands in this province. The other provinces contributing to this category are Mpumalanga and North West.

CHAPTER 3: Land emissions baseline

3.1. Introduction

3.1.1. Land cover and land cover change in SA

National land cover surveys have been used for many years to determine changes in the South African landscape and the possible drivers behind the changes observed. Fairbanks et al. (2000) in a synopsis of South African land cover characteristics found that cultivation, afforestation and urbanization were the principal activities transforming land cover. In the year 2000 it was estimated that 12.2% of the country was under cultivation. An estimated 26% of grassland had been transformed through direct removal and alien shrub and bush encroachment. The exotic plantation industry, however, was found to be a larger driving force in the transformation of grasslands, particularly over the past 10 years.

Land capability assessments combine the three main natural resource elements of soil, climate and terrain to determine the production potential of specific areas and are based on the country-wide Land Type Survey of natural resources. The land capability analysis shows that a large proportion of the country (69%) is suitable for grazing. Currently livestock farming accounts for the largest land area used in the agricultural sector, followed by cultivated land. Approximately 81% of South Africa's surface is under farmland and only 11% of the country falls under arable land.

Land cover projections made during the NTCSA (DEA, 2015) revealed an overall trend of land transformation for South Africa that will continue to the year 2020. The transformation overall has resulted in a loss of indigenous vegetation. Historically, model projections found that between the years 2001–2010 the expansion of all cultivated land was the largest driver of land cover change in the country. This supports finding of Fairbanks et al. (2000).

Looking forward, modelled projections in the NTCSA for the period 2010–2020 showed a decrease in the area dedicated to sugarcane and subsistence cultivation while commercial agriculture continue to expand. In addition, mines, settlements and plantations were projected to increase in area with a corresponding decrease in thicket, savanna and grasslands (DEA, 2015). The department of Agriculture Forestry and Fisheries (DAFF) is currently pursuing a targeted nett afforestation rate of 10 000 hectares a year (DAFF, 2014; http://www.gov.za/about-sa/forestry). Overall the afforestation potential of the country is small with only the Eastern Cape and KwaZulu-Natal provinces having the potential to expand into new areas due the scarcity of water within the country and the stringent regulatory environment for afforestation (DAFF, 2015), as it is considered a streamflow reduction activity.

A recent land cover map developed by GeoTerra Image (GTI) for the Department of Environmental Affairs (GTI, 2015) shows that indigenous forests and plantations occupy less than 2% (2 300 011 ha) of South Africa's land surface. Just over 2% is occupied by settlements (3 235 841 ha), while woodlands/open bush and grasslands cover 10% (12 387 490 ha) and 21% (25 745 474 ha) respectively (Figure 8). Croplands cover a further 11%, with 1.6% of this being subsistence crops. In addition to this, a map was created for 1990 and land cover change between 1990 and 2013/14 were determined (Figure 9). Results showed that there was a 12.8% increase in woodlands/open bush and a 6.1% decline in grasslands. Settlement areas increased by 6%, while irrigated croplands increased by a massive 219.7%.

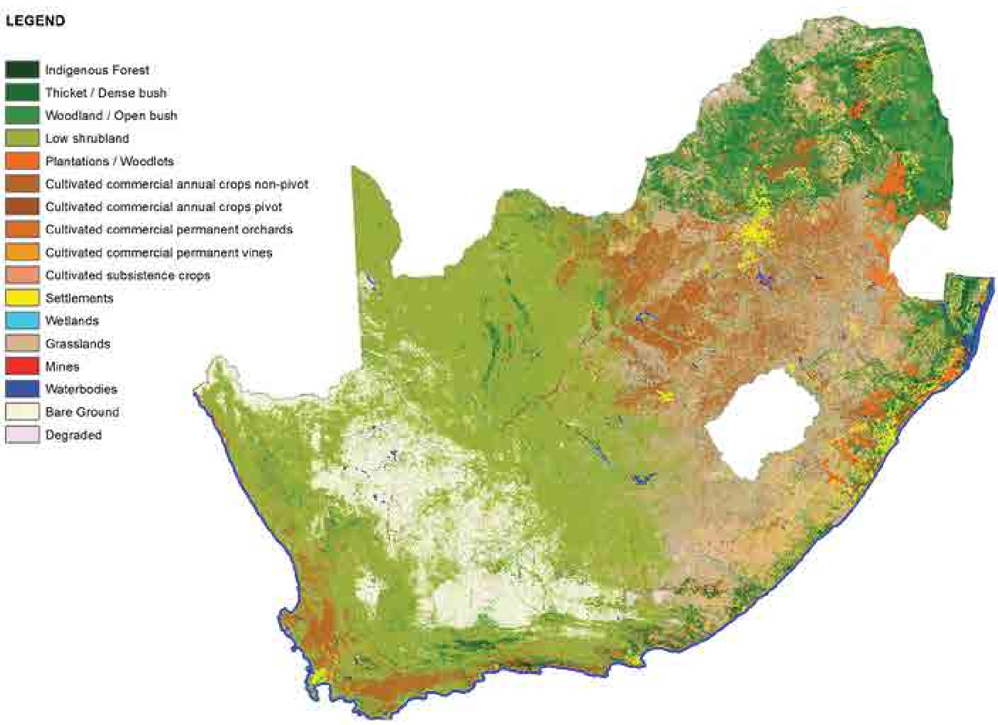

Figure 8: Land Cover Map of South Africa for 2013/14 (GTI, 2015).

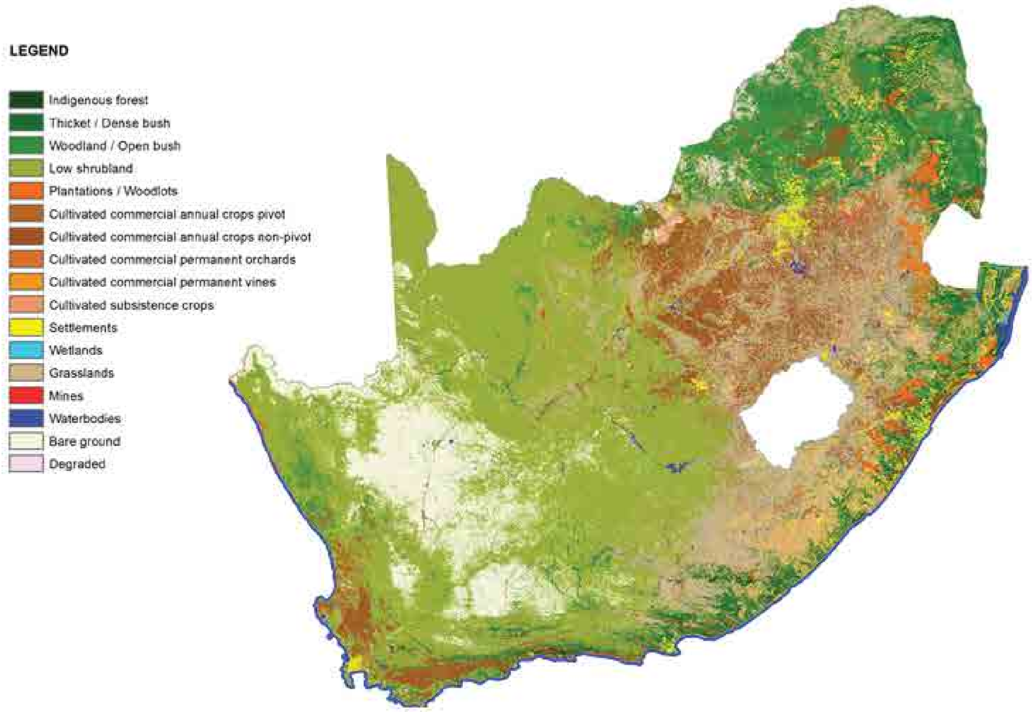

Figure 9: Changes in Land Cover in South Africa between 1990 and 2013/14 (GTI, 2015).

3.1.2. Land change drivers

Land cover change has significant impacts on the carbon sink potential of land. Examples of changes in land cover include the conversion of natural vegetation to agricultural crops and forest plantations; changes to natural vegetation through bush encroachment and overgrazing; soil erosion; and accelerating urbanisation. The main drivers of change as identified by the South African Land Cover Change Consortium include: environmental, political, social and economic growth and their associated land use practices (agriculture, forestry and mining).

Environmental drivers consist of increases in CO_2, nitrogen deposition, rainfall, bush encroachment, land degradation, grazing, fire and climate (Gillson et al., 2012; Higgins et al., 2015; Hoffman and Todd, 2000; DEA, 2015). Political drivers include those of historical land use and land policies, land reform and land tenure. Policies can also influence the expansion of agricultural areas, protected areas and the built environment. Furthermore, policies related to water use and distribution will also have significant impacts on land use. Economic drivers consist of the carbon market, foreign investment, commodity prices and foreign aid. Social drivers incorporate human population growth (e.g. immigration into an area, birth rates and death rates), economic status and per capita consumption. Human population growth also drives industrialisation, energy demand (fuelwood consumption) and food provision. These activities feed into land use practices, mainly agricultural, forestry and mining. The expansion or contraction of such activities largely drives land cover change (Gillson et al., 2012).

To add to the complexity, there are direct and indirect activities involved in any given driver and the level of activity is what gives drivers their momentum and potential for change. There are also primary and secondary drivers in any one category of land cover that can be interchangeable in another category or at a future point in time within the same category depending on the level of activity. This makes identifying drivers at a national level and making future projections based on historic trends a challenging process as certain drivers may not apply at a future date. Therefore, there is a large amount of uncertainty associated with the projected data.

An increase in population is a driver of land use change, with conversion of land to settlements, mines and croplands. Predictions of the future population of South Africa vary according to different prediction methods, but it is roughly estimated to be more than 57 million in 2030 and over 63 million by 2050 (United Nations, 2013; http://databank.worldbank.org), although some predictions are as high as between 78 and 89 million by 2050 (Go et al., 2013). The level of urbanisation is currently estimated at between 60 and 70% of the population and shows an increasing trend. Rural population size increased by 9% between 2007 and 2014, while urban population size increased by 29% over the same period (BFAP, 2015). At current population growth rates, arable land per capita is set to decline from 0.4 ha per capita to around 0.3 ha by 2030 (DEA, 2006).

Climate variability is another important driver. Studies show that certain commercial cultivation activities are decreasing, in particular maize and wheat as these are strongly influenced by climate change. The area planted to maize dropped from 4.49 million ha in 1980 to 3.14 million ha in 2012, with the wheat planting area shrinking from 1.63 million ha to 511,000 ha over the same period (Statistics South Africa, 2013). Current projections indicate that the area planted to yellow maize will exceed that planted to white maize in the year 2021 given current consumption patterns that result in a flat demand for white maize in the food consumption market, compared to the continued growth in demand for animal feed.

Wheat-producing regions in marginal areas of the winter rainfall region are currently projected to suffer losses of 15–60% by 2030–2050, due to predicted climate change (Midgley et al. 2007). Wheat cultivation in the winter rainfall areas is projected to decline by approximately 40 000 ha as producers progressively incorporate canola in crop rotation systems (BFAP, 2015). Wheat planted under dryland conditions in the summer rainfall regions has also shown a declining trend but is projected to stabilize by 2024 (BFAP, 2015). A major contributor to declining yields in wheat production is the seasonal variability in rainfall pattern experienced across the country. Thus a primary driver determining the expansion of commercial cultivation is localised climatic conditions, especially with regards to maize and wheat. Secondary drivers of commercial maize and wheat production are social and political drivers, as these two commodities form a staple food source for many communities as well as a traditional food source. This places more pressure on commercial expansion to keep up with demand for food security despite the climatic pressures and means that these land use practices in particular will most likely be driving future land cover change over the projection period.

Land degradation leads to the transformation of landscapes, and the restoration of degraded land is seen as an important mitigation option for South Africa. Land degradation is a composite term which has no single identifiable feature, but is rather how land resources have changed for the worse. Land degradation is the temporary or permanent lowering of the productive capacity of land (UNEP, 1992). It thus covers the various forms of soil degradation, adverse human impacts on water resources, deforestation, and lowering of the productive capacity of rangelands. Desertification is a component of land degradation (and is land degradation in arid, semi-arid and dry sub-humid areas) resulting from adverse human impact (UNEP, 1992). Land restoration is the reversal of the land degradation processes by conversion to restorative land uses, adoption of recommended management practices and amendments (i.e. any material added to a soil to improve its processes and properties) to enhance land resilience and restoration of soil functions and ecosystem services.

Areas of severe degradation and desertification in South Africa are perceived to correspond closely with the distribution of communal rangelands and where overstocking occurs, specifically in the steeply sloping environments adjacent to the escarpment in Limpopo, KwaZulu-Natal, and the Eastern Cape (Hoffman & Todd, 2000; Biggs et al., 2004; Boardman et al., 2003). Soil erosion is a cause of land degradation, and recent erosion maps and estimates show that all provinces are affected by erosion. The Northern and Eastern Cape, in alignment with perceived trends, are the most severely affected provinces according to the maps. Estimates in the Peddie District in the Eastern Cape show an increase of 12–13% and 2–6% in sheet and gully erosion, respectively, between 1938 and 1988 (Hoffman & Todd, 2000). Over 0.7 million ha of land is degraded and left bare by soil erosion (sheet and gully erosion); 4.6 million ha of natural vegetation are degraded, mainly in indigenous forests, woodlands, and grasslands; a further 0.2 million ha are degraded by mine tailings, waste rock dumps, and surface-based mining according to DEAT (2006).

Erosion is a form of land degradation, and research shows that 70% of South Africa is affected by varying intensities of soil erosion (Garland et al., 2000). Hoffman & Todd (2000) indicated that 25% of the country is highly susceptible to wind erosion, however, water is the dominant agent resulting in erosion within the country (Le Roux et al., 2008). Erosion is a natural process but is accelerated by human activities such as vegetation clearing for agricultural and land use purposes along with poor land management practices. Loss of fertile topsoil and reduction of soil productivity is coupled with serious off-site impacts. The increased soil mobilization leads to the sedimentation of rivers and associated rise in pollution levels. Le Roux et al. (2008) assessed water erosion at a national scale to derive potential and actual erosion maps. Comparison of potential and actual erosion is important in policy development as it indicates those areas that are inherently susceptible to erosion (potential risk), but which are currently protected to some extent by vegetation cover (actual risk) (Gobin et al., 2003).

3.1.3. Land activities covered in the land emissions baseline

The Land sector includes carbon changes in:

- Forest land,
- Cropland,
- Grasslands,
- Wetlands,
- Settlements,
- Other land, and
- Emissions from biomass burning.

The base year for the projections was 2014 as this was the final date of the land change map, therefore, projections were made based on the cover in this year.

3.2. Methodology

3.2.1. Land cover maps and vegetation classes

The 2013/2014 land cover change data (DEA, 2015) recently produced for the GHG inventory was the basis for the land cover projections. The original maps had 72 classes but for the purpose of determining emissions these classes were condensed to 17 (Table 14). Furthermore, the land change mapping between 1990 and 2013/14 was only done on the 17 land classes. Most of the remaining classes were related to land use, many of which fall within the settlement or mine categories. Emissions were determined based on these classes, but then these were further condensed to the 6 main IPCC classes (Table 14) for reporting purposes. There is always some debate as to the classification of the classes into these six categories, especially when it comes to the woodlands. In some countries, such as Australia, the savannas are placed within the grassland category. However, the classifications in Table 14 are currently being used by the GHG inventory, therefore, to maintain consistency in reporting, the baseline was also calculated using this classification.

Table 14: Land Cover Classes of South Africa

IPCC Land Class	Sub-categories
Forest Land	Indigenous Forests
	Plantations/woodlots
	Thicket/dense bush
	Woodland/open bush
Cropland	Cultivated commercial annual crops (pivot)
	Cultivated commercial annual crops (non-pivot)
	Cultivated commercial perennial crops (viticulture)
	Cultivated commercial perennial crops (orchards)
	Cultivated subsistence crops
Grasslands	Grasslands
Settlements	Settlements
	Mines
Wetlands	Wetlands
	Waterbodies
Other Lands	Low Shrublands
	Bare ground
	Degraded land

BOX 2: CONSISTENT LAND CLASSIFICATION AND DEFINITIONS

One of the challenges in developing the baseline is the inconsistent classification of vegetation classes. This makes it difficult to compare and validate data sets. All maps are developed for a particular purpose and so the classifications used are usually project relevant. For example, in the classification of the 2000 land cover data set (NLC2000), the MODIS maps developed for the 2010 GHG inventory (GTI, 2013) and the recent land cover maps (GTI, 2015) different areas for various vegetation classes are provided (Table 15). The differences in areas are partly due to differences in classification but also due to different resolutions. For example the MODIS 2010 maps were a resolution of 1km whereas the 2013/14 map has a resolution of 30m. Data can, therefore, not be accurately compared. For emissions reporting South Africa needs to develop a standard classification system that can be used for mapping land cover, land use and change mapping. The classification system can be flexible in that it should be able to be collapsed or expanded into the relevant categories required for the different reporting purposes. The classification which DAFF uses for forests and REDD+ (Reducing Emissions from Deforestation and Forest Degradation) activities, as well as the maps for the GHG inventory all need to be consistent so that South Africa presents clear and defined classifications to the international bodies. The Department of Rural Development and Land Reform has started to develop a uniform classification system, through the Spatial Planning and Land Management Act (SPLUMA), and this effort needs to be supported, but it is important that the requirements for inventory and baseline reporting are also considered when developing the classification system.

The land sector inventory is still developing and during this process the needs and requirements in terms of mapping are becoming evident. The level of detail is still being deliberated as there is a fine line between too much detail, which then has to be consistently kept up, and insufficient detail. As the inventory sector develops the appropriate amount of detail will become clearer.

In addition to these challenges, for projecting into the future there also needs to be more data on land change, i.e. the maps need to be developed using the same methodology and classification system over time so that land change and transformation trends can be established. Similar problems have been noted in other reports (WCDEA & DP, 2013).




Table 15: A Comparison of Vegetation Classes and Land Areas for the NLC2000 (CSIR), MODIS 2001 LC map (GTI, 2013) and the National 2013/14 LC map (GTI, 2015). For comparison purposes areas have been estimated for the year 2000 using a linear extrapolation of the land change maps.

IPCC category	NLC2000	Area (ha)	Vegetation class for the MODIS 2001 LC map	Area (ha)a	Vegetation class for 2013/14 LC maps	Area (ha)b
Forest land	Indigenous forest	527 048	Indigenous Forest	557 483 (552 997)	Indigenous Forest	376 650 (428 444)
	Thicket	3 782 900	Thicket	3 395 581 (3 328 715)	Thicket/Dense bush	6 645 984 (8 291 669)
	Woodlands	10 839 102	Woodlands/ Savanna	36 963 800 (36 790 970)	Woodland/Open bush	11 007 836 (12 434 932)
	Savannas	19 884 675				
	Plantations		Plantations	2 297 293 (2 279 219)	Plantations/ Woodlots	1 922 829 (1 873 701)
Cropland	Cultivated land	12 602 400	Annual commercial crops (non-pivot)	5 841 137 (5 837 445)	Cultivated commercial annual crops non-pivot	11 486 563 (10 610 838)
			Annual commercial crops (pivot)	334 348 (344 358)	Cultivated commercial annual crops pivot	244 268 (782 049)
			Permanent crops (orchard)	162 435 (165 843)	Cultivated commercial permanent orchards	313 571 (346 950)
			Permanent crops (viticulture)	231 286 (231 850)	Cultivated commercial permanent vines	162 354 (188 711)
			Annual semi-commercial / subsistence crops	709 996 (693 425)	Cultivated subsistence crops	1 984 303 (2 040 527)
			Sugarcane	225 603 (239 813)		
Grassland	Grasslands	25 759 325	Grassland	24 306 160 (24 485 269)	Grasslands	27 490 966 (25 793 973
			Fynbos	5 929 312 (5 910 879)		
Settlements	Settlements	1 832 725	Settlements	1 767 650 (1 777 353)	Settlements (incl. smallholdings)	2 742920 (2 908 280)
			Mines	200 574 (196 066)	Mines	291 756 (328 973)
Wetlands	Wetlands	2 268 400	Wetlands	1 1 099 356 (1 106 767)	Wetlands	1 526 138 (1 025 900)
	Waterbodies	528 550	Water Bodies	1 867 776 (1 834 430)	Waterbodies	2 202 041 (2 045 618)
Other lands			Bare Ground	13 813 697 (15 634 395)	Bare Ground	13 902 450 (13 057 933)
	Other land	995 300	Other	1 187 891 (1 166 441)		
	Arid shrubland	32 500 450	Nama-karoo	15 570 787 (14 138 005)	Low shrubland	41 139 829 (41 827 260)
	Fynbos and shrubland	9 242 350	Succulent karoo	5 600 588 (5 348 415)		
					Degraded	1 489 359 (944 061)

• Number provided is for 2000 which was estimated from linear extrapolation of the 2001-2010 MODIS LC maps (GTI, 2013). Number in brackets is the actual value from the 2001 map, i.e. the value for the year 2001.
• Number provided is for 2000 which was estimated from linear extrapolation of the 1990-2013/14 LC change map (GTI, 2015). Number in brackets is the value from the 2013/14 map, i.e. it is the area for the 2013/14 period.

