GHG Inventory for South Africa

2000 – 2010

August 2013

PREFACE

This report has been compiled for the Department of Environmental Affairs (DEA) in response to South Africa's obligation to report their greenhouse (GHG) emissions to international climate change bodies. The report is prepared in accordance with the United Nations Framework Convention on Climate Change (UNFCCC). This inventory was compiled by making use of the Intergovernmental Panel on Climate Change (IPCC) 2006 Excel spread sheet Guidelines and the revised IPCC 2006 software.

This report is published by DEA, South Africa. An electronic version of the report will be available on the website of DEA (http://www.saaqis.org.za/) once the review process is completed.

Information from this report may be reproduced, provided the source is acknowledged.

ACKNOWLEDGEMENTS

Many people and institutes were involved in the compilation of the updated National Inventory Report (NIR). Information on the Energy and Industrial Processes and Product Use (IPPU) sectors was provided by the Department of Energy (DoE), Department of Mineral Resources (DMR), Business Unity South Africa (BUSA) members, Chamber of Mines, ESKOM, SASOL, PetroSA. The Agriculture, Forestry and Other Land Use (AFOLU) sector was prepared by the University of the Witwatersrand (Wits) in collaboration with Tshwane University of Technology (TUT), North West University (Potch), DEA, Department of Agriculture, Forestry and Fisheries (DAFF), GeoTerraImage (GTI), and the ARC; and Waste was provided by the Council of Scientific and Industrial Research (CSIR) and DEA.

We greatly appreciate all the contributions from organizations and individuals who were involved in the process of completing this NIR. Special thanks to the British High Commission in South Africa for providing funding for the AFOLU sector as well as funds for the compilation of this NIR. We would also like to thank all reviewers of the various sector sections as well as the reviewers of the completed NIR.

AUTHORS AND CONTRIBUTORS

General responsibility: Jongikhaya Witi and Luanne Stevens

Individual chapters:

- Summary: Luanne Stevens
- Chapter 1: Introduction - Luanne Stevens, Jongikhaya Witi
- Chapter 2: Trend in GHG Emissions - Luanne Stevens
- Chapter 3: Energy Sector - Jongikhaya Witi, Lungile Manzini
- Chapter 4: Indutrial Processes and Product Use - Jongikhaya Witi, Lungile Manzini
- Chapter 5: Agriculture, Forestry and Land Use - Luanne Stevens, Lindique du Toit, Jongikhaya Witi
- Chapter 6: Waste - Ndeke Musee, Jongikhaya Witi

Report reviews: Environmental Resources Management
Report compilation: Luanne Stevens
Language editor:

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

AFOLU	Agriculture, Forestry and Other Land Use
AGB	Above ground biomass
BECF	Biomass expansion and conversion factor
BEF	Biomass expansion factor
C	Carbon
C_2F_6	Carbon hexafluoroethane
CF_4	Carbon tetrafluoromethane
CFC	Chlorofluorocarbons
CH_4	Methane
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide equivalents
CRF	Common reporting format
DEA	Department of Environmental Affairs
DMR	Department of Mineral Resources
DoE	Department of Energy
DOM	Dead organic matter
DTI	Department of Trade and Industry
DWAF	Department of Water Affairs and Forestry
EF	Emission factor
GDP	Gross domestic product
Gg	Gigagram
GHG	Greenhouse gas
GHGI	Greenhouse Gas Inventory
GIS	Geographical Information Systems
GPG	Good Practice Guidelines
GWH	Gigawatt hour
GWP	Global warming potential
HFC	Hydrofluorocarbons
IEF	Implied emission factor
INC	Initial National Communication
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
ISO	International Standardization Organization
LPG	Liquefied petroleum gas
LTO	Landing/take off
MCF	Methane conversion factor
MEF	Manure emission factor
MW	Megawatt
MWH	Megawatt hours
NCCC	National Climate Change Committee
NE	Not estimated
NER	National Electricity Regulator
NIR	National Inventory Report

NOx	Oxides of nitrogen
PFC	Perfluorocarbons
PPM	Parts per million
QA/QC	Quality assurance/quality control
RSA	Republic of South Africa
SAAQIS	South African Air Quality Information System
SAPIA	South African Petroleum Industries Association
SAR	Second Assessment Report
SF_6	Sulphur hexafluoride
SNE	Single National Entity
TAM	Typical animal mass
TM	Tier method
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change

UNITS, FACTORS AND ABBREVIATIONS

Multiplication factor	Abbreviation	Prefix	Symbol
1 000 000 000 000 000	10^{15}	Peta	P
1 000 000 000 000	10^{12}	Tera	T
1 000 000 000	10^{9}	Giga	G
1 000 000	10^{6}	Mega	M
1 000	10^{3}	Kilo	K
100	10^{2}	Hector	H
0,1	10^{-1}	Deci	D
0,01	10^{-2}	Centi	C
0,001	10^{-3}	Milli	M
0,000, 001	10^{-6}	Micro	µ

Unit	Equivalency
1 tonne (t)	1 Megagram (Mg)
1 Kilotonne	1 Gigagram (Gg)
1 Megatonne	1 Teragram (Tg)

EXECUTIVE SUMMARY

ES1 Background information on South Africa's GHG inventories

In August 1997 the Republic of South Africa joined the majority of countries in the international community in ratifying the UNFCCC. The first national GHG inventory in South Africa was prepared in 1998, using 1990 data. It was updated to include 1994 data and published in 2004. It was developed using the 1996 IPCC Guidelines for National Greenhouse Gas Inventories. For the 2000 national inventory, a decision was made to use the recently published 2006 IPCC Guidelines to enhance accuracy and transparency, and also to familiarise researchers with the latest inventory preparation guidelines.

This report documents South Africa's submission of its national greenhouse gas inventory for the year 2010. The reporting of these emissions is in line with the 2006 guidelines of the IPCC. The utilisation of the 2006 IPCC guidelines was to ensure that the GHG inventory report is accurate, consistent, complete and transparent. It also reports on the GHG trends for a ten-year period (2000-2010). It is in accordance with the guidelines provided by the UNFCCC and follows the 2006 IPCC guidelines and IPCC Good Practice Guidance (GPG). The Common Reporting Format (CRF) spread sheet files and the IPCC 2006 software were used in the compilation of this inventory. This report provides an explanation of the methods (Tier 1 and Tier 2 approaches), activity data and emission factors used to develop the inventory. In addition, it assesses the uncertainty and describes the Quality Assurance and Quality Control (QA/QC) activities. Quality assurance for this GHG inventory was undertaken by independent reviewers.

Key categories

Key categories refer to the emission sources which contribute about 95% of the total GHG emissions in the country. The key categories were identified by carrying out the IPCC Tier 1 level and trend assessment with the 2000 and 2010 GHG inventories. The Level Assessment showed the key categories for 2010 (excluding the *Land* sub-sector) to be *Energy industries* (solid fuels), *Road transportation*, *Manufacturing and construction* (solid fuels) and *Enteric fermentation*; while the Trend Assessment (base year being 2000) indicated them to be *Other sectors* (solid fuels), *Other emissions from energy production*, *Enteric fermentation,* and *Iron and Steel production.* If the Land sector is included then *Forest land remaining forest land* becomes the 14th key category in the Level Assessment and the 4th category in the Trend Assessment. Further details are provided in section 1.3.3 with full results given in Appendix A and B.

Institutional arrangements for inventory preparation

South Africa is currently in the process of creating a national GHG inventory system that will manage and simplify its climate change obligations to the UNFCCC process. This process will ensure that the country prepares and manages data collection and analysis, as well as all relevant information related to climate change in the most consistent, transparent and accurate manner for both internal and external reporting. This national system will be based on the "Single National Entity" (SNE) concept, and will be managed by the DEA. The South African Air Quality Information System (SAAQIS) will play a major role in managing reporting and processing of data. Due to their complex emission estimating methods, emission sectors such Agriculture, Forestry, Land Use and Waste are to be estimated outside the SAAQIS system. The SAAQIS will in turn, ingest the outputs of models used in these sectors so that it can generate a national emissions profile (Figure A).

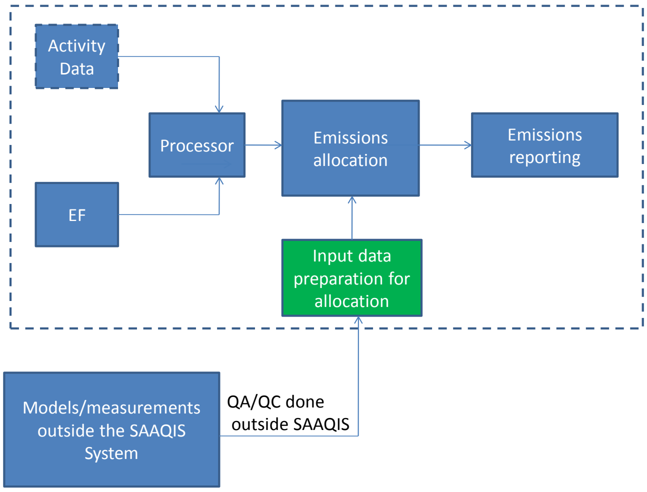

Figure A: Information flow in SAAQIS.

Organisation of report

This report follows a standard NIR format. Chapter 1 is the introductory chapter which contains background information for RSA, the country's inventory preparation and reporting process, key categories, description of the methodologies, activity data and emission factors, and a description of the QA/QC process. A summary of the aggregated GHG trends by gas and emission source is provided in Chapter 2. Chapters 3 to 6 deal with detailed explanations of the emissions in the Energy, IPPU, AFOLU and Waste sectors, respectively. They include an overall trend assessment, data sources, methodology, recalculations, uncertainty and time-series consistency, QA/QC and planned improvements and recommendations.

ES2 Summary of national emission and removal trends

In 2010 the total GHG emissions in South Africa were estimated to be at 579 256 Gg CO_2eq (excl. *Land* sub-sector) (

Table A:). Emissions, excluding the *Land* sub-sector, steadily increased by 24.9% between 2000 and 2010. Including the *Land* sub-sector, which is estimated to be a net carbon sink, leads to greater annual fluctuations in the total CO_2 emitted (

Table A:). It should be noted that the *Land* sub-sector only accounts for the biomass carbon component as there was insufficient data to adequately estimate the soil component and only a partial Dead Organic Matter (DOM) pool was included. CH_4 and PFC emissions have increased by 12% and 3.4% respectively between 2000 and 2010, while N_2O emissions showed a decline of 1.8% over the same period. HFC's were only included from 2005 and have increased dramatically over the 5 year period.

Table A: Trends and levels in GHG emissions for South Africa between 2000 and 2010.

	Energy	IPPU	AFOLU (excl. Land)	AFOLU (incl. Land)	Waste	Total (excl. Land)	Total (incl. Land)
				(Gg CO2 eq.)			
2000	381 790	29 961	39 565	9 037	12 434	463 750	433 221
2001	383 620	28 652	39 725	12 772	13 122	465 118	438 166
2002	392 107	30 368	38 916	16 060	13 789	475 180	452 324
2003	421 121	30 987	36 995	10 310	14 477	503 581	476 895
2004	439 835	32 548	37 049	19 545	15 179	524 611	507 107
2005	433 719	33 400	37 235	29 667	15 907	520 262	512 693
2006	453 536	34 190	37 148	23 869	16 649	541 523	528 244
2007	479 058	33 871	36 522	23 435	17 409	566 860	553 773
2008	475 817	30 229	37 580	25 280	18 170	561 797	549 497
2009	476 346	27 456	36 658	21 688	18 989	559 450	544 480
2010	495 432	29 634	37 577	18 248	19 806	582 449	563 120

ES3 Overview of source and sink category emission estimates and trends

The Energy sector contributed 82.3% to the total GHG inventory (excl. *Land*) in 2000 and this increased to 85.1% in 2010 (Table A). The second biggest contributor (6.4% - 8.5%) is the AFOLU sector (excl. *Land*). The emissions from this sector declined by 5% over the 10 year period; while the IPPU sector emissions declined by 1.1% over the same period. Including the biomass carbon component of the *Land* into the AFOLU sector decreased the total GHG emissions to 563 120Gg CO_2eq in 2010. The total emissions including *Land* increased by 22% between 2000 and 2007, but then declined by 2% between 2007 and 2009. Emissions increased again in 2010 (Table A).

ES4 Other information

General uncertainty evaluation

Uncertainty analysis is regarded by the IPPC guidelines as an essential element of any complete inventory. Chapter 3 of the 2006 IPCC Guidelines describes the methodology for estimating and reporting uncertainties associated with annual estimates of emissions and removals. There are two methods for determining uncertainty:

- Tier 1 methodology which combines the uncertainties in activity rates and emission factors for each source category and GHG in a simple way; and
- Tier 2 methodology which is generally the same as Tier 1, however it is taken a step further by considering the distribution function for each uncertainty, and then carries out an aggregation using the Monte Carlo simulation.

The reporting of uncertainties requires a complete understanding of the processes of compiling the inventory, so that potential sources of inaccuracy can be qualified and possibly quantified. Given the absence of quantitative data and even sometimes qualitative uncertainty data, it is not possible to make an overall statement of uncertainty. More detailed data are required to speculate about levels of quantitative uncertainty. In Chapters 3 - 6 of this report, the default IPCC uncertainty values for conversion of activity levels to emissions or removals, as well as known uncertainties on activity data, are quoted in the sections on quality control in each sector; however the uncertainty has not been incorporated into the final report through any calculation procedure. Furthermore, any assumptions made in the compilation of the inventory have been made clear. As in the previous inventory, it continues to be a recommendation that the uncertainty calculation spread sheet be utilized to determine the trend uncertainty between the base year and current year, as well as the combined uncertainty of activity data and emission factor uncertainty.

Completeness of the national inventory

The GHG emission inventory for South Africa does not include the following sources identified in the 2006 IPCC Guidelines:

- CO_2 and CH_4 fugitive emissions from oil and natural gas operations due to unavailability of data;
- CO_2, CH_4 and N_2O from spontaneous combustion of coal seams due to unavailability of data and estimation methodologies;
- CH_4 emissions from abandoned mines due to unavailability of data and estimation methodology;
- CO_2, CH_4 and N_2O emissions from water-borne navigation. Fuel consumption for this source-category is included elsewhere;
- Other process use of carbonates due to lack of activity data;
- Electronics Industry due to lack of activity data;
- Ozone Depleting Substance replacements for fire protection and aerosols;
- Other product Manufacture and Use;
- Soil carbon and components of the Dead Organic Matter (DOM) pools due to insufficient data;
- Harvested wood products due to insufficient data;
- All Land converted to another Land category due to large uncertainties and insufficient data;
- Rice cultivation as it is not relevant to SA;

- Indirect N_2O emission due to nitrogen deposition because of a lack of data;
- Precursor emissions have only been estimated for biomass burning, and only for CO and NO_x

Methodological changes, recalculations and improvements

In the past year various improvements have been made to the GHG inventory due to the incorporation of more detailed activity data, updated emission factors and more consistent land cover maps. For the Energy sector, country-specific CO_2 emission factors were incorporated, while for IPPU the calculations made, used more accurate activity data acquired from actual process analysis. In the Agriculture sector updated livestock emission factors and a greater disaggregation of the livestock categories were incorporated. In the section on Land Use, new land cover maps have been introduced with more detailed activity data. South Africa published the 2000 GHG inventory report in 2009, which reported on GHG emissions of the base year 2000. For the purpose of this report, the GHG emissions for the period 2000 were recalculated using the updated activity data and emission factors so as to form a more consistent time series over the 10 year period. In this way, the trends over time can be assessed. All the updates and recalculation methods and procedures are discussed in detail in Chapters 3 to 6 of this report.

The recalculated value for 2000 (excluding *Land*) was 463 716 Gg CO_2eq which is 0.2% higher than the estimate provided in the 2000 National Inventory (Table B). The updated emission data lead to an increase in the estimates from the Energy and Waste sectors, while the estimates for the IPPU and AFOLU (excl. *Land*) sectors were slightly reduced. The changes made to the *Land* component of the AFOLU sector produced total GHG emission estimates which are 0.4% higher than the previous estimates. The reasons for these differences are discussed further in Chapters 3-6 of this report.

Table B: Previous and recalculated GHG emission estimates for 2000 for South Africa.

	Energy	IPPU	AFOLU (excl. Land)	AFOLU (incl. Land)	Waste	Total (excl. Land)	Total (incl. Land)
				(Gg CO_2eq.)			
Initial 2000 estimates	380 988	32 081	40 582	20 022	9 393	463 044	442 484
Recalculated 2000 estimates	381 790	29 961	39 532	19 974	12 434	463 716	444 159

The main challenge in the compilation of South Africa's GHG inventory remains the availability of accurate activity data. The DEA is in the process of implementing a project that will ensure easy accessibility of activity data.

ES5 Conclusions and recommendations

The 2000 to 2010 GHG emissions results revealed a continuous increase in emissions from the Energy sector, and a decline in emissions from the IPPU and AFOLU Agriculture sub-sector. The compilation of the GHG inventory continues to be a challenge, especially in the availability of activity data for computation of GHG emissions. The inclusion of the *Land* sub-sector in AFOLU caused a greater annual variation in the AFOLU emission numbers, but there was a general increasing trend in the AFOLU sector.

The Energy sector in South Africa continued to be the main contributor of GHG emissions (>80%) and was found to be a key category, therefore it is important that activity data from this sector is always available to ensure that the results are accurate. The accurate reporting of GHG emissions in this sector is also important for mitigation purposes.

The AFOLU sector was also shown to be an important one as it is (excl. *Land* sub-sector) the second biggest contributor and *Enteric fermentation* is one of the top five key categories. It is also critical that the estimates for the *Land* component are improved. South Africa needs to produce a more complete picture of the sinks and sources in this sector, and needs to develop a 20 year historical land cover data set so that the soil carbon pool can be incorporated as this will have a major impact on the *Land* component carbon estimates. More data needs to be collected in terms of crop harvests, agricultural practices and land management so that Croplands can be incorporated into the inventory.

In the Waste sector the emission estimates from both the solid waste and wastewater sources were largely computed using default values suggested in IPCC 2006 guidelines, which could lead to large margins of error for South Africa. South Africa needs to improve the data capture on the quantities of waste disposed into managed and unmanaged landfills. This sector would also benefit from the inclusion of more detailed economic data (e.g. annual growth) according to different population groups in respect to the actual growth for a given year. The assumption that the GDP growth is evenly distributed under all different populations groups is highly misleading, and exacerbated the margins of error.

1 INTRODUCTION

1.1 Climate change and GHG inventories

The Republic of South Africa ratified the UNFCCC, and it is therefore required to undertake several projects related to climate change. This includes the preparation of the greenhouse gas (GHG) inventories, which comprises one of the outputs to the agreed National Communications to the UNFCCC.

The first national GHG inventory in South Africa was compiled in the year 1998 and the activity data used was for the year 1990. South Africa compiled the second GHG inventory for the year 1994 and this was published in 2004. For both 1990 and 1994 the GHG inventories were compiled based on the 1996 guidelines of IPCC.

The third national GHG inventory was compiled in the year 2000 using activity data from the year 2000. For that inventory the latest national GHG inventory preparation guidelines, namely the 2006 IPCC guidelines, were introduced. Those guidelines ensured accuracy, transparency and consistency. The 2006 IPCC guidelines made significant changes on the 1996 guidelines, particularly on the restructuring of inventory sectors. Countries are not required by UNFCCC to report their GHG emissions using the updated guidelines. However, since RSA is starting out with the compilation of its inventories, it is appropriate that the country uses the latest IPCC guidelines to avoid future difficulties in converting from the 1996 to the 2006 guidelines.

1.2 Country background

1.2.1 National circumstances

South Africa is a significant industrial and economic power in Africa and has the largest economy in southern Africa. The country has a well-developed mining, transport, energy, manufacturing, tourism, agriculture, commercial timber and pulp production, service sectors, and it is a net exporter of energy, food, telecommunications, and other services to neighbouring countries. South Africa shares borders with six countries: Namibia, Botswana, Zimbabwe and Mozambique to the north and then Lesotho and Swaziland are landlocked within South Africa. There are various factors that can influence a nation's GHG emissions, including government's (infra-) structure, population growth, geography, economic growth, energy consumption, technology development, climate and soils, agriculture and land use management.

1.2.1.1 Government structure

South Africa is a multiparty, three tier democracy with National, Provincial and Local governance. Governmental responsibilities affecting the economic development, energy, natural resources and many other issues are shared amongst the three spheres.

1.2.1.2 Population profile

South Africa is a diverse nation with an estimated population at roughly 50 million people (Stats SA, 2010). The population of South Africa has grown by 11.54% from 2001 to 2010 and has a projected population growth rate of 0.5% for 2010 – 2015 (SA 2nd NC, 2011). Strong socio-economic and policy drivers of migration into urban centres have been at play, as indicated by the urban population increase from 52 to 62% over the past two decades (UNDP, 2010). South Africa has nine provinces namely, Eastern Cape, Free State, Gauteng, KwaZulu-Natal, Limpopo, Mpumalanga, Northern Cape, North West and Western Cape. The Gauteng province is the most populated, with 22.4% of residents. It is followed by KwaZulu- Natal with 21.3% and the Eastern Cape with 13.5%. The Northern Cape has the smallest population (2.2%). South Africa has eleven official languages which displays its cultural diversity.

1.2.1.3 Geographic profile

The Republic of South Africa is a medium sized country, which covers roughly 122 062 764 ha of the southernmost part of the African continent. It measures approximately 1600 km from North to South and approximately the same size from East to West. The country lies between 22° and 35° south, flanked on the West by the Atlantic Ocean and East of the Indian Ocean (GCSI, 2009). The coastline extends 2 298 km from a desert border in the Northwest downwards to the Cape Agulhas, and then extends upwards to the Indian Ocean, to the border of Mozambique in the Northeast (GCSI, 2009). It has narrow coastal plateaus in the south and west which are edged by coastal mountain ranges. Further to the interior, an escarpment borders on the extensive elevated interior plateau of much of central South Africa.

1.2.1.4 Economic and industry profile

The Republic of South Africa is deemed a developing country with well-developed financial, Legal, Communications, Energy and Transport sectors. The national GDP was R1 750 billion in 2007, which translated to a per capita GDP of R36 461 (SA 2nd NC, 2011). The growth in GDP slowed to 3.1% in 2008, which was lower than the annual growth rates of 4.9% and 5.3% from 2004 to 2007 (GCSI, 2009). That was as a result of the deterioration of the global economic conditions. In November 2009 South Africa recovered from the recession by achieving a growth of 0.9%. The hosting of the 2010 FIFA World Cup in June and July contributed significantly to the country's economy by registering a 3.4% growth in the fourth quarter of that year (StatsSA 2013).

Annual inflation consumer price index less mortgage interest increased from 10% in March 2008 to 13.6% in August 2008. The annual rate of increase in food prices remained constant at 14.9% in March 2009, compared to a peak of 19.2% in August 2008. Processed food prices remained at high levels reflecting higher cost of transport, wages and general production.

South Africa has an abundant supply of mineral resources and it is a world leader in mining and minerals, with significant global reserves and production. The economy was originally built on natural resources with agriculture and mining being the major components of the GDP, however the mining industry has seen the loss of several thousand jobs over the past few years (SA 2nd NC 2011). South Africa's mining industry remains one of the country's main employers.

The transport sector is dominated by road travel and South Africa has a higher than world average car ownership ratio which is attributed to the large distances between settlements and places of employment. Within the road transport sector 19% is due to private vehicle trips, and 11.5% due to minibus-taxis. The minibus-taxi industry has 63% of the commuting share, compared with 22% for the bus and 15% for the train sectors (SA 2nd NC 2011), and it continues to grow annually.

With the growing population and economy, waste processing and disposal continue to be a significant challenge. Households with adequate refuse removal services remains at about 60% since 2006, but are over 80% in urban areas and as low as 20% in rural areas.

1.2.1.5 Natural resources profile

South Africa is located in a subtropical region, making it a warm and sunny country. Its climate is moderated by oceanic influences along the extensive coastline and by the altitude of the interior plateau. South Africa's climate is generally warm temperate dry (Moeletsi et al., 2013), however, there are exceptions creating climatic diversity. There is a temperate Mediterranean-type climate in the south-west to a warm subtropical climate in the north-east, and a warm, dry desert environment in the central wet and north-west. South Africa is a semi-arid region with an annual rainfall of approximately 464 mm, whilst the Western Cape receives most of its rainfall in winter, the rest of the country is mostly a summer rainfall region (GCSI, 2009).

South African soils show high variability but most of the soils are categorized as high activity clay mineral soils (> 60%) followed by sandy minerals predominantly over northern Cape, Northwest and Western Cape (Moeletsi et al., 2013). The other category with significant area is the low activity clay mineral soils over the Mpumalanga and KwaZulu-Zulu Natal.

The land cover in South Africa is dominated by shrublands (~40%), savanna woodlands (~33%) and grasslands (~27%) (SA 2nd NC, 2011). Natural forests are very small in South Africa covering less than 0.5% of the land area, while settlements occupy approximately 1.5% of the land area (SA 2nd NC, 2011, GeoTerraImage, 2013). South Africa's natural forests have been reduced by 46% over the past two centuries (Le Roux 2002). Roughly 11% of land is formally cultivated, with 1.4% of this being plantations (SA 2nd NC, 2011). Maize and wheat are the dominant annual crops by area. Plantations are based on non-native trees with the dominant species being *Eucalyptus grandis*.