3.2.2. Land cover projections

Projecting land cover and land use change is extremely challenging and the projections made here should be used in light of the assumptions that have been made. This provides a first estimate but future improvements and adjustments will need to be made so as to incorporate more land use change details to improve the forward projections.

There are different methods that could be applied to project the land change. In the NTCSA (DEA, 2015) projections to 2020 were estimated by using a spatial modelling approach which required the input of various spatial data sets. The difficulty associated with using this methodology is evident when projections have to be made to 2050, as it is a challenge to get detailed maps of future plans beyond 2020. For this study we adopted a different approach by utilizing information from land cover change maps. The base maps used to determine change were the 1990 and 2013/14 land cover maps recently developed by GeoTerra Image for the DEA (GTI, 2015) from Landsat 8 imagery. As a starting point, annual rates of land cover change were calculated from these maps, and then additional data provided information to restrict or validate the change rates.

Before the projections are presented a few points regarding the base maps need to be noted. There are several factors which can influence the outputs of the land change maps. For example, the time of the year when the maps were created, or whether it was a wet or dry year etc. In the 1990 and 2013/14 maps it needs to be considered that 1990 was a much wetter year than 2013/14. The seasonal representation and range of monthly acquisition dates was generally better for the 1990 land-cover dataset, than used for the 2013/14 dataset, despite the same average number of acquisition dates per frame being used for the two datasets. This is because the 2013/14 dataset was limited to what cloud free imagery was recorded between April 2013 and the designated March 2014 cut-off, whereas the 1990 dataset had access to a wider range of imagery from 1989–1993. This greater seasonal representation may have influenced the modelling results in terms of the distribution and extent of some of the natural vegetation classes (excluding indigenous forests), since a better seasonal profile was often possible in 1990 compared to 2014 in some image frame locations. Furthermore, the 1990 period appears to have been generally wetter than the 2013/14 period in most regions, as observed through the increase in observable surface water features in 1990. These differences will reflect as changes between the two assessment periods but do not necessarily represent a permanent loss of water bodies over the ± 24 year period, but rather a seasonal (or climatic) induced difference. More frequent land cover and land use change maps or detection systems would provide more information to assist in determining which trends are more likely to be occurring as opposed to those that are due to seasonal changes. There are also challenges of consistency when dealing with several maps. The development of the maps and the classifications need to be consistent over the various time periods otherwise the real change is hard to detect (Box 2). Hence the importance of developing standard methods and procedures going forward.

The first step in the projection process was to determine the annual rate of change based on the 1990 and 2013/14 maps, and this was done on a provincial level (Table 16). The rate of change in the transformed landscapes (plantations, settlements, mines, cultivated lands, as well as the smaller indigenous forest category) were investigated in more detail by obtaining data from literature and expert opinions. This information was used to restrict the rates of change for these categories. This process is discussed in the sections below. In the next step the natural vegetation classes were added and the areas were normalized to the provincial areas. In other words the natural vegetation areas were allowed to decline or increase (based on the rate of change established from the 1990–2013/14 change map) against the increasing transformed land categories. This approach led to slower rates of change than were projected between 1990 and 2013/14. This slower change rate could be considered more appropriate, as a baseline is required to take a conservative approach.




Table 16: Annual Provincial Percentage Change in Land Cover between 1990 and 2013/14 (Source: GTI, 2015)

	Limpopo	Mpumalanga	Gauteng	Free State	North West	Northern Cape	Western Cape	Eastern Cape	KZN	Average
Indigenous forest (%)	0.70	1.42	56.2	0.46	1.34		0.05	0.74	0.47	0.57
Thicket/ dense bush (%)	0.15	1.52	0.44	1.16	-1.09	-0.92	1.44	3.31	0.78	1.05
Woodland/ Open bush (%)	0.67	-0.20	0.82	-0.81	0.34	-0.19	1.34	4.83	0.86	0.54
Low shrubland (%)	-0.73	-2.14	-2.70	2.02	0.41	-0.10	0.30	-0.35	-1.95	0.07
Plantations/ woodlots (%)	-1.00	0.05	-1.47	-0.15	-0.65	-1.42	-1.35	0.04	0.15	-0.11
Commercial annual crops (non-pivot) (%)	-0.84	-0.53	-0.21	-0.21	-0.57	-0.79	-0.14	-0.43	0.49	-0.32
Commercial annual crops (pivot) (%)	-2.93	10.9	8.87	20.4	10.6	4.68	12.0	17.2	10.8	6.69
Commercial permanent orchards (%)	1.68	1.47	2.41	1.96	0.06	1.19	-0.08	-0.76	0.01	0.44
Commercial permanent vines (%)						0.43	0.73			0.68
Cultivated subsistence crops (%)	-0.56	-1.14	-2.34	2.34	-0.60	-0.42	-1.24	0.27	1.26	0.11
Settlements (including smallholdings) (%)	1.20	0.83	0.44	0.64	0.57	0.75	0.52	-0.12	-0.24	0.25
Wetlands (%)	-1.71	-0.59	-0.63	-1.65	-2.59	-2.64	-1.03	-1.26	-0.82	-1.37
Grasslands (%)	-1.18	-0.08	-0.12	-0.61	-0.49	1.54	-1.10	0.37	-0.61	-0.26
Mines (%)	-0.05	2.79	-0.68	-0.05	1.23	-0.08	2.10	-1.93	-0.08	0.53
Waterbodies (%)	1.06	0.47	-0.01	-1.63	-0.94	-2.49	0.05	-0.13	-0.26	-0.89
Bare ground (%)	26.4	9.76	4.06	5.03	91.0	0.20	-0.81	-2.63	4.34	-0.26
Degraded (%)	-0.97	-2.21	-2.48	-3.55	8.05	-4.16	-2.22	-3.71	-2.15	-1.53

A limitation of the provincial projections is that changes are limited to the borders of each province, however, the overall national land changed was checked for consistency. Considering the challenges related to using provincial data, it is recommended that future baseline projections be based on national land change data.

3.2.2.1. Indigenous forests

Indigenous forests showed an increase of 51 793 ha between 1990 and 2013/14; which translates to a 2 158 ha per year increase if it is assumed that the change is linear. An increase is shown in all provinces with the largest increase occurring in Gauteng (although the area in Gauteng is very small). The forests in Gauteng are most likely artificial urban forests and so this could be a classification issue. This is perhaps an issue which could be further assessed in the next iteration of the land cover maps. The overall point is that forest land in Gauteng is increasing and this raises the question of how important urban woody vegetation is to the provincial GHG inventories. Earlier maps derived from MODIS data (GTI, 2014) which showed change from 2001–2005–2010 indicated that indigenous forests declined by an almost similar amount. These latter maps are at a lower resolution but the variance indicates that there is uncertainty in this change. According to the Food and Agriculture Organization of the United Nations Forest Resource Assessment Report (FAO, 2010) natural forests are stable but there is evidence on the ground that indicates a decline in some areas and expansion in others. Furthermore, in the NTCSA (DEA, 2015), projections were made for the year 2020 and this indicated that the change in indigenous forests between 2010 and 2020 would be almost insignificant. The Protected Area Expansion Act (DEA, 2010) aims to protect 23% of the forest area over 20 years, with 1.7% of this still required to meet the target. This will protect the existing forests but will not increase the coverage area of indigenous forests. Therefore, for the purpose of the baseline, which indicates a business as usual strategy, it is assumed that expansion will not occur, and no change in the indigenous forest area over the projected time period was assumed.

3.2.2.2. Plantations

Plantations at a national scale are shown to increase by 1.5%. This varies across the provinces with Mpumalanga and the Eastern Cape showing increases, while other provinces show a small decline. The Forest Resource Assessment (FAO, 2010) reports that there was an insignificant decrease which may be attributed to the fact that there had been very little new afforestation over the decade before 2010. This could also be due to the delayed replanting of temporary unplanted areas (TUPs). This assessment also indicates that plantations increased by 8.4% between 1990 and 2010, but the increase slowed from 6% between 1990 and 2000, to 0.7% between 2005 and 2010. It suggests that expansion is expected to be significant due to afforestation plans going to 2020. Although over 8000 ha of virgin land was planted since the signing of the Forest Charter in 2009, the State of the Forest Report (2010–2012) (DAFF, 2015b) reported an insignificant increase in plantation area over this 2-year period, therefore, the data could be considered stable. Government did, however, announce that it was targeting approximately 100 000 ha of new land for afforestation (60 000 ha in EC and 40 000 ha in KZN) and the NTCSA indicates this amount is available for afforestation (DAFF, 2011; DEA, 2015). These increases are proposed and it is, therefore, not given that they will occur. Therefore, for purposes of the baseline it is assumed that there is no change in plantation area.

3.2.2.3. Cultivated land

The 1990 and 2013/14 change maps show a decrease in cultivated commercial annual dry land crops, and a massive 220% increase in cultivated commercial annual pivot crops. The DAFF and the Crop Estimates Committee agree that there has been a significant increase in pivot irrigation (Anneliza Collett, Pers Comm.; Terry Newby, ARC, Pers. Comm.). However, this information has not been analysed in detail so it cannot be said if this change was due to conversion from an existing irrigation system to pivots, or un-irrigated cultivated land converting to irrigated, or if it is new land put under cultivation. It is, however, doubtful that it is due to an increase in irrigated land given the current water situation. The Department of Water and Sanitation indicates that the availability of additional water for agricultural purposes is limited (Nic Opperman, AgriSA., Pers. Comm.). It is doubtful that water licences will be issued for further large new areas of irrigation due to water restrictions. According to South Africa's National Development Plan for 2030, 500 000 hectares of irrigation in agriculture could be established, however, estimates through the Department of Water and Sanitation show only 80 000 hectares to be available. The land capabilities map (extracting the agricultural land), protected areas map and erosion maps (water, wind and gullies (supplied by DAFF)) combined with the land cover map were considered in determining the area available for agricultural expansion. However, there are obviously other factors that come in to play as well, such as mines as there was still land indicated to be available for agriculture so it was difficult to restrict the data with these outputs. Part of the issues could also be related to mapping classification and scale. DAFF (Anneliza Collett, Pers Comm.), indicates that in their comparison of current cropland area to the land capabilities map it can be seen that there is very little land available for expansion in agriculture. Considering all this information, and adopting a more conservative approach, the pivot crops were restricted to a 2% per annum increase between now and 2030 (which would mean a conservative 140 000 ha addition), after which it was assumed, particularly in light of water restrictions, that there is no more expansion of irrigated crops. The projections produced by the NTCSA (DEA, 2015) estimate an insignificant change in pivot crops and a 12% increase in non-pivot crops between 2010 and 2020 (I.e. 1.2% increase per year). This is slightly lower than what is predicted in this baseline.

Orchards and vineyards are indicated to have increased by 10.6% and 16.2% respectively between 1990 and 2013/14, which is an annual increase of 0.44% and 0.68% respectively. The FAO Statistics (http://faostat.fao.org/) data on area planted to grapes and orchards also indicates an increase, although the percentage increase over the same period (1990–2013) is shown to be double these map estimates. This could be due to increases in productivity. The increases in orchards and vineyard areas are also supported by the earlier MODIS maps, but the MODIS maps also show that the increase has slowed over the period 2001 to 2010. The NTCSA projections estimated insignificant changes in orchards and vineyards to 2030. For the purposes of this project, the vineyards and orchards are taken to increase at the more conservative annual rate suggested in the 1990 and 2013/14 land cover maps.

3.2.2.4. Settlements

Settlement areas have been increasing with the area under urban and small holdings increasing by 6% between 1990 and 2013/14. This follows the increasing population trend. Settlement areas increased by 10–18% in most provinces, with Limpopo and Mpumalanga increasing by 28% and 20% respectively. A slight decline was seen in the Eastern Cape. It was assumed that settlements would continue to increase throughout the projection period.

3.2.2.5. Mines

The area under mines, although small, has increased over the last 24 years. This obviously varies across the provinces with land under mines increasing in Mpumalanga, North West and Western Cape (GTI, 2015). The increase is consistent with the NTCSA projections, although that report indicated a nearly 40% increase in mines between 2010 and 2020. This is much higher than the 6% increase shown between 1990 and 2013/14 (GTI, 2015). The Department of Agriculture, Forestry and Fisheries (DAFF) and the Bureau for Food and Agricultural Policy (BFAP) also highlighted the increase in mining rights and prospecting rights particularly in Mpumalanga as it is competing with agriculture and reducing the availability of high value agricultural land. The DAFF is therefore trying to formulate a policy to protect all high value agricultural land. Not all areas with prospecting rights will necessarily be mined, but the chances are that they will eventually be mined. Mines were, therefore, assumed to increase to the maximum area provided in the BFAP report (BFAP, 2015a) by 2050, for Mpumalanga, North West, Limpopo, Gauteng, and Free State. In future iterations of the baseline it is recommended that more detailed information regarding mining applications from the past and in the future be obtained from the Department of Mineral Resources. For other provinces the change in mines was assumed to be zero.

3.2.2.6. Degraded lands and bare ground

The degraded land on the 2013/14 land change map is defined as areas that have significantly lower total vegetation cover to surrounding areas. A significant portion of the difference in degraded areas between 1990 and 2013/14 could be attributed to the wetter conditions in 1990 compared to the drier 2013/14 conditions. It was, therefore, advised (GTI report, Mark Thompson) that an average area from both years be used as the total degraded area and assume no change. Degraded lands are, however, an important issue when it comes to mitigation, and stakeholders indicated the importance of incorporating degraded lands. For this section of degraded land, which is a relatively small area on the map (0.7% of 2013/14 area), the degradation index provided by Hoffman and Todd (2000) (Table 17) was used to assign a rate of increase. For provinces with a soil degradation index of 0-100 were assigned an increase of 0.5% per annum, 101-200 was assigned an increase of

2.5% and if the index was over 200 the province was assigned a rate of change of 5% per annum. As mentioned this area of degraded land was relatively small so other elements of degradation were incorporated as discussed below.

Degradation has many challenges as it is a complex issue due to there being varying types and degrees of degradation. Because of these complexities there is a large variability in the reported degraded areas across South Africa. There are different forms of degradation and these have been split into two main categories, namely soil and vegetation degradation. Soil degradation includes, amongst others, wind and water erosion, while vegetation degradation also includes the loss of vegetation cover. Maps have been developed for gullies[3] , water and wind erosion (data supplied by DAFF; Mararakayne & Le Roux, 2011; Le Roux et al., 2010) which assist in understanding soil degradation and its potential, but vegetation degradation is more of a challenge in that it is overlaid with the vegetation type, i.e. thicket or grassland degradation. In order to determine the changes in carbon due to degradation, information on the vegetation class is required as well (i.e. degraded grassland or degraded thicket). A change in carbon in a degraded thicket will have different impacts and values to degraded grasslands for example. This issue links with the requirement for mapping detail. Having a degraded category is useful for soil degradation; however, for vegetation the degraded category needs to be a component of each of the vegetation classes.

An alternative approach to determine degradation is through the use of remote sensing. There have been several local studies investigating this approach in South Africa (Gibson, 2006; Makhanya, 1993; Palmer and van Rooyen, 1998; Tanser and Palmer, 1999; Wessels et al., 2004; Archer, 2004). Other studies have also assessed the usefulness of long-term satellite derived biological productivity as an indicator of degradation (Herrmann et al., 2005; Olsson et al., 2005; Budde et al., 2004; Li et al., 2004; Diouf and Lambin, 2001; Sannier et al., 1998, Prince, 2002). Few studies have looked at larger provincial, national or regional scales of degradation using these techniques and thus this would be a recommendation for future research.

Soil and vegetation degradation are separated in this baseline. Vegetation degradation was incorporated into the relevant land categories, with gains and losses for degraded lands being reduced relative to intact areas (discussed further in the biomass methodology section). Degraded thickets were incorporated this way. It should be noted that a limitation of this approach is that thickets are incorporated into the forest land category and under this category soil carbon changes are assumed to be zero. Therefore, the impacts of thicket degradation on soil carbon are not included in the baseline at this stage and a mechanism for incorporating this in future should be considered. Determining the exact area of the degraded thickets is a challenge due to the varied thicket classifications, and the broader thicket/dense bush category included in the 1990 and 2013/14 land cover map. Van Luijk et al. (2013) indicated that almost half of South Africa's subtropical thickets are degraded.

This was also assumed to be the case in the NTCSA (DEA, 2015). This assumption was adopted in this baseline study with 0.46% of all thickets assumed to be degraded in 2014. Most of the literature provides an estimate of degradation at one point in time, but there is almost no information on the rate of degradation in order for projections to be made. A recent study by Nyamugama and Kakembo (2015) investigated transformation of thickets in the Eastern Cape between 1972 and 2010. This data shows that thicket degradation has slowed since 1972 to 0.5% per annum between 2002 and 2010. Thicket degradation was therefore assumed to increase by 0.5% per annum to 2050 in the Eastern and Western Cape thickets. For thickets in other provinces the degraded area just increased as the thicket area increased. Degraded woodlands are not yet included in this baseline due to insufficient detail in the extent of degraded woodlands in the maps and information on carbon changes, but this can be incorporated in a similar way to thickets in the future. Grassland degradation was incorporated in the grassland section, but it is only for the grassland area that remains as grassland, as without the detailed grassland categorization incorporated in the base map classification the land changes are difficult to include. Another limitation is that only soil carbon is considered, as biomass in grasslands is assumed to be in balance so no equations are included for grassland biomass changes at this stage. Information on the extent of degraded grasslands is lacking but the carbon sinks assessment (DEA, 2015) indicates that 10% of mesic grasslands is estimated to be degraded with 5% at risk over the next two decades. Matsika (2007) indicated that 12.8% of grasslands are degraded. Therefore taking a conservative estimate it was assumed that 5% of all grasslands are degraded. Therefore, 5% of the grassland areas in each province were assumed to be degraded and the soil stock change factor for degraded soils was applied.

For soil degradation it is assumed that once soil is eroded the land moves from its land classification into the degraded or bare ground category. This works on the assumption that eroded soil will become bare ground (sheet and gully erosion). It is noted that there are varying degrees of soil degradation and this detail may need to be distinguished in the future revisions. According to the land cover change maps there was an overall 6.1% decline in bare ground between 1990 and 2013/14, and if provincial data are considered then the change in bare ground varied between a 63.01% reduction in the Eastern

[3] SPOT 5 imagery for period 2006-2008; resolution of 2.5m (panchromatic sharpened) and 5m (multispectral bands merged with panchromatic; analysis in ArcGIS was conducted at a 1:10 000 scale for South Africa




Cape to a 635.08% increase in Limpopo and over 2185% increase in the North West. Hoffman and Ashwell (2001) also indicate that Limpopo is one of the most degraded provinces in South Africa, with the province having a high soil degradation index (Hoffman and Todd, 2000), however, the index for North West is relatively low (Table 17). The MODIS maps (GTI, 2014) indicated a substantial increase in the area of bare ground between 2001 and 2010, however, the NTCSA (DEA, 2015) reported a minimal change between 2010 and 2020. Erosion and land degradation studies by Le Roux et al. (2008) and Hoffman et al. (2014) respectively support the increases in bare ground, with over 0.7 million ha of land in the country estimated to be degraded and left bare by soil erosion (sheet and gully erosion).

The rate of increase in bare ground in Limpopo and North West needed to be restricted as it is not reasonable to continue this trend in the future as the entire province would become bare. The rate of change could be influenced by the wet/dry years, but some expansion of dry ground can be expected to occur due to increasing drought, cultivation and human populations which all contribute towards soil degradation. As with vegetation degradation there is very little information on the rate of change in degradation, soil erosion or desertification. In order to restrict the bare ground expansion, the gullies and potential water and wind erosion maps (supplied by DAFF) were overlaid with the land cover maps to determine the potential area for expansion. The area of gullies was found to be small compared to the existing bare ground category. For the potential water and wind erosion data the high risk zones were extracted and combined with the 2013/14 land cover map. There were potential erosion areas under almost all vegetation categories, but the literature (Le Roux et al., 2008) showed that actual erosion risk declines if there is vegetation cover. It was shown that most erosion is associated with transformations in croplands, grasslands and settlements. Based on this it was, therefore, assumed that bare ground could expand to all the potential high risk areas under these transformed categories by 2050. This data still showed that there was a high percentage of provincial area that could be eroded so the data could not be used to restrict the expansion particularly in Limpopo and North West (indicated to be able to expand degraded area by 10% and 33% respectively). Taking a conservative approach the rate of change to degraded land was limited to the lower 10% per annum.

Table 17: Degradation index for soil (SDI), vegetation (VDI) and a combined index for each province (Source: Hoffman and Todd, 2000).

Province	SDI	VDI	SDI+VDI
Eastern Cape	200	116	316
Free State	48	86	134
Gauteng	113	31	143
KwaZulu-Natal	253	187	440
Mpumalanga	143	81	223
Northern Cape	92	140	232
Northern Province	255	189	444
North West	149	122	270
Western Cape	292	183	475

3.2.2.7. Waterbodies and wetlands

As with degraded lands, the change in wetlands and waterbodies may not have been a reflection of true change due to 1990 being a wetter year than 2013/14. Therefore, an average area from the two years was determined for the wetland category (as indicated in GTI, 2014) and no change was assumed. Going into the future wetland areas may decline due to climate change, and dams may increase due to new proposed dams to collect more water during the dry periods ahead, but these changes in area are expected to be minimal. The NTCSA projections to 2020, also show minimal changes in these categories. Therefore, no change is assumed going into the future.

3.2.2.8. Woodlands, thickets, grasslands, and other lands

Woodlands, thickets, grasslands and other natural lands were allowed to decrease or increase (based on the change rates provided in the 1990-2013/14 change maps) at the expense of the transformed land categories. The land cover change map indicated a decrease in grasslands in nearly all provinces, however, it also showed an increase in woodlands/open bush and thickets/dense bush in most provinces. Therefore the projections show an increase in these woody vegetation classes. There is some discussion regarding the increase in woodlands and thickest in the discussion of this document (see section 3.3), however, here we consider the increase in thickets. The two provinces that show the highest increase in thicket area are the Eastern and Western Cape where thickets are shown to increase by 3.3% and 1.4% per annum respectively. This is interesting as literature suggests that these two provinces are the ones that have the highest rate of thicket degradation (although this does not mean the area coverage is reducing). The reason for this increase in thicket area should be investigated in further detail in future (perhaps mitigation activities on thicket restoration are starting to become evident), but literature evidence (Nyamugama and Kakembo, 2015; Mills and Fey, 2004; Stevens et al., 2015) suggests that the subtropical thicket areas in the Cape remains constant or show signs of decline due to transformations and desertification. Projections in the NTCSA (DEA, 2015) show a 2% decline in thickets, with the Eastern Cape in particular showing a loss. Due to this evidence the increase in the thicket areas in the Eastern and Western Cape was slowed to 0.5% per annum over the period 2014 to 2050.

3.2.3. Land use change

The 1990 and 2013/14 national land cover change maps have incorporated some aspects of land use into the maps. In the future it is more likely to be land use changes as opposed to land cover changes that will influence the emissions. So even if land cover remains the same in a category, it does not mean there aren't transformations in that category. The statistics on the 1990 and 2013/14 maps show that all land classes have a percentage of land which remains in that land category, while the rest of the land shows transformations to and from other land classes. It is these changes that influence the GHG emissions from land, for example it is the losses of carbon when a forest is converted to cropland that are incorporated into the emissions. Land that remains as a land category is assumed, unless it is forest land, to be in equilibrium (i.e. carbon gains and losses over a year are equal). For this project land use change matrixes for each province were determined from the land cover change maps (see Appendix B). From this the annual percentage change between each category was calculated. These annual changes between the land classes were assumed to continue going into the future. It is acknowledged that this is a major assumption and it comes with large uncertainties. Improved ways of incorporating land use change in future need to be determined.

3.2.4. Soil maps and soil carbon

Changes in soil carbon are calculated based on soil carbon reference values (see section 3.2.7.) which are calculated for each climate zone and soil type. A reference value is the soil carbon content of untransformed land, and it is the carbon content which a transformed land will eventually reach (over a default period of 20 years). Moeletsi et al. (2013) developed soil and long term climate maps based on the classifications suggested by IPCC. Instead of using default values for the reference carbon these values were derived from the AfSIS Africa Soil Property map data used for the carbon sinks assessment. This used 3,000 soil profiles from South Africa and 6,000 soil profiles from Africa. These profiles were analysed in a Bayesian statistical extrapolation technique to determine the distribution of organic carbon throughout South Africa at a 1 m depth. The data was integrated into ArcGIS 10 and extrapolated based on the 2013/14 Land-Cover dataset, climate and soil classification map to determine a soil carbon value for each soil type. Since a reference value is untransformed land, the land cover change map enabled the separation of the converted land data from the land remaining as a land class. In this way a reference soil carbon value was determined for only the untransformed 'land remaining land'. The climate map is very broad with nearly all of SA falling in the warm temperate zone. Both this climate map and the soil map are limiting and it would be advised that for the purpose of the inventory these maps be reconsidered and perhaps recreated with more detail. Also developing a set of soil reference values for the new soil classes would provide more country specific data.

3.2.5. Woody, herbaceous and litter biomass

Above ground biomass data for plantations was taken from the 2010 inventory (DEA, 2014) as these were derived from forestry data (Table 18). The NTCSA (DEA, 2015) was used as a source of data for other vegetation classes. The NTCSA

(DEA, 2015) developed a 'wall-to-wall' approach to calculate the mean stock and flux for woody biomass, herbaceous biomass and above-ground litter in South Africa. The above-ground woody biomass was estimated using ICESAT-GLAS remotely-sensed tree height and MODIS canopy cover. The below-ground woody biomass was derived from published literature on root to shoot ratios. Above-ground herbaceous and litter production was calculated using published relationships between rainfall and annual grass and litter production. The NTCSA (DEA, 2015) used the MODIS land cover maps, so some of the vegetation classes are different from the new 2014 map. To determine the biomass for these updated categories the carbon data from NTCSA study was integrated into ArcGIS 10 and extrapolated based on the 2013/14 Land-Cover dataset to determine the mean above-ground litter, woody and herbaceous biomass for each land class (Table 18). There were some differences between the data from the NTCSA and from the overlay of this data with the new land cover map. The indigenous forest biomass value estimated from the overlay was very low (19.5 t dm ha^{-1}) and the difference could be because the overall area of this class is very small. Therefore the value provided in the NTCSA report was used as it was found to be in a similar range to the IPCC default values. For the other categories values were in a similar range, therefore comparisons were made to IPCC default factors and literature was also assessed to determine the most appropriate biomass value for each category (Table 18).

Table 18: Biomass Carbon Stock Values for the Different Land Classes

Land class	Above ground biomass (t dm ha^{-1})	Data source
Plantations		Values for plantation species were calculated from FSA data and Dovey and Smith (2005) dry matter ratios
Eucalyptus grandis	84	
Other Eucalyptus	111	
Softwood pulp	71	
Acacia	132	
Other species	92	
Indigenous forest	140	DEA, 2015; IPCC GPG 2003; IPCC 2006
Thicket	60	Mills et al., 2005; Mills and Cowling, 2006; Lechmere-Oertel, 2003; DEA, 2015
Woodland/open bush	18	Scholes and Hall, 1996; Rutherford, 1982; Shackelton and Scholes, 2011; Colgan et al., 2012; DEA, 2015
Grasslands	6.1	IPCC 2006 Guidelines; DEA, 2015
Cultivated annual	10	IPCC 2006 Guidelines; DEA, 2015
Orchards	59	DEA, 2015 (overlay with 2014 LC maps); IPCC 2006; NIR Greece, 2014;
Vines	22	DEA, 2015 (overlay with 2014 LC maps); Morande, 2015; Mills et al., 2012; Williams et al., 2011;
Settlements	25	DEA, 2015 (overlay with 2014 LC maps)

3.2.6. Carbon stock change calculations

Unlike the agriculture data, the land change data was available at the provincial level. Therefore, emission models were developed for each province and then these were combined into a national file. In hindsight, this approach is limiting, particularly in terms of updating the provincial divisions as this requires a lot of data, and it is suggested to follow a national mapping approach in future. Table 19 shows the possible mitigation actions and assumptions used in the calculation of changes in carbon stock.

Table 19: Mitigation Actions Which Could Affect Carbon Stock Calculations and Related Baseline Assumptions

Mitigation actions considered	Baseline assumptions
• Restoration of sub-tropical thickets. • Small-grower afforestation • Restoration of grasslands • Reduced land degradation • Reduced tillage • Increased biochar application	• Thickets continue to degrade at current rate • No increase in plantations • Grasslands continue to decline at current rates • Degradation continues to increase at current rates • Tillage practices continue as they currently are (i.e. no increases) • No biochar application (soil carbon reference levels remain as they are)

3.2.6.1. Overall baseline

The overall change in carbon due to land use change is determined from the sum of the change in biomass, dead organic matter and soil organic carbon:

$$\Delta C_{LU} = \Delta C_B + \Delta C_{DOM} + \Delta C_{SOC}$$

Where:
ΔC_B = annual carbon stock change in biomass (t C yr^{-1});
ΔC_{DOM} = annual carbon stock change in dead organic matter (t C yr^{-1});
ΔC_{SOC} = annual carbon stock change in soil organic carbon (t C $yr^{-1)}$

3.2.6.2. Biomass

Biomass carbon changes for forestlands were determined via a gain-loss method. Gains are due all biomass growth, both above and below ground; while losses are due to removal of harvested wood, and losses due to disturbance and fuelwood collection.

$$\Delta C_B = \Delta C_G - \Delta C_L$$

$$\Delta C_G = \sum (A_{i,j} * G_{TOTALI,J} * CF_{i,j})$$

Where:
ΔC_G = annual increase in carbon stocks due to biomass growth (t C yr^{-1});
i = ecological zone
j = climate zone
A = area of land remaining in same land use category (ha)
G_{TOTAL} = mean annual biomass growth (t dm ha^{-1} yr^{-1})
CF = carbon fraction of dry matter (t C $(t\ dm)^{-1}$)




$$\Delta C_L = L_{wood\text{-}removals} + L_{fuelwood} + L_{disturbance}$$

$$L_{wood\text{-}removals} = \{H * BCEF_R * (1+ R) * CF\}$$

$$L_{wood\text{-}removals} = [\{FG_{trees} * BCEF_R * (1 + R)\} + FG_{part} * D] *CF$$

$$L_{wood\text{-}removals} = \{ A_{disturbances} * B_w * (1 + R) * CF * fd$$

Where:
ΔC_L = annual decrease in carbon stocks due to biomass loss in land remaining in same land use category (t C yr^{-1})
$L_{wood\text{-}removals}$ = annual carbon loss due to wood removals (t C yr^{-1});
$L_{fuelwood}$ = annual biomass carbon loss due to fuelwood removals (t C yr^{-1});
$L_{disturbance}$ = annual biomass carbon losses due to disturbance (t C yr^{-1})
H = annual wood removals (m^3 yr^{-1})
$BCEF_R$ = biomass conversion and expansion factor for conversion of removals in merchantable volume to total biomass removals (t biomass removed (m^3 of removals)$^{-1}$
R = ratio of below-ground biomass to above-ground biomass (t dm BG biomass (t dm AG biomass)$^{-1}$)
FG_{trees} = annual volume of fuelwood removal of whole trees (m^3 yr^{-1})
FG_{part} = annual volume of fuelwood removal as tree parts (m^3 yr^{-1})
D = basic wood density (t dm m^{-3})
$A_{disturbance}$ = area affected by disturbance (ha yr^{-1})
B_w = average above-ground biomass of land areas affected by disturbances (t dm ha^{-1})
Fd = fraction of biomass lost in disturbance

Annual biomass growth data for plantations was determined from forestry data on mean annual increments (Forestry South Africa), while literature was the source for indigenous forests, thickets and woodlands. For forests, an annual above ground biomass growth value of 1.5 tons of dry matter per hectare per year (t dm ha^{-1} yr^{-1}) was used as Midgley and Seydack (2006, 2007) reported that growth was 1% of AGB. Data for thickets were limited and variable. Mills and Cowling (2006) reported growth rates for above ground biomass of 0.04 to 0.131 grams of carbon per square meter per year (g C m-2 yr^{-1}) (or 0.85 to 2.76 t dm ha^{-1}) in thickets, which provides an average estimate of 1.8 t dm ha^{-1} yr^{-1}. This is the same as the IPCC default value for subtropical dry forest in Africa (>20yrs) (IPCC, 2006) and thickets have been likened to dry tropical forests. A limitation is that this growth rate is applied to the entire thicket/dense bush classification on the map. These growth rates are based on data from subtropical thickets, which contain Portulacaria afra (Spekboom) which are fast growing and sequester large amounts of carbon. This value may, therefore, lead to an overestimation of the annual carbon growth in thickets in general. Since thickets are particularly important in mitigation it is recommended to have further divisions of this thicket/dense bush category to allow for the incorporation of more specific carbon growth rates (if these are available as data on other thickets is very limited). For degraded thickets the above ground biomass is 15% of the intact thicket, while roots are half of the intact thicket (Powell, 2009; Mills et al., 2005). For Woodland/Open bush a value of 0.9 t ha^{-1} yr^{-1} was taken from the 2010 inventory (DEA, 2014) as this was shown to be consistent with values of 0.9–2.6 t ha^{-1} yr^{-1} from the literature (Scholes and Walker, 1993; Wessels, et al., 2013; Chidumayo, 1993; CHAPOSA, 2002; Malimbwi and Zahabu, 2009). The ratios of below ground to above ground biomass were 0.24 for woodlands/dense bush and 0.48 for thickets (DEA, 2014).

The plantation area was divided into the 5 different species so that species specific information could be utilized. Annual wood harvest from plantations has been recorded every year since 1980 (Forestry South Africa; http://www.forestry.co.za/). In order to project the data, an average volume of wood removal per hectare was calculated and then applied to the area of plantations determined for 2020 to 2050. This implies that there is an assumption that plantations will grow and be harvested at current rates and that there is no improved productivity over this time period. Similarly, for fuelwood removal and disturbance in plantations, it is assumed that current rates will continue.

Fuelwood removal from woodlands is a source of much uncertainty and is a factor which can have an impact on the carbon balance. Damm and Triebel (2008) estimated that approximately 11.2 t of wood are consumed annually. Rural communities are the main users of fuelwood and its consumption depends on the availability of other sources of energy, the cost of the energy and the income of the households. The number of households and percentage of households using fuelwood in each province (Statistics SA, 2014), was combined with an average household consumption (Shackleton, 1998; Shackleton & Shackleton, 2004; Madubansi & Shackleton, 2007; Matsika et al., 2013) to estimate fuelwood usage.

A BCEFR of 0.73 t biomass removed per m3 of removals was applied (DEA, 2009; IPCC 2006 Guidelines). There are uncertainties associated with this approach as a household may be reported to use wood, however, the consumption may be less than average due to the use of other energy sources. There are conflicting reports of the impact of electrification on fuelwood use, but there does seem to be a decline in fuelwood use (Wayne Twine, Pers. Com.; data from Agincourt Health and Socio-Demographic Surveillance System). It is suggested that the use of wood will however continue and not decline completely as it is traditional and cheap (particularly in the face of rising electricity costs). On the other hand, there are also reports that suggest the younger generation would rather make use of electricity or alternative fuels. Furthermore, there is a strong push to develop alternative sources of energy as there are numerous health issues associated with burning wood. Lastly, more households may be buying their wood or using charcoal which means a decrease in wood removal from woodlands. It can, therefore, be seen that there are numerous factors at play here and a model needs to be developed to estimate fuelwood use (at the national scale) from data such as population or income.

An assumption in this report is that rural communities are the main users of fuelwood; however, DWAF (2007) completed an aassessment of the Gauteng firewood market and the origin of protected tree firewood products sold. This report indicates that a total of 31 842 t per month of braai wood are consumed in Gauteng and Tshwane alone. This may indicate another area of fuelwood consumption which needs monitoring in the future.

A search of the literature indicated that models for determining fuelwood consumption are very few. FAO indicated that data for area-based wood fuel flow analyses are not often available and their collection is expensive and requires skilled personnel, therefore, FAO developed a model called Woodfuel Integrated Supply/Demand Overview Mapping (WISDOM). This is a spatially explicit method using geographic information system (GIS) technology for the representation and visualization of wood fuel consumption and production areas. This model was used by Serrano-Medrano et al. (2013) to project fuelwood and charcoal consumption in Mexico. This model requires various detailed input data (e.g. information on consumption per capita for mixed and excusive wood use, and saturation data), which was not available during this project, but this type of model could be used in the future to predict fuel wood consumption. This information would not only be useful for the AFOLU sector but also as an input for the energy sector.

For the purpose of this project, some assumptions were made regarding future fuelwood use. South Africa's electrification programme is set to continue to 2025, after which alternative sources will be explored. But it is also assumed that, with growing populations, there will be more remote households without access to electricity and fuelwood is the cheapest alternative. Therefore, it is assumed that the current rate of decline in households using fuelwood will continue to 2030, after which the rate will decline to half and quarter of the rate between 2030–2040 and 2040–2050 respectively, as rural populations increase and access to electricity slows.

Disturbance losses due to fire were determined for woodlands by using the biomass burning equations discussed later on.

Carbon stock changes in land that was converted to forests is calculated in the same way as described above, while carbon changes in other lands that are transformed are calculated in a two phased approach. Phase 1 is the loss of carbon due to the clearing of the land when it is transformed ($\Delta C_{CONVERSION}$), and phase 2 is the carbon change due to 1 years' worth of growth (minus the losses during that time).

$$\Delta C_B = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

$$\Delta C_{CONVERSION} = \sum_i \{(B_{AFTERi} - B_{BEFOREi}) * \Delta A_{TO\text{-}OTHERS}\} * CF$$

Where:
$\Delta C_{CONVERSION}$ = initial change in carbon stocks in biomass on land converted to another land-use category (t C yr^{-1})
i = type of land-use converted to another land-use category
$B_{AFTER\ i}$ = biomass stocks on land type i immediately after the conversion (t dm ha^{-1})
$B_{BEFORE\ I}$ = biomass stocks on land type I before the conversion (t dm ha^{-1})
$\Delta A_{TO\_OTHERS\ I}$ = area of land use I converted to another land-use category in a certain year (ha yr^{-1})
CF = carbon fraction




Biomass carbon stocks immediately after the conversion are assumed to be zero for grasslands and croplands as it is assumed that the land is cleared prior to the conversion. For croplands, a 25 year harvest cycle was assumed for perennial orchards and vineyards and biomass was assumed to accumulate linearly for the entire 25 year period. Therefore for phase 2 of the equation the growth rate was calculated as the biomass (Table 18) divided by harvest cycle. These derived growth rates (1.16 t dm ha^{-1} for orchards and 0.44 t dm ha^{-1} for vineyards) are lower than the IPCC default values, but similarly low growth rates have been used by other countries (National Inventory Report for New Zealand, 2012). Carbon gains of 5 t C ha^{-1} were applied for annual crops (IPCC, 2006, Table 5.1). The carbon fraction was the default of 0.5 t C per t dm. It is acknowledged that the cropland data incorporated into the model is very limited and this is because it is the land conversions that are important for emissions, and land conversions are determined through the base maps. Therefore, the conversions are limited to the classifications provided in the maps.

In this case the maps had five cropland divisions (annual pivot, annual non-pivot, vines, orchards and subsistence farms) so the conversions were limited to these categories. Determining land use change within the cropland category is also problematic as there are numerous seasonal changes (for example different crops in summer and winter) that occur, providing further challenges. In the future, land use change is going to become more important, especially for croplands where the land area is limited so land cover will not change much. For this reason it is important that methods be developed for incorporating land use change. In preparation for this research, investigating land use changes should be supported to provide data for future projections.

3.2.6.3. Dead organic matter

Since untransformed land is assumed to be carbon neutral, changes in dead organic matter are only calculated for transformed land. Furthermore, this was only calculated for forest lands. Dead organic matter takes a while to be restored once a land conversion takes place and the carbon changes are calculated as follows:

$$\Delta C_{DOM} = \frac{[(C_N - C_O) * A_{on}\}}{T_{on}}$$

Where:
C_n = dead wood/litter stock under the new land-use category (tonnes C ha^{-1});
C_o = dead wood/litter stock under the old land-use category (tonnes C ha^{-1});
A_{on} = area under going conversion from old to new-land use category (ha);
T_{on} = time period of the transition from old to new land-use category (yr).

The Tier 1 assumption is that carbon stocks in litter and dead wood pools in all non-forest land categories are zero. The NTCSA (DEA, 2015) showed that the litter pool was relatively small so for this study the Tier 1 assumption was applied, and in future iterations of the baseline more detailed DOM data can be incorporated. The NTCSA (DEA, 2015) provided the values of 121 ± 49 g C m^{-2}, 900 ± 50 g C m^{-2} and 254 ± 52 g C m^{-2} for woodlands, forests and thickets respectively (Shea et al., 1996; Weider and Wright, 1995; Powell, 2009). These values were used as opposed to the higher IPCC default values.

3.2.6.4. Soil organic carbon

Soil organic carbon changes are also only calculated for transformed land. For plantations it is assumed to be zero.

$$\Delta C_{SOC} = \frac{(SOC_O) - SOC_{(O-T)}}{T}$$

$$SOC = \sum_{c,s,i} (SOC_{REFC,S,I} * F_{LUC,S,I} * F_{MGC,S,I} * F_{IC,S,I} * A_{C,S,I})$$

Where:
ΔC_{SOC} = annual change in carbon stocks in mineral soils (t C yr^{-1})
SOC_0 = soil organic carbon stock after project implementation (t C)
$SOC_{(0-T)}$ = soil organic carbon stock at the beginning of the project (t C)
F_{LU} = stock change factor for land-use systems or sub-syste for a particular land-use (dimensionless)
F_{MG} = stock change factor for management regime (dimensionless)
$_{FI}$ = stock change factor for input of organic matter (dimensionless)
T = number of years over a single project time period (yr)

For Forest lands, grasslands and other lands the soil C stocks are assumed equal to the reference value (i.e. F_{LU}, F_{MG} and F_I = 1). For settlements a combined stock change factor of 0.8 was applied (DEA, 2015). Stock change factors were determined for each crop type by using data reported in Moeletsi et al. (2013) and the NTCSA (DEA, 2015) (Table 20). For degraded grasslands a FMG of 0.95 was applied. For Other lands the Tier 1 assumption is that the reference C stock at the end of the 20 year default period is assumed to be zero. Low shrublands and degraded lands are also part of Other lands, but these two categories were not assumed to reduce to a soil carbon of zero as they still have vegetation present and contain soil carbon (DEA, 2015). The bare ground category was assumed to reduce to zero.