1.2.1.6 Agriculture, forestry and fisheries profile

Agriculture, forestry and fisheries together account for less than 3% of GDP in 2006 (SA 2nd NC 2011). The agricultural sector is dominated in economic output terms, by large-scale commercial farming, but there is a very important small-scale and subsistence sector. The total contribution of agriculture to the economy increased from R27 billion in 2001 to R36 billion in 2007. During the period 2008 to 2009 the sale of animals and animal products accounted for 48.2% of the income, which was followed by 26.7% from field crops and 25.1% from horticulture (DST 2010). South Africa's largest agricultural commodity by mass in 2007 was sugar cane, followed by cattle meat, chicken meat, grapes and dairy.

South Africa's timber plantations are based on non-native trees and cover 1.4% of the cultivated (SA 2nd NC, 2011) land. It contributes more than R16 billion to South Africa's economy, with an annual production of 2.2 million m^3 of commercial round wood (SA 2nd NC 2011). Exports are mainly converted, value-added products, with raw material exports only making up 1.8% of the total. The main products exported are pulp and paper (73%), saw timber, wood chips and wattle extract.

The commercial and recreational fishing industries are a relatively small economic sector, contributing about 1% of GDP, valued at approximately R4-5 billion annually (SA 2nd NC 2011).

1.2.2 Institutional arrangements for inventory preparation

In South Africa the DEA is the central coordinating and policy making authority with respect to environmental conservation. DEA is mandated by The Air Quality Act (Act 39 of 2004) to formulate, coordinate and monitor national environmental information, policies, programs and legislation. The work of DEA is underpinned by the Constitution of the Republic of South Africa and all other relevant legislation and policies applicable to government to address environmental management including climate change.

In its capacity of a lead climate institution, DEA is responsible for co-ordination and management of all climate change-related information such as mitigation, adaption, monitoring and evaluation programs including the compilation and update of GHG inventories. The branch responsible for the management and co-ordination of GHG inventories at DEA is the Climate Change and Air Quality Management branch, whose purpose is to improve air and atmospheric quality, support, monitor and report international, national, provincial and local responses to climate change..

Although DEA takes a lead role in the compilation, implementation and reporting of the national GHG inventories, other relevant agencies and ministries play supportive roles in terms of data provision across relevant sectors. For instance, for the Agriculture, Forestry and Other Land use (AFOLU) sector, Department of Agriculture, Forestry and Fisheries (DAFF) along with the Agriculture Research Council (ARC) are responsible for the provision and compilation of GHG emissions data. For the Energy sector, DEA utilizes national Energy balances published by the national DoE. The private sector, including entities such as SASOL and other industries, also provide inventory data. The Department of Transport provides information related to transport activities. Statistics South Africa (STATSSA) provides data on the country's statistics which can also be helpful. The South African Petroleum Industry Association (SAPIA) and the Chamber of Mines are amongst other important institutions that contribute inventory data. Other entities such as Eskom – the largest power producer in South Africa – also provide information related to electricity.

1.3 Inventory preparation

It was decided, before the preparation of the 2000 inventory, that the 2006 IPCC Guidelines would be used to prepare South Africa's GHG inventory so as to ensure consistency, accuracy and transparency. To be consistent with the previous inventory, this GHG inventory for 2000 – 2010 was also prepared using the principles of the 2006 IPCC Guidelines. The method chosen for each source category is guided by the decision trees provided in the IPCC Guidelines. In general the method selected depended on whether or not the source category was considered as the main category and the availability of data. Where more disaggregated data and emission factors were available then a higher tier method was used.

The collection of data and information is still a huge challenge for South Africa when compiling the GHG inventory. The data and information are often collected from national aggregated levels rather than from point or direct sources. That makes the use of higher tier level methods difficult. It is also difficult to perform a data uncertainty analysis on data that has already been published. The current GHG inventory under review has obtained more disaggregated data than the previous inventory. Therefore, more of the source categories have been calculated using the Tier 2 methodology.

1.3.1 Data collection and storage

A variety of data suppliers provide basic input data for emission estimates. Data collection and documentation were the responsibility of individual experts in each sector. Data came mostly from government institutions, local and international literature and to a lesser extent from individual industrial plants and professional associations. Data access continues to be a challenge for South Africa, therefore this inventory is not complete. Some sources or sinks have been omitted due to lack of appropriate data.

The challenge in the compilation of GHG inventories is the availability of accurate activity data. The DEA is in the process of implementing a data management system that will improve accessibility to activity data.

1.3.2 Brief description of methodologies and data sources

1.3.2.1 Methodologies

The 2006 IPCC Guidelines were used for estimating GHG emissions for South Africa. There are four main inventory sectors, namely: Energy, IPPU, AFOLU and Waste. Table 1.1 provides an overview of the methods used to estimate GHG emissions in South Africa. In accordance with the IPCC 2006 Guideline reporting requirements, the Global Warming Potentials (GWP) used for the calculation of the CO_2 equivalence emissions (Table 1.2) are those published in the IPCC third assessment report (TAR) (IPCC, Vol. 1).

Table 1.1: Tier method (TM) and emission factor (EF) used in this inventory in the estimation of the emissions from the various sectors.

GHG Source and Sink Category	CO_2		CH_4		N_2O		HFCs		PFCs		SF_6	
	TM	EF	TM	EF	TM	EF	TM	EF	TM	EF	TM	EF
1.Energy												
A. Fuel combustion												
1. Energy industries	T1, T3	T1, CS	T1, T3	DF	T1, T3	DF						
2. Manufacturing industries and construction	T1	DF	T1	DF	T1	DF						
3. Transport	T1	DF	T1	DF	T1	DF						
4. Other sectors	T1	DF	T1	DF	T1	DF						
5. Non-specified	T1	DF	T1	DF	T1	DF						
B. Fugitive emissions from fuels												
1. Solid fuels	T2	CS	T2	CS								
2. Oil and natural gas	T3	CS										
3. Other emissions from energy production	T3	CS	T3	CS								
2.Industrial processes												
A. Mineral products	T1	DF										
B. Chemical industry	T1, T3	DF CS	T1	DF	T1	DF						
C. Metal industry	T2	CS	T1	DF					T1	DF		
D. Non-energy products from fuels and solvents	T1	DF										
F. Product used as substitutes for ODS							T1	DF				
3.AFOLU												
A. Livestock												
1. Enteric fermentation			T2	CS								
2. Manure management			T2	CS	T2	DF						
B. Land	T1, T2	CS DF										
C. Aggregated sources and non-CO_2 emissions												
1. Emissions from biomass burning	T2	CS	T2	CS	T2	CS						
2. Liming	T1	DF										
3. Urea application	T1	DF										
4. Direct N_2O from managed soils					T1	DF						
5. Indirect N_2O from managed soils					T1	DF						
6. Indirect N_2O from manure management					T1	DF						
4.Waste												
A. Solid waste disposal			T1	DF								
D. Wastewater treatment and discharge			T2 T1	CS DF	T1	DF						

Table 1.2: Global warming potential (GWP) of greenhouse gases used in this report (Source: IPCC 2001).

Greenhouse gas	Chemical formula	TAR GWP
Carbon dioxide	CO_2	1
Methane	CH_4	23
Nitrous oxide	N_2O	296
	Hydrofluorocarbons (HFCs)	
HFC-23	CHF_3	12 000
HFC-32	CH_2F_2	550
HFC-125	CHF_2CF_3	3 400
HF-134a	CH_2FCF_3	1 300
HFC-143a	CF_3CH_3	4 300
HFC-152a	CH_3CHF_2	120
	Perfluorocarbons (PFCs)	
PFC-14	CF_4	5 700
PF-116	C_2F_6	11 900
PFC-218	C_3F_8	8 600
PFC-31-10	C_4F_{10}	8 600
PFC-318	$c\text{-}C_4F_8$	10 000
PFC-4-1-12	C_5F_{12}	8 900
PFC-5-1-14	C_6F_{14}	9 000
	Sulphur hexafluoride	
Sulphur hexafluoride	SF_6	23 900

After data were collected and the sources quality assured, and the unit conversions are completed, the GHG emissions were calculated by inventory experts using the following basic principle (IPCC 2006 Guidelines):

Emission = activity data x emission factor

As required by the 2006 IPCC Guidelines, the AFOLU and Waste sectors made use of more complex calculations and models which are described further in Chapters 5 and 6.

When calculating emissions, the expert is responsible for quality assurance and checks, but also the calculations are checked by external parties to ensure accuracy and consistency. Emission factors from national sources are the most accurate, but where national emission factors are not available, default IPCC emission factors should be used. In most cases default factors where used where disaggregated data could not be obtained and the Tier 1 approach was applied. More detailed methodology for each sector and source category are presented in the chapters below.

For the current inventory, data were gathered on the following gases: CO_2, CH_4, and N_2O. Certain HFC's and PFCs were reported on in the IPPU sector and NO_x and CO were also estimated for biomass burning emissions.

1.3.2.2 Data sources

In general, the following primary data sources supplied the annual activity data used in the emission calculations:

- Energy data:
    - The Department of Mineral Resources (DME);
    - Department of Energy (DoE);
    - Power utility plants;
    - Energy balances which are published as the Digest of South African Energy Statistics provided an overview of the interrelations within South Africa's energy sector, by providing a breakdown of the different fuels and category sources.
    - South African Petroleum Industry Association (SAPIA) provided other energy data, transport fuel data and crude oil production;
    - PetroSA;
    - SASOL;
    - ESKOM;
    - FAO;
    - Chamber of Mines provided information associated with GHG emissions from mining activities;
    - Statistics South Africa (Stats SA);
    - National Energy Regulator of South Africa (NERSA);
    - Department of Government, Communications Information Systems (GCIS); and
    - South African Reserve Bank.
- Industrial processes and product use:
    - Industry Associations;
    - South African Mineral Industry (SAMI);
    - Department of Minerals and Resources (DMR);
    - Department of Energy (DoE);
    - South African Iron and Steel Institute (SAISI);
    - Direct communication with various industrial production plants.
- Agriculture:
    - Abstracts of Agricultural Statistics from Department of Agriculture, Forestry and Fisheries supplied animal numbers, crop area and harvest data;
    - Professional Livestock Associations provided data on livestock weights and manure management;
    - Fertilizer Society of South Africa supplied fertilizer data
- Land use:
    - Abstracts of Agricultural Statistics from the Department of Agriculture, Forestry and Fisheries;
    - Forest Assessment 2005;
    - Forestry South Africa (FSA) were the main source of plantation data;
    - Land cover and land use change were based on digitised maps of 2001, 2005 and 2010 derived from MODIS data (GTI, 2013);
    - Agricultural Research Council (ARC) developed the digital soil and climate maps;

    - Scientific literature was the source of much of the carbon pool data.
- Aggregated and non-CO_2 sources:
    - MODIS burnt area data;
    - Scientific literature was the source of biomass burning emission factors and amount of fuel burnt;
    - Council for Scientific and Industrial Research (CSIR) assisted with burnt area data;
    - FAO data was used for urea;
    - Fertilizer Society of South Africa supplied liming data.
- Waste:
    - Population statistics (StatSA)
    - GDP values (WRI)
    - Waste composition (DEA Waste baseline Study)

1.3.3 Brief description of key categories

The analysis of key sources was performed in accordance with the 2006 IPCC Guidelines. The key categories referred to the most significant emission sources in South Africa. There are two approaches which can be used to determine the key categories; namely, the level and the trend of approach. The former is used if only one year of data was available, while the latter can be used if there were two comparative years. The inventory provides emissions for more than one year, therefore both the level and trend assessments for key category analysis were performed. For the trend assessment, the emission estimates for the years 2000 and 2010 were used.

The most significant sources of GHG emissions in South Africa (excl. the *Land* sub-sector) were the *Energy industries* (solid fuels), *Road transportation*, *Manufacturing industries and Construction* (solid fuels), and *Enteric fermentation* (Table 1.3) using the Level Assessment, while the Trend assessment showed that *Other sectors* (solid fuels), *Other emissions from Energy Production*, *Enteric fermentation* and *Iron and Steel production* were the top key categories (Table 1.4). When the *Land* sub-sector was included, then *Forest land Remaining Forest land* become the 14th and 4th most important key category in the Level and Trend Assessment, respectively. Appendix A and B provide full details of all key category analyses.

1.4 Information on QA/QC plan

In accordance with IPCC requirements for national GHG inventory preparation, the necessary quality control and quality assurance (QC/QA) measures for emissions reporting should be summarised in a QC/QA plan. The primary purpose of a QC/QA plan is to organise, plan and monitor QC/QA measures. The objective of quality checking is to improve transparency, consistency, comparability, completeness, and accuracy of national greenhouse gas inventory. The basic requirements of QC/QA assurance measures for national GHG inventories are defined in the 2006 IPCC Guidelines, Vol. 1, Chapter 6.

Table 1.3: Level assessment results for 2010, excluding the Land sub-sector contributions.

IPCC Category code	IPCC Category	GHG	2010 Ex,t (Gg CO_2 eq)	Lx,t	Cumulative Total of Column F
1.A.1	Energy Industries - Solid Fuels	CO_2	324244.75	0.5598	0.5598
1.A.3.b	Road Transportation	CO_2	42515.18	0.0734	0.6332
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CO_2	35142.52	0.0607	0.6938
3.A.1	Enteric Fermentation	CH_4	27299.46	0.0471	0.7410
1.A.4	Other Sectors - Solid Fuels	CO_2	27024.86	0.0467	0.7876
1.B.3	Other emissions from Energy Production	CO_2	22181.07	0.0383	0.8259
1.A.4	Other Sectors - Liquid Fuels	CO_2	17589.76	0.0304	0.8563
4.A	Solid Waste Disposal	CH_4	16568.60	0.0286	0.8849
2.C.1	Iron and Steel Production	CO_2	12448.40	0.0215	0.9064
2.C.2	Ferroalloys Production	CO_2	6457.98	0.0111	0.9175
2.A.1	Cement production	CO_2	4186.73	0.0072	0.9247
1.A.1	Energy Industries - Liquid Fuels	CO_2	4051.68	0.0070	0.9317
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CO_2	3837.58	0.0066	0.9384
1.A.3.a	Civil Aviation	CO_2	3657.68	0.0063	0.9447
3.C.5	Indirect N2O Emissions from managed soils	N_2O	3392.06	0.0059	0.9505

Table 1.4: Trend assessment results for 2010 (with 2000 as the base year), excluding Land sub-sector.

IPCC code	IPCC Category	GHG	2000 Year Estimate Ex0 (Gg CO_2 eq)	2010 Year Estimate Ext (Gg CO_2 eq)	Trend Assess-ment (Txt)	% Contri-bution to Trend	Cumulative Total of Column G
1.A.4	Other Sectors - Solid Fuels	CO_2	5578.19	27024.86	0.0433	0.2741	0.2741
1.B.3	Other emissions from Energy Production	CO_2	26658.56	22181.07	0.0240	0.1520	0.4261
3.A.1	Enteric Fermentation	CH_4	29601.08	27299.46	0.0209	0.1323	0.5584
2.C.1	Iron and Steel Production	CO_2	15385.78	12448.40	0.0146	0.0925	0.6509
4.A	Solid Waste Disposal	CH_4	9704.24	16568.60	0.0096	0.0608	0.7117
1.A.1	Energy Industries - Solid Fuels	CO_2	256361.41	324244.75	0.0086	0.0548	0.7665
1.A.1	Energy Industries - Liquid Fuels	CO_2	4715.48	4051.68	0.0040	0.0251	0.7916
1.A.3.b	Road Transportation	CO_2	32623.34	42515.18	0.0038	0.0241	0.8157
1.A.4	Other Sectors - Liquid Fuels	CO_2	12766.46	17589.76	0.0035	0.0224	0.8382
3.C.5	Indirect N2O Emissions from managed soils	N_2O	3992.53	3392.06	0.0034	0.0218	0.8600
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CO_2	29056.22	35142.52	0.0025	0.0158	0.8758
1.A.3.a	Civil Aviation	CO_2	2040.00	3657.68	0.0024	0.0152	0.8909
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CO_2	2217.75	3837.58	0.0023	0.0146	0.9055
2.F.1	Refrigeration and Air Conditioning	HFCs, PFCs	0.00	799.88	0.0017	0.0109	0.9164
3.C.4	Direct N2O Emissions from managed soils	N_2O	2520.34	2524.81	0.0017	0.0109	0.9273
2.B.2	Nitric Acid Production	N_2O	499.06	104.78	0.0011	0.0071	0.9344
2.C.3	Aluminium production	PFCs	2156.76	2229.04	0.0010	0.0064	0.9408

In addition to the IPCC Guidelines, South Africa has developed its own validation and verification procedure for *GHG assertions* for corporate reporting of emissions, and for emission estimation linked to voluntary market schemes aimed at reducing emissions. A *GHG assertion* is defined as a declaration or factual and objective statement made by a person or persons responsible for the greenhouse gas inventory and the supporting GHG information. It is a standard adopted from the International Standardization Organization (ISO) series programme for data documentation and audits as part of a quality management system.

In the South African context, QA/QC measures are defined by Part 3 of the South African National Standard for Greenhouse Gases, SANS 14064-3:2006 (Specification with guidance for the validation and verification of greenhouse gas assertions). This standard specifies the requirements for selecting GHG validators/verifiers, establishing the level of assurance, objectives, criteria and scope, determining the validation/verification approach, assessing GHG data, information, information systems and controls, evaluating assertions, and preparing validation/verification statements.

1.5 Evaluating uncertainty

Uncertainty analysis is regarded by the IPCC Guidelines as an essential element of any complete GHG inventory. Uncertainty reporting is important for suggesting methods of compiling uncertainty estimates and for identifying approaches that would enable the prioritisation of national efforts to reduce future uncertainties. It identifies areas of further improvement in the inventory preparation process and will guide methodological choices in future inventories to improve accuracy, reduce bias, and transparently report on the presence and levels of uncertainty. Uncertainty can also be used to determine appropriate methods for carrying out recalculations for previous inventories. The overall objective is to minimise uncertainties to the greatest possible degree.

Chapter 3 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories describes the need and methodology for estimating and reporting uncertainties associated with annual estimates of emissions and removals, including emission and removal trends over time. Broadly speaking, the approach involves combining the category uncertainties into estimates of uncertainty for total national net emissions and their associated trends.

Uncertainty analysis for the South Africa inventory involved quantifying the uncertainties for all source categories and sinks where data were available. There is a lack of quantitative uncertainty data in many source categories, which makes it difficult to determine and assess the uncertainty of these emission sources. In many cases more detailed data collection is required to speculate about levels of quantitative uncertainty. Where sufficient data were available, the analysis involved the determination of a probability-density function for a number of parameters, using approaches and values provided in the 2006 IPCC Guidelines. Thus the uncertainty analysis included a statistical evaluation of individual data items, and experts' assessments as guided by the IPCC Guidelines.

The main sources for the uncertainty in activity and emission factor data are the IPCC default uncertainty estimates (particularly for the emission factors), scientific literature and reported variances, expert judgement and comparisons with uncertainty ranges reported by other countries.

Given the absence of quantitative, and in some cases even qualitative uncertainty data, it is not possible to make an overall statement of uncertainty. Uncertainty for each source category, as well as any assumption made in the calculations, is discussed within each sector chapter (Chapter 3 to 6). It is recommended that it be necessary to add to the rigour of descriptive uncertainty in the compilation of future inventories and to utilize the uncertainty calculation spread sheet provided in the IPCC Guidelines.

1.6 General assessment of the completeness

The South African GHG emission inventory for the period 2000 – 2010 is not complete, mainly due to the lack of sufficient data. The following sources identified in the 2006 IPCC Guidelines were not included in this inventory and the reason for their omissions is discussed further in the appropriate chapters below:

- Energy sector:
    - CO_2 and CH_4 fugitive emissions from oil and natural gas operations;
    - CO_2, CH_4 and N_2O from spontaneous combustion of coal seams;
    - CH_4 emissions from abandoned mines;
    - CO_2, CH_4 and N_2O emissions from water-borne navigation;
- IPPU sector:
    - Other process uses of carbonates;
    - Adipic acid production;
    - Caprolactam, glyoxal and glyoxylic acid production;
    - Soda ash production;
    - Fluorochemical production;
    - Magnesium production;
    - Sections 2E1, 2E2, 2E3 of the electronics industry;
    - Pulp and paper industry;
    - Food and beverages industry.
- AFOLU sector:
    - Enteric fermentation from buffalo and other game as population data are uncertain;
    - All land conversions;
    - Soil carbon and DOM due to insufficient data;
    - Harvested wood products due to insufficient data;
    - Rice cultivation as it is not relevant to SA.
- Waste sector:
    - Biological treatment of solid waste;
    - Incineration and open burning of waste.

2 TRENDS IN GHG EMISSIONS

2.1 Trends for aggregated GHG emissions

This chapter summarizes the trends in GHG emissions during the period 2000 – 2010, by greenhouse gas and by sector. Detailed explanations of these trends are found in Chapters 3 to 6, and a summary table of all emissions for 2010 is provided in Appendix C.

In 2010 the total GHG emissions (excl. the *Land* sub-sector) in South Africa were estimated at 579 256 Gg CO_2eq. There has been a slow increase of 24.9% since 2000 (463 716 Gg CO_2eq). The 2000 emissions were also 33.5% higher than the 1990 estimate of 347 346 Gg CO_2eq, although it is difficult to directly compare the 2000 to the 1990 estimates as the methodology has changed significantly over the last 20 years. The recalculated estimate for 2000 (excl. *Land*) was 0.2% higher than the estimate originally provided in the 2000 national inventory (463 044 Gg CO_2eq, excl. *Land*).

Figure 2.1: shows the trends and relative contributions of the different gases to the aggregated national GHG emissions (excl. *Land*). There was a 27.1% and 12% increase in CO_2 and CH_4 (in CO_2eq) respectively between 2000 and 2010, and a slight decline (1.8%) in N_2O emissions over this period. Fluorinated gases (F-gases) increased from 2 157 Gg CO_2eq in 2000 to 2 229 Gg CO_2eq in 2010.

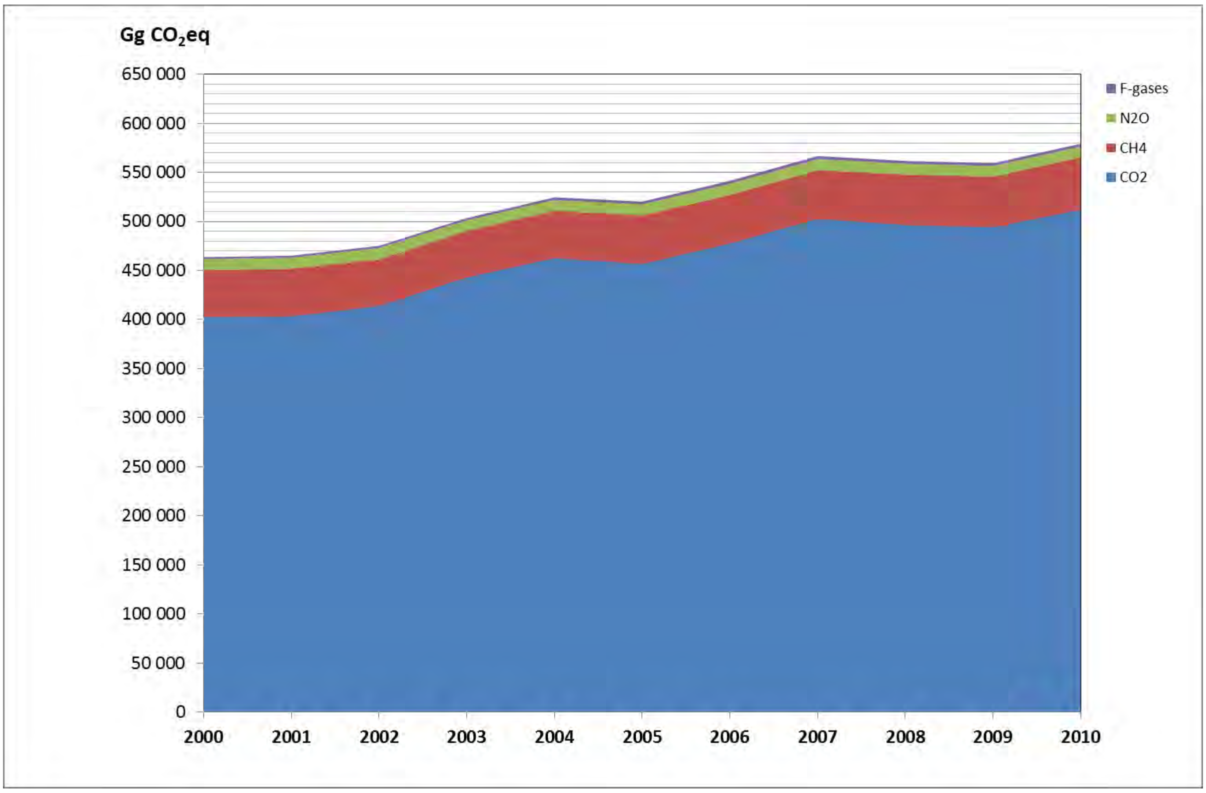

Figure 2.1: Greenhouse gases: Trend and emission levels (excluding *Land* sub-sector), 2000 – 2010.

The *Land* sub-sector shows annual variation, but was estimated to be a net sink of CO_2. Including the *Land sub*-sector CO_2 emissions and uptake in the overall inventory indicates that South Africa's GHG emissions increased from 444 159 Gg CO_2eq in 2000 to 575 419 Gg CO_2eq in 2010 (a 29.6% increase) (Figure 2.2). The recalculated total GHG emission estimates including the *Land* sector were 0.4% higher than the value reported in the National GHG Inventory for 2000 (NIR, 2009). That was due to the incorporation of more detailed Land data, correction of errors made in the 2000 calculations, as well as the inclusion of additional land categories that were not previously reported on.