Table 20: Stock Change Factors for Croplands

Cropland	F_{LU}	F_{MG}	F_I
Annual crops – irrigated	0.8[a] (±9%)	1[c] (NA)	1[e] (NA)
Annual crops – dry	0.5[g] (±9%)	1[c] (NA)	1[e] (NA)
Subsistence/semi-commercial crops	0.5[g] (±9%)	1[c] (NA)	0.95[f] (±13%)
Orchards	0.8b[,g] (±50%)	1.1[d] (±5%)	1[e] (NA)
Viticulture	0.8b[,g] (±50%)	1.1[d] (±5%)	1[e] (NA)
Sugarcane	1[b] (±50%)	1[c] (±5%)	1[e] (NA)

[a] *long term cultivated;*
[b] *perennial/tree crop;*
[c] *frequent tillage;*
[d] *no till;*
[e] *medium inputs;*
[f] *low inputs;*
[g] *from National Terrestrial Carbon Sinks Assessment (DEA, 2015).*

The data sources and validation references for the carbon stock change calculations are provided in Table 21.

Table 21: Data Sources and Validation for Carbon Stock Change Calculations

Activity data	Data sources	Validation
Land cover change	GTI Land change maps (1990 and 2013/14)	Various literature sources were used for comparison (see Table 4)
Plantation data	FSA	FAOStat IPCC guidelines (2006)
Biomass data	NTCSA (DEA, 2015) Literature IPCC guidelines (2006)	Literature and data validation in the NTCSA
Litter data	NTCSA (DEA, 2015	Validated in the NTCSA
Soil carbon data	NTCSA (DEA, 2015) Moeletsi et al. (2015)	Validated in the NTCSA
Soil management data	Moeletsi et al. (2015)	NTCSA
Fuelwood consumption – household data	Statistics SA – Household surveys (2014	Census data
Fuelwood consumption data	Literature (Shackleton, 1998; Shackleton & Shackleton, 2004; Madubansi & Shackleton, 2007; Matsika et al., 2013)	
Provincial household data	StatsSA	

3.2.7. Non-CO_2 emissions

3.2.7.1.Wetland CH_4

CH_4 emissions from wetlands are a very small (<1%) fraction of the CH_4 emissions. The emissions were calculated as described in the GHG 2010 inventory (DEA, 2014b):

$CH_4\ emissions_{WWFlood} = P * E(CH_4)_{diff} * A * 10^{-6}$

$CH_{4Flooded\ land} = A * P * E_{CH4}$

Where:
CH_4 emissions $_{WWFlood}$ = total CH_4 emissions from flooded land (Gg CH_4 yr^{-1});
P = ice-free period (days yr^{-1});
$E(CH_4)_{diff}$ = average daily diffusive emissions (kg CH_4 ha^{-1} day^{-1});
A = area of flooded land (ha).

Since wetlands and waterbodies were assumed to remain constant, the wetland emissions were also constant. The data sources and validation references are provided in Table 22.

Table 22: Data Sources and Validation for Non-CO_2 Emissions

Activity data	Data sources	Validation
Land cover change	GTI Land change maps (1990 and 2013/14)	Various literature sources were used for comparison
Emission factors	IPCC 2006 Guidelines	

3.2.7.2. Biomass burning (CH_4, N_2O, CO, NOx)

Annual burnt area maps were produced from the MODIS monthly burnt area product for the years 2000 to 2010. The MODIS Collection 5 Burned Area Product (MCD45) Geotiff version from the University of Maryland (ftp://ba1.geog.umd.edu) was used. This is a level-3 gridded 500 m product and the quality of the information is described in Boschetti et al. (2012). Every month of data was re-projected into the UTM 35S projection to remain consistent with the 2013/14 Land cover dataset project. All the monthly maps were then merged into an annual map by adding the valid burnt areas in each map. This was done for each year between 2000 and 2010. These burnt area maps were then overlaid with the 2013/14 land cover maps to determine the area burnt in each land class. The percentage of burnt area in each land class is shown in Table 23 Due to the high annual variability, which depends on a number of environmental factors, a 10 year average of the burnt area percentage of each land class was used for projections. This percentage was then applied to the land area in order to determine the biomass burning emissions. Some burnt area corrections were applied to the data. It was assumed that there was no burning in indigenous forests and thickets, so any burnt area under these categories was allocated to grasslands. The FSA reports burnt area for plantations, so these figures were used and any difference between the FSA and MODIS burnt area was added or subtracted from grasslands. Any burning on bare ground was allocated to low shrublands, and any burning under water bodies was allocated to wetlands. Due to this averaging of the burnt area percentage the emissions from biomass burning remain relatively constant over the projection period.

Table 23: Percentage Area Burnt within Each Land Class between 2000 and 2010.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Indigenous forest	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Thicket	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Woodland / Open bush	5.88	8.46	6.54	2.51	4.69	7.92	6.87	3.95	7.14	4.71	8.09
Plantations	1.08	0.92	0.89	1.55	1.51	1.20	1.54	3.77	3.78	1.06	0.84
Annual crops: pivot	3.91	3.05	3.96	3.67	4.62	5.08	3.81	3.82	2.70	2.80	4.18
Annual crops: non-pivot	3.88	3.59	4.40	3.28	2.77	4.69	4.78	2.70	3.13	3.09	3.90
Orchard	0.60	1.15	0.84	0.86	0.47	1.06	0.74	1.28	1.64	0.70	1.46
Viticulture	0.54	0.35	0.28	0.44	0.11	0.31	0.61	0.29	0.22	0.33	0.12
Subsistence crops	5.44	8.14	6.41	5.44	4.34	9.40	7.37	11.41	6.86	8.12	9.88
Settlements	1.94	2.15	1.90	1.64	1.28	2.90	2.54	2.81	1.73	2.08	2.76
Mines	3.30	2.97	4.26	2.90	3.31	4.85	4.71	2.31	2.42	1.96	3.09
Wetlands	7.37	8.90	10.07	8.24	7.06	10.45	9.28	8.17	7.45	8.37	8.41
Grasslands	10.89	12.70	12.69	9.84	8.49	13.44	11.62	11.34	10.73	10.65	12.12
Water bodies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Low shrublands	0.36	0.30	0.73	0.46	0.28	0.48	0.37	0.32	0.38	0.51	0.88
Degraded	7.19	6.51	8.72	2.56	7.70	9.43	13.98	2.13	9.95	6.46	9.91

$$L_{FIRE} = A_{BURNT} * M_B C_F * G_{ef\ -\ CH4} * 10^{-3}$$

Where:
L_{fire} = amount of GHG emissions from fire (t C)
A_{Burnt} = area burnt (ha)
M_B = mass of fuel available for combustion (t ha^{-1})
C_f = combustion factor (dimensionless)
G_{ef} = emission factor (g kg^{-1} dm burnt)

The values for fuel density were sourced from the 2000 inventory (DEA, 2009), except for Croplands where a value of 7.0 t ha^{-1} was taken from the 2004 Agricultural Inventory (DAFF, 2010). The data sources and validation references are provided in Table 24.

Table 24: Data Sources and Validation for Biomass Burning

Activity data	Data sources	Validation
Land cover maps	GTI Land cover maps (1990 and 2013/14)	Various literature sources were used for comparison
Burnt area data	MODIS	GHG Inventory (2000)
Biomass burning emission factors	GHG Inventory (2000, 2014a)	Literature GHG Inventory (2000)

3.3. Results and discussion

3.3.1. Land projections

The land change projections obviously have a huge influence on the baseline projections and the challenge is, therefore, determining the best approach or most appropriate base map for projections. In this project the base change map of 1990–2014 was used and so the calculation outputs must be seen in light of these projections. At the national level the land projections don't show large changes in land area, but the largest changes are around the decrease in grassland, and increase in forest land and bare ground (Figure 10). Since forest land plays such a focal point in carbon estimations this increasing forest land leads to increased carbon sinks. It should be noted that in the national land cover change maps the overall bare ground area decreases slightly, however since this project made use of the provincial change maps the bare ground area is seen to increase. This is due to large annual increases in bare ground in Limpopo and North West and when these are projected forward the increases are further exaggerated leading to an overall increase. These changes in bare ground should be further investigated in future as some of the change, particularly in the North West, may be due to seasonal changes.

Stevens et al. (2015) provides evidence that tree density is increasing in savannas and more trees are encroaching on the grasslands, which could explain the increase in thickets and woodlands seen between 1990 and 2013/14. The report suggests that thickets have not shown much change but indicates that in KwaZulu-Natal, for example, the density of trees has increased so much that they have transformed into thickets or forests. Since the thicket category in the base maps also includes dense bush, it could be possible that these areas are increasing over time. In further support of this there has recently been discussion that southern Africa's savannas are increasing in area due to enhanced atmospheric CO_2 concentrations (Higgins et al., 2015). The increase in thickets is shown to be possible under low and medium risk climate projections, however, in the high risk scenarios, thickets are shown to decline (DEA, 2013).

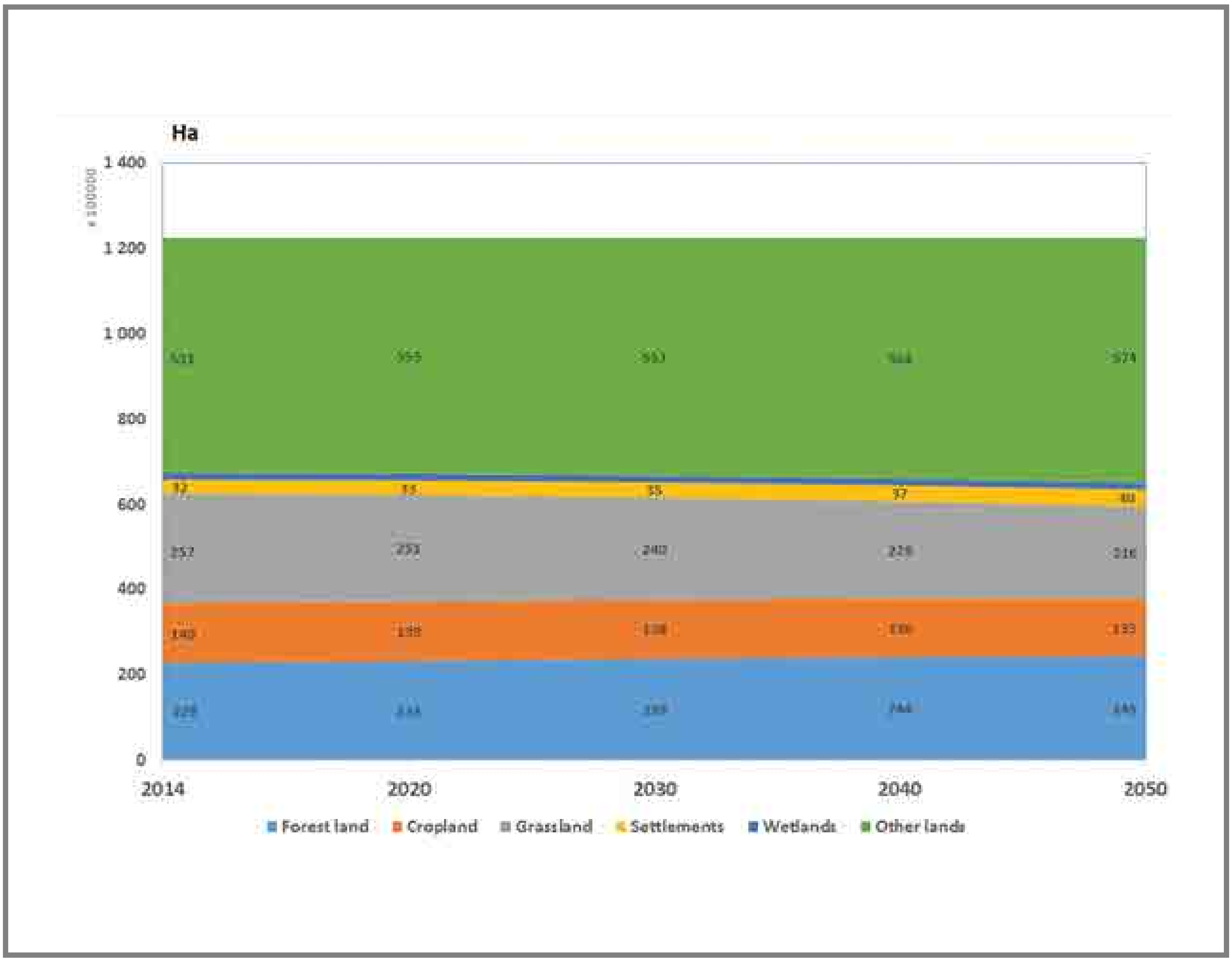

Figure 10: Projected Land Cover Change between 2014 and 2050 with the Area Given for Each Point.

The lack of data on land change which uses consistent mapping methods and classifications, makes it difficult to validate changes and this can be demonstrated by studying recent national land change outputs (Table 25). For the purpose of the 2010 GHG inventory, land cover change maps were developed for 2001, 2005 and 2010. These were based on the coarse resolution MODIS time series satellite data in conjunction with high resolution geographic masks of specific land-cover types (GTI, 2013). The land changes shown by these maps are provided in table 25, and they indicate a slight reduction in thickets and woodlands, which is a contradiction to what is predicted in the 1990–2014 change map. Both sets of maps show a decline in grasslands and an increase in transformed lands (croplands, mines, settlements).

Based on these MODIS change maps between 2001 and 2010, the NTCSA (DA, 2015) made some projections to 2020. These projections were done by obtaining future maps (e.g. protected areas, mines, etc.) and allowing the transformed areas to expand into the natural vegetation classes (unless they were protected areas). This led to the outputs that showed an increase in transformed area and an associated loss in the natural systems. The conclusions were that there was obviously an increase in transformed land, but also a slight reduction in thickets and savannas which is different from what is predicted in this baseline. It is this difference in prediction which leads this baseline to be an increasing sink, whereas the NTCSA (DEA, 2015) predicts a decreasing sink (DEA, 2015). This is an issue which need further research in future as it has a significant impact on the future projections and baseline. This highlights the importance of monitoring and research to assist in understanding the change that is occurring. It is also important that land change (both cover and use) be monitored more frequently (perhaps every 5 years), with a standardized method, so as to provide some trends to aid in determining which long term changes are actually occurring as opposed to seasonal changes.

Table 25: Annual Percentage (%) Change between Two Different Data Sets

Vegetation class[4]	% change 2001-2005	% change 2005-2010	% change 2001-2010	% change 2010 - 2020	% change 1990-2013/14
MODIS maps					**Landsat maps**
Indigenous forest	-0.81	-2.14	-1.51	-0.10	0.60
Thicket[5]	-2.01	-1.21	-1.51	-0.35	1.09
Woodlands/savanna	-0.47	-0.14	-0.28	-0.30	0.56
Plantations	-0.79	-0.55	-0.65	2.00	-0.11
Annual commercial crops (non-pivot)	-0.06	2.14	1.16	1.30	-0.33
Annual commercial crops (pivot)	2.94	2.19	2.66	-0.05	6.98
Permanent crops (orchard)	2.05	0.26	1.07	-0.10	0.46
Permanent crops (viticulture)	0.24	0.09	0.16	-0.05	0.71
Annual semi-commercial / subsistence crops	-2.39	12.55	5.25	-0.20	0.11
Sugarcane	5.93	1.14	3.42	-0.15	
Settlements	0.55	0.07	0.28	3.20	0.26
Wetlands	0.67	0.03	0.32	-0.08	-1.42
Grassland	0.73	-0.28	0.17	-0.40	-0.27
Mines	-2.30	0.14	-0.95	4.00	0.55
Water bodies	-1.82	0.18	-0.71	0.02	-0.93
Bare ground	11.65	-0.22	5.00	-0.02	-0.27
Other	-1.84	-2.93	-2.33	-0.05	
Fynbos	-0.31	0.25	0.00		0.07
Nama karoo	-10.13	2.08	-3.82		
Succulent karoo	-4.71	-3.42	-3.64		

[4] Note that the classification of the vegetation classes differed slightly between the MODIS and Landsat maps, but the idea is to show the overall increase or decrease in the vegetation class.

[5] In the 1990-2013/14 map this was classified as thicket and dense bush.

3.3.2. Land baseline

The estimated national baseline for the land sector shows an increased sink between 2014 and 2040 (21 104 Gg CO_2eq to 32 223 Gg CO_2eq), after which the sink slows and becomes stable (Table 26). The increasing sink is mainly due to the predicted increase in forestland, but is also combined with the decrease in wood removal from woodlands in the period until 2030. Keeping fuel wood removal constant (i.e. assuming no reduction in wood removals due to electrification) produces a much more constant sink (varying less than 3 000 Gg CO_2eq between 2014 and 2050), but it still shows a slight increase in the sink to 2030 after which it declines to 2050. If the thicket area is increased by 1% then the sink increases by 17% by 2050, which shows the importance of understanding whether the thicket area is increasing, decreasing or remaining constant. Moving towards 2050, there is also a predicted increase in bare ground (based on the provincial projections) and this leads to loss of carbon (both biomass and soil) causing the overall land carbon sink to stabilize. Initially the Other land category (which consists of bare ground, low shrubland and degraded land – see Table 14) is a sink of CO_2 due to the larger area being converted from bare ground to low shrublands. However, as the area being converted to bare ground increases so the loss of biomass and soil carbon increases leading to a source of CO_2 between 2040 and 2050. If the bare ground restriction is increased from 10% to 15% (in Limpopo and North West which were the provinces that were restricted in terms of bare ground) then the sink in 2050 is reduced by a further 13%. This also highlights the need to have a better understanding of the rate of desertification and degradation.

The inclusion of degraded woodlands, soil thicket carbon losses due to degradation, and degraded grassland biomass changes in future, would lead to further decreases in the carbon sink capacity estimated in the baseline. The baseline is also limited in terms of the cropland detail, particularly land use changes within the cropland division that is included, and this is a major limitation of the model which needs to be addressed in the next update. The emphasis on the forest land detail is also the main reason for the forest land components having the largest influence on the outputs at this stage.

Table 26: Estimated National Baseline for the Land Sector

	2014	2020	2030	2040	2050
Total Land	-21 104.5	-25 860.4	-31 390.6	-32 223.2	-30 683.2
Land	-22 920.7	-27 663.2	-33 169.9	-33 977.9	-32 407.6
Biomass burning	1 818.47	1 805.02	1 781.55	1 756.86	1 726.61

This is a first attempt at developing a land baseline and it comes with large uncertainties so should be used with caution. A full uncertainty assessment still needs to be conducted on the data, as time limitations do not allow for the completion of this assessment. The data suggests that if the forestland is increased through afforestation and thicket restoration, then the carbon sink would increase. It also indicates that if soil erosion and degradation is prevented, the future decrease in the sink would be alleviated, highlighting the importance of the mitigation actions suggested in the NTCSA (DEA, 2015). Due to the focus on forest land, the provinces that have the largest impact are those which have significant woodland or thicket areas, such as Limpopo, KwaZulu-Natal, Mpumalanga and even Eastern and Western Cape with their thickets.

CHAPTER 4: Combined AFOLU emission baseline

4.1. AFOLU emissions baseline

Combining the land and the agriculture baseline creates a baseline which shows a 8.2% decline between 2014 and 2020, after which it increases by 37% to 38 938 Gg CO_2eq in 2050 (Figure 11 and Table 27). The increasing land sink contributes to the slight decline in the early years while the increasing agricultural emissions combined with the stabilizing carbon sink leads to the increase between 2030 and 2050. Land sequesters almost as much as the aggregated non-CO_2 emission emit and so the baseline is very similar in magnitude to the enteric fermentation value (Table 27).