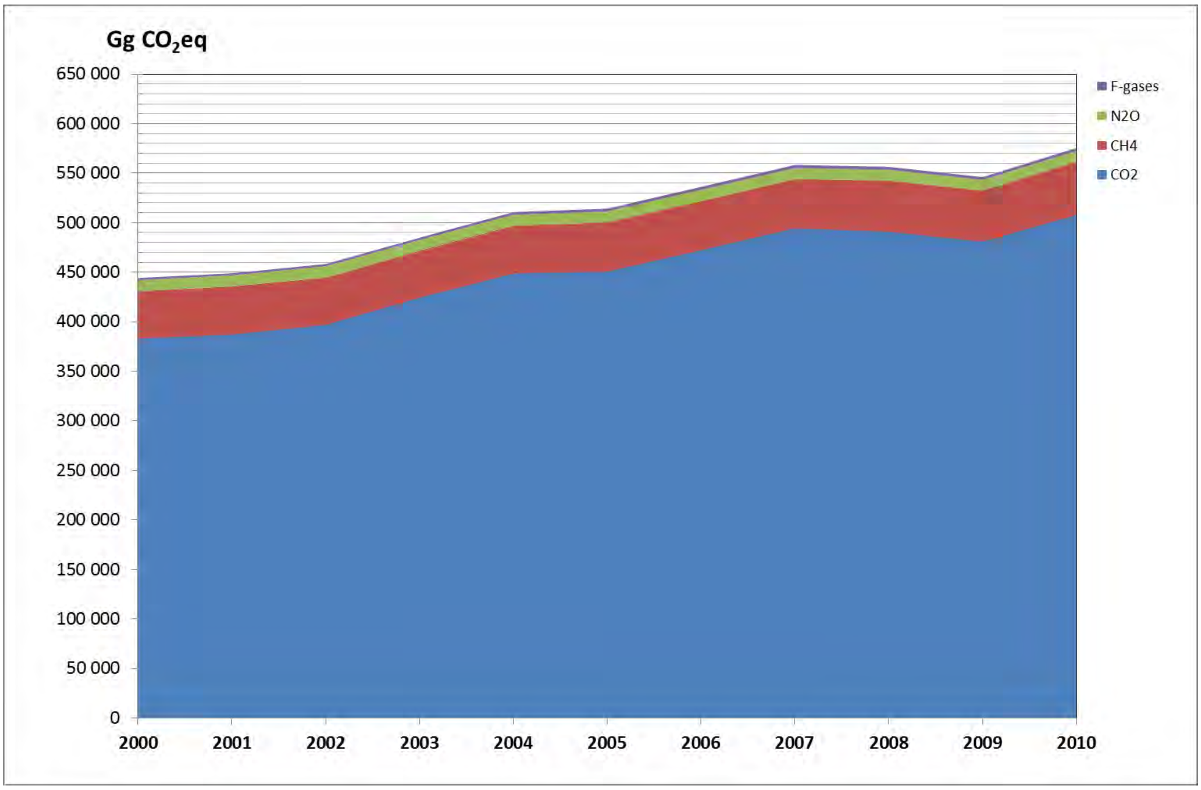

Figure 2.2: Greenhouse gases: Trend and emission levels (including *Land* sub-sector), 2000 – 2010.

2.2 Emission trends by gas

2.2.1 Carbon dioxide

Figure 2.3 presents the contribution of the main sectors to the trend in national CO_2 emissions (excl. *Land*). The emissions increased by 27.1% between 2000 and 2010. The Energy sector was by far the largest contributor to CO_2 emissions in South Africa, contributing an average of 88.9% between 2000 and 2010, with the categories *1A1 Energy Industries* (70.6%), *1A3 Transport* (10%) and *1A2 Manufacturing industries and Construction* (8.4%) being the major contributors to CO_2 emissions in 2010.

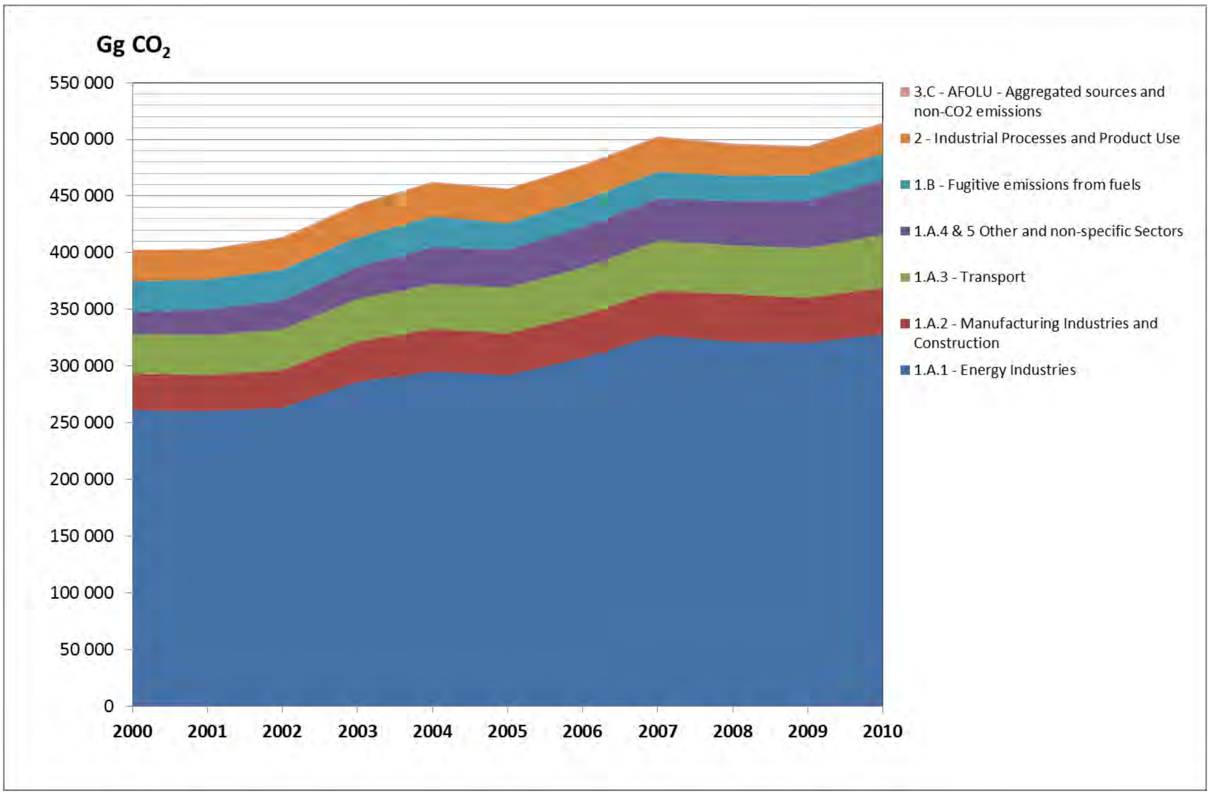

Figure 2.3: CO_2: Trend and emission levels of sectors (excluding *Land* sub-sector), 2000 – 2010.

2.2.2 Methane

The sector contributions to the total CH_4 emissions in South Africa are shown in **Error! Reference source not found.**. The national CH_4 emissions increased from 47 807 Gg CO_2eq in 2000 to 53 527 Gg CO_2eq in 2010 (12% increase). The AFOLU Livestock category and Waste sectors were the major contributors in 2010, providing 51.9% and 35.8% of emissions in 2010 respectively. The contribution from Livestock has declined by 7.6%, while the contribution from the Waste sector has increased by 61.7% over the period 2000 to 2010.

2.2.3 Nitrous oxide

Figure 2.5 shows the contribution from the major sectors to the national N_2O emissions in South Africa. The emissions have declined by 1.8% over the 2000 to 2010 period. The category *3C Aggregated and non-CO_2 sources on land* (which includes emissions from managed soils and biomass burning) contributed an average of 63.8% to the total N_2O emissions over the period 2000 to 2010, while the *Energy* and *Agriculture* (which includes manure management) contributed an average of 23% and 4.1% respectively.

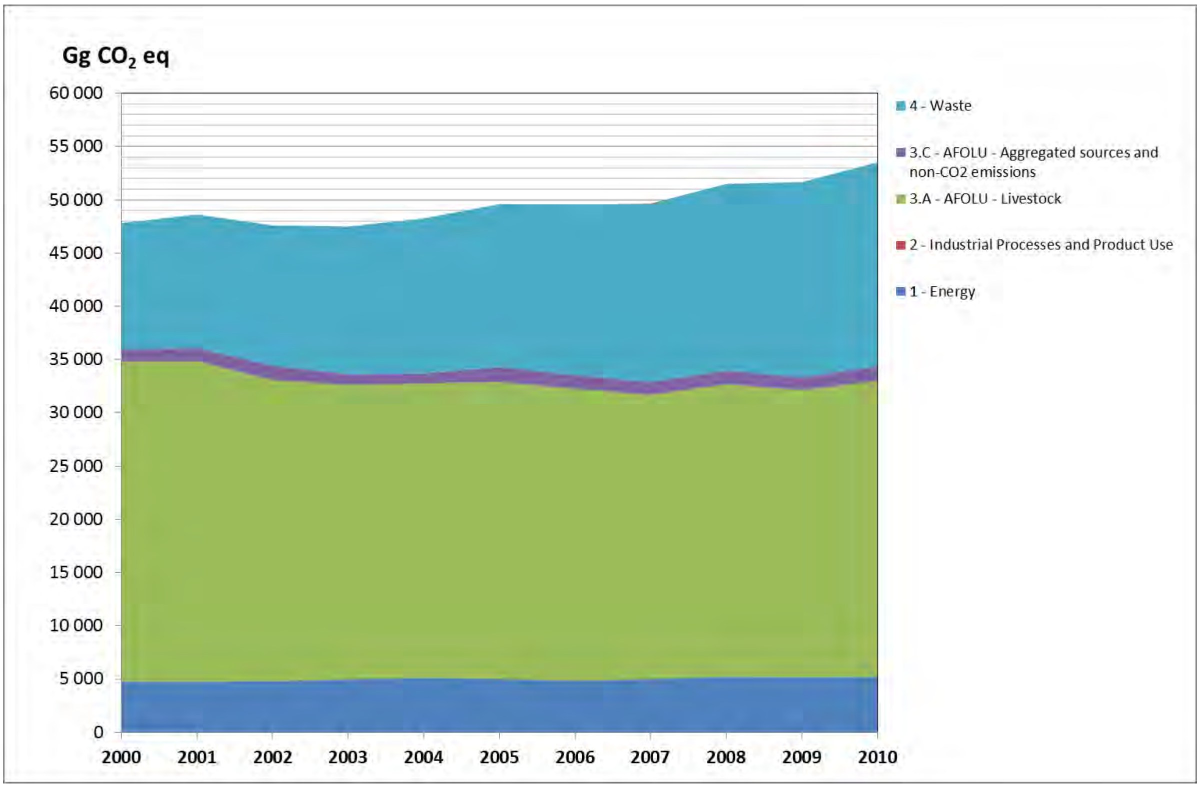

Figure 2.4: CH_4: Trend and emission levels of sectors (excluding *Land* sub-sector), 2000 – 2010

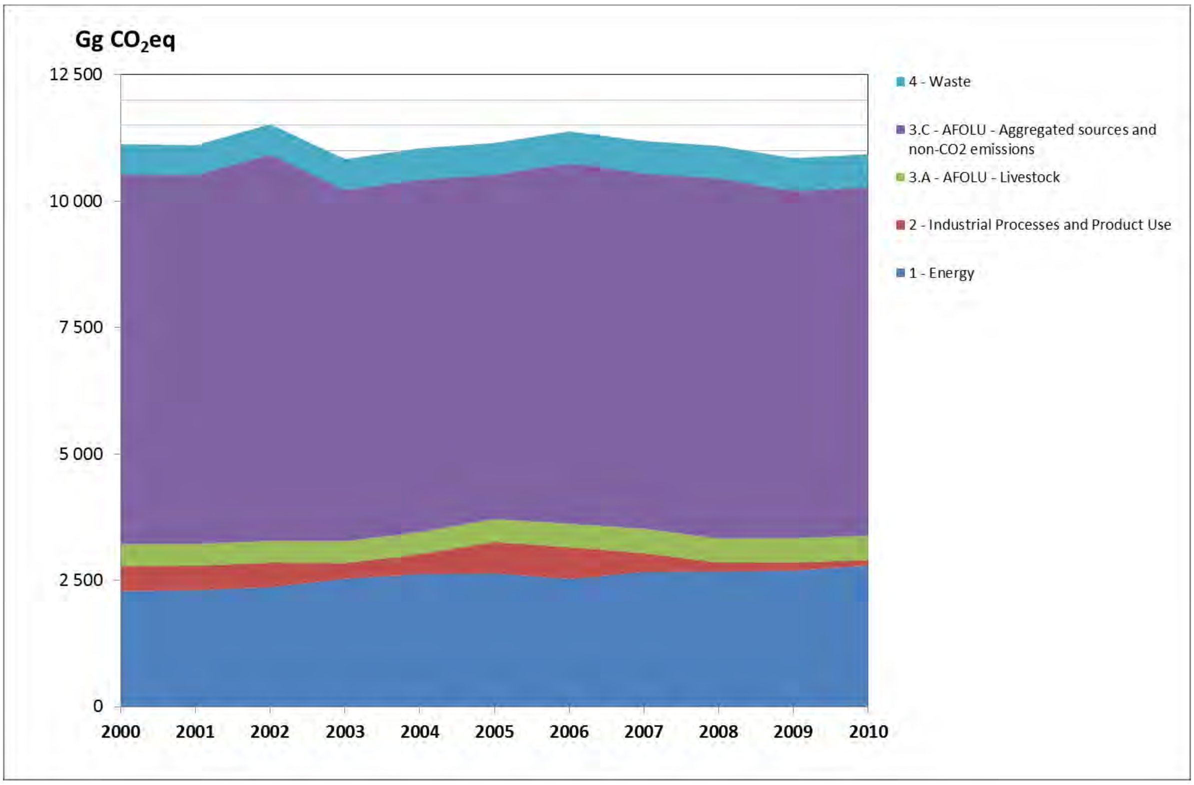

Figure 2.5: N_2O: Trend and emission levels of sectors, 2000 – 2010.

2.2.4 Fluorinated gases

Estimates of hydrofluorocarbons (HFC) and perfluorocarbons (PFC) emissions were only given for the IPPU sector in South Africa. HFC emissions in 2005 were estimated at 134 Gg CO_2eq and this increased to 799 Gg CO_2eq in 2010. There were no data prior to 2005. The PFC emissions were estimated at 2 157 Gg CO_2eq in 2000 and that increased to 2 229 Gg CO_2eq in 2010.

2.3 Emission trends specified by source category

Figure 2.6 provides an overview of emission trends per IPCC sector in Gg CO_2eq (excluding the *Land* sub-sector). The Energy sector was by far the largest contributor to the total GHG emissions, providing 82.3% in 2000 and increasing to 85.0% in 2010. The total GHG estimate of 463 716 Gg CO_2 eq (excluding *Land*) for 2000 was 33.5% higher than the 1990 estimate. The Livestock category of the AFOLU sector and the IPPU sector contribute 4.9% and 5.1%, respectively, to the total GHG emissions in 2010. Their contributions have decreased by 1.7% and 1.3% respectively since 2000. The percentage contribution from the Waste sector has increased from 2.7% to 3.4% over the 10 year period. Trends in emissions by sub-categories in each sector are described in more detail in Chapters 3-6.

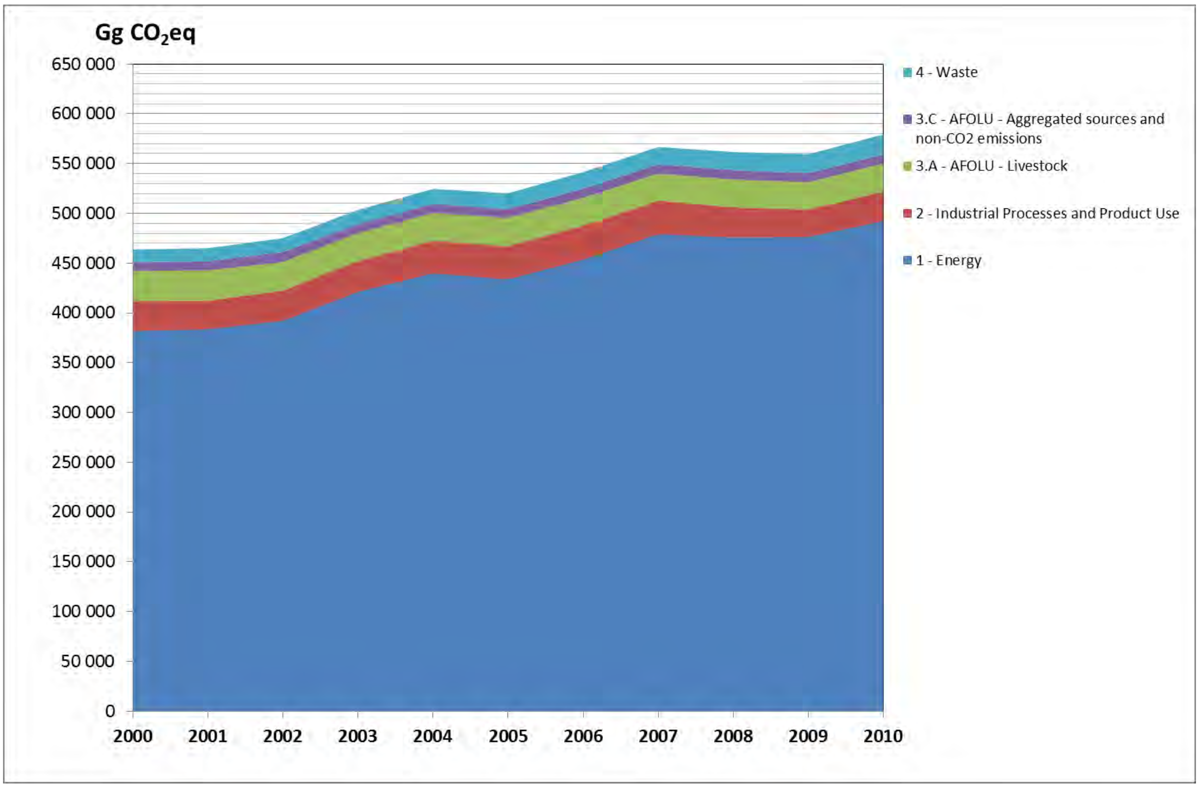

Figure 2.6: Total GHG: Trend and levels from sectors (excluding *Land* sub-sector), 2000 – 2010.

2.4 Emission trends for indirect GHG

The trend in total emissions of carbon monoxide (CO) and nitrogen oxides (NO_x) is shown in **Error! Reference source not found.**. These emissions were only recorded for biomass burning, which has a high annual variability. An average of 1 382 Gg CO and 54 Gg NO_x were estimated to be produced from biomass burning over the period 2000 to 2010. Biomass burning was high in 2002, 2010, with a maximum in 2005 when 1 645 Gg CO and 66 Gg NO_x were produced. The lowest values were recorded in 2004. The CO and NO_x emission estimates were not reported in the previous inventory (NIR, 2009).

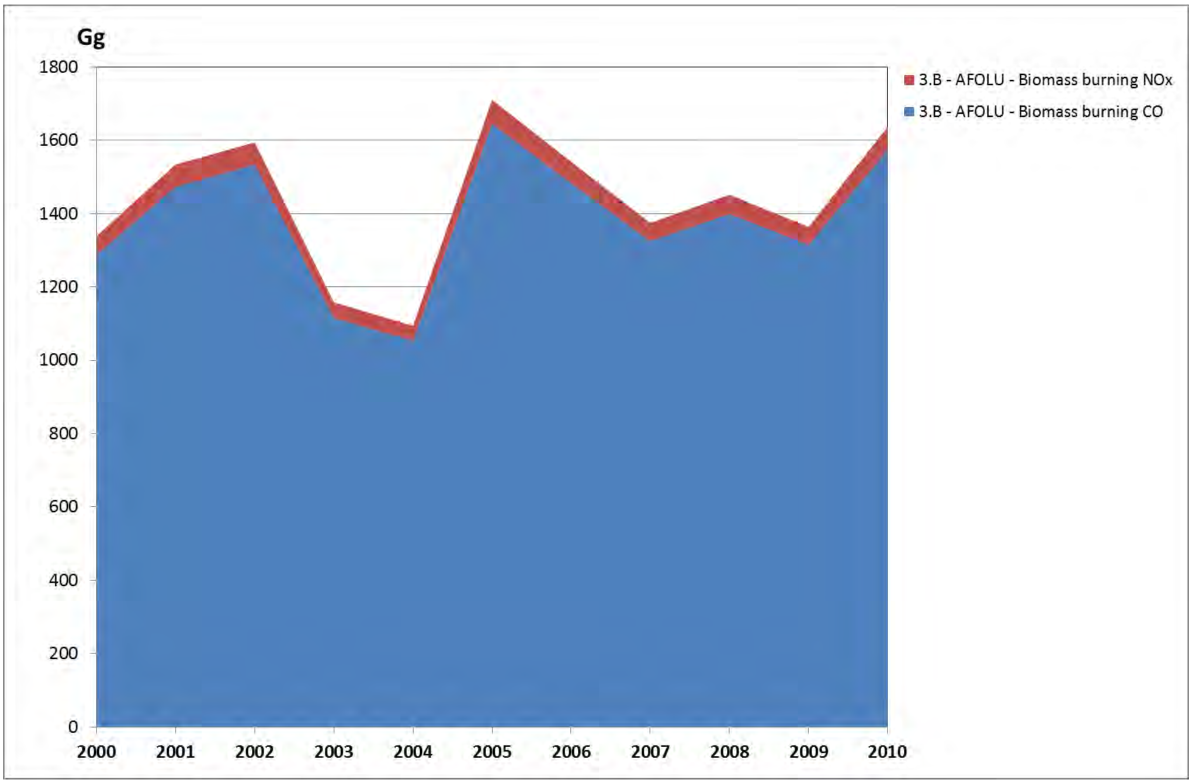

Figure 2.7: Precursor GHG: trend and emission levels in CO and NO_x from biomass burning, 2000 – 2010.

3 ENERGY SECTOR

3.1 An Overview of the Energy Sector

South Africa's GDP is the 26th highest in the world, but in primary energy consumption South Africa is ranked 16th in the world. South Africa's energy intensity is high mainly because the economy is dominated by large scale, energy-intensive primary minerals beneficiation industries and mining industries. Furthermore, there is a heavy reliance on fossil fuels for the generation of electricity and significant proportion of the liquid fuels consumed in the country. The energy sector is critical to the South African economy because it accounts for a total of 15% in the GDP.

In May 2009, the Department of Minerals and Energy was divided into two separate departments, namely the Department of Mineral Resources and the Department of Energy. The Department of Energy is responsible for ensuring management, processing, exploration, utilisation, development of South Africa's energy resources.

The Department of Energy's Energy Policy is mainly focused on the following key objectives:

- Diversifying primary energy sources and reducing dependency on coal;
- Good governance, which must also facilitate and encourage private-sector investments in the energy sector;
- Environmentally responsible energy provision;
- Attaining universal access to energy by 2014;
- Achieving a final energy demand reduction of 12% by 2015; and
- Providing accessible, affordable and reliable energy, to the poorer communities of South Africa.

The Energy sector in South Africa is highly dependent on coal as the main primary energy resource. The largest source of Energy sector emissions in South Africa is the combustion of fossil fuels. Emission products of the combustion process include CO_2, N_2O, CH_4 and H_2O. A large quantity of liquid fuels is imported in South Africa in the form of crude oil. Renewable energy is comprised of biomass and natural processes that can be used as an energy source. Biomass is used commercially in industry to produce process heat and also in households, for cooking and heating.

The 2004 White Paper on Renewable Energy has indicated that the target for Renewable energy should reach 10 000 GWh by 2013. The DoE has recently developed a Biofuel Strategy to contribute towards the production of renewable energy and to also minimize South Africa's reliance on the import of crude oil.

3.1.1 Energy Demand

In terms of the energy demand South Africa is divided into six sectors namely, industry, agriculture, commerce, residential, transport and other sectors. The industrial sector (which includes mining, iron and steel, chemicals, non-ferrous metals, non-metallic minerals, pulp and paper, food and tobacco, and other) is the largest user of energy and electricity in South Africa.

3.1.2 Energy Reserves and Production

The primary energy supply in South African energy is dominated by coal (65.7%), followed by crude oil (21.6%), renewable and wastes (7.6%) as well as natural gas (2.8%) (DoE, 2010) (Figure 3.1).

COAL

The majority of the country's primary energy needs is provided by coal. The contribution of coal to the total primary energy decreased by 8% between 2000 to 2006, but then it increased by 5% between 2006 and 2009. South Africa produces an average of 224 Mt of marketable coal annually, making it the fifth largest coal-producing country in the world (GCSI, 2009). South Africa has coal reserves of 48Gt, representing 5.7% of total global reserves.

NUCLEAR

Nuclear power contributes a small amount (1.9%) to South Africa's energy supply (DoE, 2010). The Koeberg Nuclear Power Station's supplies 1 800 MW to the national grid, thus providing a significant amount of South Africa's electricity (GCSI, 2009). The National Nuclear Regulator is the main safety regulator responsible for protecting persons, property and the environment against nuclear damage by providing safety standards and regulations. The total consumption of nuclear energy has decreased by 1.4% for the period 2000 to 2009.