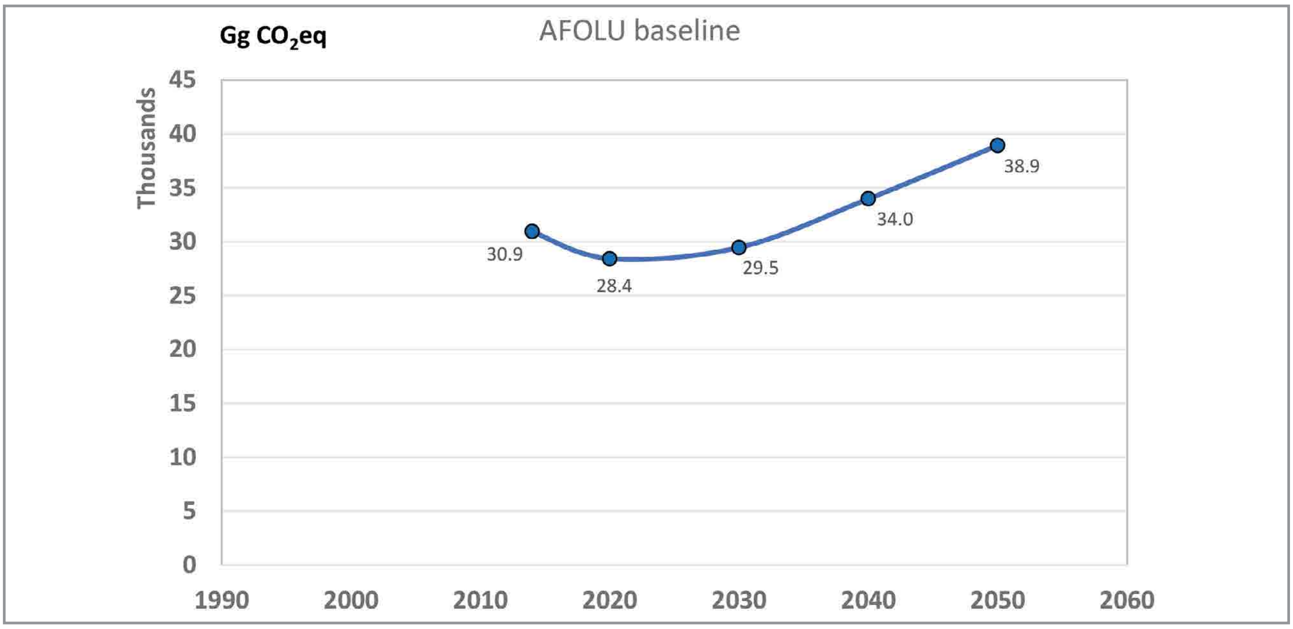

Figure 11: Combined AFOLU Baseline

Table 27: Combined Land and Agriculture Baseline Emissions

Categories	(Gg CO_2eq)				
	2014	2020	2030	2040	2050
Total AFOLU	**30 949.4**	**28 442.4**	**29 461.9**	**33 978.7**	**38 938.2**
Livestock	30 727.59	32 256.49	36 353.45	39 516.62	41 177.52
Aggregate sources and non-CO_2 emissions sources on land	21 326.34	22 026.32	24 499.04	26 685.29	28 443.83
Land	-22 920.7	-27 663.2	-33 169.9	-33 977.9	-32 407.6
Biomass burning	1 818.47	1 805.02	1 781.55	1 756.86	1 726.61

Considering the provincial data it can be seen that the Free State, KwaZulu Natal and North West contribute the most to the overall baseline (Figure 12). The contribution from the Free State is mostly due to livestock (47% - 49%) with land contributing less than 5%. In KwaZulu Natal livestock emissions increase by 38.4% between 2014 and 2050, while the land started as a source in 2014 after which the sink increased. In the North West it is the livestock that dominate (72% - 78%) the emissions. Limpopo is one of the two provinces, the other being the Western Cape, that are a sink for the overall AFOLU sector. In Limpopo the sink declines to become a weak source in 2050 due to increasing degradation and bare ground. The Eastern Cape, KwaZulu Natal, Mpumalanga and Western Cape all showing increasing land sinks between 2014 and 2050 due to increases in the forest land area. Gauteng shows very little change over the period. Western Cape has a small source for the AFOLU baseline in 2040 and 2050 as the agricultural emissions almost balance the land sink. The Eastern Cape, KwaZulu Natal, Mpumalanga and Western Cape all show increasing land sinks between 2014 and 2050 due to increases in the forest land area. Gauteng shows very little change over the period.

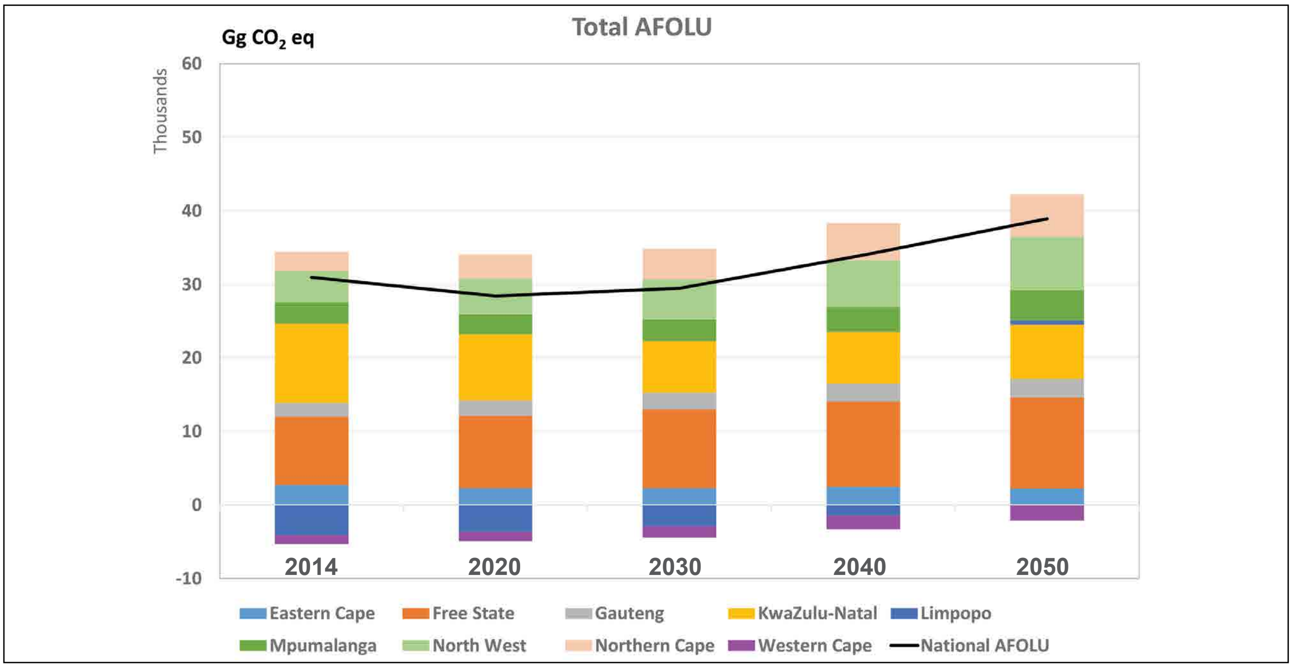

Figure 12: Provincial Baseline Emissions

4.2. AFOLU baseline and GHG inventory

The baseline is an indication of what the expected emissions are going to be based on a business-as-usual scenario. The inventory provides information on what the actual emissions are. Both are developed based on current knowledge, and under the current reporting regime the inventory is updated every two years. The baseline is not usually updated very frequently as it is seen to be fairly constant and something to strive to deviate from. However, there are still many unknown factors in the AFOLU sector, particularly in land, and therefore there are continuous improvements being made to the AFOLU sector inventory. Since the baseline is dependent on the inventory, it is suggested that the baseline be updated again in the near future, so as to incorporate any new information in this sector. The biggest unknown factor is the land change and this is extremely difficult to predict. The projections made in this study are based on the changes reflected in the most recent land change maps for South Africa. This is a limitation of the baseline, and should there be a deviation from this predicted trend, particularly in terms of the forest land, then it would be important to update the baseline, as the land cover change drives the land sector baseline.

The baseline data is not directly aligned to the current inventory data, as the inventory does not take into account any degraded lands, and by including these, the land sink would be reduced. Furthermore, the baseline is a model and in some cases uses averaged data in order to make forward projections, whereas the inventory uses actual data for each year, so there is more annual variation. Even though the inventory and the baseline are two separate components for monitoring mitigation, they are linked. Improved data for the inventory means more accurate data for enabling forward projections of the numbers. The extent to which the national AFOLU inventory is sensitive to the effects of mitigation efforts depends on the quality of the livestock and land characterization.




An inventory based on well-characterised data is more sensitive to mitigation efforts. The AFOLU inventory has been developing over the last few years and a much more detailed livestock characterization, along with associated emission factors, has been incorporated into the inventory. The focus has been more on the agricultural sector, as it is a key category and partly because it is an easier sector to improve. Even though South Africa has made strides towards a better understanding of the land sector and its carbon fluxes, the detail is still lacking in the inventory and much of it still remains at the IPCC Tier 1 approach. A more detailed land characterization needs to be incorporated into the inventory in order for the inventory to be more sensitive to land mitigation actions. Going forward into the next inventory round it is recommended that the mitigation team interact with the inventory team during the inventory planning meeting. In this way the relevant mitigation actions can be highlighted, indicating what information would need to be included in the inventory, challenges with incorporating the data, along with solutions, so that South Africa can move forwards with providing an inventory which better reflects its mitigation efforts.

There are plans in place to upgrade the cropland and forest land sub-sections of the inventory in the next inventory update. These improvements will include adding further forest categories and age classes for plantations, and for croplands. It will incorporate the different types of crops as well as the different management and input types. Considering the mitigation actions, it may also be important to improve the grassland detail as well. There will be a move towards using the recently developed Agriculture and Land Use software (http://www.nrel.colostate.edu/projects/ALUsoftware/) to assist with calculations and this would provide valuable information in terms of validation of the methodology. The other advantage is that spatial data can be incorporated through the use of this model.

These will all be important upgrades to the inventory, but the much larger issue in this sector is capacity and co-ordination. The AFOLU sector is a very large sector with multiple components (agriculture, soils, land change mapping, etc.) and in order to make significant progress in moving the inventory forward to a Tier 3 approach (which South Africa is capable of due to the large amounts of data) a detailed, long term plan is required. Similarly to the mitigation activities suggested in the NTCSA (DEA, 2015), technical teams around the various components of the AFOLU sector (e.g. livestock, land change mapping, soils, croplands, forest lands) should be set up so as to draw on experts from all fields. The technical teams should be tasked with assessing the current information and methods and making recommendations on how to improve each section. There should be a move towards spatial analysis and the use of models to predict change from year to year. The technical team could assess various models and make recommendations on the most appropriate models to use for South African conditions. Making use of more detailed models could make it easier to make forward projections for the baseline. The challenge is to co-ordinate all the information and/or models from the various sub-sectors into one large picture for the AFOLU sector. The development of such a system will take time and resources in the beginning; however, as time goes forward, the effort to compile the inventory and update the baseline should become less due to the increased ease of the process.

Baselines are not often updated as they are considered to remain fairly constant, however, conditions change over time and the assumptions may become less adequate. Generally the inventory should at least follow the baseline predictions or, under mitigation scenarios, show a reduction compared to the baseline. The difference in the baseline and the current inventory should be due to mitigation activities and not due to major differences in assumptions or data detail. In light of the fact that there are still several challenges in the land sector, and that detail is still being incorporated, it is recommended that there be a more frequent update of the baseline in the next few years until the inventory (and, therefore, ultimately the baseline projections) reaches a more stable point. After that the frequency of updating the baseline can be extended.

4.2.1. Updating the baseline

It is difficult to assess exactly when assumptions become no longer valid, or when the deviation becomes important enough to warrant selection of a different scenario from the original sensitivity analysis or a fuller re-run or re-design of the projection approach. Re-running of the baseline becomes important particularly when the baseline is being used to measure national mitigation pledges, or when it is being used to measure credited emission reductions. It is suggested (Clapp et al., 2009) that baselines be updated if measured data on any key driver deviates more than a certain percentage from the value assumed for the construction of the baseline scenario. The availability of sensitivity analyses around the chosen baseline would be particularly useful to show how changes in key drivers would affect emissions, and therefore, at what point a new baseline ought to be considered based on updated parameters for these key drivers. The AFOLU sector is very complex and has many variables, and due to time constraints a full sensitivity analysis of the baseline has not been completed yet, but is a recommendation for the future.

In terms of the AFOLU baseline some of the key factors or drivers are likely to be:

- Agriculture:
  - Livestock population data;
  - Manure management systems;
  - Fertilizer consumption;
  - Livestock emission factors.

- Land:
  - Land cover/use change;
  - Fuel wood consumption;
  - Biomass growth and expansion factors for forest lands;
  - Soil reference carbon;
  - Degraded areas and rate of degradation;
  - Rate of desertification.

Since the AFOLU emissions estimates and methodologies are still developing, if there are any significant changes in methodology in the GHG inventory then the baseline will need to be updated in order stay in alignment with the inventory outputs.

4.3. AFOLU baseline and future mitigation potential

The NTCSA (DEA, 2015) suggests eight principle mitigation options (Table 28) for the land sector and indicates that, if the roll out period begins now, the mitigation potential will slowly increase to 16.9 million t CO_2eq by 2035 (Figure 13). Combining the mitigation potential from these eight options (Figure 13) with the baseline means that the carbon sink will be enhanced two fold in the period going to 2030 (Figure 14), but thereafter sinks will begin to decline. This emphasises the need to sustain the mitigation efforts and attempt to extend them further in the future beyond 2030. It is also important that research into various mitigation options is continued so as to find alternative options for the period 2030–2050.

Table 28: Mitigation Activities Suggested in the NTCSA and their Mitigation Potentials (source: DEA, 2015).

Mitigation activity	Reduction per unit area per year (t C)	Emission reductions per year (t CO_2eq)	Percent contribution
Restoration of subtropical thicket, forests and woodlands	4,1	4 159 874	25.1
Restoration and management of grasslands	2,7	2 921 000	17.7
Commercial small-grower afforestation	3,0	660 000	1.7
Biomass energy		2 783 125	16.8
Anaerobic biodigesters		4 370 890	26.4
Biochar	0,3	770 000	4.7
Reduced tillage	0,1	1 266 742	7.7
Total		**16 932 231**	**100**

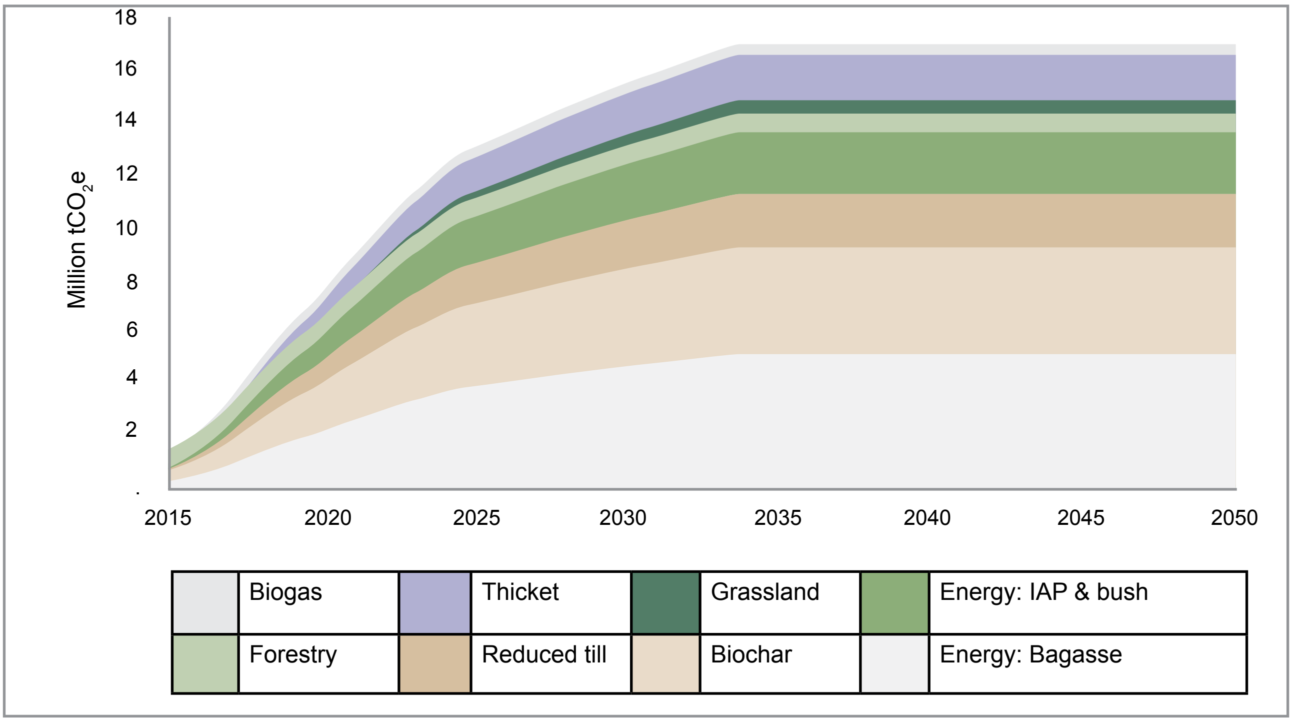

Figure 13: Total Terrestrial Carbon Sink Potential by Activity Over Time (Source: DEA, 2015).

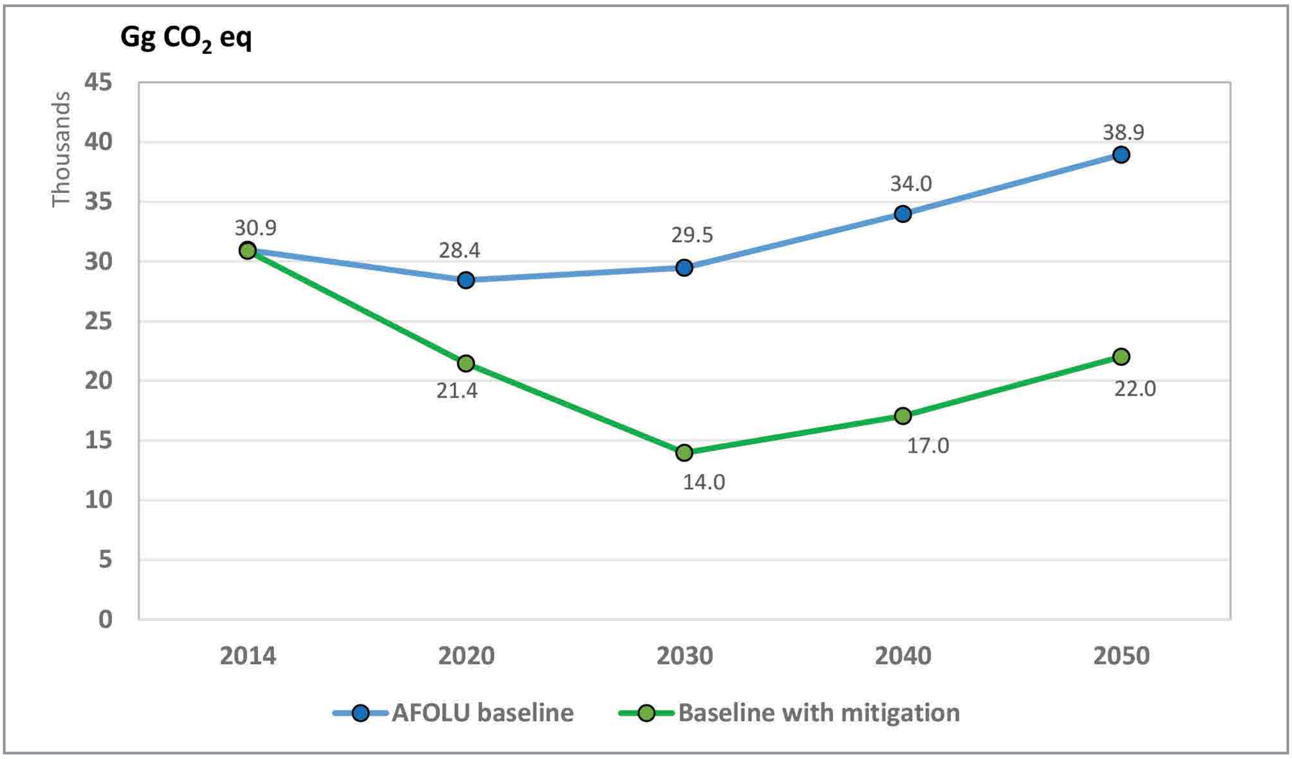

Figure 14: AFOLU baseline and the Mitigation Potential from the NTCSA (DEA, 2015).

CHAPTER 5: Recommendations and way forward

This is the first attempt at creating a baseline for the AFOLU sector in South Africa. It is a challenging task given the variability and uncertainty of the available data. However, the process of developing the baseline has provided many lessons. Several recommendations can be made so as to improve the baseline in the future. Since the baseline relies on data in order to project emissions it relies on information that would be collected for the improvement of the inventory. Some of the recommendations below would therefore be for the inventory improvement programme, but have still been listed below to provide a complete picture of what is required.

5.1. Develop consistency in data sets

The first challenge is around data and the variability in the data sources. This applies both to the agricultural and land sector data. In terms of livestock there is a mismatch between reported data from official statistics and various livestock associations, particularly for the pig and to a lesser extent for the dairy industry (see Box 1). In the dairy industry the mismatch is more around the herd composition as opposed to the actual population numbers. However, all these numbers have an impact on the overall population and this can influence future projections. Currently, national statistics numbers are being used, however, in order to get buy in from stakeholders, who are generally willing to assist, it is important that an attempt is made to resolve these discrepancies in the population data as it will reduce uncertainties on the data and the projections. It is, therefore, recommended that a workshop be held between the various stakeholders, or rather data collectors, to discuss these issues and come up with a recommendation on the best population data set to use, and determining who would be responsible for supplying that data set.

In terms of the land sector the issue is around the classification of land cover/use types (see Box 2). It is understood that the Department of Rural Development and Land Reform through SPLUMA is developing a standard classification system for spatial maps, which is what is required, but in the development of this classification the requirements for emission reporting should be considered. A classification system that can be expanded or compressed, depending on the level of detail required, would be optimal, as this would enable the movement from Tier 1 to Tier 2 or 3 reporting. Although the IPCC requires reporting for the 6 broad land categories (forest land, cropland, grassland, wetlands, settlements and other land) it is important for mitigation that more detail within each category can be included. During the development of this baseline it was difficult to determine the exact size of the thicket due to variations in the classification. It is also critical that there is consistency between the various branches, i.e. that the forest definition is the same for forest resource assessments, REDD+ projects, the inventory and the baseline.

5.2. Issues of scale

The impact of mitigation actions on the emissions are often calculated from the bottom up, by looking at data on the ground and scaling this up to the national level. On the other hand, at present the inventory and baseline are developed from the top down, in that they make use of national scale maps. The different scales of the data present a challenge in finding a way to bring the two sets of numbers together. Part of this challenge has to do with the differences in land classifications, for example, identifying the exact area of degraded thickets that can be restored. The incorporation of more detailed country specific data should bring these two sets of data closer together.

5.3. Land cover/change projections

There are enormous challenges in predicting land cover and land use change. The method used in this study relies on historical change data and expert opinion. Land change maps can provide varied outputs depending on when in the year or in which year they were created. As mentioned before, South Africa needs to detect change on a more regular basis

and using a consistent methodology and classification in order to provide trend data which will assist in improving forward projections. Alternatively, different approaches for determining change could be compared in order to determine the most appropriate method, or to provide a range of possible changes.

5.4. Incorporation of degradation data

Several mitigation options in the land sector involve the restoration of degraded land. Degradation, as mentioned before, is complex due to the different types and the extent of the degradation, making it very difficult to include in the baseline (or the inventory). There are maps on thicket degradation (Lloyd et al. 2002), potential soil and water degradation (sourced from DAFF) and gullies, as well as mapped degradation indexes. The challenge is combining all this information, together with land cover/use maps to determine the exact extent of degradation in the various land classes. For the baseline it is not only the area and extent of degradation but also the rate at which degradation changes that is important. This could be determined through the development of models. It may not be possible to include all degradation into the inventory or baseline, but it should be decided what level of degradation can be incorporated and a definition of this degradation should be provided so that the method and definition can be used consistently in future.

5.5. Improved livestock information

In terms of the baseline it would be useful to develop improved methods for estimating and projecting livestock population numbers. Issues around the challenges are discussed in Box 2. This can possibly be linked with the research of BFAP, as they upgrade their supply and demand model every 2 years at the moment.

Another area for improvement is in terms of nitrogen emissions from fields/pastures as well as from urine and dung deposits. Research is needed in this area to improve the emission factors, because until now, only default IPCC (2006) emission factors are used.

5.6. Emission mitigation research in agriculture

Mitigation options for the agriculture sector are not often highlighted in terms of the AFOLU sector as they are seen to have limited potential. There are various options which have been touched on in this report, but there are also others. The specific options for South Africa need to be explored in more detail to determine the actual mitigation impacts. The major limitation is country specific emission data. Research around monitoring emissions and their possible reductions in the livestock sector, both for enteric fermentation and manure management, should be supported. Even though international studies have been conducted it is important for South Africa to start conducting research in country as the livestock and environmental condition are country specific. Livestock emissions research can be costly due to the equipment required, however there are some groups starting to build up skills in this area (e.g. University of Pretoria, Agricultural Research Council) and these groups should be supported.

This also applies to research on N_2O emissions from manure and managed soils. Small changes in N_2O emissions can have a relatively big impact because of the higher GWP of N_2O. The estimated emissions for managed soil and indirect emissions are relatively high, but default emission factors are being used. Furthermore, the emission factors have high uncertainties due to the variability with environmental conditions. South Africa needs to determine it's own emission factors to improve the emission estimates and reduce uncertainty.

5.7. Register of biodigesters and their fuel sources

Another mitigation option in the AFOLU sector is the use of biodigesters to reduce emissions from manure and crop residues (as well as the benefits for the energy sector). This is an activity which is growing in South Africa and several biodigsters have been installed on farms as well as at households. The savings from biodigesters are often recorded in terms of energy savings, but there are also the savings from reduced manure storage and application of residues which are relevant to the AFOLU sector. In order to make better estimations of the reduction in emissions due to these installations, information is required on the number of biodigesters and the quantity and type of fuel they use. The information on biodigesters is scattered and so it would be useful to have a central register of this information to assist in estimating and predicting emission savings in terms of the AFOLU sector. It should be noted that in our investigations it was found that several organizations were interested in this information. The South African Biogas Industry Association (SABIA), together with GIZ, are making an effort to put such a list together. Furthermore, the WWF is also interested in initiating a project to evaluate all national medium to large scale biodigesters. These studies may therefore close this gap.

5.8. Fuelwood consumption data

In the land sector the changes in carbon are estimated by calculating the gains and removing the losses from the system. One of these losses from forests and woodlands is through fuelwood collection. This is a number which is largely unknown at the national scale. There have been numerous studies investigating wood removal at the local scale, and even some indications that it is unsustainable (Wessels et al., 2013). Initial estimates suggested that 11.8 million tons of wood were removed annually due to fuelwood collection (FAO Statistics, http://faostat.fao.org/; Damm and Triebel, 2008), and 4.5 - 6.7 million tons used by rural populations (Shackleton and Shackelton, 2004). Statistics (Census, 2007 and 2011) indicate that the number of households using fuelwood have declined due to the electrification programme that was implemented by the department of energy. Research shows that fuelwood collection in rural areas has declined due to electrification, but in many cases households that have access to electricity still utilize fuelwood due to the high costs of electricity. Removal of fuelwood from forests or woodlands leads to a reduction in the carbon stock on these lands, so fuelwood collection could have implications for carbon sequestration. Since there is a lack of information at a national scale as to whether fuelwood removal is declining, it would be important to develop an understanding of the amount of fuelwood consumed at a national scale. Information could be based on collating all research in various areas of South Africa (as there is a lot of information, however, it is very scattered) or alternatively a more complex model incorporating household access to electricity, household income, rural population percentage and consumption values would be useful for making future predictions for the baseline.




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Appendix A

National emission projections are useful, however, provincial data can also provide further information regarding which mitigations options would be appropriate in the different regions. Therefore, the national livestock emission estimates were split into provincial numbers to provide an idea of the important emissions in the various regions.

The provincial emissions were determined by the following methods:

Livestock emissions were divided by applying the livestock ratios provided in Meissner et al. (2013) (Table 28). Horse, mule and ass provincial ratios were supplied by Du Toit et al. (2013). These numbers were compared to data from SAPA (2012), DAFF (Animal Production Report), and Du Toit et al. (2013a, b, c, d). In general the numbers showed similar provincial distributions.

N_2O (direct and indirect) *emissions from manure application and deposition of urine and dung* were divided in a similar manner.

Synthetic fertilizer consumption is related to area planted to crops that use fertilizers and the amount of fertilizer applied. Grains, oilseeds and sugar cane are the biggest users of fertilizers in SA (GrainSA, 2011; FAO, 2005; Prud'homme et al., 2005), with maize consuming 62.2% of nitrogen fertilizer and sugar cane accounting for 8.9% in 2012. A ratio for each province was determined from the provincial planted area (Crop Estimates Committee; Sugar Association) of the main crops consuming fertilizer and the nitrogen application rates (FAO, 2005; FSSA, 2004).

Crop residues are assumed to be related to cropland area, therefore, the ratio of cropland area to total cropland area for each province was applied. This method was also used for division of the *lime and urea application* emissions.

Table 29: Provincial Distribution (%) of Livestock

Province	Beef cattle		Dairy cattle	Sheep		Goats		Pigs		Poultry		Game	Horses
	C	S		C	S	C	S	C	S	B	L		
WC	2.78	4.05	23.61	11.03	11.03	3.58	3.56	15.54	8.06	10.3	9	1.14	13.8
NC	7.66	3.63	0.95	24.86	24.89	8.32	8.32	1.98	1.29	10.3	9	22.43	16.3
EC	19.46	22.19	25.44	29.73	29.74	37.17	13.78	4.55	5.0	6.5	3	11.4	16.1
KZN	17.91	19.47	19.59	3.14	3.12	13.12	13.14	16.14	8.06	15.4	12.8	3.91	16.7
FS	15.66	15.89	14.47	19.81	19.83	3.87	3.87	8.71	4.52	5.3	16.5	5.28	19.1
MP	11.03	10.52	4.39	7.11	7.12	1.45	1.43	13.56	7.18	20	3.8	9.13	6.8
LP	8.26	7.55	0.88	1.05	1.02	20.17	20.17	11.29	6.05	2	6.1	37.08	1.2
GP	4.08	4.27	3.22	0.42	0.43	0.64	0.63	10.99	5.81	5.3	22	3.01	1.7
NW	13.15	12.44	7.46	2.84	2.82	11.68	11.67	17.23	8.87	24.3	9	6.62	8.5

C = Commercial, S = Subsistence, B = Broilers, L = Layers

Furthermore, game farming was assumed to increase to the detriment of cattle farming in the following provinces:

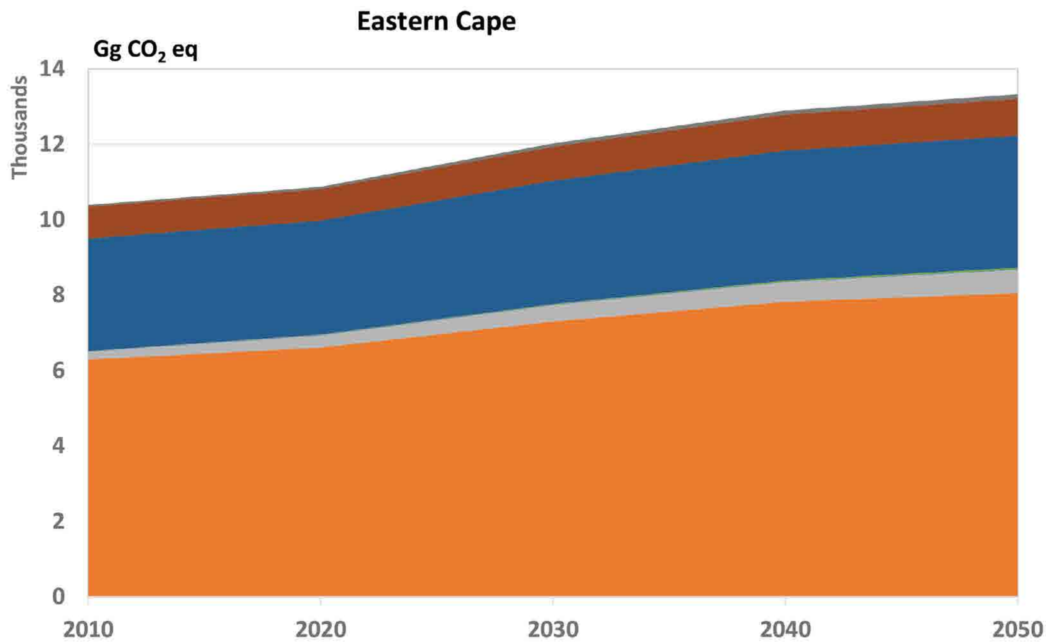
- Northern Cape;
- Eastern Cape;
- Limpopo;

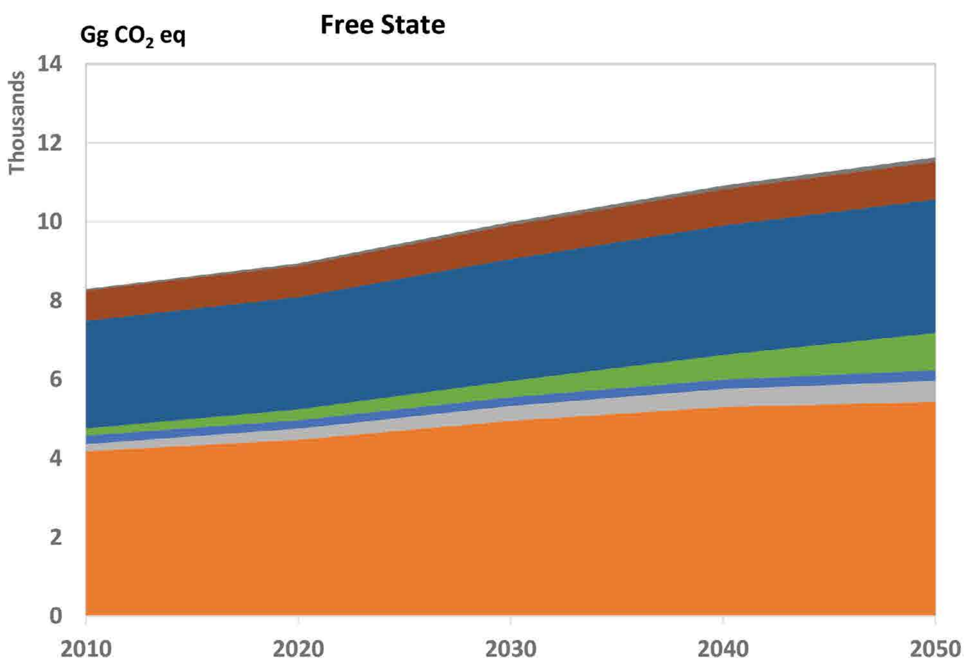
While the feedlot cattle were increased in the following provinces:

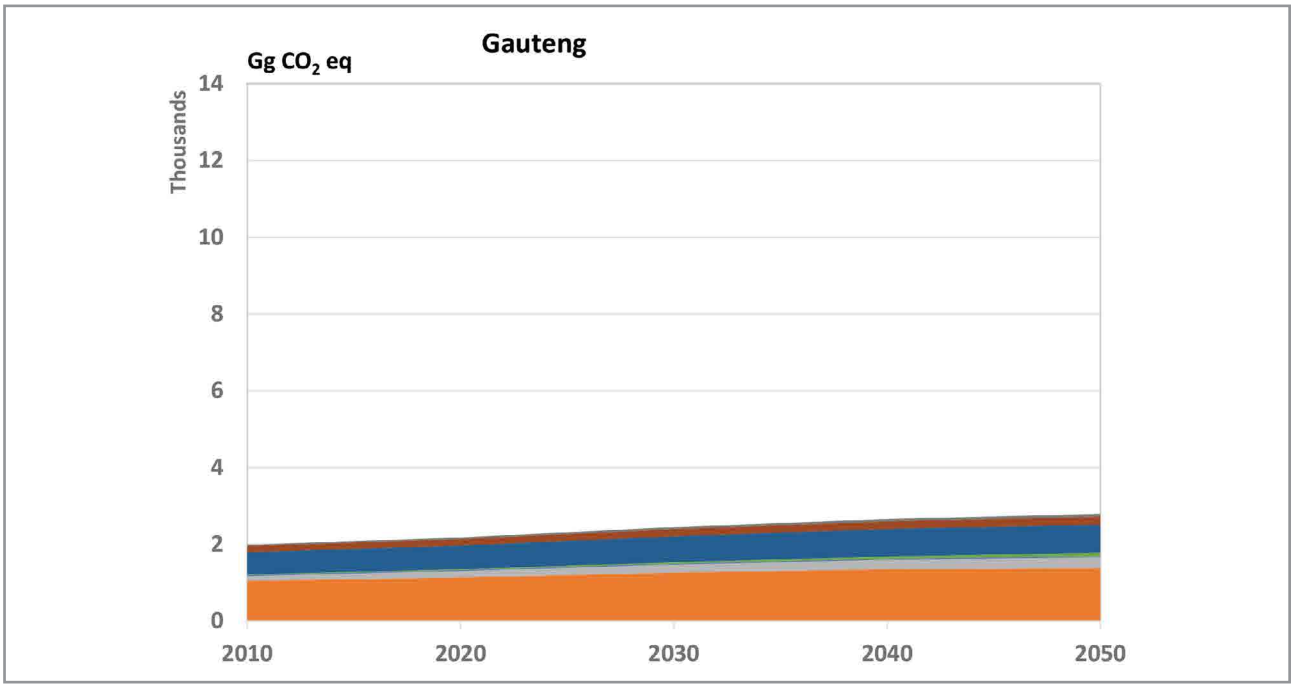
- KwaZulu-Natal;
- Free State;
- Mpumalanga;
- Gauteng.

Results are provided in the figures below. Eastern Cape, Free State and KwaZulu-Natal are the largest contributors to the total agricultural emissions. Free State, Mpumalanga and North West have the largest contributions in terms of fertilizer and liming application emissions.

	Indirect N_2O Emissions from Mm		Indirect N_2O Emissions from MS
	Direct N_2O Emissions from MS		Urea application
	Liming		Manure Management
	Enteric Fermentation		






Gauteng
Gg CO_2 eq
Thousands
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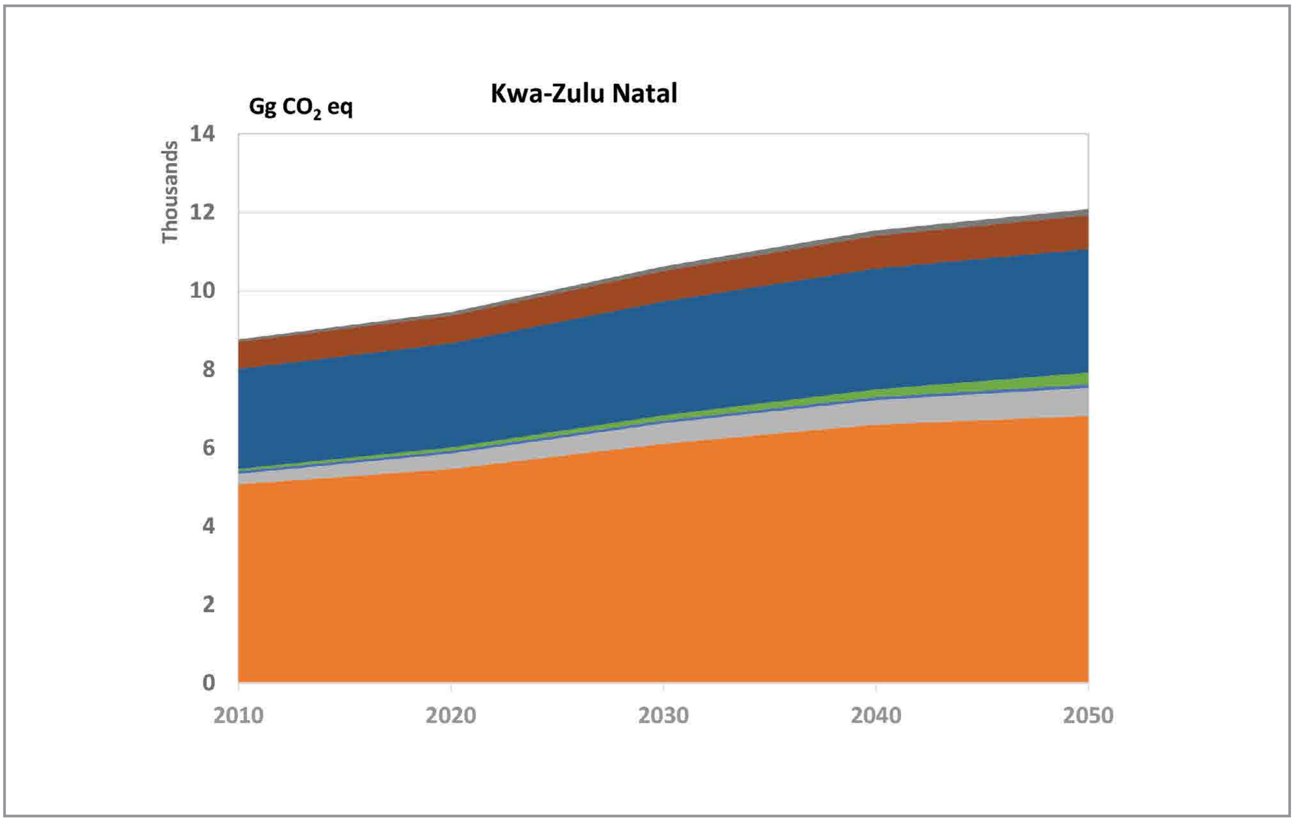
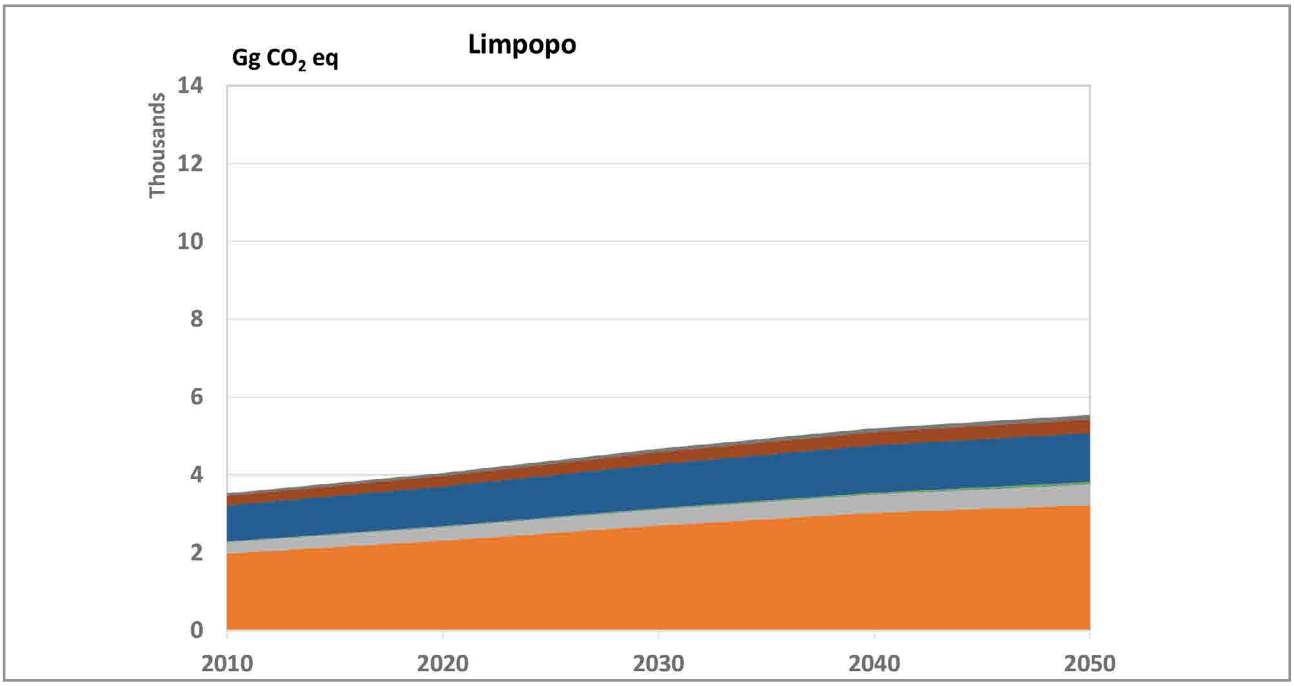
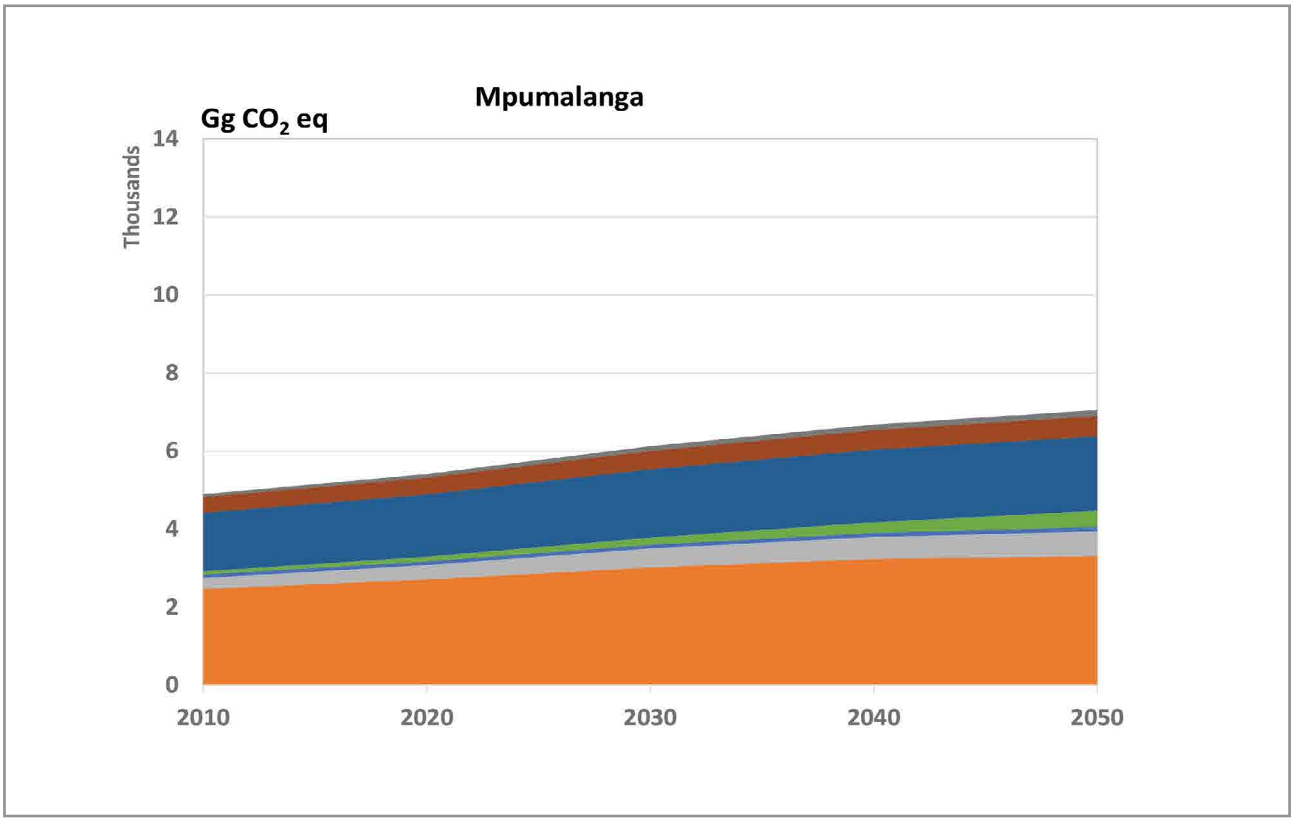
12
10
8
6
4
2
0
2010
2020
2030
2040
2050