RENEWABLE ENERGY

Renewable energy and wastes contributes a total of 7.6% to the energy supply (DoE, 2010). Wind as an energy source contributes a total of more than 4GWh annually. Hydro and Geothermal solar contributes a total of 0.2% and 0.1 respectively to the primary energy supply, and their contribution has increased by 0.2% and 2.0%, respectively, between 2000 and 2009.

LIQUID FUELS

In the third quarter of 2008, the demand for petrol decreased by 10% compared to the same period in 2007, whilst the demand for diesel increased by 3.0% as industries scaled down operations because of the global economic deterioration (GCSI, 2009). The petrol price in South Africa is linked to international petrol markets in the United States' dollar currency, which means that the supply and demand of petroleum products in the international markets, combined with the Rand-Dollar exchange rate influence the domestic price.

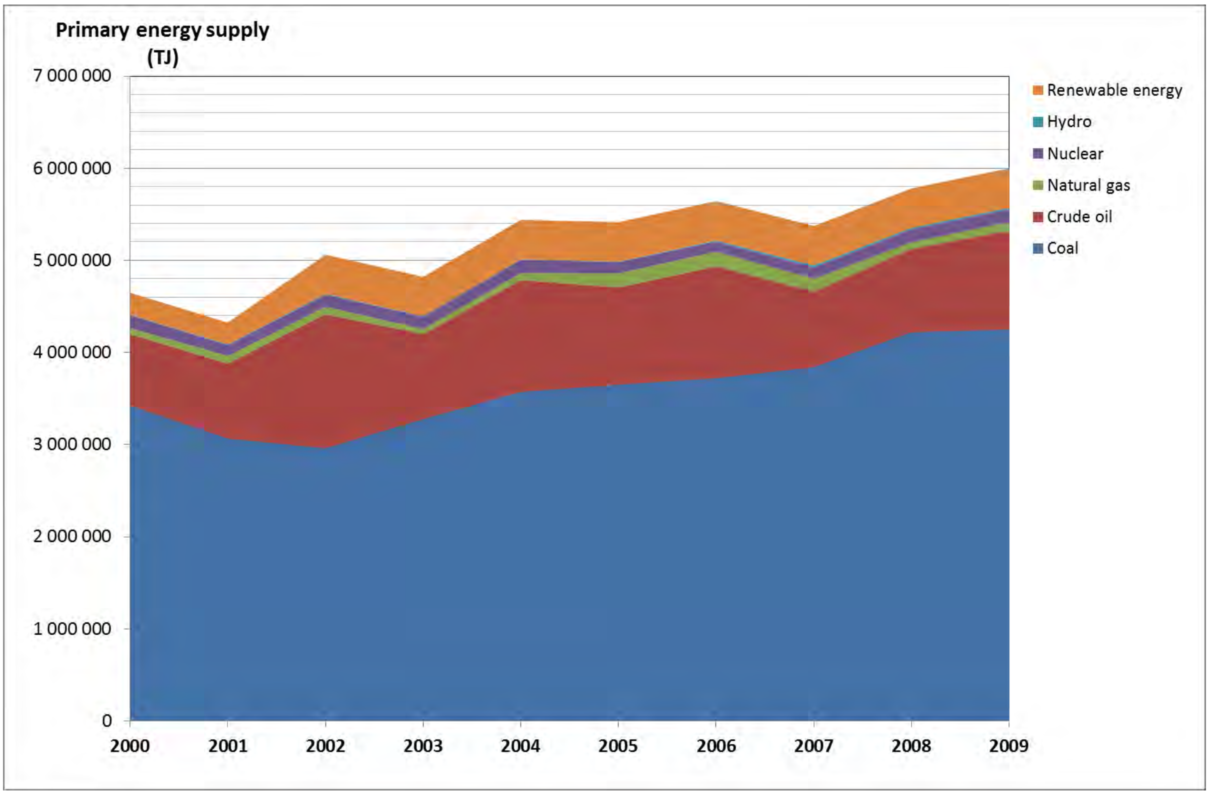

Figure 3.1: Sector 1 Energy: Trend in the primary energy consumption in South Africa, 2000 – 2009.

OIL AND GAS

South Africa has limited crude oil reserves and imports from the Middle East and other African countries to meet 95% of the country's crude oil requirements. Crude oil consumption has increased from 17% in 2000 to 29% in 2002, but then declined again to 18% by 2009. Limited natural gas reserves exist around the South African coast. The consumption of gas varied between 1 and 3% between 2000 and 2010. Refined petroleum products such as petrol, diesel, residual fuel oil, paraffin, jet fuel, aviation gasoline, liquefied petroleum gas and refinery gas are produced by refining crude oil (oil refineries), converting coal to liquid fuels, and gas to liquid fuels and turning natural gas into liquid fuels. Industry is the largest customer.

ELECTRICITY

South Africa's largest power producer, ESKOM, generates 95% of electricity in South Africa and about 45% in African countries (GCSI, 2009). Approximately 88% of South Africa's electricity is generated in coal-fired power stations, 6.5% capacity from Koeberg Nuclear Station, 2.3% is provided by hydroelectric and other renewable (GCSI, 2009).

3.1.3 Transport

South Africa has roads, rail and air facilities (both domestic and international). In 2010, the South African transport sector employed 392 381 people, representing a total of 0.8% of the population (StatsSA 2011). South Africa had an overall investment of R170 billion into the country's transport system in the five-year period from 2005/06 to 2009/10, with R13.6 billion of the total being allocated to improve public transportation systems for the 2010 World Cup.

RAIL

The state-owned Transnet is a focused freight-transport and logistics company. Transnet Freight Rail (TFR) has a 20 247 km rail network, of which about 1 500 km comprise heavy haul lines. TFR infrastructure represents about 80% of Africa's rail infrastructure. The Gautrain Rapid Rail Link commenced in 2006, and has 80 km of routes. Parts of the Gautrain have started operating, such as the Sandton to the OR Tambo airport route, and the Johannesburg – Pretoria route. This is expected to reduce the traffic congestion along the Johannesburg-Pretoria traffic route which accommodates approximately 300 000 vehicles per day.

ROAD TRANSPORT

South Africa has the longest road network of any country in Africa. The bus rapid transit (BRT) system implements high-quality public transport networks that operate on exclusive right of way and incorporate current bus and minibus operators.

CIVIL AVIATION

South Africa is home to more than 70% of aviation activities in the SADC region. South Africa's aviation industry has experienced a significant growth in the past 10 years. The Airports Company of South Africa (ACSA) owns and operates the 10 principal airports, including the three major international airports located in Johannesburg, Durban and Cape Town.

PORTS

Transnet National Ports Authority (TNPA) is the largest port authority on the African continent. It owns and manages South Africa's ports. Commercial ports play a crucial role in South Africa's transport, logistics and socio-economic development. Approximately 98% of South Africa's exports are conveyed by sea.

3.2 GHG Emissions from the Energy sector

The Energy sector in South Africa is highly dependent on coal as the main primary energy provider. The largest source of Energy sector emissions in South Africa is the combustion of fossil fuels. Emission products of the combustion process include CO_2, N_2O, CH_4 and H_2O.

The Energy sector includes:

- Exploration and exploitation of primary energy sources;
- Conversion of primary energy sources into more useable energy forms in refineries and power plants;
- Transmission and distribution of fuels; and
- Final use of fuels in stationary and mobile applications.

3.2.1 Overview of shares and trends in emissions

Total GHG emissions increased by 29.7% between 2000 and 2010, and produced a total accumulated GHG estimate of 4 829 210 Gg CO_2eq over the 10 year period. An analysis of key categories was completed in order to determine the most significant emission sources in the energy sector. The majority of emissions were from *Energy Industries* (67.8%) (Figure 3.2), followed by 9.3% from *Transport* and 8.5% from *Manufacturing industries and construction*.

The main source of emissions in this sector is CO_2 from fossil fuel combustion. The largest source of emissions for the period 2000 - 2010 was the main activity electricity producer which accounted for 59.2% (2 859 372 Gg CO_2eq) of the total accumulated emissions. The second largest emitting subcategory was the *Transport* sector which accounted for 9.3% (450 627 Gg CO_2eq) of the total emissions for the period 2000 - 2010. The *Manufacturing industry and construction* and the *Fugitive emissions from energy production* accounted for 409 647 Gg CO_2eq and 320 930 Gg CO_2eq (6.7% of the total emissions), respectively, between 2000 and 2010. The *Manufacture of solid fuels and other energy industries* accounted for an accumulated 327 140 Gg CO_2eq of the total GHG emissions in the energy sector for the period 2000 to 2010. The residential and commercial sectors are both heavily reliant on electricity for meeting energy needs, with electricity consumption for operating appliances heating, air conditioning and lighting, contributing a total of 170 750 Gg CO_2eq and 157 584 Gg CO_2eq of emissions respectively.

The total GHG emissions in the Energy sector increased from 381 789 GgCO_2eq in 2000 to 492 261 Gg CO_2eq Gg CO_2eq in 2010 (Figure 3.3). The majority of emissions were from electricity production, which accounted for a total of 67.8% of the total GHG emissions from the Energy sector in 2010. Total GHG emissions increased between 2000 and 2004 and that was mainly because of the economic growth and development, which lead to increased demands for electricity and fossil fuels. The expansion of industrial production during that period increased the demand for electricity and fossil fuels. Economic growth has also increased the rate of travelling, leading to higher rates of consumption of petroleum fuels. There was a decrease in emissions in 2005, after which emissions continued to increase until 2008 when there was a slight decrease (Figure 3.4). In 2009 emissions started to increase again although the increase was minimal in 2009 (0.11%).

Table 3.1: shows the contribution of the source categories in the Energy sector to the total national GHG inventory.

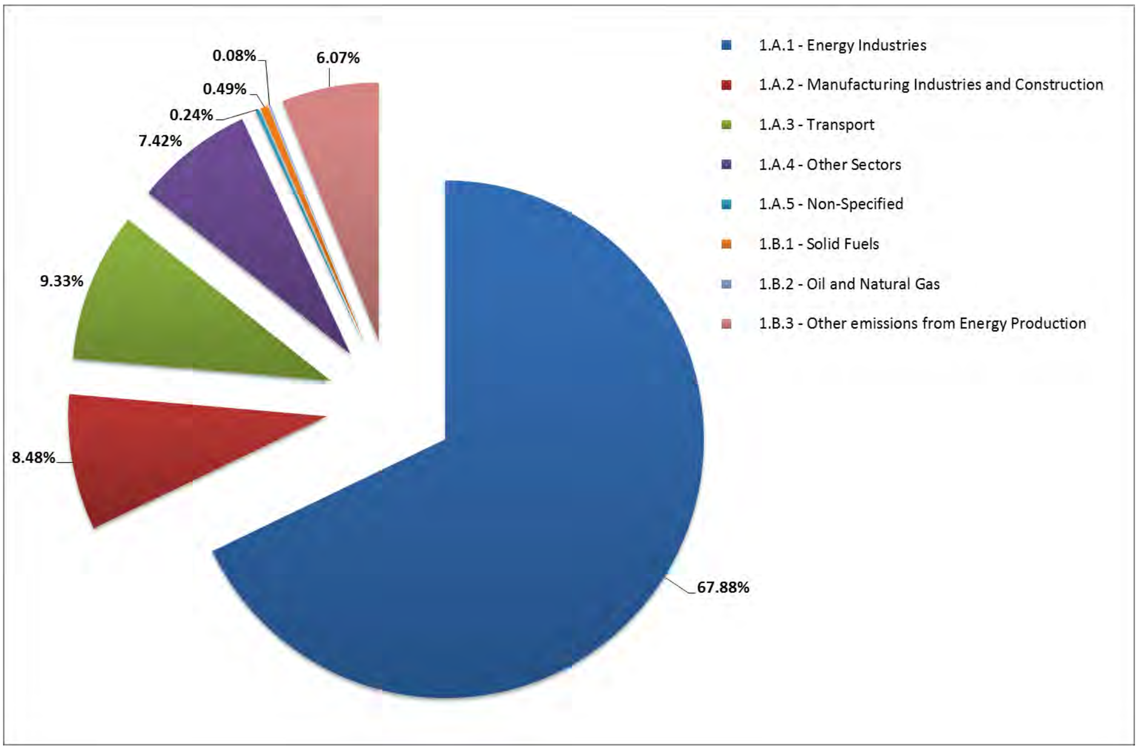

Figure 3.2: Sector 1 Energy: Contribution of source categories to the total energy sector GHG emissions between 2000 and 2010.

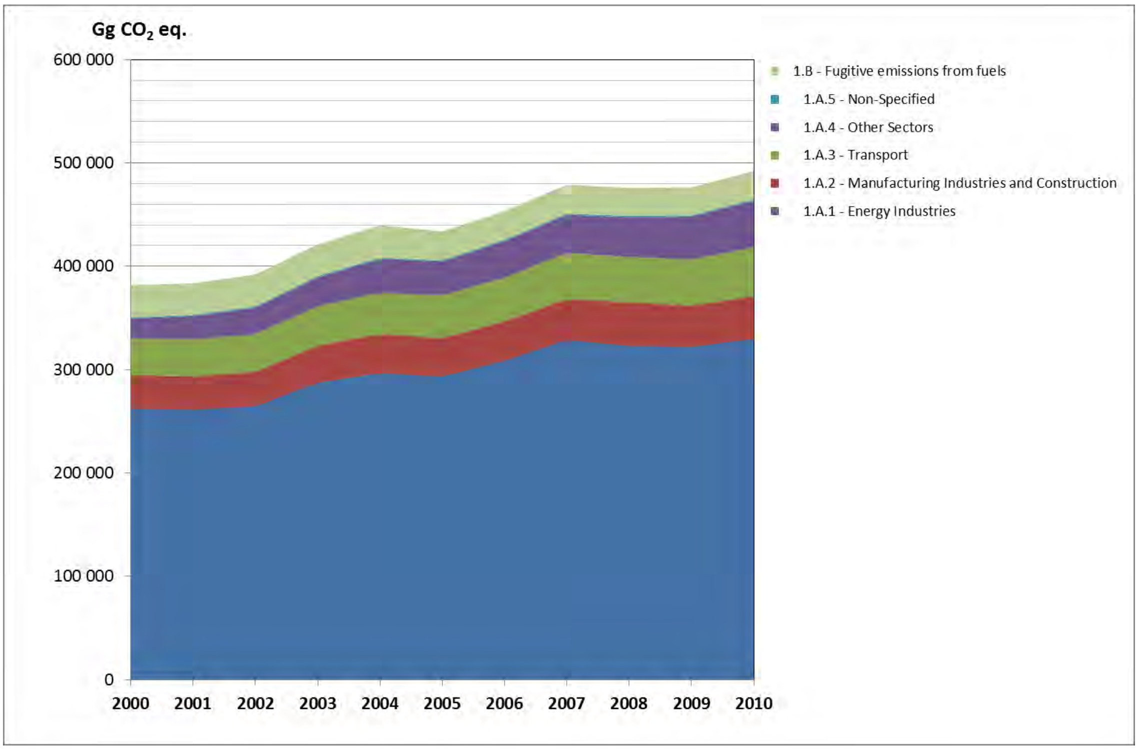

Figure 3.3: Sector 1 Energy: Trend and emission levels of source categories, 2000 – 2010.

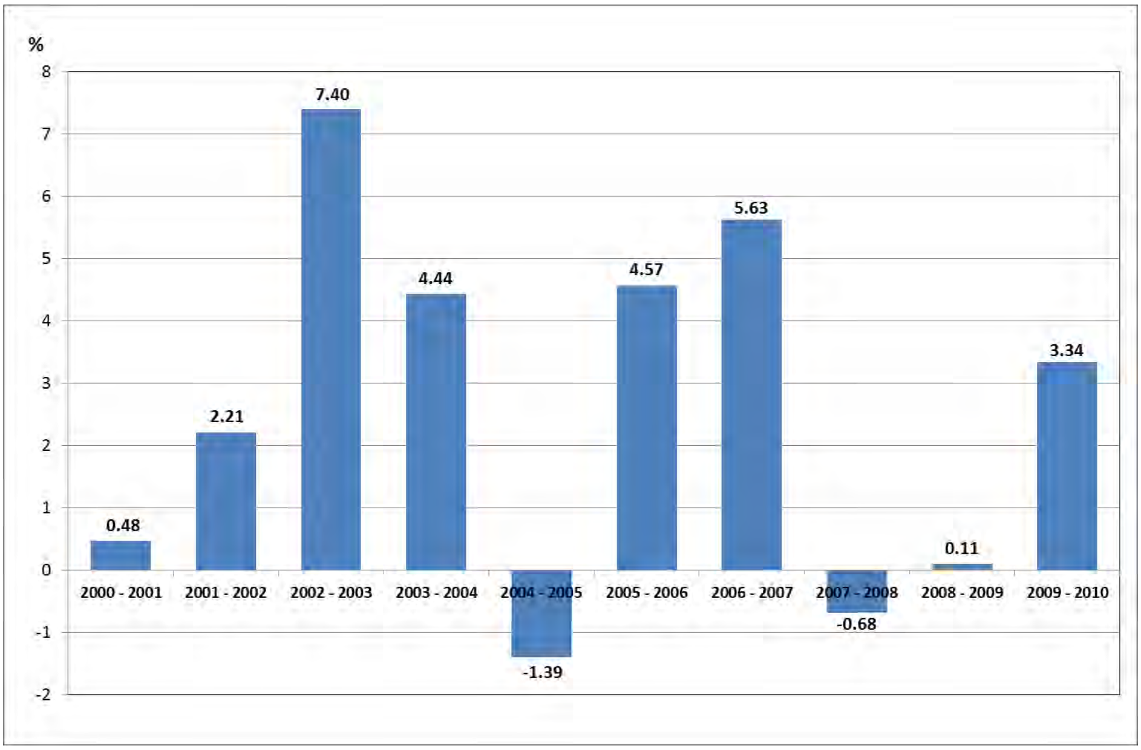

Figure 3.4: Sector 1 Energy: Annual change in total GHG emissions between 2000 and 2010.

In 1990 and 1994 the Energy sector was estimated to produce 260 886 Gg CO_2eq and 297 564 Gg CO_2eq, respectively. Between 1990 and 2000 there was an increase of 46.3% in total GHG emissions from the energy sector, and between 2000 and 2010 there was a further 28.9% increase (Figure 3.5). It should, however, be noted that improvements in activity data, emission factors and emission calculations were made between 1990 and this 2000 inventory, therefore some of the increase experienced over this period may be attributed to methodological changes.

Table 3.1: Sector 1 Energy: Contribution of the various sources to the total Energy GHG emissions.

	Total CO_2 (Gg CO_2 eq.)										
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Electricity Generation	228 574	224 865	231 171	252 834	263 182	262 297	277 659	296 440	291 376	290 203	298 671
Petroleum Refining	3 848	6 027	2 661	2 921	2 706	2 594	2 525	2 563	2 731	2 649	2 576
Manufacture of Solid Fuels and Other Energy Industries	29 926	30 534	30 708	31 605	30 811	28 528	28 457	29 781	28 981	29 165	28 644
Manufacturing Industries and Construction	32 607	32 136	33 344	35 850	37 826	37 098	38 020	39 409	42 220	40 075	41 063
Domestic Aviation	2 047	2 079	2 204	2 626	2 837	3 146	3 118	3 374	3 413	3 468	3 670
Road Transportation	33 354	33 569	34 068	35 479	36 834	37 902	39 046	41 255	40 130	40 695	43 440
Railways	197	204	215	229	242	256	274	307	307	307	333
Commercial/Institutional	9 554	11 048	12 213	13 191	16 171	15 217	16 506	15 169	15 402	15 985	17 129
Residential	7 094	9 218	11 097	12 299	13 973	15 005	16 201	18 401	20 260	22 419	24 782
Agriculture/Forestry/Fishing/Fish Farms	2 387	2 256	2 327	2 449	2 581	2 665	2 809	3 072	3 021	3 065	3 308
Non-Specified	989	984	983	1 015	1 045	1 062	1 073	1 100	1 053	1 076	1 139
Solid Fuels	2 002	1 990	1 961	2 118	2 167	2 181	2 180	2 205	2 245	2 230	2 266
Venting	325	250	196	1 065	254	266	291	325	228	237	619
Other emissions from Energy Production	28 885	28 461	28 958	27 442	29 207	25 501	25 376	25 657	24 450	24 771	24 621
Total	**381 790**	**383 620**	**392 107**	**421 121**	**439 835**	**433 719**	**453 536**	**479 057**	**475 817**	**476 346**	**492 261**

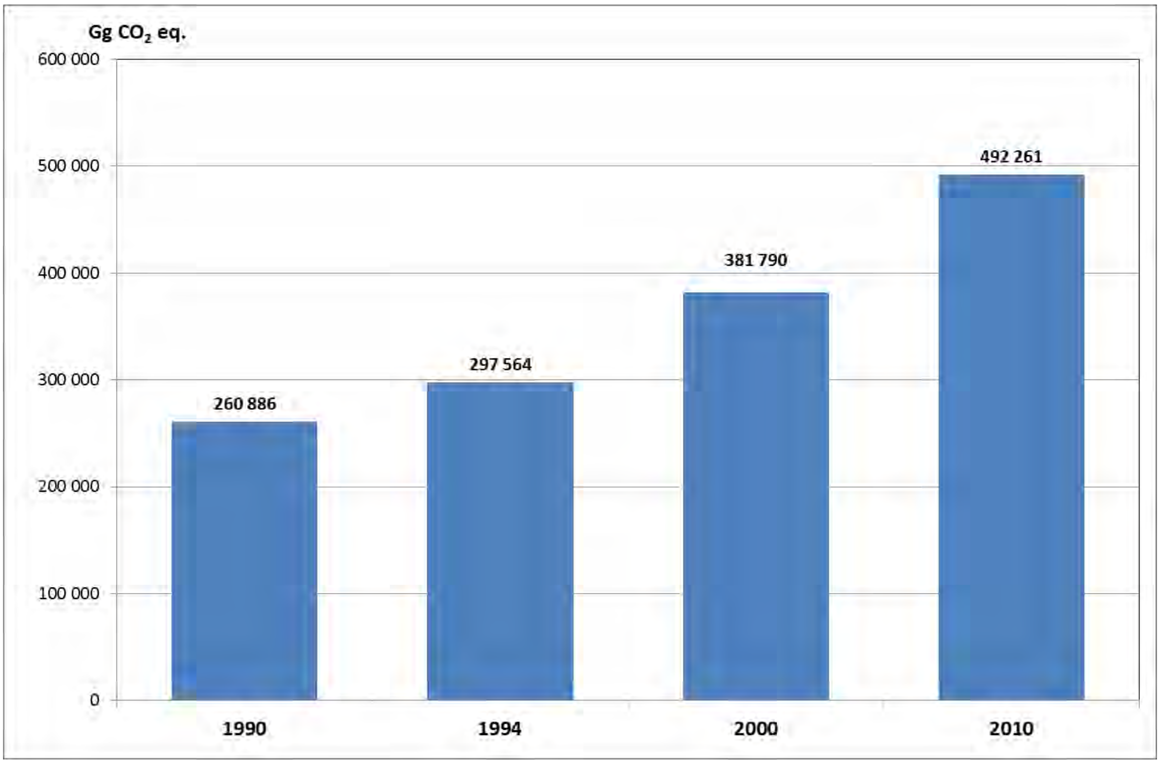

Figure 3.5: Sector 1 Energy: Trend and emission levels of total GHG's from the energy sector, 1990 – 2010.

3.2.1.1 Energy emissions and the South African economy

Trends in the GHG emissions from fossil fuel combustion are mainly influenced by long and short term factors such as population increase, economic fluctuations, energy price fluctuations and energy supply challenges. Gross Domestic Production (GDP) performance is the key driver for trends in energy demand in many sectors. Population changes also play an important role in the fluctuation of GHG emissions in the residential sector. In broad terms energy consumption patterns respond to the changes that affect the scale of consumption, that is the number of cars, size of houses, population, efficiency of energy usage and behavioural choices/tendencies.

The South African economy is directly related to the global economy, mainly through exports and imports. The GHG emissions in this sector have increased by 29.8% from the year 2000 to 2010, mainly because of economic growth and development, as well as the preparation of the 2010 world cup. The real domestic production has been responding positively to the growth in real expenditure and registered a growth rate of 3.7% in 2004. According to Statistics South Africa (Stats SA), in February 2004 South Africa's economy increased by 1.9% in 2003 compared with an economic growth rate of 3.6% in 2002. The slowdown in overall growth for 2003 as a whole was mainly attributed to a contraction in growth in the agricultural and manufacturing sectors. The real value added by the non-agricultural sector in 2003 increased by 2.2% compared with 2002. During the year 2002 and 2003 GHG emissions also increased by 2.8% and 6.4% respectively mainly because of the economic growth that occurred in those years.

The South African economy grew by 5% in 2005 whilst the GHG emissions increased by 4.6% between 2005 and 2006. Real domestic production responded positively to the growth in real expenditure and registered a growth rate of 4.9% in 2005. That compared favourably with the growth in real gross domestic production of 4.5% recorded in 2004, and was the highest growth rate since 1984. The economic growth and development were favourable in 2004, so the reason for the decline in GHG emissions between 2004 and 2005 is uncertain.