Kwa-Zulu Natal
Gg CO_2 eq
Thousands
14
12
10
8
6
4
2
0
2010
2020
2030
2040
2050


Limpopo
Gg CO_2 eq
Thousands
14
12
10
8
6
4
2
0
2010
2020
2030
2040
2050


Mpumalanga
Gg CO_2 eq
Thousands
14
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2030
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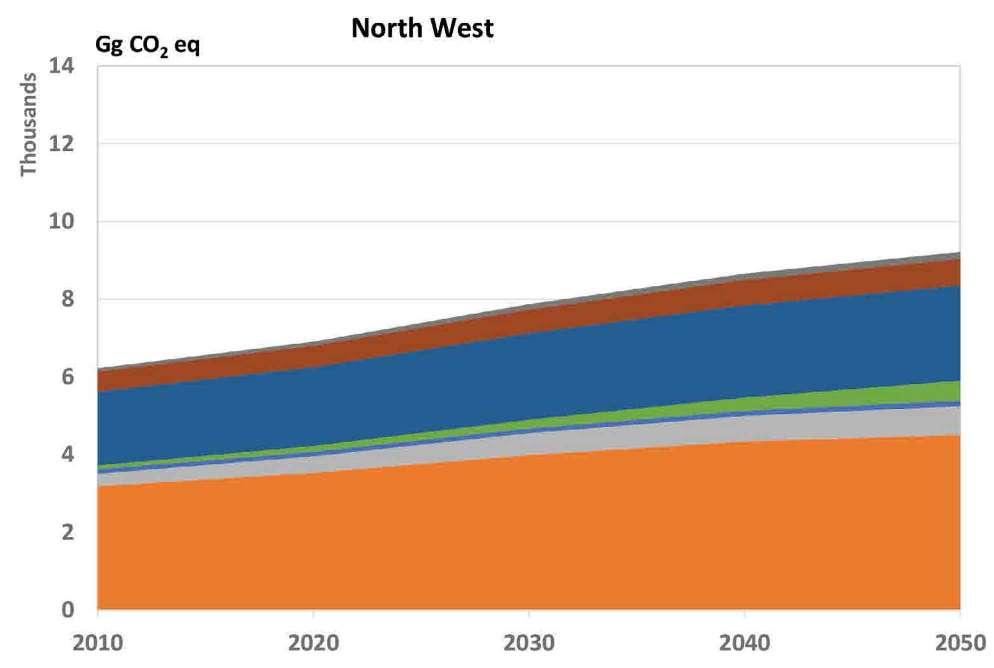
2050


North West
Gg CO_2 eq
Thousands
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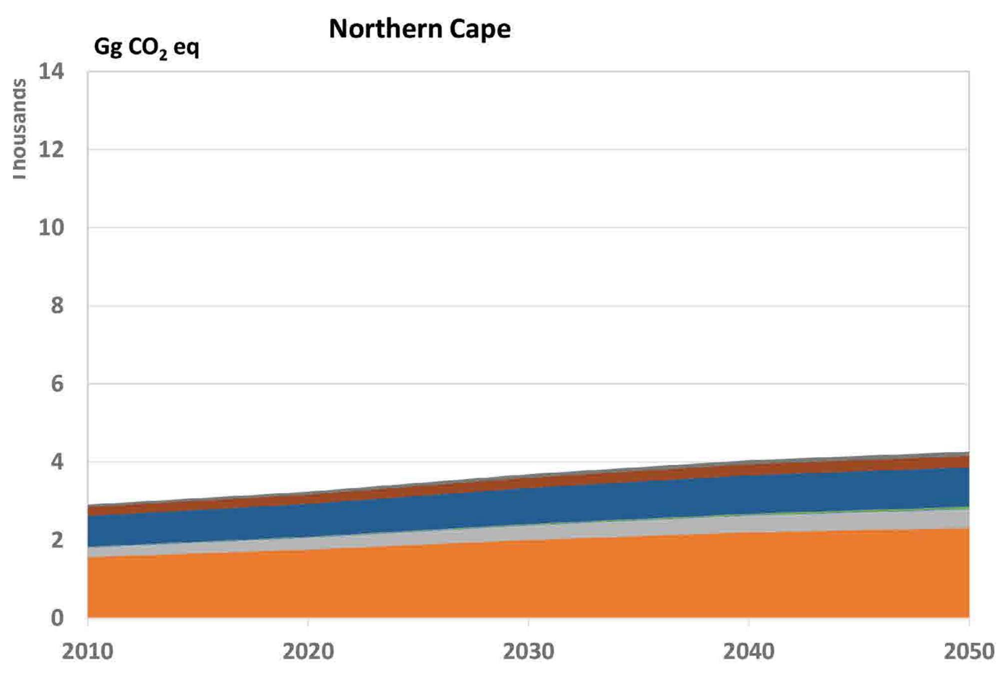
Northern Cape
Gg CO_2 eq
Thousands
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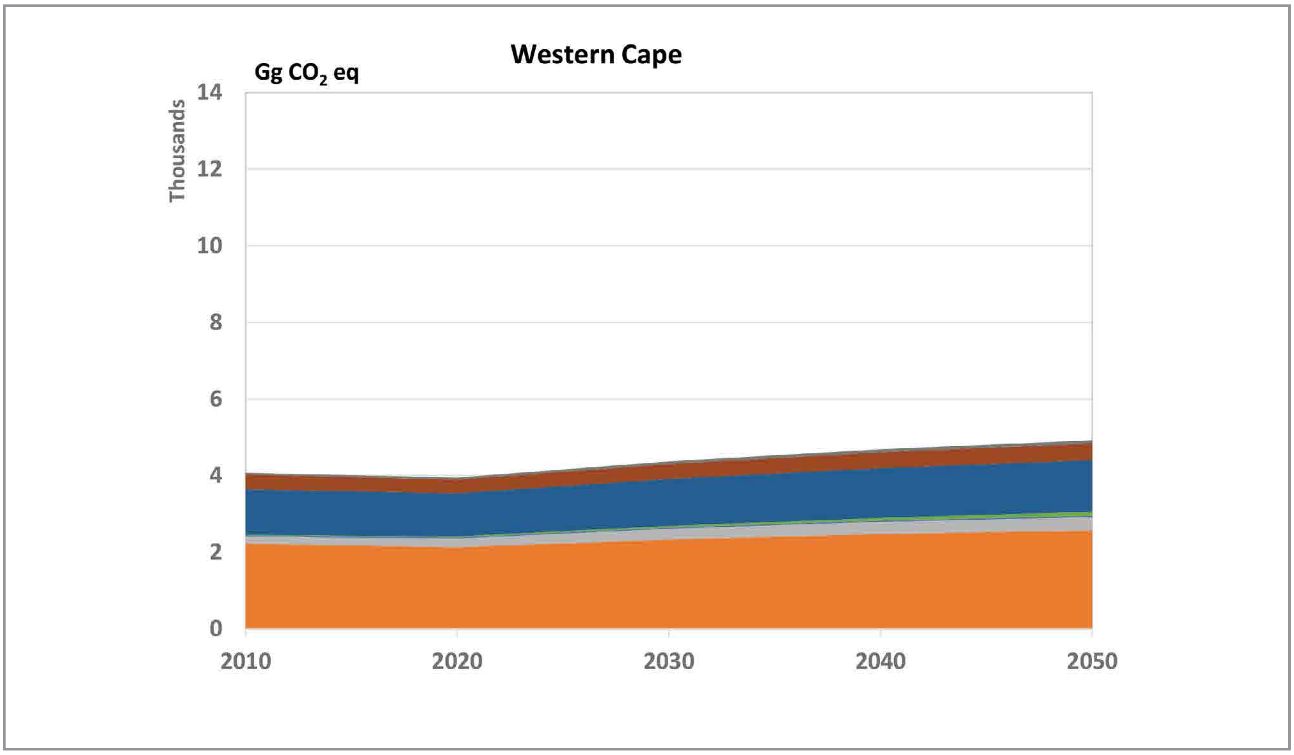

Figure 3: Category Contribution to the Total Provincial Agricultural Emissions (Gg CO_2eq).

Appendix B

Provincial land change matrix

Change from 1990 to 2013	2013 EASTERN CAPE																
Quantitative units: ha (based on 30 m pixels for 1990 vs 2013)	Indigenous Forest	Thicket/dense bush	Woodland/open bush	Low shrubland	Plantations/woodlots	Cultivated commercial annual: non-pivot	Cultivated commercial annual: pivot	Cultivated commercial permanent orchards	Cultivated commercial permanent vines	Cultivated subsistence crops	Settlements	Wetlands	Grasslands	Mines	Waterbodies	Bare ground	Degraded	**TOTAL Change (Pixels)**
1990 EASTERN CAPE																		
Indigenous Forest	89 569	13 154	4 945	469	19	75	3	4	0	357	195	152	1 373	0	9	230	0	110 554
Thicket/dense bush	17 678	941 350	52 411	22 940	314	7 515	763	1 863	0	6 921	4 693	4 545	139 186	50	627	1 303	90	1 202 249
Woodland/open bush	2 931	161 736	36 371	14 964	2 723	2 124	255	271	0	2 197	673	1 674	32 370	36	545	1 849	160	260 880
Low shrubland	2 323	192 838	141 868	2 581 125	1 918	12 584	7 908	1 933	0	1 678	4 418	9 897	1 460 967	66	2 957	55 427	4 297	4 482 204
Plantations/woodlots	5 733	15 976	1 877	4 240	103 496	1 528	72	592	0	436	1 783	788	16 364	5	31	44	38	153 005
Cultivated commercial annual: non-pivot	241	16 733	11 341	17 350	1 714	409 854	26 019	1 191	0	188	762	5 254	51 686	41	325	456	107	543 262
Cultivated commercial annual: pivot	2	80	36	134	1	376	8 752	126	0	223	2	25	375	0	1	3	0	10 135
Cultivated commercial permanent orchards	34	4 553	995	417	709	4 841	1 365	38 755	0	1 844	196	155	4 303	0	27	9	0	58 203
Cultivated commercial permanent vines	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cultivated subsistence crops	201	14 740	1 213	323	1 040	501	721	0	0	648 849	862	640	48 784	16	35	2 922	447	721 293
Settlements	195	10 148	1 861	1 455	2 072	785	20	223	0	10 300	564 657	456	38 986	25	146	554	274	632 158
Wetlands	330	20 949	5 895	13 415	1 045	6 093	1 106	267	0	6 608	311	72 905	86 195	11	2 070	1 274	40	218 513
Grasslands	10 951	737 169	247 662	494 186	37 836	37 654	4 046	2 344	0	81 063	32 679	44 683	4 640 640	511	3 768	17 931	13 408	6 406 531
Mines	0	399	343	191	10	24	7	1	0	140	50	74	2 929	3 224	2	25	74	7 494
Waterbodies	15	2 567	1 406	1 850	88	267	27	16	0	85	105	3 997	3 994	32	46 155	2 494	8	63 106
Bare ground	87	20 719	49 160	884 237	57	569	307	12	0	86	696	3 797	106 279	10	4 420	461 450	1 414	1 533 300
Degraded	6	4 996	5 583	66 765	1 522	2 501	688	25	0	6 192	1 568	3 383	344 109	2	110	21 089	33 397	491 938
	130 297	2 158 107	562 967	4 104 062	154 564	487 292	52 057	47 623	0	767 167	613 649	152 425	6 978 540	4 030	61 228	567 061	53 755	

Change from 1990 to 2013	2013 FREE STATE																	
Quantitative units: ha (based on 30 m pixels for 1990 vs 2013)	Indigenous Forest	Thicket/dense bush	Woodland/open bush	Low shrubland	Plantations/woodlots	Cultivated commercial annual: non-pivot	Cultivated commercial annual: pivot	Cultivated commercial permanent orchards	Cultivated commercial permanent vines	Cultivated subsistence crops	Settlements	Wetlands	Grasslands	Mines	Waterbodies	Bare ground	Degraded	**TOTAL Change (Pixels)**
1990 FREE STATE																		
Indigenous Forest	4 476	39	151	1	1	6	0	0	0	0	0	13	1 437	0	0	1	0	6 125
Thicket/dense bush	312	36 651	6 395	6 120	273	5 727	769	28	0	9	402	2 856	56 556	360	429	342	14	117 243
Woodland/open bush	565	14 171	9 334	41 050	1 665	14 438	2 242	44	0	11	629	1 660	50 684	766	740	2 291	33	140 324
Low shrubland	17	3 663	15 599	1 724 140	376	44 258	16 538	104	0	75	2 129	2 558	379 406	187	1 116	35 694	412	2 226 269
Plantations/woodlots	156	6 285	2 572	391	28 056	2 067	44	13	0	19	1 723	834	10 026	306	35	38	2	52 566
Cultivated commercial annual: non-pivot	0	5 240	6 111	80 721	2 172	3 293 567	101 763	810	0	9 501	3 348	6 043	276 699	1 111	114	1 036	61	3 788 297
Cultivated commercial annual: pivot	0	208	90	352	5	2 884	23 057	271	0	0	1	88	650	0	2	3	0	27 611
Cultivated commercial permanent orchards	0	38	15	28	13	85	133	1 910	0	0	1	14	113	0	0	1	0	2 351
Cultivated commercial permanent vines	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cultivated subsistence crops	0	3	4	151	23	13	0	0	0	18 004	21	4	584	0	0	5	33	18 845
Settlements	1	1 301	731	1 028	599	687	11	1	0	11	80 079	320	4 451	98	46	116	9	89 488
Wetlands	21	14 747	8 144	38 997	2 589	15 216	1 273	32	0	122	567	133 514	153 760	369	1 984	1 336	13	372 683
Grasslands	1 241	63 117	57 744	1 372 930	14 777	218 515	16 897	237	0	1 610	14 001	41 596	4 042 645	4 324	3 826	13 193	3 544	5 870 197
Mines	0	704	727	540	41	61	2	0	0	1	23	264	5 482	16 248	16	48	17	24 173
Waterbodies	5	2 671	2 855	12 347	105	767	80	5	0	3	65	33 345	17 801	108	85 662	2 718	5	158 544
Bare ground	6	592	2 049	16 988	20	72	83	2	0	0	199	1 080	4 489	13	2 197	9 598	2	37 390
Degraded	0	331	390	12 396	10	256	60	0	0	37	36	469	12 108	1	30	16 279	2 562	44 966
	6 800	149 761	112 910	3 308 180	50 725	3 598 621	162 952	3 457	0	29 403	103 223	224 658	5 016 891	23 890	96 197	82 699	6 706	

Change from 1990 to 2013	2013 GAUTENG																	
Quantitative units: ha (based on 30 m pixels for 1990 vs 2013)	Indigenous Forest	Thicket/dense bush	Woodland/open bush	Low shrubland	Plantations/woodlots	Cultivated commercial annual: non-pivot	Cultivated commercial annual: pivot	Cultivated commercial permanent orchards	Cultivated commercial permanent vines	Cultivated subsistence crops	Settlements	Wetlands	Grasslands	Mines	Waterbodies	Bare ground	Degraded	**TOTAL Change (Pixels)**
1990 GAUTENG																		
Indigenous Forest	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
Thicket/dense bush	1.6	38 876.3	18 913.5	299.3	246.8	4 360.0	153.7	58.7	0.0	56.9	6 466.4	4 212.4	23 635.8	826.3	300.0	91.5	65.9	98 565
Woodland/open bush	0.0	13 266.6	93 791.1	1 078.4	440.3	6 355.2	325.9	67.1	0.0	130.9	10 453.6	1 447.5	34 178.5	752.4	197.5	195.5	417.3	163 098
Low shrubland	0.0	840.3	3 867.1	1 615.9	156.2	1 504.4	57.8	11.8	0.0	23.2	2 966.7	113.1	12 788.9	4.1	33.2	313.5	368.8	24 665
Plantations/woodlots	0.0	6 359.0	1 468.9	65.4	19 086.2	1 557.5	93.0	10.9	0.0	1.4	9 948.5	613.9	5 482.3	98.6	22.6	50.9	7.7	44 867
Cultivated commercial annual: non-pivot	0.0	2 882.5	6 580.0	789.8	687.5	302 650.8	13 736.2	674.6	0.0	88.7	9 097.5	3 146.6	58 239.9	1 667.5	75.6	298.6	115.3	400 731
Cultivated commercial annual: pivot	0.0	19.5	114.7	4.6	0.1	1 256.0	5 181.9	4.1	0.0	0.7	88.9	13.0	216.3	0.7	0.8	0.1	0.5	6 902
Cultivated commercial permanent orchards	0.0	16.8	13.1	0.1	0.5	433.6	1.1	555.5	0.0	0.0	16.3	2.4	31.7	0.2	0.0	0.1	0.0	1 071
Cultivated commercial permanent vines	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
Cultivated subsistence crops	0.0	37.3	351.0	14.2	0.9	1 362.4	0.0	0.3	0.0	261.5	198.5	26.3	462.7	6.2	0.0	1.6	5.2	2 728
Settlements	0.0	13 154.8	5 294.3	812.4	4 025.8	4 011.2	39.2	49.0	0.0	27.4	276 231.5	1 391.8	11 802.7	417.2	101.4	160.0	49.7	317 568
Wetlands	0.0	4 321.0	2 939.5	50.0	292.8	3 398.5	107.0	10.9	0.0	189.8	1 118.5	32 616.3	17 397.3	117.9	440.7	68.0	2.6	63 071
Grasslands	0.8	27 144.3	55 163.3	3 456.3	3 906.2	52 801.7	1 882.5	243.7	0.0	395.7	33 379.1	8 751.5	453 151.2	3 980.6	709.5	785.9	1 614.2	647 366
Mines	0.0	1 658.2	2 190.0	17.8	175.8	153.7	1.2	0.1	0.0	0.9	182.6	363.2	6 963.0	12 717.5	13.8	8.1	180.0	24 626
Waterbodies	0.0	236.2	175.0	12.6	29.2	30.6	0.8	0.1	0.0	0.2	147.6	812.2	442.3	1.9	8 079.1	107.0	0.5	10 075
Bare ground	0.0	63.4	119.3	61.1	13.6	11.6	0.5	0.1	0.0	0.0	250.0	22.4	416.7	2.0	72.1	187.8	4.1	1 225
Degraded	0.0	176.0	4 072.2	402.7	19.1	538.9	5.1	5.3	0.0	15.8	171.6	20.8	3 472.8	0.6	8.6	149.9	1 408.6	10 468
	3	109 052	195 053	8 681	29 081	380 426	21 586	1 692	0	1 193	350 717	53 553	628 682	20 594	10 055	2 418	4 241	