The increase in GHG emissions was significantly lower during 2007 to 2009, with only a 0.1% increase during 2009. South Africa officially entered an economic recession in May 2009; that was the first in 17 years. Until the global economic recession affected South Africa in the late 2008 to early 2009, the economic growth and development were stable and consistent. According to Statistics South Africa, the GDP increased by 2.7% in 2001, 3.7% in 2002, 3.1% in 2003, 4.9% in 2004, 5.0% in 2005, 5.4% in 2006, 5.1% in 2007 and 3.1% in 2008. However in the third and fourth quarters of 2008, the economy experienced enormous recession, this continued into the first and second quarters of 2009. As a result of the economic recession, GHG emissions during that same period decreased enormously almost across all categories in the energy sector.

In November 2009, South Africa recovered from the recession by achieving a 0.9% growth, the growth was primarily from the manufacturing sector. The hosting of the 2010 FIFA world cup in June and July 2010 contributed positively to the country’s economy, and as result GHG emissions increased by 4.1% during that year.

The South African economy is highly dependent on reliable and secure electricity services. Another reason for the decline in GHG emissions during the period of November 2007 to end of January 2008 is because South Africa experienced substantial disruptions in electricity supply during that period. Energy disruption demonstrated a fundamental importance of having adequate generating capacity for efficient and secure operation of the electricity industry.

Since January 2006 the main power producer experienced increasing difficulties in meeting customer demand (NERSA, 2008). This situation deteriorated in the late 2007 and early 2008, where the main power generator resorted to load shedding. The extent of the load shedding had a disruptive impact on business operations, traffic, industry, mining operations, commerce, hospitals, clinics, schools and other institutions such as the education, civil services, domestic households and the livelihoods of the South African public. The situation deteriorated to an extent where major mining operations had to close down on the 24th of January 2008 for safety considerations (NERSA, 2008).

3.2.2 Key sources

The level and trend key category analyses were completed for 2010 using 2000 as the base year. The level assessment shows that the *Energy industries* (solid fuels), *Road transportation*, *Manufacturing industries and construction* (solid fuels) and *Other sectors* (solid fuels) to be the top categories in the Energy sector. In the trend assessment, it is the *Other sectors* (solid fuels), *Other emissions from Energy Production*, and *Energy industries* (liquid and solid fuels) which top the list (see Table 1.3 and Table 1.4). This differs from the 2000 inventory which showed fugitive emissions from coal mining

(1B1) to be the second most important emitter, whereas in this inventory these emissions are not seen as a key category. Also emissions from Road transportation have move much higher up on the key categories list in this inventory.

3.3 Fuel Combustion Activities [1A]

The combustion of fuels includes both mobile and stationary sources, with their respective data combustion related emissions. GHG emissions from the combustion of fossil fuels in this inventory will include the following categories and subcategories:

- 1A1 Energy Industries
    - 1A1a Main activity electricity and heat production
    - 1A1b Petroleum Activity
- 1A2 Manufacturing industries and construction
    - 1A2c Chemicals
    - 1A2m Non-specified sectors
- 1A3Transport Sector
    - 1A3a Civil Aviation
    - 1A3b Road Transportation
    - 1A3c Railways
    - 1A3d Water-borne Navigation
    - 1A3e Other Transportation
- 1A4 Other Sectors
    - 1A4a Commercial/ Institutional
    - 1A4b Residential
    - 1A4c Agriculture / Forestry/ Fishing/ Fish Farms

3.3.1 Comparison of the sectoral approach with the reference approach

The Reference approach is a quick estimate of the total CO_2 emitted in a country using a first-order estimate of national GHG emissions based on the energy supplied to a country. The reference approach can be used to estimate a country's CO_2 emissions from fuel combustion and can be compared with the results of the sectoral emission estimates. That was done for this inventory and over the period 2000 to 2009 (2010 energy balance data was not available) the CO_2 emissions were on average 50% higher using the sectoral approach. There are a number of possible reasons for the discrepancy:

- large statistical differences between the energy supply and the energy consumption in the energy balance data;
- fuel consumption activities may be underreported or not reported at all when compiling the national energy balance data;
- the use of approximate net calorific and carbon content values for primary fuels which are converted rather than combusted; or

- missing information on stock changes;

The significant difference between the two approaches warrants further investigation when the next inventory or energy balance is produced.

3.3.2 Feed stocks and non-energy use of fuels

There are cases where fuels are used as raw materials in production processes. For example, in iron and steel production, coal is used as a feedstock in the manufacture of steel. The 2006 IPCC guidelines emphasizes the significance of separating between energy and process emissions, to ensure that double counting is prevented between the industrial and energy sectors. Therefore, to avoid double counting, coal used for metallurgical purposes has been accounted for under the IPPU sector. Information on feed stocks and non-energy use of fuels has been sourced from the national energy balance tables. Sources considered include coal use in iron and steel, use of fuels as solvents and lubricants and waxes and use of bitumen in road construction.

3.3.3 Energy Industries [1A1]

The combustion of fuels by large fuel extraction and energy producing industries, electricity producers and petroleum refineries are the main sources of fossil fuels in South Africa. The GHG emissions from manufacturing of solid and/or liquid fuels are reported under refinery emissions.

The South African energy demand profile reveals that the industry/manufacturing sector utilizes the largest amount of electricity followed by mining, commercial and residential sectors (DoE, 2009a). In an event of any power disruptions, these sectors are more likely to be impacted. In the case of the manufacturing/industry, mining and commercial sectors, this can result in reduced productivity. Table 3.2 below gives a summary of the main electricity users in South Africa.

Table 3.2: Sector 1 Energy: Summary of electricity users in South Africa (Source: DoE, 2009a).

Consumer group	Electricity consumption	Number of consumers
Residential	17%	7.5 million
Agriculture	3%	103 000
Commercial	13%	255 000
Mining	15%	1100
Industry/ Manufacturing	38%	33000
Transport (mainly railway)	3%	1800
Exports	6%	7
Own use of distributors	5%	N/A
Total	**100%**	**7.9 million**

N/A – not available

3.3.3.1 Source category description

MAIN ACTIVITY ELECTRICITY AND HEAT PRODUCTION [1A1A]

Main activity electricity refers to public electricity plants that feed into the national grid, and auto electricity producers are industrial companies that operate and produce their own electricity. The main energy industries include electricity and heat production, petroleum refineries and manufacture of solid or liquid fuels. This category includes electricity produced both by the public and auto electricity producers.

The energy balances published by the DoE indicate the type of fuel and the quantity consumed, which is mainly bituminous coal. Electricity generation is the largest key GHG emission source in South Africa, mainly because the electricity is generated from coal which is abundantly available in the country. Eskom is the leading company in the South African electricity market, supplying more than 95% of South Africa's electricity needs (DoE 2009). The net maximum electricity generation capacity and electricity consumption for 2000 to 2010 is illustrated in Table 3.3.

Table 3.3: Sector 1 Energy: Net electricity generation capacity and associated consumption (Source: ESKOM, 2005, 2007, 2011).

Period	Net maximum electricity generation capacity (MW)	Total net electricity sold (GWh)
2000	39 810	198 206
2001	39 810	181 511
2002	39 810	187 957
2003	39 810	196 980
2004	39 810	220 152
2005	39 810	256 959
2006	39 810	207 921
2007	37 764	218 120
2008	38 747	239 109
2009	40 506	228 944
2010	40 870	232 812

The largest public electricity producer in South Africa is Eskom. Eskom generates 95% of the electricity used in South Africa (Eskom, 2011). Eskom generates, transmits and distributes electricity to various sectors such as the industrial, commercial, agricultural and residential sectors. Additional power stations are in the process of being built to meet the increasing demand of electricity in South Africa (Eskom, 2011). Eskom will invest more than R300 billion in new generation, transmission and distribution capacity up to 2013. In 2008 Eskom's electricity total sales were approximated to be 224 366 Gigawatt hour^{-1} (GWh). To save electricity, Eskom introduced the Demand Side Management (DSM to effect a reduction of 3000 megawatt (MW) by March 2011, and is aiming for a 5000 MW reduction by March 2026. This process involves the installation of energy-efficient technologies to alter Eskom's load and demand profile. The DSM programme within the residential, commercial and industrial sectors has exponentially grown and exceeded its annual targets. The 2009 saving was 916 MW, against the target of 645 MW. That increased the cumulative saving to 1 999 MW since the inception of DSM in 2003.

PETROLEUM REFINING [1A1B]

Petroleum refining includes crude oil refining and the manufacturing of synthetic fuels from coal and natural gas. However, emissions related to manufacture of synthetic fuels from coal and natural gas are accounted for under fugitive emissions. South Africa has limited oil reserves and approximately 95% of its crude oil requirements are met by imports. Refined petroleum products such as petrol, diesel, fuel oil, paraffin, jet fuel and LPG are produced by crude oil refining, coal to liquid fuels and gas to liquid fuels.

In 2000 and 2010 the total production of crude oil distillation capacity of South Africa's petroleum refineries was 700 000 bbl day^{-1} and 703 000 bbl day^{-1} respectively (SAPIA, 2006 & 2011). The production of oil was 689 000 tonnes in 2000 and 684 000 tonnes in 2006 (SAPIA, 2011). Activity data on fuel consumption by Refineries is sourced from the DoE energy balances. The energy balances combines fuel consumption for refineries and the chemical sector. Hence emissions associated with fuel combusted in refineries are accounted for under 1A2 (*Manufacturing Industries and construction*).

MANUFACTURE OF SOLID FUELS AND OTHER ENERGY INDUSTRIES [1A1C]

This category refers to combustion emissions from solid fuels used during the manufacture of secondary and tertiary products, including the production of charcoal. The GHG emissions from the various industrial plants' own on-site fuel use, and emissions from the combustion of fuels for the generation of electricity and heat for their own use is also included in this category.

3.3.3.2 Overview of shares and trends in emissions

MAIN ACTIVITY ELECTRICITY AND HEAT PRODUCTION [1A1A]

Public Electricity Producer

The total estimation of cumulative fuel consumption for the public electricity producer for the period 2000 to 2010 was 29 610 241 TJ. The consumption of fuels increased by 35.6% over this period (Table 3.4).

The total estimation of cumulative GHG emissions from the main electricity producer was 2 859 372 Gg CO_2 eq between 2000 and 2010. In the year 2003, the total sales by Eskom increased by 196 980 GWh. The peak demand on the integrated system amounted to 31 928 MW and the total GHG emissions during that period were equivalent to 196 Mt CO_2eq. These figures demonstrate the growth of the South African economy and the importance of energy as a key driver of the country's economic growth and development. Between January 2003 and January 2004, South Africa increased its electricity output by 7.1% with a peak demand of 34 195 MW on 13 July 2004, as opposed to the 31 928 MW peak in 2003.

Table 3.4: Sector 1 Energy: Summary of GHG emissions from the public electricity producer.

	Consumption (TJ)	CO_2 (Gg)	CH_4	N_2O (Gg CO_2 eq)	Total GHG
2000	2 250 949	216 316	52	999	217 367
2001	2 281 243	219 227	52	1 013	220 293
2002	2 342 586	225 123	54	1 040	226 217
2003	2 536 186	243 727	58	1 126	244 912
2004	2 661 047	255 727	61	1 182	256 969
2005	2 688 193	258 335	62	1 194	259 591
2006	2 835 670	272 508	65	1 259	273 832
2007	3 021 549	290 371	69	1 342	291 782
2008	2 978 675	286 251	69	1 323	287 642
2009	2 962 989	284 743	68	1 316	286 127
2010	3 051 154	293 216	70	1 355	294 641

In the year 2000 the GHG emissions from the public electricity producer accounted for a total of 217 367 Gg CO_2eq. The main source of emissions in this category was the combustion of coal for electricity generation. The consumption of electricity increased marginally from the period 2000 to 2007 (DoE, 2009a). The GHG emissions steadily increased throughout the same period from 217 367 Gg CO_2eq to 291 782 Gg CO_2eq in 2007. The main reason for the increase in GHG emissions during that period was the robust economic growth which increased the demand for electricity and fossil fuels consumption. The public electricity producer experienced difficulties in the supply of electricity in the late 2007 and early 2008, where it resulted to shedding customer loads. The extent of load shedding had a negative impact on the key drivers of economic growth. In that same year GHG emissions from the sector decreased by 1.4% as a result of the electricity disruptions.

Approximately 45% of all electricity consumed in SA is used in the manufacturing sector, 20% by the mining sector, 10% by the commercial sector, 20% by the residential sector and 5% by other sectors (DoE, 2009a). The global economic crisis affected key drivers of growth such as manufacturing and mining sectors.

Auto Electricity Producer

The total estimation of accumulated GHG emissions for the period 2000 to 2010 in the category auto electricity production was 58 457 Gg CO_2 eq. Overall, from 2000 through to 2010, the GHG emissions decreased by 61.9% (Table 3.5). For the period 2001, 2004 and 2005 GHG emissions in this category decreased by 59.2%, 21.6% and 56% respectively. In 2003 the emissions increased by 8.4%, and this may have been due to the economic growth in that period which increased the demand for electricity. In the year 2008 there was a global economic crisis and this could have been the main cause of the 17% decline in GHG emissions during this year.

Table 3.5: Sector 1 Energy: Summary of GHG emissions from the auto electricity producer.

	Consumption (TJ)	CO_2 (Gg)	CH_4	N_2O (Gg CO_2 eq)	Total GHG
2000	116 046	11 152	3	52	11 206
2001	47 346	4 550	1	21	4 572
2002	51 311	4 931	1	23	4 955
2003	82 036	7 884	2	36	7 922
2004	64 333	6 182	1	29	6 212
2005	28 029	2 694	1	12	2 707
2006	39 627	3 808	1	18	3 827
2007	48 233	4 635	1	21	4 658
2008	40 066	3 850	1	18	3 869
2009	44 149	4 243	1	20	4 263
2010	44 171	4 245	1	20	4 266

The total GHG emissions from the auto-electricity producers in South Africa fluctuated significantly from year to year, and that variability was greater during the first 5 years. There were two periods of significant decreases in total emissions from the auto-electricity producers, namely a 59.2% reduction between 2000 and 2001, and a 65.8% decrease between 2003 and 2005. However between 2001 and 2003 there was a 75.3% increase, as well as a 72.1% increase between 2005 and 2007.

PETROLEUM REFINING [1A1B]

The total cumulative consumption of fuels for Petroleum refining was estimated at 540 248 TJ, with refinery gas contributing 91.5% in 2010. The total GHG emissions from Petroleum refining was estimated at 3 848 Gg CO_2eq in 2000 and 2 576 Gg CO_2 eq in 2010 (Table 3.6). There was an increase of 56.6% in 2001, but this then decreased by 55.9% in 2002 after which emissions remained fairly constant until 2010. In 2000 refinery gas contributed 50.7% to the total GHG emissions in this category and this has increased to 87.1% in 2010. Emissions from residual fuel oil decreased from contributing 41.5% in 2000 to only 3.1% in 2010. A shift from residual fuel oil to refinery gas in most refineries is the main driver of emissions reduction in this source category.

Table 3.6: Sector 1 Energy: Summary of consumption and GHG emissions in the petroleum refining category (1A1b).

	Consumption (TJ)	CO_2 (Gg)	CH_4	N_2O (Gg CO_2 eq)	Total GHG
2000	57 477	3 841	2.41	5.20	3 848
2001	88 182	6 014	4.06	9.16	6 027
2002	43 854	2 658	1.20	1.91	2 661
2003	47 965	2 917	1.32	2.13	2 921
2004	44 407	2 703	1.23	1.98	2 706
2005	42 706	2 591	1.16	1.83	2 594
2006	42 296	2 523	1.10	1.65	2 525
2007	42 196	2 561	1.14	1.80	2 563
2008	44 976	2 728	1.21	1.91	2 731
2009	43 668	2 645	1.18	1.85	2 649
2010	42 521	2 573	1.14	1.79	2 576

MANUFACTURE OF SOLID FUELS AND OTHER ENERGY INDUSTRIES [1A1C]

The total GHG emissions from the Manufacture of solid fuels and other energy industries was 29 926 Gg CO_2 eq in 2000, and that declined by 4.3% over the next 10 years to 28 644 Gg CO_2 eq in 2010 (**Error! Reference source not found.**). Emissions remained fairly constant over the period 2000 to 2010, with annual changes varying between -7.4% to 4.7%. The CO_2 emissions contributed 99.5% to the total GHG emissions from this category.

Table 3.7: Sector 1 Energy: Contribution of CO_2, CH_4 and N_2O to the total emissions from the Manufacture of Solid fuels and Other Energy Industries category (1A1c).

	CO_2 (Gg)	CH_4	N_2O (Gg CO_2 eq)	Total GHG
2000	30 197	6.95	134	30 338
2001	29 848	8.10	156	30 013
2002	29 969	8.07	156	30 133
2003	30 182	8.23	159	30 349
2004	30 730	8.33	161	30 899
2005	27 820	7.48	144	27 972
2006	27 746	7.48	144	27 897
2007	29 385	8.07	156	29 549
2008	27 377	7.82	151	27 535
2009	27 897	7.91	153	28 057
2010	27 897	7.91	153	28 057

3.3.3.3 Data sources

MAIN ACTIVITY ELECTRICITY AND HEAT PRODUCTION [1A1A]

Data on fuel consumption for public electricity generation and auto electricity producers was obtained directly from the national power utility for the period 2000 to 2010; Chamber of Mines, and the DoE Energy Digest for the period 2006 to 2009. The South African Minerals Industry (SAMI) annual publications where also used to verify total coal consumption in this source category.

A country-specific Net Calorific Values of 0.0243 TJ tonne^{-1} was used to convert fuel quantities into energy units and this was sourced from the digest of energy statistics report (DoE, 2009a).

PETROLEUM REFINING [1A1B]

The activity data for petroleum refining was sourced directly from refineries from the DoE energy balances. The IPCC methods for filling data gaps were used to complete activity data time series.

MANUFACTURE OF SOLID FUELS AND OTHER ENERGY INDUSTRIES [1A1C]

The GHG emissions results were sourced from manufacturing plants (PetroSA and Sasol) and they were calculated based on actual process balance analysis. Due to the lack of data on fuel use in charcoal production plants, it was assumed that the consumption was included under *Manufacturing and industries* (1A2).

3.3.3.4 Methodology

MAIN ACTIVITY ELECTRICITY AND HEAT PRODUCTION [1A1A]

Electricity production is the largest source of emissions and according to the 2006 IPCC guidelines, it is *good practice* to use higher tier methods and emission factors for key categories. As such, CO_2 emissions from electricity production were estimated based on country specific emission factors and plant specific activity data. Hence, net-caloric values (NCVs) reported on an annual basis by the power utility and activity data for each power plant were used in these estimations.

A Tier 2 approach with default emission factors was used to estimate CO_2 emissions from coal consumption (Table 3.8). For the calculation of CH_4 and N_2O emissions, the emission factors were sourced from the 2006 IPCC guidelines. Default factors from these guidelines were also used for determining the GHG emissions from other fuels such as other kerosene and diesel oil.

PETROLEUM REFINING [1A1B]

GHG emissions from petroleum refining were estimated based on a Tier 1 approach and IPCC 2006 default EF's (Table 3.9).

Table 3.8: Sector 1 Energy: Emission factors for GHG emissions (Source: 2006 IPCC Guidelines, Vol 2).

Type of Fuel	Emission factor (kg TJ^{-1})		
	CO_2	CH_4	N_20
Sub-Bituminous Coal	96 100	1	1.5
Other Kerosene	71 500	3	0.6
Gas/ Diesel Oil	74 100	3	0.6

MANUFACTURE OF SOLID FUELS AND OTHER ENERGY INDUSTRIES [1A1c]

A country-specific methodology was applied for the calculation of GHG emissions from the manufacturing of solid fuels and energy industries. The GHG emissions from this category were calculated based on actual process material balance analysis.

Table 3.9: Sector 1 Energy: Emission factor for the calculation of GHG emissions from Petroleum refining (Source: 2006 IPCC Guidelines).

Type of Fuel	Emission factor (kg TJ^{-1})		
	CO_2	CH_4	N_20
Residual Fuel Oil	77 400	3	0.6
Petroleum Coke	97 500	3	0.6
Refinery Gas	57 600	1	0.1

3.3.3.5 Uncertainties and time-series consistency

ENERGY INDUSTRIES [1A1]

According to the IPCC guidelines, the uncertainties in CO_2 emission factors for the combustion of fossil fuels are negligible. The emission factors were determined from the carbon content of the fuel. Uncertainties in CH_4 and N_2O emission factors were quite significant. The CH_4 emission factor has an uncertainty of between 50 to 150%, while the uncertainty on the N_2O emission factor can range from one-tenth of the mean value to ten times the mean value. With regards to activity data, statistics of fuel combusted at large sources obtained from direct measurement or obligatory reporting are likely to be within 3% of the central estimate (IPCC 2006). Those default IPCC uncertainty values have been used to report uncertainty for energy industries.

Activity data time series for the period 2000 to 2010 were sourced directly from energy industries. In cases where data gaps were observed, the IPCC methodologies for filling data gaps were used. That was mostly the case in Petroleum Refining (1A1b) as some refineries did not record fuel consumption in the first four years of the time series. To ensure consistency in time series emission estimates, IPCC default emission factors were used for the entire time series for all energy industries. In some cases (e.g. 1A1c) mass balances methods were applied consistently across the time series. The national power utility changed its annual reporting planning cycle from a calendar year to an April-March financial year from 2006 onwards. That affected the time series consistency, therefore, the national power utility was asked to prepare calendar year fuel consumption estimates using its monthly fuel consumption statistics.

3.3.3.6 Source-specific QA/QC and verification

ENERGY INDUSTRIES [1A1]

To ensure quality control of the activity data used to compile emission estimates in energy industries, various publications were used to verify facility-level activity data. The South African Mineral Industry (SAMI) publication by the Department of Mineral Resources (DMR) was used to verify fuel used for electricity generation (SAMI, 2010). Similarly, a combination of crude oil input reported in the SAPIA reports and in the energy balances applied with the IPCC default assumptions on fuel input in refineries were used to verify fuel consumption data reported by refineries (SAPIA 2010).

3.3.3.7 Source-specific recalculations

For the purpose of this report, more accurate activity data were collected from the year 2000 for all sources within the Energy Industries sector, which resulted in the recalculation of GHG emissions for the year 2000. The recalculation improved the accuracy of the 2000 GHG emissions result for the Energy sector.

3.3.3.8 Source-specific planned improvements and recommendations

MAIN ACTIVITY ELECTRICITY AND HEAT PRODUCTION [1A1A]

South Africa has one major producer of electricity, therefore it should be easier to obtain disaggregate electricity production data. The regular collection of activity data from the national power producer is important in order to improve time series and consistency. Another improvement is for the national power producer to provide DEA with information that will assist in the explanation of the trends throughout the reporting period. Electricity generation is a key source category and therefore development of country-specific emission factors is necessary.

PETROLEUM REFINING [1A1B]

To improve the reporting of GHG emissions in this category, it is important that the petroleum refineries provide plant-specific activity data and also develop a country specific emission factor which can be used for the calculation of GHG emissions in this category.

MANUFACTURE OF SOLID FUELS AND OTHER ENERGY INDUSTRIES [1A1C]

To improve the estimation of GHG emissions from the manufacture of solid fuels and energy industries, a more regular collection of activity data would be useful. That would improve the time series and consistency of the data in this category. Another improvement would be to monitor the cause of fluctuations in the manufacture of solid fuels and other energy industries regularly, to enable the inventory compilers to elaborate on the fluctuations.

3.3.4 Manufacturing Industries and Construction [1A2]

3.3.4.1 Source category description

According to the 2006 IPCC guidelines, this category is comprised of a variety of fuel combustion emission sources, mainly in the industrial sector. In manufacturing industries, raw materials are converted into products using fuels as the main source of energy. The industrial sector consumes 40.8% of the final energy supplied in South Africa. The sector can be divided into mining, iron and steel, chemicals, non-ferrous metals, non-metallic minerals, pulp and paper, food and tobacco and other productions (includes manufacturing, construction, textiles, wood products etc.). The largest subsector is iron and steel which consumes 27.4% of the total energy utilized by the industrial sector (DoE, 2009a). Emissions from the combustion of fossil fuels in the construction sector are also included in this category. According to the energy balances compiled by the DoE, fossil fuels in the construction sector include liquefied petroleum gas (LPG), gas/diesel oil, residual fuel oil, other kerosene, bitumen, sub-bituminous coal and natural gas.

3.3.4.2 Overview of shares and trends in emissions

The estimation of the cumulative total GHG emissions in the category *Manufacturing industries and construction* was 409 647 Gg CO_2 eq. The emissions were estimated at 32 607 Gg CO_2eq in 2000 and this increased by 25.9% to 41 063 Gg CO_2eq in 2010 (Figure 3.6). Solid fuels contributed 86% to the total in 2010, while liquid and gaseous fuels contributed 4.7% and 9.4% respectively. There has been a 2.5% increase in the contribution from gaseous fuels, 1% increase from liquid fuels and a 3.0% decline in the contribution from solid fuels over the 10 year period.

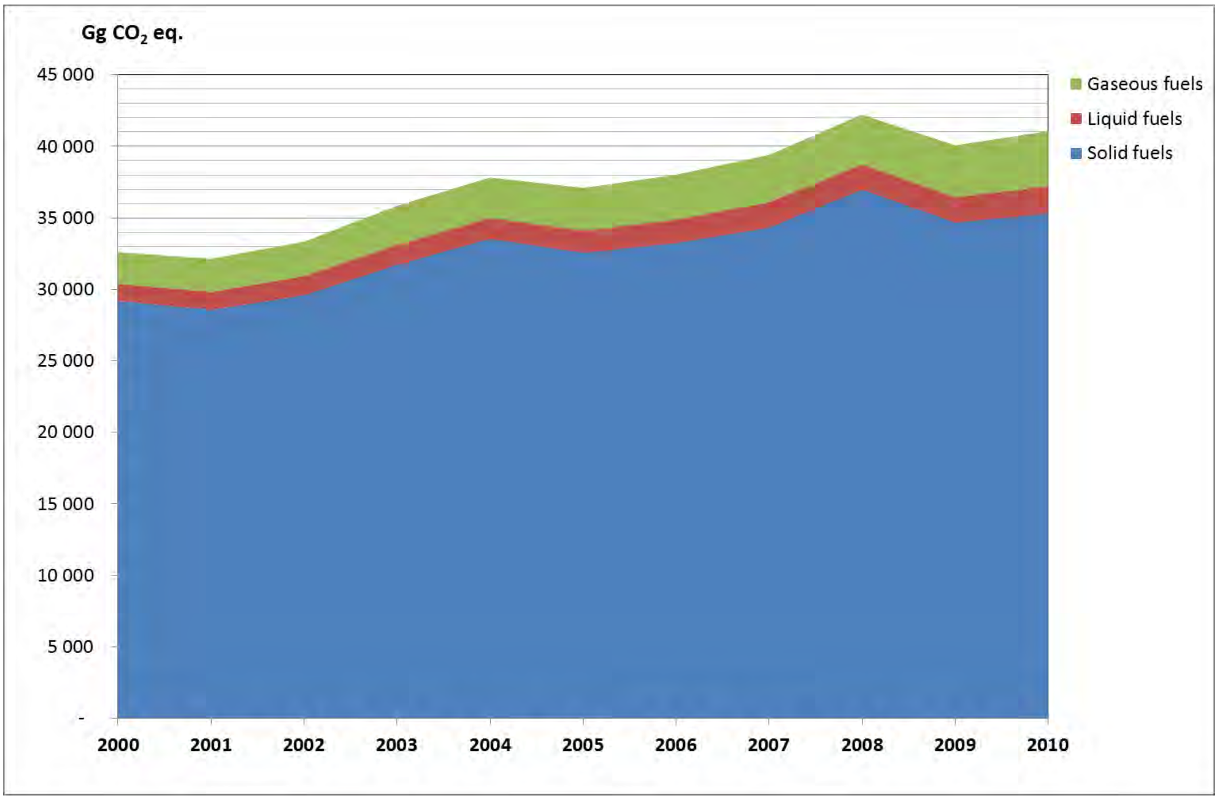

Figure 3.6: Sector 1 Energy: Trend in sources of CO_2 emissions from fuel used in Manufacturing Industries and Construction category (1A2), 2000 - 2010.

In the years 2003 and 2004 GHG emissions increased by 7.5% and 5.5%, respectively. There was a 5.1% decline in emissions in 2009, and that may have been caused by the global economic crisis that occurred in that year. The real value added by the construction sector increased at an annual rate of 10.6% in the second quarter of 2008, lower than the rate of 14.9% recorded in the first quarter of 2008. That reduced growth reflected deteriorating conditions in the residential and non-residential building sectors, as developers experienced a strain of higher interest rates and escalating inflationary pressures.

3.3.4.3 Data sources

Data in the *Manufacturing and construction* sector were sourced from the DoE energy balances, SAPIA and SAMI. Data from industries were also acquired and used to compare the figures in the energy balances. Table 3.10 shows the total fuel consumption in this category for the period 2000 – 2010. A Net Calorific Value of 0.0243 TJ $tonne^{-1}$ was used to convert fuel quantities into energy units (DoE, 2009a).

Table 3.10: Sector 1 Energy: Fuel consumption (TJ) in the Manufacturing Industries and Construction category, 2000 – 2010.

	Other Kerosene	Gas/Diesel Oil	Residual Fuel Oil	LPG	Bitumen	Sub-Bituminous Coal	Natural Gas	Total
2000	698	9 531	194	109	5 053	302 354	39 532	357 471
2001	640	9 888	194	115	5 584	295 804	41 241	353 465
2002	606	10 410	187	113	6 161	306 401	43 048	366 927
2003	626	11 069	185	107	6 276	328 424	48 749	395 436
2004	649	11 702	199	108	6 382	347 344	50 361	416 745
2005	619	12 367	171	106	7 038	337 162	53 166	410 629
2006	601	13 271	166	116	7 245	344 183	56 038	421 621
2007	567	14 870	164	122	7 707	355 304	58 908	437 643
2008	433	14 877	164	118	7 475	383 032	61 778	467 877
2009	444	14 877	207	105	7 602	359 011	64 645	446 892
2010	469	16 129	219	111	8 044	365 687	68 406	459 066

3.3.4.4 Methodology

GHG emissions included in this subcategory are mainly from fuel combusted for heating purposes. Fuels used as feed stocks and for other non-energy use of fuels are accounted for under the IPPU sector. For this subsector, a tier 1 methodology was applied by multiplying activity data (fuel consumed) with IPCC default emission factors. In the future, facility level data has to be sourced and country emission factors need to be developed in order to move towards tier 2 methodology.

EMISSION FACTORS

The IPCC 2006 default emission factors were used in estimating emissions from the *Manufacturing industries and construction* sector (Table 3.11). The default EF's were applicable to all activities within this sector since similar fuels were combusted.

3.3.4.5 Uncertainty and time-series consistency

According to the 2006 IPCC guidelines, uncertainty associated with default emission factors for industrial combustion is as high as 7% for CO_2; ranges from 50-150% for CH_4 and is an order of magnitude for N_2O. Uncertainty associated with activity data based on less developed statistical systems was in the range of 10-15%. To ensure time series consistency in this source-category the same emission factors were used for the complete time series estimates. Activity data sourced on fuel consumption was complete and hence there was no need to apply IPCC methodologies for filling data gaps.

Table 3.11: Sector 1 Energy: Emission factors used in the Manufacturing Industries and Construction category (Source: 2006 IPCC Guidelines).

Type of Fuel	Emission factor (kg TJ^{-1})		
	CO_2	CH_4	N_20
Sub-Bituminous Coal	96 100	1	1.5
Gas/ Diesel Oil	74 100	3	0.6
Residual Fuel Oil	77 400	3	0.6
Liquefied Petroleum Gas (LPG)	63 100	1	0.1
Natural Gas (Dry)	56 100	1	0.1
Other kerosene	71 900	3	0.6
Bitumen	80 700	3	0.6

3.3.4.6 Source-specific QA/QC and verification

The national energy balances and the Digest of energy statistics were used to verify fuel consumption data reported in the South African Mineral Industry report.

3.3.4.7 Source-specific recalculations

The GHG emission estimates for 2000 were recalculated due to the inclusion of more robust activity data.

3.3.4.8 Source-specific planned improvements and recommendations

In the future facility level data needs to be sourced and country specific emission factors have to be developed in order to move towards tier 2 methodology. The reliance on energy balances and other publications for compilation of emissions needs to be reduced by sourcing facility level activity data. This will help to reduce the uncertainty associated with activity data.

3.3.5 Transport [1A3]

According to the 2006 IPCC guidelines the estimation of GHG emissions from mobile combustion refers to major transport activities such as road, off-road, air, railways and water borne navigation. This category only includes direct emissions from transport activities, mainly from liquid fuels (gasoline, diesel, aviation gas and jet fuel). Secondary fuels such as electricity used by trains are reported under the Energy sector and not this sector. The diversity of sources and combustion takes into consideration the age of fleet, maintenance, sulphur content of fuel and patterns of use of the various transport modes. The GHG inventory includes transport emissions from combustion and evaporation of fuels for all transport activity.

The 2006 IPCC guidelines indicate that, where possible, activities such as agricultural machinery, fishing boats and military transport should be recorded separately under the appropriate sectors and not in the transport sector (IPCC 2006, p.3.8). Furthermore GHG emissions from fuels sold to any air or marine vessels engaged in international transport are excluded from the national total emissions and are reported separately under the Memo Items.

3.3.5.1 Source category description

CIVIL AVIATION [1A3A]

Civil Aviation emissions are produced from the combustion of jet fuel (jet kerosene and jet gasoline) and aviation gasoline. Aircraft engine emissions (ground emissions and cruise emissions) are roughly composed of 70% CO_2, less than 30% water and 1.0% of other components (NO_x, CO, SO_x, NMVOC's, particulates, trace components). Civil aviation data were sourced from both domestic and international aircrafts, including departures and arrivals. That also included civil commercial use of airplanes, scheduled and charter traffic for passengers and freight, air taxing, agricultural airplanes, private jets and helicopters. The GHG emissions from military aviation are separately reported under the *Other* category or the memo item *Multilateral operations*.

International Aviation (International Bunkers) [1A3aI]

GHG emissions from aircrafts that have returned from an international destination or that are going to an international airport were included under this sub-category. That included civil commercial use of airplanes, scheduled and charter traffic for passengers and freight, air taxiing, agricultural airplanes, private jets and helicopters. The GHG emissions from military aviation were reported separately under the *Other* category or under the memo item *Multilateral operations*.

ROAD TRANSPORT [1A3B]

According to the 2006 IPCC guidelines, road transportation emissions included fuel consumption by light duty vehicles (cars and light delivery vehicles), heavy duty vehicles (trucks, buses and tractors) and motorcycles (including mopeds, scooters and three – wheelers). Fuels used by agricultural vehicles on paved roads were also included in this category. The Energy balances list fuels under road transport as being diesel, gasoline, other kerosene, residual fuel oil and LPG. Road transportation was responsible for the largest fuel consumption in the Transport sector (91.3 in 2010). Motor gas contributed 64.9% towards the road transport fuel consumption in 2010, followed by gas/diesel oil (35%). Between the years 2000 and 2010 there was an increase in the percentage contribution of gas/diesel oil to the road transport consumption (8.2%), and a corresponding decline in the contribution from motor gasoline (Figure 3.7).

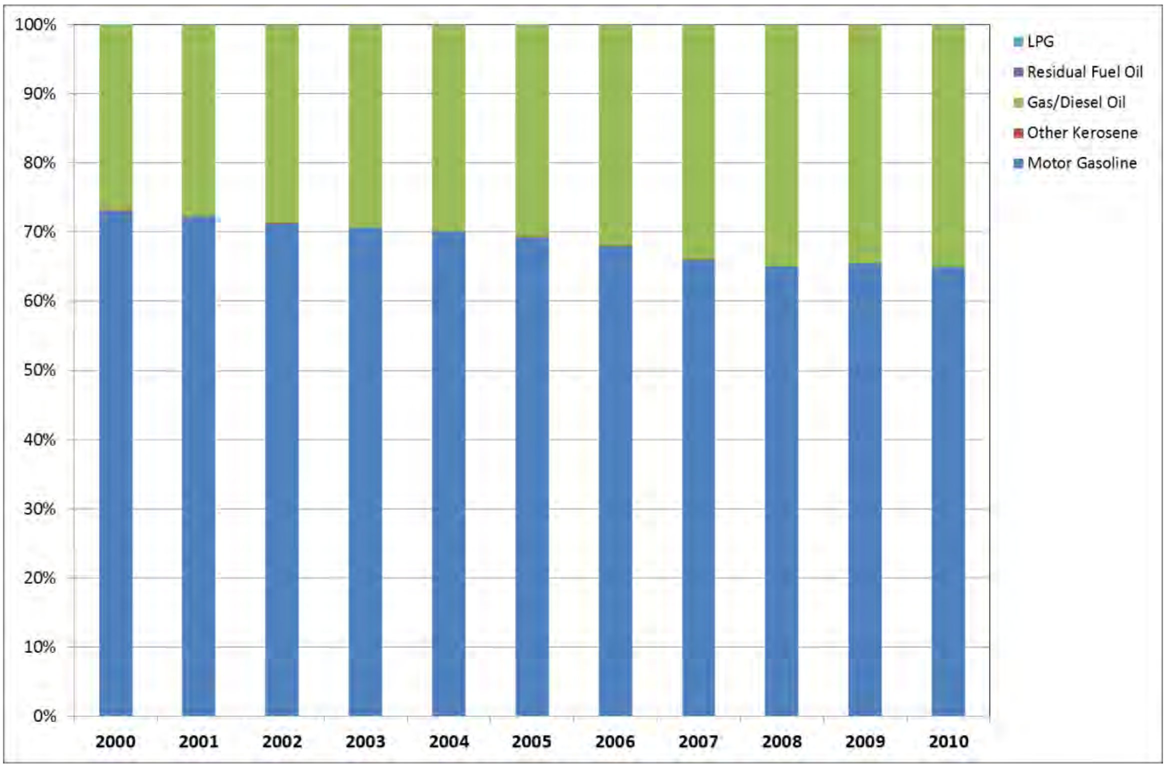

Figure 3.7: Sector 1 Energy: Percentage contribution of the various fuel types to fuel consumption in the Road transport category (1A3b), 2000 – 2010.

RAILWAYS [1A3C]

Railway locomotives are mostly one of three types: diesel, electric or steam. Diesel locomotives generally use engines in combination with a generator to produce the energy required to power the locomotive. Electric locomotives are powered by electricity generated at power stations and other sources. Steam locomotives are generally used for local operations, primarily as tourist attractions and their GHG emissions contributions are very low (DME, 2002). Both freight and passenger railway traffic generate emissions. South Africa's railway sector uses electricity as its main source of energy, with diesel being the only other energy source (DME, 2002).

WATER-BORNE NAVIGATION [1A3D]

According to the 2006 IPCC guidelines, water-borne navigation sources included emissions from the use of fossil fuels in all waterborne transport, from recreational craft to large ocean cargo ships but excluded fishing vessels. Fishing vessels were accounted for under the *Other* sector, in the fishing sub-category. The vessels are driven primarily by large, medium to slow diesel engines and sometimes by steam or gas turbines.

International Water- borne Navigation (International Bunkers) [1A3dı]

International Water-borne Navigation GHG emissions included fuels used by vessels of all flags that were engaged in international water-borne navigation. The international navigation may take place at sea, on inland lakes and waterways and in coastal waters. According to the 2006 IPCC guidelines (p. 3.86) it includes GHG emissions from journeys that depart in one country and arrive in a different country, excluding consumption by fishing vessels. International Water-borne Navigation was not estimated in this inventory due to a lack of data. As a result, fuel consumption for marine bunkers was included in the national totals. That was not consistent with the 2006 IPCC guidelines which required marine bunkers to be reported separately from the national totals. In the future, improved data on marine activities will assist in improving accuracy in estimating both water-borne navigation and marine bunkers.

3.3.5.2 Overview of shares and trends in emissions

It was estimated that for the period 2000 to 2010, the total cumulative GHG emissions from transport activities were 450 627 Gg CO_2 eq. GHG emissions from transport activities have increased by 33.3% from 35 598 Gg CO_2 eq in the year 2000 to 47 443 Gg CO_2 eq in 2010 (Figure 3.8). The CO_2 emissions from all modes contributed the most to the GHG emissions, while the CH_4 and N_2O emission contributions were relatively small (<1.39% in 2010) (Figure 3.9).

Road transport contributed 91.6% towards the total transport GHG emissions in 2010 (43 440 Gg CO_2 eq), while 7.7% was from domestic civil aviation and 0.7% from railways. Emissions in road transport increased because of motor vehicle sales which increased from 4.2% in 2000 to 15.7% in 2010 (Stats SA, 2011). In 2008 vehicles sold amounted to 34 400, which was 16.5% lower than the total units sold in 2007 (Stats SA, 2007), hence the 2.4% decrease in emissions. The decrease in 2008 was linked to the global economic crisis that took place in 2008 and early 2009. Motor vehicle sales decreased by 10.5% in 2009, however in November 2009 the economy of SA recovered from recession by achieving an economic growth of 0.9%, this was accompanied by an increase in GHG emissions by 1.4%.

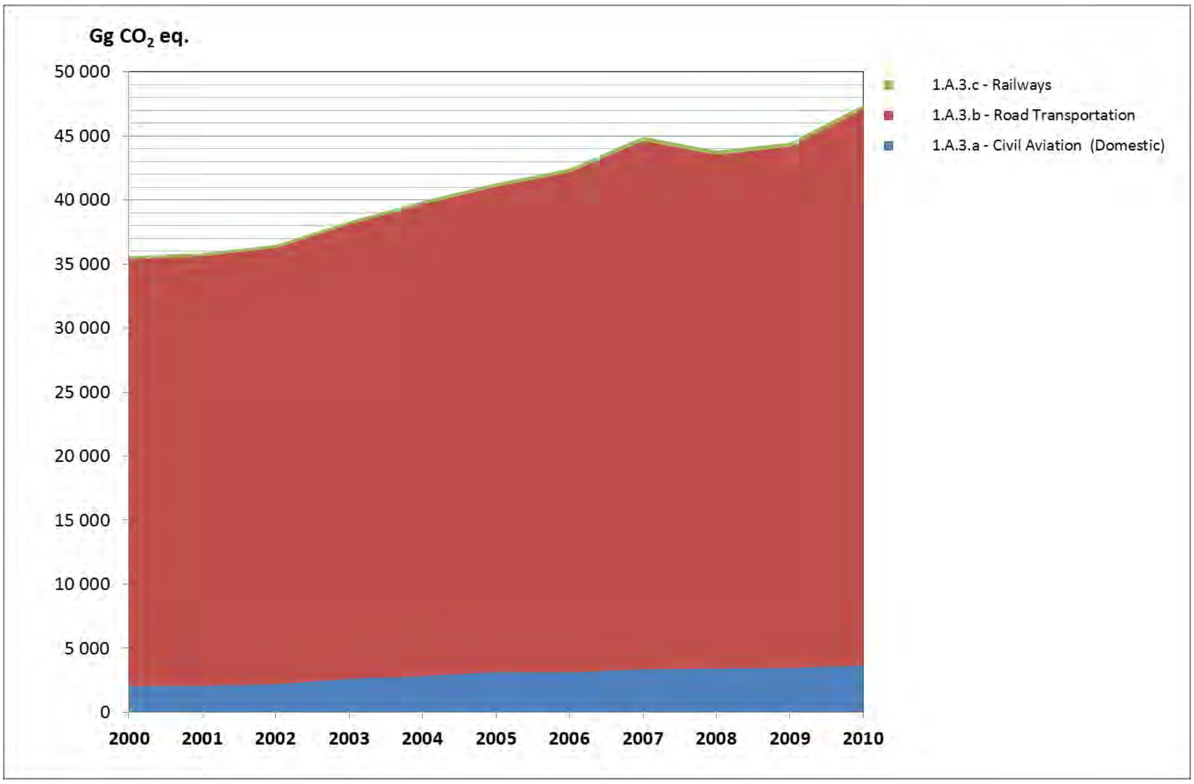

Figure 3.8: Sector 1 Energy: Trend in total GHG emissions from the Transport sector, 2000 – 2010.

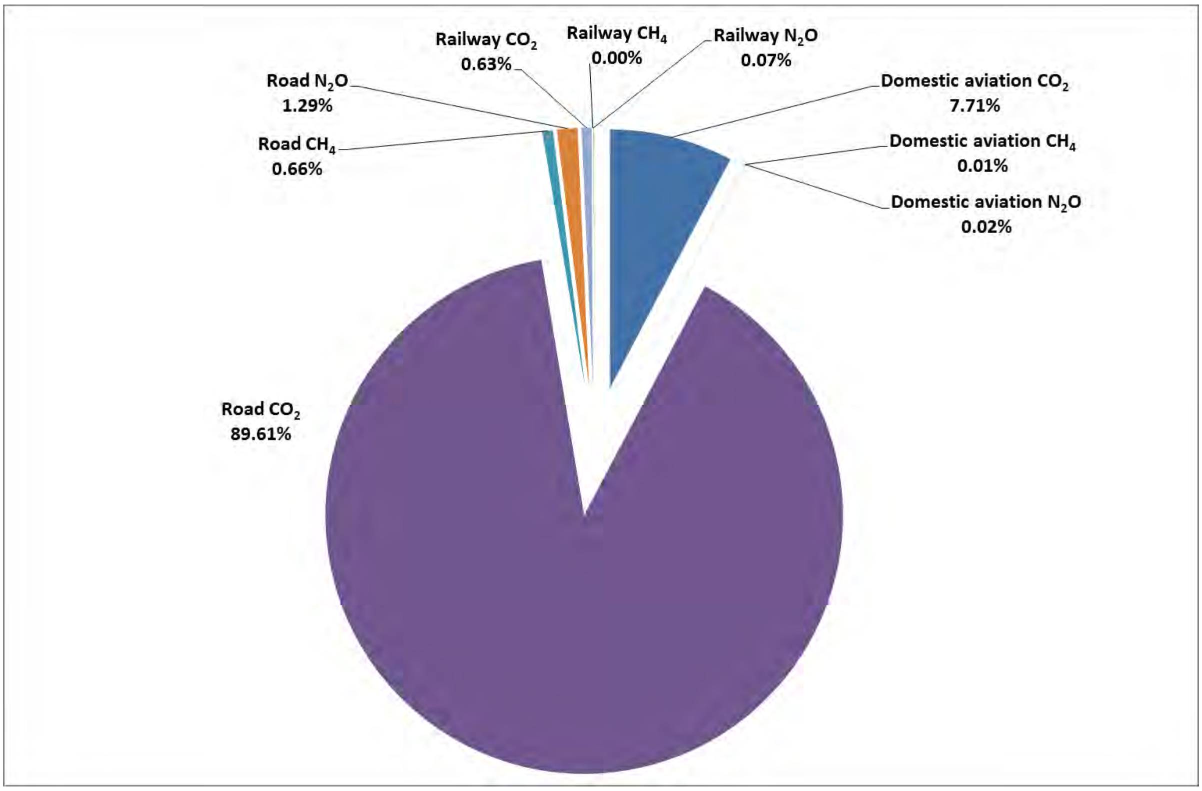

Figure 3.9: Sector 1 Energy: Percentage contribution of CO_2, CH_4 and N_2O from the Transport sector, 2000 – 2010.

TRANSPORT EMISSIONS AND THE ECONOMY

In the transport sector 92% of the GHG emissions were generated from road transport. There was a strong linkage between vehicle population and energy demand. It was estimated that the purchase of motor vehicles increased from 4.81% in 2000 to 10.23% in 2006 (Stats SA, 2007).

Energy fuels from transport activities consisted mainly of liquid fuels. The most dominant fuel being petrol (53.3%), followed by diesel (34%) and then jet fuel (10.9%). The demand for petrol and diesel has remained relatively static over the years. The demand for jet fuel has, however, grown steadily as a result of increased business and tourism activities. In 2001, total liquid-fuel sales grew by 0, 3% to 20 934 million litres (Ml). These figures demonstrate the growth of the South African economy and the importance of energy as a key driver of the country's economy. In the year 2002/03 the price of petroleum products increased enormously as the deterioration in the Rand/Dollar exchange rate, hence the decrease in GHG emissions by 1% compared to the previous year. The GHG emissions from transport activities have been consistently increasing annually, with 35 598 Gg CO_2eq in the year 2000 to 44 936 Gg CO_2eq for the year 2007. The demand for petrol decreased more than 10% in the third quarter of 2008 compared to the same period in 2007, whilst the demand for diesel slowed down more than 3%, as big industrial consumers scaled down operations because of the global economic decline. According to SAPIA (2008) figures, sales of major petroleum products in South Africa amounted to 18, 9 billion litres in the first nine months of 2008.

The primary driver for the transport sector was economic GDP growth. For road passenger travel, GDP growth meant increased commuting needs and personal wealth, often both in terms of number of wealthier people and expendable incomes. This resulted in more money being available for motorcar purchasing and leisure activities, which in turn increased the demand for transport and transport fuel.

In terms of civil aviation there was an in increase in the number of passengers who disembarked from international scheduled flights in past years. In 2008 the total number of passengers decreased by 7.3% (7.8 million) in the 08/09 financial year compared to the 07/08 financial year. However, passenger activity rose by 5% in the 10/11 financial year amounting to 8.2 million passengers (ACSA, 2013).

In railway, passengers carried on commuter rail increased to 646.2 million in the financial year 2008/09 which was a 9% increase from the financial year 2008/09 (Stats SA, 2007). Passenger kilometers travelled by the trains also increased by 9% to 16.9 billion kilometres in 2008/09.

In the year 2004 GHG emissions from the transport sector increased by 4.1% which was a decline compared to the previous year (5.1%). This was mainly because the price of oil was at the narrow range of approximately $22/28/bbl, however in the year 2005 the price of oil escalated significantly.

According to SAPIA, the factors which influenced the escalating prices on crude oil in 2005 were:

- Feared shortages due to limited surplus crude oil production and refining capacity at a time of strongly rising world demand for petroleum products, notably in the USA and China;
- A particular shortage of sweet (low sulphur) crudes due to the lack of refining capacity to process sour (high sulphur) crudes into the requisite product qualities needed in world markets;

- Political tensions in certain crude oil producing countries; and
- The petrol price in South Africa, linked to the price of petrol in United States' (US) dollars and in certain other international petrol markets.

The local prices of petroleum products are affected by the ZAR-USD exchange rates and the dollar price of crude oil. It is important to note that in late 2001 when the ZAR-USD exchange rate moved above twelve ZAR to the USD and the oil price was about $20/bbl, crude oil cost some R240/bbl, and in 2004 when the rand strengthened to six rand to the dollar and the crude oil price was $40/bbl, oil still cost some R240/bbl. That meant, despite some fluctuations, the rand price of crude oil was relatively stable until the dollar price increased above $40/bbl. At a price of $65 and a rand at R6,5 = $1 the cost became R423/bbl, a very significant rise!