	Change from 1990 to 2013	2013 KWAZULU-NATAL																		
	Quantitative units: ha (based on 30 m pixels for 1990 vs 2013)	Indigenous Forest	Thicket/dense bush	Woodland/open bush	Low shrubland	Plantations/woodlots	Cultivated commercial annual: non-pivot	Cultivated commercial annual: pivot	Cultivated commercial permanent orchards	Cultivated commercial permanent vines	Cultivated subsistence crops	Settlements	Wetlands	Grasslands	Mines	Waterbodies	Bare ground	Degraded	**TOTAL Change (Pixels)**
1990 KWAZULU-NATAL	Indigenous Forest	123 790	6 773	1 592	23	786	459	0	55	0	585	1 703	1 040	3 348	263	4	133	30	140 585
	Thicket/dense bush	9 592	1 059 345	148 003	4 706	6 326	51 620	1 525	4 248	0	34 494	14 072	9 158	289 789	581	2 207	1 549	2 771	1 639 985
	Woodland/open bush	3 873	221 760	135 860	2 899	12 404	5 834	594	424	0	17 509	1 432	1 764	88 440	105	923	2 756	1 816	498 392
	Low shrubland	1 060	9 127	7 121	5 371	924	676	55	6	0	1 689	717	311	35 178	3	117	7 425	1 477	71 255
	Plantations/woodlots	5 576	59 029	8 257	226	548 275	14 064	177	450	0	1 366	8 730	4 218	35 050	454	72	129	243	686 316
	Cultivated commercial annual: non-pivot	138	26 511	4 247	469	12 594	583 844	41 802	1 353	0	1 173	1 349	3 582	42 766	86	341	330	658	721 243
	Cultivated commercial annual: pivot	0	131	28	18	8	3 263	14 190	5	0	38	506	19	516	2	2	9	3	18 738
	Cultivated commercial permanent orchards	53	1 405	1 639	238	187	2 148	177	16 136	0	64	38	63	2 469	8	1	11	154	24 791
	Cultivated commercial permanent vines	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Cultivated subsistence crops	49	23 962	2 731	332	470	23 399	179	40	0	337 556	1 894	488	17 291	16	27	1 098	494	410 026
	Settlements	771	31 777	5 445	860	5 709	9 086	10	35	0	17 665	731 798	498	30 709	88	76	671	471	835 670
	Wetlands	2 513	23 651	4 682	581	1 770	6 472	176	58	0	5 898	210	92 894	43 578	9	1 455	551	818	185 315
	Grasslands	8 587	468 705	270 640	18 287	119 490	100 982	8 359	1 948	0	113 400	25 181	29 442	2 683 473	1 507	4 444	21 766	18 723	3 894 932
	Mines	2	374	256	15	228	79	0	0	0	92	25	33	1 909	2 145	17	90	116	5 381
	Waterbodies	193	8 021	2 635	599	246	768	10	65	0	700	268	4 280	3 806	1	188 792	3 300	231	213 916
	Bare ground	162	6 300	5 739	666	128	128	2	6	0	197	236	551	7 363	2	2 150	10 072	98	33 800
	Degraded	8	728	2 029	2 467	1 277	2 385	470	5	0	1 745	261	356	39 043	11	98	19 360	11 597	81 838
		156 367	1 947 598	600 905	37 757	710 822	805 207	67 727	24 835	0	534 170	788 418	148 696	3 324 727	5 282	200 726	69 248	39 699	

	Change from 1990 to 2013	2013 LIMPOPO																	
	Quantitative units: ha (based on 30 m pixels for 1990 vs 2013)	Indigenous Forest	Thicket/dense bush	Woodland/open bush	Low shrubland	Plantations/woodlots	Cultivated commercial annual: non-pivot	Cultivated commercial annual: pivot	Cultivated commercial permanent orchards	Cultivated commercial permanent vines	Cultivated subsistence crops	Settlements	Wetlands	Grasslands	Mines	Waterbodies	Bare ground	Degraded	**TOTAL Change (Pixels)**
1990 LIMPOPO	Indigenous Forest	25 578	12 285	656	33	13	98	2	575	0	17	28	23	148	0	6	39	14	39 512
	Thicket/dense bush	11 795	830 076	681 513	6 581	437	9 237	2 142	9 139	0	8 307	10 185	5 566	106 710	2 185	2 338	2 875	3 688	1 692 774
	Woodland/open bush	1 556	673 941	3 429 436	75 252	1 753	35 965	24 478	7 684	0	37 606	43 041	7 536	910 341	5 141	3 346	8 734	104 489	5 370 299
	Low shrubland	19	13 185	141 470	37 267	34	3 473	1 664	693	0	2 412	10 441	276	59 042	84	359	5 181	20 398	295 998
	Plantations/woodlots	6 535	11 407	4 101	133	73 975	691	21	2 751	0	180	965	480	1 228	14	46	26	137	102 692
	Cultivated commercial annual: non-pivot	17	7 713	123 977	6 381	195	456 762	54 705	13 796	0	2 166	8 162	1 555	21 485	377	180	504	14 933	712 908
	Cultivated commercial annual: pivot	0	455	4 535	144	16	9 938	59 314	2 466	0	61	210	115	577	57	25	37	405	78 358
	Cultivated commercial permanent orchards	53	2 136	4 961	104	236	2 754	664	64 290	0	1 667	206	64	594	3	16	38	105	77 889
	Cultivated commercial permanent vines	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Cultivated subsistence crops	19	34 718	131 409	810	38	6 486	576	2 592	0	279 013	3 475	57	3 901	1 060	7	1 037	896	466 094
	Settlements	10	4 448	10 046	2 152	162	304	23	170	0	1 819	330 258	139	3 022	128	14	419	819	353 933
	Wetlands	87	21 268	20 765	927	81	1 648	1 138	623	0	994	155	27 891	2 381	53	860	334	263	79 468
	Grasslands	437	122 357	1 475 171	96 292	1 075	35 103	19 732	3 604	0	19 003	42 756	2 155	749 790	3 158	1 150	9 255	163 928	2 744 966
	Mines	0	1 270	8 138	319	0	68	9	6	0	103	414	54	1 727	15 508	8	268	561	28 453
	Waterbodies	25	1 878	1 385	327	66	71	6	74	0	18	35	276	311	0	10 457	760	50	15 739
	Bare ground	7	750	2 999	1 018	8	137	15	17	0	51	247	41	611	24	767	1 994	575	9 260
	Degraded	3	13 539	190 678	16 153	26	5 758	3 099	779	0	50 479	5 348	405	105 532	331	118	39 615	87 081	518 946
		46 142	1 751 426	6 231 240	243 892	78 117	568 492	167 589	109 258	0	403 895	455 925	46 632	1 967 402	28 124	19 698	71 115	398 344	




Change from 1990 to 2013	2013 MPUMALANGA																	
Quantitative units: ha (based on 30 m pixels for 1990 vs 2013)	Indigenous Forest	Thicket/dense bush	Woodland/open bush	Low shrubland	Plantations/woodlots	Cultivated commercial annual: non-pivot	Cultivated commercial annual: pivot	Cultivated commercial permanent orchards	Cultivated commercial permanent vines	Cultivated subsistence crops	Settlements	Wetlands	Grasslands	Mines	Waterbodies	Bare ground	Degraded	**TOTAL Change (Pixels)**
1990 MPUMALANGA: Indigenous Forest	16 320	6 132	298	3	99	15	0	39	0	14	1	75	226	0	2	12	0	23 234
Thicket/dense bush	6 228	358 119	150 958	1 679	3 486	11 674	1 251	5 675	0	1 191	5 126	4 426	79 850	732	2 089	1 059	130	633 672
Woodland/open bush	1 010	297 468	783 598	7 979	15 150	13 412	1 296	2 553	0	5 578	13 089	3 342	206 441	736	2 683	2 168	1 239	1 357 743
Low shrubland	48	2 208	9 086	3 579	1 822	4 753	215	75	0	310	2 432	283	48 317	264	324	3 042	320	77 078
Plantations/woodlots	5 185	15 910	23 865	846	624 567	2 664	122	2 003	0	304	2 603	7 025	54 463	2 659	617	492	139	743 465
Cultivated commercial annual: non-pivot	8	13 155	11 144	1 891	9 723	989 706	38 042	9 201	0	1 268	2 750	9 057	192 088	25 415	250	1 829	241	1 305 768
Cultivated commercial annual: pivot	0	167	161	16	88	2 209	11 743	261	0	1	74	67	1 024	83	5	10	1	15 909
Cultivated commercial permanent orchards	2	2 431	475	50	227	4 527	476	21 675	0	464	495	47	779	42	15	12	34	31 750
Cultivated commercial permanent vines	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cultivated subsistence crops	1	9 513	22 054	169	383	4 948	5	144	0	49 150	1 375	144	2 889	89	883	36	77	91 860
Settlements	9	3 983	3 506	395	863	1 350	11	199	0	760	161 024	618	5 450	423	21	194	53	178 860
Wetlands	443	12 997	7 943	368	2 478	5 332	250	335	0	1 151	449	151 673	51 496	966	1 151	507	13	237 552
Grasslands	1 912	139 118	273 686	19 575	92 569	98 946	4 235	767	0	5 763	24 043	23 400	2 138 660	21 317	4 941	10 735	2 307	2 861 972
Mines	0	1 201	1 914	49	342	574	0	1	0	55	276	769	16 291	24 787	29	118	82	46 488
Waterbodies	0	1 173	996	123	203	44	3	26	0	3	130	2 940	2 492	28	31 452	1 343	1	40 957
Bare ground	12	693	920	216	90	56	3	3	0	3	268	183	2 173	17	1 153	1 498	25	7 314
Degraded	0	650	2 623	530	64	243	4	27	0	772	287	197	4 300	9	24	1 438	1 065	12 234
	31 178	864 918	1 293 229	37 468	752 153	1 140 453	57 657	42 983	0	66 786	214 423	204 244	2 806 940	77 567	45 637	24 493	5 726	

Change from 1990 to 2013	2013 NORTH WEST																	
Quantitative units: ha (based on 30 m pixels for 1990 vs 2013)	Indigenous Forest	Thicket/dense bush	Woodland/open bush	Low shrubland	Plantations/woodlots	Cultivated commercial annual: non-pivot	Cultivated commercial annual: pivot	Cultivated commercial permanent orchards	Cultivated commercial permanent vines	Cultivated subsistence crops	Settlements	Wetlands	Grasslands	Mines	Waterbodies	Bare ground	Degraded	**TOTAL Change (Pixels)**
1990 NORTH WEST: Indigenous Forest	541	7	65	3	0	0	0	0	0	0	0	1	113	0	0	0	0	731
Thicket/dense bush	154	123 907	126 275	3 991	54	2 741	636	197	0	185	2 022	1 676	40 962	1 120	435	934	3 318	308 610
Woodland/open bush	42	43 529	731 114	319 724	595	11 418	3 040	153	0	7 628	10 802	1 445	374 014	4 664	1 078	7 257	96 329	1 612 832
Low shrubland	4	1 560	250 596	1 957 113	118	45 529	4 945	28	0	3 077	9 949	230	437 591	588	206	3 709	64 233	2 779 474
Plantations/woodlots	6	3 036	1 693	87	8 848	533	25	57	0	31	480	272	2 138	26	7	10	20	17 269
Cultivated commercial annual: non-pivot	0	4 594	47 224	172 422	484	1 712 092	51 097	274	0	2 690	1 493	1 164	139 538	7 793	45	1 497	13 269	2 155 674
Cultivated commercial annual: pivot	0	252	293	604	1	2 708	18 827	23	0	27	37	33	840	189	1	4	78	23 917
Cultivated commercial permanent orchards	3	140	168	131	24	268	168	4 234	0	0	5	11	114	1	0	1	0	5 268
Cultivated commercial permanent vines	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cultivated subsistence crops	0	388	22 633	11 087	13	8 339	323	0	0	203 400	866	30	3 804	234	9	628	16 184	267 939
Settlements	2	1 621	5 683	4 167	222	1 386	17	5	0	743	166 824	193	3 326	161	22	340	1 191	185 903
Wetlands	4	11 083	14 219	6 876	336	2 026	510	29	0	479	170	22 708	30 358	314	892	334	328	90 666
Grasslands	210	35 014	505 646	560 999	3 740	70 864	5 021	325	0	5 555	17 625	4 047	1 429 902	12 673	1 194	10 316	160 244	2 823 376
Mines	0	787	2 560	738	52	86	4	0	0	19	164	157	9 769	29 168	55	123	493	44 175
Waterbodies	1	1 158	1 502	1 205	20	183	17	4	0	2	81	2 247	3 827	3	20 557	980	107	31 891
Bare ground	0	109	309	373	5	22	11	0	0	2	104	20	194	15	175	491	74	1 904
Degraded	0	939	32 449	11 140	50	1 257	132	12	0	5 249	911	104	15 788	257	46	16 878	54 928	140 138
	966	228 125	1 742 429	3 050 661	14 561	1 859 451	84 771	5 341	0	229 085	211 532	34 339	2 492 280	57 205	24 722	43 503	410 796	

Change from 1990 to 2013

Quantitative units: ha (based on 30 m pixels for 1990 vs 2013)

1990 NORTHERN CAPE \ 2013 NORTHERN CAPE	Indigenous Forest	Thicket/dense bush	Woodland/open bush	Low shrubland	Plantations/woodlots	Cultivated commercial annual: non-pivot	Cultivated commercial annual: pivot	Cultivated commercial permanent orchards	Cultivated commercial permanent vines	Cultivated subsistence crops	Settlements	Wetlands	Grasslands	Mines	Waterbodies	Bare ground	Degraded	**TOTAL Change (Pixels)**
Indigenous Forest	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thicket/dense bush	0	57 468	62 396	113 764	7	2 198	1 332	250	1 172	1	321	1 826	50 253	2 520	687	8 474	0	302 670
Woodland/open bush	0	43 974	253 716	626 950	130	3 697	1 803	219	286	5	832	2 356	128 890	2 981	1 140	94 227	0	1 161 205
Low shrubland	0	46 517	568 054	20 401 005	85	13 319	16 182	431	2 658	179	8 971	3 652	1 436 621	2 439	1 685	2 090 170	181	24 592 150
Plantations/woodlots	0	162	217	213	424	80	10	3	6	0	49	35	230	2	0	8	0	1 439
Cultivated commercial annual: non-pivot	0	3 802	5 350	14 229	77	108 814	25 485	1 547	0	129	60	875	4 719	569	366	2 969	0	168 990
Cultivated commercial annual: pivot	0	1 315	453	836	12	438	39 439	48	92	0	17	60	729	323	3	94	0	43 859
Cultivated commercial permanent orchards	0	265	105	199	2	140	439	4 481	1	0	0	32	68	3	3	65	0	5 801
Cultivated commercial permanent vines	0	2 698	328	224	2	976	287	62	24 446	0	17	0	89	0	1	146	0	29 277
Cultivated subsistence crops	0	1	57	540	0	40	5	0	0	3 539	0	0	167	0	0	0	0	4 349
Settlements	0	615	648	2 680	19	51	1	0	13	7	39 799	32	897	71	5	611	0	45 449
Wetlands	0	15 483	11 124	41 918	87	1 599	1 249	101	786	1	92	30 513	17 306	62	693	3 063	0	124 076
Grasslands	0	27 701	113 255	903 028	64	3 356	5 543	174	208	43	1 294	3 690	315 407	3 418	843	86 440	0	1 464 462
Mines	0	867	2 442	4 986	3	9	90	0	0	0	94	27	4 808	88 326	12	1 859	0	103 523
Waterbodies	0	6 984	2 915	7 701	10	1 206	10	27	2	0	11	1 599	1 146	52	35 983	75 011	0	132 656
Bare ground	0	26 018	84 831	1 786 797	25	1 233	1 175	120	2 608	1	2 048	733	43 191	757	11 691	7 288 352	1	9 249 581
Degraded	0	1 137	1 531	84 261	0	8	17	0	0	2	17	268	1 114	1	20	48 009	87	136 473
	0	235 006	1 107 422	23 989 334	948	137 165	93 068	7 462	32 277	3 905	53 621	45 697	2 005 634	101 525	53 133	9 699 499	269	

Change from 1990 to 2013	2013 WESTERN CAPE																	
Quantitative units: ha (based on 30 m pixels for 1990 vs 2013)	Indigenous Forest	Thicket/dense bush	Woodland/open bush	Low shrubland	Plantations/woodlots	Cultivated commercial annual: non-pivot	Cultivated commercial annual: pivot	Cultivated commercial permanent orchards	Cultivated commercial permanent vines	Cultivated subsistence crops	Settlements	Wetlands	Grasslands	Mines	Waterbodies	Bare ground	Degraded	**TOTAL Change (Pixels)**
1990 WESTERN CAPE																		
Indigenous Forest	47 427	6 186	100	907	2	192	10	4	0	0	94	79	66	1	14	132	0	55 216
Thicket/dense bush	2 312	260 119	31 810	221 816	87	6 329	430	2 091	2 684	2	4 001	6 452	46 281	195	1 318	4 680	189	590 795
Woodland/open bush	114	45 491	86 240	210 472	1 364	3 261	137	211	1 408	13	273	1 490	15 360	117	886	40 505	26	407 366
Low shrubland	1 468	332 168	283 490	4 728 951	6 801	103 511	16 638	10 507	11 281	91	14 782	18 099	277 785	4 153	5 659	310 639	17 067	6 143 090
Plantations/woodlots	3 588	17 824	2 081	18 133	68 736	2 513	25	494	734	0	1 308	1 166	2 831	18	549	145	35	120 180
Cultivated commercial annual: non-pivot	321	12 783	6 372	105 465	1 658	1 482 832	36 713	2 879	8 655	0	775	5 202	22 643	350	496	1 261	1 260	1 689 666
Cultivated commercial annual: pivot	2	195	66	741	1	1 824	14 353	289	837	0	9	34	402	1	4	5	75	18 839
Cultivated commercial permanent orchards	2	3 794	151	4 836	210	2 868	238	82 141	10 102	0	111	553	1 340	1	56	41	2	106 447
Cultivated commercial permanent vines	0	2 372	228	5 089	191	1 928	299	3 360	116 832	0	536	682	1 360	3	160	27	11	133 077
Cultivated subsistence crops	0	23	27	97	0	11	0	0	271	590	2	2	9	0	0	1	0	1 032
Settlements	53	4 093	249	5 476	210	278	0	39	207	1	91 497	297	796	19	153	195	61	103 626
Wetlands	198	27 924	3 769	29 327	192	5 983	256	896	1 537	22	652	64 131	4 183	27	2 114	2 499	29	143 739
Grasslands	386	55 045	57 847	402 325	1 664	17 531	2 100	1 201	1 607	5	1 790	3 308	112 014	1 195	1 385	46 535	876	706 816
Mines	0	167	241	1 935	7	51	0	1	1	0	34	103	315	3 183	43	38	66	6 185
Waterbodies	8	1 429	952	3 504	58	442	14	64	136	0	192	4 947	1 132	22	40 740	1 721	11	55 371
Bare ground	1	24 858	63 802	822 897	18	711	204	67	71	0	525	1 427	25 643	13	2 437	1 781 608	343	2 724 625
Degraded	0	580	663	25 085	28	3 227	2 077	59	70	0	15	171	7 322	1	52	8 487	4 232	52 070
	55 879	795 051	538 087	6 587 057	81 227	1 633 492	73 494	104 300	156 434	724	116 596	108 144	519 481	9 298	56 067	2 198 520	24 285	

Department of Environmental Affairs

Environment House
473 Steve Biko
Arcadia
Pretoria, 0083
South Africa

DEA call centre:
+27 86 111 2468