In the year 2007, aggregate sales of major petroleum products showed a strong increase of 7.3% in the first quarter, when compared with the first quarter of 2006. The most significant increases were in diesel (13.1%), bitumen (36.3%) and LPG (15%). Petrol sales grew by 4.4% and jet fuel sales by 4.6%. Paraffin sales declined by 13.4%, indicating that the product was being used less frequently for household energy. In the first quarter, the percentage split of petrol sales between unleaded petrol (ULP) and lead replacement petrol (LRP) was 64% and 36% respectively. In 2008 GHG emissions from the transport sector decreased by 2.4%, and that was attributed to the global economic crisis that occurred between 2008 and early 2009. Total sales of major petroleum products showed an increase of 4% in the first quarter of 2008 as compared to the first quarter of 2007. The most significant increases were in diesel (9.5%) and industrial heating fuels (35.6%). Petrol and paraffin sales declined by 0.9% and 3.2% affected by price increases, while jet fuel sales grew by 3.3%. LPG volumes were the same as in 2007 and bitumen volumes increased by 7.6%. In November 2009 the economy of SA recovered from recession.

International Aviation (International Bunkers) [1A3aι]

It was estimated that for the period 2000 to 2010 the total cumulative GHG emissions from international aviation activities were 28 067 Gg CO_2 eq. Table 3.12 provides a summary of GHG emissions for the period 2000 to 2010 from the international aviation. The GHG emissions in the international aviation have decreased by 13.8% over the 10 year period. In the year 2006 there was an increase in GHG emissions of 10.7%, followed by a further 1.8% increase in 2007.

3.3.5.3 Data sources

CIVIL AVIATION [1A3A]

Activity data on fuel consumption was sourced from the South African Petroleum Industry Association's (SAPIA) annual reports (Table 3.13). The 2006 IPCC Guidelines (p. 3.78) requires only domestic aviation to be included in the national totals. Hence, in order to separate International from domestic aviation, the DoE energy balances were used to estimate the ratio of domestic to international consumption. Furthermore, according to the 2006 IPCC guidelines, it is *good practice* to separate military aviation from domestic aviation. However, based on the SAPIA data and national energy balances, it is not possible to estimate the amount of fuels used for military aviation activities. It is not indicated in data sources but military aviation emissions are therefore thought to be accounted for under domestic aviation. In the energy balances civil aviation fuels included gasworks gas, aviation gasoline and jet kerosene.

Table 3.12: Sector 1 Energy: Summary of GHG emissions from International aviation (International bunkers), 2000 – 2010.

	Consumption	CO_2	CH_4	N_2O	Total GHG
	(TJ)	(Gg)		(Gg CO_2 eq)	
2000	41 572	2 972	0.12	0.02	2 973
2001	37 880	2 708	0.11	0.02	2 709
2002	37 580	2 687	0.11	0.02	2 687
2003	36 142	2 584	0.11	0.02	2 584
2004	32 395	2 316	0.10	0.02	2 316
2005	31 704	2 267	0.10	0.02	2 267
2006	35 100	2 510	0.11	0.02	2 510
2007	35 760	2 557	0.11	0.02	2 557
2008	34 657	2 478	0.10	0.02	2 478
2009	33 884	2 423	0.10	0.02	2 423
2010	35 855	2 564	0.11	0.02	2 564

Table 3.13: Sector 1 Energy: Fuel consumption (TJ) in the Transport sector, 2000 – 2010.

	Domestic Aviation		Road Transportation					Railways
	Aviation Gasoline	Jet Kerosene	Motor Gasoline	Other Kerosene	Gas/Diesel Oil	Residual Fuel Oil	LPG	Gas/Diesel Oil
2000	835	27 714	337 766	316	123 904	113	54	2 383
2001	880	28 113	335 947	289	128 540	114	0	2 472
2002	843	29 888	335 784	274	135 336	109	0	2 603
2003	764	35 854	346 571	283	143 895	108	0	2 767
2004	760	38 803	356 889	294	152 129	116	0	2 926
2005	802	43 070	362 751	280	160 774	100	54	3 092
2006	745	42 727	366 455	272	172 523	97	0	3 318
2007	758	46 286	375 519	257	193 306	96	0	3 717
2008	752	46 840	359 632	196	193 405	96	0	3 719
2009	746	47 613	367 559	201	193 405	121	0	3 719
2010	790	50 383	388 942	201	209 678	128	0	4 032

International Aviation (International Bunkers) [1A3aI]

The energy balance by the DME was the major source of data for the amount of fuel consumed (Table 3.14). That did not indicate whether aviation fuel consumption figures included military aviation activities (which might have been excluded for security reasons).

ROAD TRANSPORT [1A3B]

SAPIA annual reports were the main sources of activity data for the transport sector (Table 3.13). The SAPIA report on the Impact of liquid fuels on air pollution was used to disaggregate fuel consumption into the various users (SAPIA, 2008). Where possible, the DoE energy balances where used to verify activity data even though they do not provide sufficient information for proper understanding of fuel consumption.

Table 3.14: Sector 1 Energy: Fuel consumption (TJ) in the international aviation category, 2000 – 2010.

	Jet Kerosene
2000	41 572
2001	37 880
2002	37 580
2003	36 142
2004	32 395
2005	31 704
2006	35 100
2007	35 760
2008	34 657
2009	33 884
2010	35 855

RAILWAYS [1A3C]

Diesel consumption activity data was sourced from the SAPIA annual reports. The SAPIA report on the impact of liquid fuels on air pollution was used to estimate actual diesel consumption for railway transport sector (Table 3.13). An assumption was made that the split of diesel consumption for railway activities was constant for the whole time series (2000-2009) which may not necessarily be accurate. To improve accuracy in the future, data should be collected at the sub-category level where annual variations in the activity data can be sourced.

WATER-BORNE NAVIGATION [1A3D]

Lack of source-specific activity data made it difficult to separately estimate emissions for this sub-category. Heavy Fuel Oil (HFO) consumption as reported in the SAPIA annual reports, which is used for activities in this sub-category, was accounted for under the *Industrial, Commercial and Residential* sub-category in the *Other* sector. As a result, emissions from this sub-category are "implied elsewhere" (IE). Hence, to improve transparency in reporting, and the accuracy in emission estimates in the future activity data needs to be further disaggregated to the sub-category level.

3.3.5.4 Methodology

A Net Calorific Value of 0.0243 TJ $tonne^{-1}$ was used to convert fuel quantities into energy units (DoE, 2009a).

CIVIL AVIATION [1A3A]

The main challenge in this category was splitting the fuel consumption between international and domestic flights. The 2006 IPCC guidelines (p.3.78) proposes that international/domestic splits should be determined on the basis of departure and landing locations for each flight stage and not by nationality of the airline. The energy balances have noted that splits for international/national were made, but the methodology for this was not mentioned. Furthermore the energy balances does not give details on whether military aviation activities were included as discussed above, this may be due to confidentiality issues. The tier 1 methodology was used for the calculations of aviation emissions as operational data was not available. The Tier 1 approach makes use of consumption of fuel and fuel emission factors.

ROAD TRANSPORT [1A3B]

The 2006 IPCC guidelines suggest that the fuel consumption approach is appropriate for CO_2 emissions as it depends entirely on the carbon content of fuel combusted, whereas the kilometer approach (distance travelled by vehicle type) is appropriate for CH_4 and N_2O. Hence, in order to use higher-tier for calculating road transportation emissions, a better understanding of fuel sold and vehicle kilometers travelled is required for the entire South Africa vehicle fleet. This data was not available for the entire 10 year period therefore a tier 1 approach based on fuel consumption and 2006 IPCC emission factors was used to calculate the emissions.

RAILWAYS [1A3C]

The tier 1 approach was used for the calculation of railway emissions. Default emissions factors from the 2006 IPCC guideline were used. The use of higher tier approach depends on the availability of fuel consumption data by locomotive type and/or country specific emission factors.

EMISSION FACTORS

IPCC 2006 default emission factors were used in the estimation of GHG emissions from the transport sector (Table 3.15). The GHG emission factors are applicable to all activities within this sector since similar fuels are combusted.

Table 3.15: Sector 1 Energy: Emission factors used for the Transport sector emission calculations (Source: 2006 IPCC Guidelines).

Type of Fuel	Emission factor (kg TJ^{-1})		
	CO_2	CH_4	N_20
Motor Gasoline	69 300	33	3.2
Other Kerosene	71 900	3	0.6
Gas/ Diesel Oil	74 100	3.9	3.9
Gas/ Diesel Oil (Railways)	74 100	4.15	28.6
Residual Fuel Oil	77 400	3	0.6
Aviation Gasoline	70 000	3	0.6
Jet Kerosene	71 500	3	0.6

3.3.5.5 *Uncertainty and time-series consistency*

CIVIL AVIATION [1A3A]

According to the 2006 IPCC guidelines, the uncertainty on emission factors may be significant. For non-CO_2 emission factors the uncertainty ranges between -57% to +100% and for CO_2 emission factors it ranges at approximately 5%, as they are dependent on the carbon content of the fuel and the fraction oxidized (IPCC,2006, p.3.65).

ROAD TRANSPORT [1A3B]

According to the 2006 IPCC guidelines, the uncertainties in emission factors for CH_4 and N_2O were relatively high and were likely to be a factor of 2-3%, and they depended on the following: fleet age distribution; uncertainties in maintenance pattern of vehicle stock; uncertainties related to combustion conditions and driving patterns and application rates of post emission control technologies (e.g. three-way catalytic convertors) just to mention a few.

Activity data were another primary source of uncertainty in the emission estimate. According to the IPCC guidelines possible sources of uncertainty, are typically +/-5% due to the following: uncertainties in national energy sources of data; unrecorded cross border transfers; misclassification of fuels; misclassification of vehicle stocks; lack of completeness and uncertainty in conversion factors from one set of activity data to another.

RAILWAYS [1A3C]

The GHG emissions from railways or locomotives are typically smaller than those from road transportation because less fuel is consumed. Also because operations often occur on electrified lines, in which case the emissions associated with railway energy use will be reported under power generation and will depend on the characteristics of that sector. According to the IPCC guidelines, possible sources of uncertainty are typically +/-5% due to uncertainties in national energy sources of data; unrecorded cross border transfers; misclassification of fuels; misclassification of vehicle stocks; lack of completeness and uncertainty in conversion factors from one set of activity data to another.

WATER-BORNE NAVIGATION [1A3D]

According to the IPCC guidelines CO_2 emission factors for fuel are generally well determined, because of their dependence on the carbon content fuel. Therefore the uncertainties around water-borne navigation emission estimates are related to the difficulty of distinguishing between domestic and international fuel consumption. With complete survey data, the uncertainty may be as low +/-5%, while for estimates or incomplete surveys the uncertainties maybe be high as -50%.

3.3.5.6 Source-specific QA/QC and verification

No source-specific QA/QC and verification steps were taken for this source-category.

3.3.5.7 Source-specific recalculations

The 2000 GHG inventory report was published in the year 2009, but for the purpose of this report, more accurate data was collected for 2000 for the Transport sector. That resulted in the recalculation of GHG emissions for that year so as to reduce the uncertainty of the emission estimates.

3.3.5.8 Source-specific planned improvements and recommendations

CIVIL AVIATION [1A3A]

Improvement of emission estimation for this category requires the understanding of aviation parameters, including the number of landing/take-offs (LTOs), fuel use and understanding the approaches used to distinguish between domestic/international flights. This will ensure the use of higher tier levels for the estimation of emissions. To improve transparency of reporting, military aviation should be removed from domestic aviation and reported separately (IPCC, 2006, p.3.78).

ROAD TRANSPORT [1A3B]

To improve road transportation emission estimates, calculations should include the ability to compare emission estimates using fuel consumption and kilometer (based on travel data). This requires more knowledge on South Africa's fleet profile, and also the understanding of how much fuel is consumed in the road transportation sector as a whole. Furthermore the development of local emission factors by fuel and vehicle-type will enhance the accuracy of the emission estimation. A recent report (Otter, 2009) provided detailed data at the Tier 2 level for the year 2007 for the Road transport category. It is recommended that this data be reviewed and the methodology applied to all years to update the Transport sector emissions in the next inventory.

RAILWAYS [1A3C]

National level fuel consumption data are needed for estimating CO_2 emissions for tier 1 and tier 2 approaches. In order to estimate CH_4 and N_2O emissions using tier 2 approach, locomotives category level data are needed. These approaches require that railway, locomotive companies or relevant transport authorities provide fuel consumption data. The use of representative locally estimated data is likely to improve accuracy although uncertainties will remain large.

WATER-BORNE NAVIGATION [1A3D]

The provision of data by water-borne navigation is vital for the accurate estimation of emissions from this category. As mentioned above, complete and accurate data which will enable the consumption data to be split into domestic and international consumption, as well as the separate reporting of military consumption, would provide much improved emission estimates.

3.3.6 Other sectors [1A4]

3.3.6.1 Source category description

COMMERCIAL/ INSTITUTIONAL [1A4A]

This source category included commercial/institutional buildings, as well as government, information technology, retail, tourism and services. There are great opportunities for improved energy efficiency in buildings which contain the activities of this category. This category consumes 14.8% of South Africa's total final energy demand (DoE, 2008). Fuels included were residual fuel oil, other kerosene, gas/diesel oil, sub-bituminous coal, gas work gas and natural gas (Figure 3.10). Liquid fuels contributed the largest source of emissions in this sector (75.5% in 2010) followed by the consumption of solid fuels (24.3% in 2010).

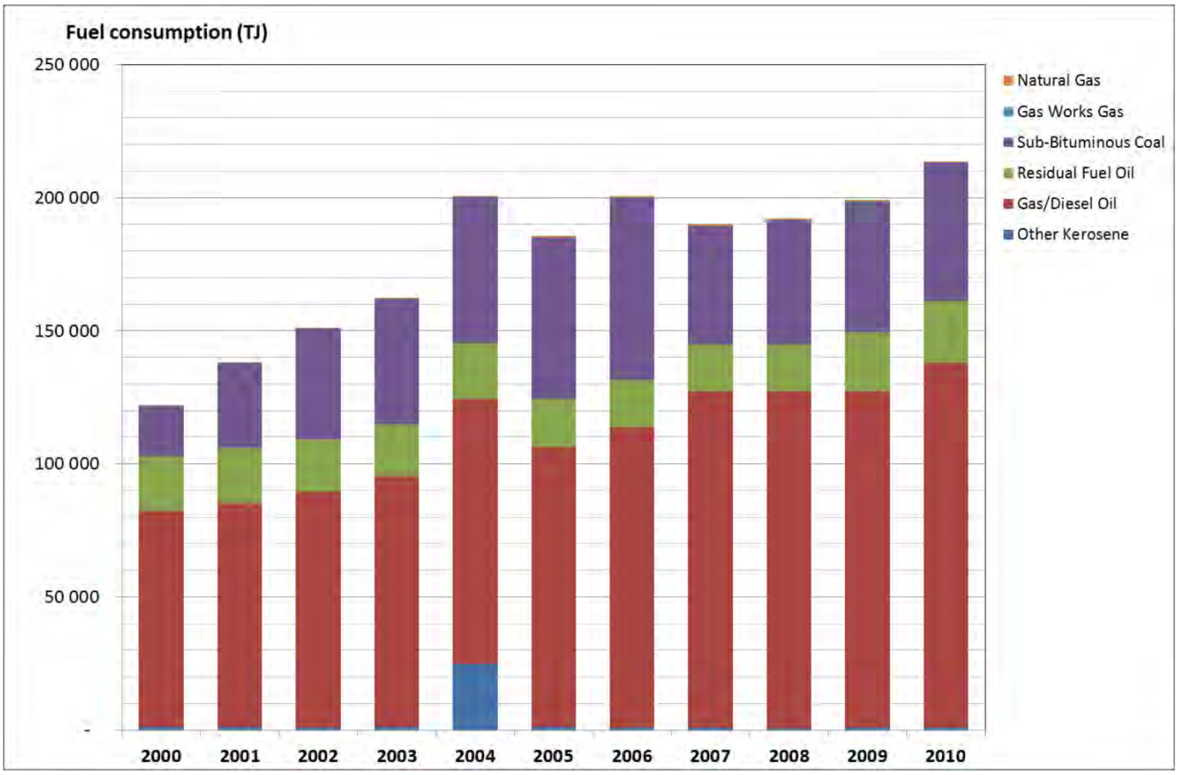

Figure 3.10: Sector 1 Energy: Fuel consumption in the Commercial/Institutional category, 2000 – 2010.

RESIDENTIAL [1A4B]

The residential sector included fuel combustion in households. Fuels consumed in this category were other kerosene, residual fuel oil, LPG, sub-bituminous coal, wood/wood waste, other primary solid biomass and charcoal. In 2000 biomass fuel sources dominated (79.8%), however from 2006 to 2010 there were no data reported for Other primary solid biomass. Therefore between 2006 and 2010 solid fuels contributed the most (56.7% in 2010) (Figure 3.11).

AGRICULTURE/ FORESTRY/ FISHING/ FISH FARMS [1A4C]

The GHG emissions in this category included fuel combustion from agriculture (including large modern farms and small traditional subsistence farms), forestry, fishing and fish farms. Fuels included in this category were motor gasoline, other kerosene, gas/diesel oil, residual fuel oil, LPG and sub-bituminous coal. Liquid fuels dominate in this category (Figure 3.12). According to the energy balance data (DME, 2009) sub-bituminous coal was only used in 2000.

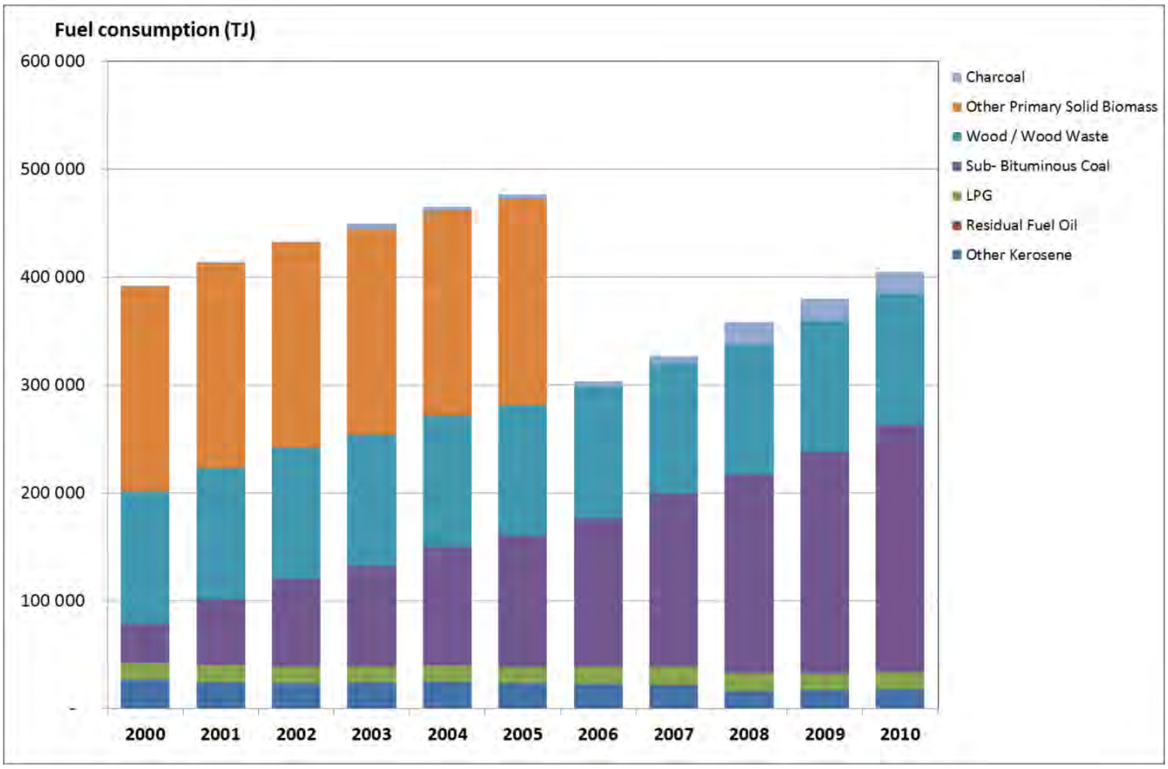

Figure 3.11: Sector 1 Energy: Trend in fuel consumption in the Residential category, 2000 – 2010.

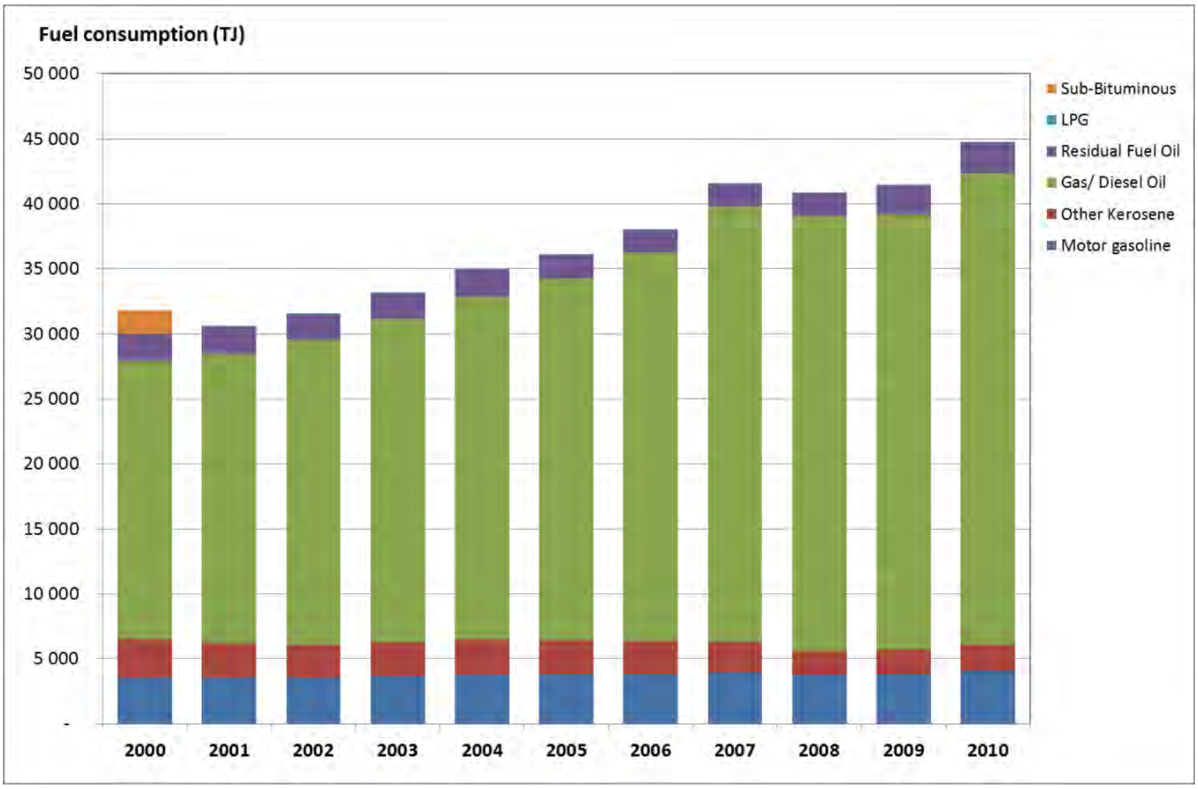

Figure 3.12: Sector 1 Energy: Trend in fuel consumption in the Agriculture/Forestry/Fishing category, 2000 – 2010.

3.3.6.2 Overview of shares and trends in emissions

COMMERCIAL/ INSTITUTIONAL [1A4A]

The estimation of total cumulative GHG emissions in the commercial/institution category for the period 2000 to 2010 was 157 584 Gg CO_2 eq. Emissions increased by 79.3% over the 10 year period from 9 554 Gg CO_2 eq in 2000 to 17 129 Gg CO_2 eq in 2010 (Figure 3.13). Emissions were dominated by CO_2 emissions, with a small percentage of CH_4 and N_2O.

In 2001 GHG emissions in this category increased by 15% compared with the previous year, and continued to increase annually from 2002 to 2004. That might have been as a result of economic growth and development during that period (from a 15% increase in 2001 to 22.6% increase in 2004). The increase in 2004 was linked to the increased used of other kerosene (Figure 3.10). There was a slight decline in emisisons in 2007 which was due to a reduction in sub-bituminous coal consumption that year. That was possibly linked to boiler-fuel switching from coal to gas in small-to-medium enterprises. In the year 2007 GHG emissions decreased by 8.1%, and this was mainly because of the electricity crisis in that year, which increased the consumption of coal for heating purposes. As the country recovered from the recession the GHG emissions increased by 3.8% in 2009.

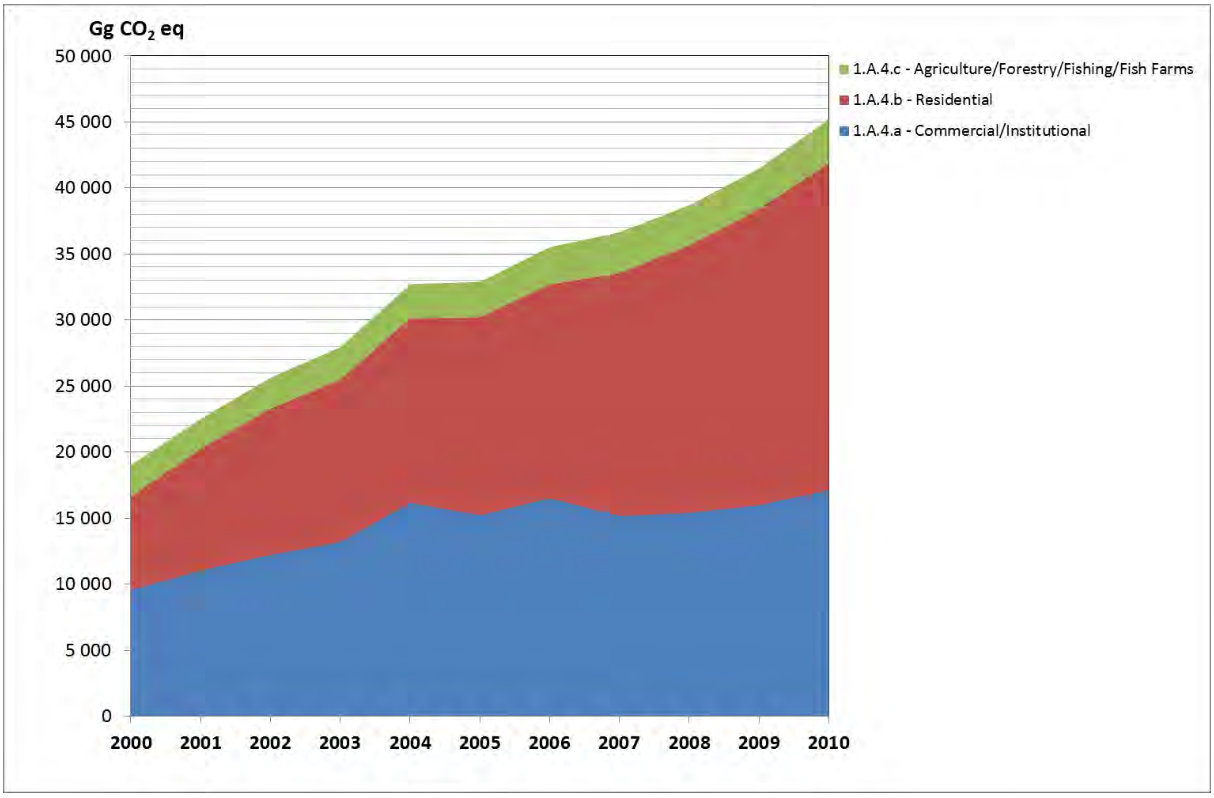

Figure 3.13: Sector 1 Energy: Trend in total GHG emissions from Other sectors, 2000 – 2010.

RESIDENTIAL [1A4B]

The estimation of total GHG emissions in the residential category for the period 2000 to 2010 was 170 750 Gg CO_2eq. Emissions in the residential sector have increased more than 3 fold from 7 093 Gg CO_2eq in 2000 to 24 782 Gg CO_2eq in 2010 (Figure 3.13). The increase was attributed mainly to population growth and an increase in economic growth (70.44% in 2000 to 75% in 2009). The GHG emissions in this category increased annually.

The South African residential category consumes a total of 20% of the total energy supply; this included gas, electricity, candles, wood, dung, coal, LPG, paraffin, gas and other vegetable matter. In 2006, 72.8% of energy consumed by South African households was in the form of electricity, 29.1% in the form of coal, and 7.4% in the form of petroleum products (such as LPG and paraffin) (DoE, 2009b). By the year 2009, 75% of households (9 245 357 households) in South Africa were electrified (DoE, 2009b). It has been recorded that more than 10 million electrified households in South Africa were fitted with eight incandescent lights per household. In 2008 Eskom rolled out Compact Fluorescent Lamps (CFLs), which resulted in a saving of 800 MW of electricity. By September 2009, more than 30 million lamps had been replaced. Energy consumed by households represented 17% of the country's net use. Most of household energy was obtained from fuel wood (50% of the net household energy), primarily in the rural areas, with the remainder being obtained from coal (18%), illuminating paraffin (7%) and a small amount from LPG. An estimated number of households with access to electricity increased from 4.5 million (50.9%) in 1994 to 9.1 million (73%) in 2008. Coal is used by approximately 950 000 households countrywide.

The overall emissions from 2000 to 2010 in this category have increased by 249% which is attributed to growing population and other relative changes such as an increased economic growth and development. The GHG emissions in this category increased annually, with the lowest increase occurring in the years 2005 and 2006. This could have been due to an increase of more than 10% in the food price. The price of basic foodstuffs such as maize, wheat, soya beans and rice increased as a result of changing climatic conditions and rising demand. In 2007 GHG emissions in the residential category increased by 13.6% compared to the previous year.

AGRICULTURE/ FORESTRY/ FISHING/ FISH FARMS [1A4C]

Primary agriculture contributed approximately 3.2% to the GDP of South Africa and almost 9% of formal employment. The majority of energy for agriculture was sourced from diesel and vegetable wastes (DoE, 2010). In 2006 approximately 69% of energy for use in agriculture was sourced from petroleum products, 29.9% from electricity and 1.1% from coal (DoE, 2010). The total estimation of GHG emissions in the agriculture/ forestry/ fishing/ fish farms category for the period 2000 to 2010 was 29 940 Gg CO_2eq. The emissions increased from 2 387 Gg CO_2eq in 2000 to 3 308 Gg CO_2 eq in 2010, with annual increases of between 1.5% and 9.3% (Figure 3.13). That followed a GDP growth of 1.1% during the same period. There was a decline in emissions between 2000 and 2001, and the contribution of this category to the GDP also decreased by 3.3% in the same period. In 2008 the GHG emissions decreased by 1.7% and that was accompanied by a massive GDP contribution of 16.1% in the same period. However in 2009 the contribution to the GDP decreased to 0.3% and the

GHG emissions increased by a small quantity of 1.5%. That was mainly because of the global economic crisis that affected South Africa in 2008/09.

3.3.6.3 Data sources

COMMERCIAL/ INSTITUTIONAL [1A4A]

Data on fuel consumption in the commercial/institutional buildings was sourced from the Chamber of Mines annual reports, DoE energy balances, DoE energy digest reports (solid fuels and natural gas) and SAPIA (liquid fuels). The energy balances were used to split the consumption of other bituminous coal between the residential and commercial sector. The split between the commercial/institutional and residential sector was 33% and 67% respectively. A Net Calorific Value of 0.0243 TJ/tonne was used to convert fuel quantities into energy units (DoE, 2009a).

RESIDENTIAL [1A4B]

Data on fuel consumption in the residential sector was obtained from the Chamber of Mines, DoE energy balances, DoE energy digest reports and SAPIA. The energy balances were used to split the consumption of other bituminous coal between the residential and commercial sector. The split for the commercial/institutional and residential sector was 33% and 67% respectively. A Net Calorific Value of 0.0243 TJ $tonne^{-1}$ was used to convert fuel quantities into energy units (DoE, 2009a).

AGRICULTURE/ FORESTRY/ FISHING/ FISH FARMS [1A4C]

Data on fuel consumption in the agriculture, forestry, fishing and fish farms was obtained from the energy balances that are compiled by the DoE (mostly solid fuels) and SAPIA for liquid fuels. The trends for the consumption of fuels in this category has been increasing and decreasing through the period of 2000 to 2010. According to the energy balances, solid fuels in the form of sub-bituminous coal were only consumed in 2000.

3.3.6.4 Methodology

The tier 1 approach was used for estimating emissions from all the *Other* sectors. To estimate the total GHG emissions in this sector, the amount of fuel combusted was multiplied with the default emission factors from the 2006 IPCC guidelines (Table 3.16).

Table 3.16: Sector 1 Energy: Emission factors used for all Other sectors (Source: 2006 IPCC Guidelines).

Type of Fuel	Emission factor (kg TJ^{-1})		
	CO_2	CH_4	N_20
Motor gasoline	69 300	3	0.6
Other Kerosene	71 900	3	0.6
Gas/ Diesel Oil	74 100	3	0.6
Residual Fuel Oil	77 400	3	0.6
LPG	63 100	1	0.1
Sub-bituminous Coal	96 100	1	3
Gas Work Gas	44 400	1	0.1
Natural Gas	56 100	1	0.1
Wood/wood waste	112 000	30	4
Other primary solid biomass	100 000	30	4
Charcoal	112 000	30	4

3.3.6.5 Uncertainty and time-series consistency

The uncertainties in CO_2 emissions are relatively low in fossil fuel combustion. These emission factors are determined by the carbon content of the fuel. Emission factors for CH_4 and more specifically N_2O are highly uncertain. The uncertainty on the CH_4 emission factor is 50 – 150%, while for N_2O it is an order of magnitude. This high uncertainty is due to the lack of relevant and accurate measurements and/or insufficient understanding of the emission generating process.

3.3.6.6 Source-specific QA/QC and verification

No source-specific QA/QC and verification steps were taken for this source-category

3.3.6.7 Source-specific recalculations

The 2000 GHG inventory report was published in the year 2009, it reported on GHG emissions for the base year 2000. For the purpose of this report, the 2000 GHG emissions were recalculated after including more robust activity data, resulting in improved emission estimates for 2000.

3.3.6.8 Source-specific planned improvements and recommendations

COMMERCIAL/ INSTITUTIONAL [1A4A]

The tier 1 approach is used for the simplest calculation methods or methods that require the least data; therefore this approach provides the least accurate estimates of emissions. The tier 2 and tier 3 approaches require more detailed data and resources to produce accurate estimates of emissions. The commercial/institutional sector should be willing to cooperate in the provision of data for the purposes of inventories. A regulatory framework should be established and implemented to ensure that sectors provide data necessary for the compilation of the inventory.

RESIDENTIAL [1A4B]

Investigations and studies of the residential sector in South Africa are necessary for the accurate estimation of emissions. Due to the many households, uniform reporting would be possible by the collection of data by local government.

AGRICULTURE/ FORESTRY/ FISHING/ FISH FARMS [1A4C]

A regulatory framework should be established and implemented to ensure that sectors provide data necessary for the compilation of the inventory.

3.3.7 Non-specified [1A5]

3.3.7.1 *Source category description*

This category refers to all remaining emissions from fuel combustion that was not specified elsewhere in this document. It should include emissions from fuel delivered to the military in the country and delivered to the military of other countries that are not engaged in multilateral operations.

STATIONARY [1A5A]

This section included emissions from fuel combustion in stationary sources that are not specified elsewhere. The only fuel which was reported under this category was the consumption of motor gasoline.

3.3.7.2 *Overview of shares and trends in emissions*

The non-specified stationary category showed a steady increase of 15.1% in total GHG emissions between 2000 and 2010. Emissions were estimated at 989 Gg CO_2 eq in 2000 and 1 139 Gg CO_2 eq in 2010 (Table 3.17). There was a small decline between 2000 and 2002 and 4.2% decline in 2008.

Table 3.17: Sector 1 Energy: Trend in consumption and GHG emissions from the Non-Specified sector, 2000 – 2010.

	Consumption (TJ)	CO_2 (Gg)	CH_4	N_2O (Gg CO_2 eq)	Total GHG
2000	14 222	986	0.98	2.53	989
2001	14 145	980	0.98	2.51	984
2002	14 138	980	0.98	2.51	983
2003	14 592	1 011	1.01	2.59	1 015
2004	15 027	1 041	1.04	2.67	1 045
2005	15 274	1 058	1.05	2.71	1 062
2006	15 430	1 069	1.06	2.74	1 073
2007	15 811	1 096	1.09	2.81	1 100
2008	15 142	1 049	1.04	2.69	1 053
2009	15 476	1 072	1.07	2.75	1 076
2010	16 376	1 135	1.13	2.91	1 139

3.3.7.3 Data sources

Data on fuel consumption in the non- specified category was sourced from the energy digest reports (solid fuels and natural gas) and SAPIA (liquid fuels). The NCVs applied for the conversion of fuel quantities into energy units were sourced from the digest of energy statistics report (Energy Digest, 2009).

3.3.7.4 Methodology

The tier 1 approach was used for the calculation of emissions in the non-specified sector. To estimate the total GHG emissions for this sector, the activity data (fuel consumed) was multiplied by the default emission factor from the 2006 IPCC guidelines.

EMISSION FACTORS

IPCC default emission factors from the 2006 IPCC guidelines were used in the estimation of GHG emissions from non-specified sector (Table 3.18).

Table 3.18: Sector 1 Energy: Emission factors for calculating emissions from the Non-Specified sector (Source: 2006 IPCC Guidelines).

Type of Fuel	Emission factor (kg TJ^{-1})		
	CO_2	CH_4	N_20
Motor gasoline	69 300	3	0.6

3.3.7.5 Uncertainty and time-series consistency

The uncertainties in CO_2 emissions are relatively low in fossil fuel combustion. These emission factors are determined by the carbon content of the fuel. Emission factors for CH_4 and more specifically N_2O are highly uncertain. This high uncertainty is due to the lack of relevant and accurate measurements and/or insufficient understanding of the emission generating process.

3.3.7.6 Source-specific QA/QC and verification

No source-specific QA/QC and verification steps were taken for this source-category

3.3.7.7 Source-specific recalculations

The 2000 GHG inventory report was published in the year 2009 and it reported GHG emissions for the base year 2000. The results for the published 2000 GHG inventory had to be recalculated as a result of availability of more robust activity data.

3.3.7.8 Source-specific planned improvements and recommendations

The tier 1 approach is used for the simplest calculation methods or methods that require the least data; therefore this approach provides the least accurate estimates of emissions. The tier 2 and tier 3 approaches require more detailed data and resources to produce accurate estimates of emissions. Sourcing of activity data for pipeline transport, fuel consumption associated with ground-activities at airports and harbours is planned for the next inventory compilation cycle.

3.4 Fugitive emissions from fuels [1B]

Fugitive emissions refer to the intentional and unintentional release of greenhouse gases that occur during the extraction, processing and delivery of fossil fuels to the point of final use. Methane is the most important emission sourced from solid fuels fugitive emissions.

In coal mining activities, fugitive emissions considered were from the following sources:

- Coal mining, includes both surface and underground mining
- Processing of coal
- Storage of coal and wastes
- Processing of solid fuels (mostly coal)

3.4.1 Solid Fuels [1B1]

3.4.1.1 Source category description

1B1A COAL MINING AND HANDLING [1B1A]

The geological processes of coal formation produce CH_4 and CO_2. CH_4 is the major GHG emitted from coal mining and handling. In underground mines, ventilation of the mines cause significant amounts of methane to be pumped into the atmosphere, such ventilation is the main source of CH_4 emissions in hard coal mining activities. However, methane releases from surface coal mining operation are low. In addition methane can continue to be emitted from abandoned coal mines after mining has ceased.

According to the 2006 IPCC guideline, the major sources for the emission of GHG for both surface and underground coal mines are:

- *Mining emissions:* These emissions are sourced from release of gas stored during the breakage of coal and the surrounding strata, during mining operations
- *Post mining emissions:* Post mining emissions refer to emissions during the handling, processing and transportation of coal. Therefore coal will continue to emit gas even after it has been mined, but much slower than during coal breakage stage.
- *Low temperature oxidation:* The emissions are released when coal is exposed to oxygen in air; the coal oxidizes to slowly produce CO_2.
- *Uncontrolled combustion:* Uncontrolled combustion is when heat produced by low temperature oxidation is trapped. This type of combustion is characterized by rapid reactions, sometimes visible flames and rapid CO_2 formation, and may be anthropogenic or naturally.

3.4.1.2 Overview of shares and trends in emissions

1B1A COAL MINING AND HANDLING [1B1A]

In the year 2000 the total coal output was equivalent to 215.7 Mt and the fugitive emissions in that same period were 2.00 Mt CO_2eq. In the year 2004, South African mines produced 242.82 Mt of coal, 178.37 Mt were consumed locally and the fugitive emissions were equivalent to 2.14 Mt CO_2eq. In 2005 South African mines produced 245 million tons of coal, and 174 million tons was consumed locally. In 2006 246 million tons were produced and the fugitive emissions accounted for 2.16 Mt CO_2eq during the same year. At a value of R14,69 billion an amount of 247.7 million tons of coal and 2.21 Mt CO_2eq of fugitive emissions were produced in 2007.

Total GHG fugitive emissions from coal mining increased from 2 002 Gg CO_2eq in 2000 to 2 266 Gg CO_2eq in 2010 (Table 3.19). This increase was largely attributed to the increased demand for coal, particularly for electricity generation. Since opencast mining of coal dominated overall coal production, CH_4 emissions have remained relatively stable over the 2000 to 2010 time series. Country-specific emission factors have confirmed that South African coal seams have little trapped CH_4 in situ.

Table 3.19: Sector 1 Energy: Fugitive emissions from coal mining for the period 2000 to 2010.

	CO_2	CH_4	Total GHG
	(Gg)	($Gg\ CO_2$ eq)	
2000	24	1 979	2 002
2001	23	1 966	1 990
2002	23	1 938	1 961
2003	25	2 093	2 118
2004	25	2 141	2 167
2005	26	2 156	2 181
2006	26	2 154	2 180
2007	26	2 179	2 205
2008	26	2 219	2 245
2009	26	2 204	2 230
2010	27	2 239	2 266

3.4.1.3 Data sources

1B1A COAL MINING AND HANDLING [1B1A]

Data on coal production (Table 3.20) was obtained from the South Africa's Mineral Industry (SAMI), a report compiled by the Department of Mineral Resources (SAMI, 2009) and Coaltech.

Table 3.20: Sector 1 Energy: Coal mining activity data for the period 2000 to 2010.

Period	Opencast	Underground
	(tonnes)	
2000	152 430 357	135 174 090
2001	151 473 376	134 325 446
2002	149 287 553	132 387 075
2003	161 217 666	142 966 609
2004	164 944 899	146 271 891
2005	166 040 627	147 243 575
2006	165 935 025	147 149 928
2007	167 855 716	148 853 182
2008	170 937 442	151 586 034
2009	169 791 125	150 569 488
2010	172 502 123	152 973 581

3.4.1.4 Methodology

1B1A COAL MINING AND HANDLING [1B1A]

The tier 2 approach was used for the calculation of fugitive emissions from coal mining and handling. Fugitive emission estimates were based on coal production data. Coal waste dumps were also considered as another emission source. The methodology required coal production statistics by mining-type (above-ground and below-ground) and this split (53% surface mining and 47% underground mining) was based on the SAMI report for 2008. It was assumed that the split was constant for the entire time series.

Emission Factors

Country specific emission factors were sourced from the study done by the local coal research institute (DME, 2002). This study has showed that emission factors for the South African coal mining industry are significantly lower than the IPCC default emission factors (Table 3.21). The 2006 IPCC guidelines do not provide CO_2 emission factors related to low temperature oxidation of coal, however, South Africa has developed country specific CO_2 emission factors for this and has therefore estimated emissions related to this activity.

Table 3.21: Sector 1 Energy: Comparison of country-specific and IPCC 2006 default emission factors for coal mining.

Mining method	**Activity**	**GHG**	**Emission factor (m^3 $tonne^{-1}$)**	
			South Africa specific	**2006 IPCC default**
Underground Mining	Coal Mining	CH_4	0.77	18
	Post-mining (handling and transport)		0.18	2.5
Surface Mining	Coal mining		0	1.2
	Post-mining (storage and transport)		0	0.1
Underground Mining	Coal mining	CO_2	0.077	NA
	Post-mining (storage and transport)		0.018	NA
Surface Mining	Coal mining		0	NA
	Post-mining (storage and transport)		0	NA

3.4.1.5 Uncertainty and time-series consistency

1B1A COAL MINING AND HANDLING [1B1A]

The major source of uncertainty in this category was activity data on coal production statistics. According to the 2006 IPCC guidelines, country-specific tonnages are likely to have an uncertainty in the 1-2% range, but if raw coal data are not available, then the uncertainty will increase to about ±5 %, when converting from saleable coal production data. The data are also influenced by moisture content, which is usually present at levels between 5-10 %, and may not be determined with great accuracy

3.4.1.6 Source-specific QA/QC and verification

1B1A COAL MINING AND HANDLING [1B1A]

An inventory compilation manual documenting sources of data, data preparation and sources of emission factors was used to compile emission estimates for this source category. Emission estimates were also verified with emission estimates produced by the coal mining industry.

3.4.1.7 Source-specific recalculations

1B1A COAL MINING AND HANDLING [1B1A]

Emissions were recalculated for the year 2000 using country-specific EF's. The recalculation performed resulted in the reduction of emissions from 40 Mt CO_2eq to 2 Mt CO_2eq, resulting in a 95% reduction in the emission estimate.

3.4.1.8 Source-specific planned improvements and recommendations

1B1A COAL MINING AND HANDLING [1B1A]

More attention needs to be placed on the collection of fugitive emissions from abandoned mines and spontaneous combustion of underground coal seams.

3.4.2 Oil and Natural gas [1B2]

3.4.2.1 Source category description

The sources of fugitive emission from oil and natural gas included but were not limited to equipment leaks, evaporation and flashing losses, venting, flaring, incineration and accidental losses (e.g. tank, seal, well blow-outs and spills) as well as transformation of natural gas into petroleum products.

3.4.2.2 Overview of shares and trends in emissions

The total estimation of cumulative GHG emissions from venting was equivalent to 3 828 Gg CO_2 for the period 2000 to 2010. Emissions increased from 325 Gg CO_2eq in 2000 to 619 Gg CO_2eq in 2010 (Table 3.22).

Table 3.22: Sector 1 Energy: Total GHG emissions from venting and flaring for the period 2000 – 2010.

	Gg CO_2eq
2000	325
2001	250
2002	196
2003	1065
2004	254
2005	266
2006	291
2007	325
2008	228
2009	237
2010	619

3.4.2.3 Data sources

This was the first time that this sub-category had been accounted for in the national greenhouse gas inventory. Data on oil and natural gas emissions was obtained directly from refineries and to a lesser extent, DoE Digest reports.

3.4.2.4 Methodology

Fugitive emissions are a direct source of greenhouse gases due to the release of CH_4 and formation CO_2 (CO_2 produced in produced oil and gas when it leaves the reservoir). Use of facility level production data and facility level gas composition and vent flow rates has facilitated the use of tier 3 methodology. Hence, CO_2 emission from venting and flaring has been estimated using real continuous monitoring results and therefore no emission factors were used in this case.

3.4.2.5 Uncertainty and time-series consistency

According to the 2006 IPCC guidelines, gas compositions are usually accurate to within ±5 % on individual components. Flow rates typically have errors of ±3% or less for sales volumes and ±15% or more for other volumes. Given that the activity data used is sourced at facility level, the uncertainty is expected to be less than 3%.

3.4.2.6 Source-specific QA/QC and verification

No source-specific QA/QC and verification steps were taken for this source-category

3.4.2.7 Source-specific recalculations

This is the first time that this category has been included so no recalculations were necessary.

3.4.2.8 Source-specific planned improvements and recommendations

To improve completeness in accounting of emissions from this sub-sector, future activity data collection activities need to focus on upstream natural gas production and downstream transportation and distribution of gaseous products.

3.4.3 Other Emissions from Energy Production [1B3]

3.4.3.1 Source categories description

According to the 2006 IPCC guideline (p.4.35) *Other emissions from energy production* refers to emissions from geothermal energy production and other energy production not included in 1.B.1 and/or 1.B.2 categories. In the South African context, this refers to the Coal to Liquid (CTL) and Gas to Liquid (GTL) processes. These GHG emissions are most specifically fugitive emissions related to the two mentioned processes (CTL and GTL) with the emphasis on CO_2 removal.

3.4.3.2 Overview of shares and trends in emissions

The total estimation of cumulative GHG emissions from *Other emissions from energy production* is equivalent to 293 328 Gg CO_2eq for the period 2000 to 2010. Emissions fluctuated up and down throughout the 10 year period (Table 3.23).

3.4.3.3 Data sources

Data on other Emissions from Energy Production were obtained from both Sasol and PetroSA.

Table 3.23: Sector 1 Energy: Total GHG emissions from the category Other Emissions from Energy Production (1B3), 2000 – 2010.

	$GgCO_2$-eq
2000	28 885
2001	28 461
2002	28 958
2003	27 442
2004	29 207
2005	25 501
2006	25 376
2007	25 657
2008	24 450
2009	24 771
2010	24 621

3.4.3.4 Methodology

The use of facility level production data and facility level gas composition and vent flow rates enabled the use of tier 3 methodology. Hence, CO_2 emissions from *Other emissions from Energy Production* has been estimated using real continuous monitoring results and material balances.

3.4.3.5 Uncertainty and time-series consistency

No source-specific uncertainty analysis has been performed for this source category. Currently, uncertainty data does not form part of the data collection and measurement programme. This is an area that will require improvement in future inventories. Facilities are to be encouraged to collect uncertainty data as part of data collection and measurement programmes. Time-series activity data was validated using information on mitigation projects that have been implemented in the past 10 years and other factors such as economic growth and fuel supply and demand.

3.4.3.6 Source-specific QA/QC and verification

Quality Assurance is currently done in an adhoc manner wherein the department reviews the material balance and measurement data supplied by facilities.

3.4.3.7 Source-specific recalculations

No source-specific recalculations were done for this section.

3.4.3.8 Source-specific planned improvements and recommendations

No improvements are planned for this section.

4 INDUSTRIAL PROCESSES AND OTHER PRODUCT USE

4.1 An overview of the IPPU sector

The IPPU sector includes GHG emissions sourced from industrial processes, the use of GHG emissions in products and the use of fossil fuels (non-energy uses). The main emissions sources are releases from industrial processes that chemically or physically transform raw material (e.g. ammonia products manufactured from fossil fuels). GHG emissions released during these processes are CO_2, CH_4, N_2O, HFCs, SF_6 and PFCs. Also included in the IPPU sector are GHG emissions used in products such as refrigerators, foams and aerosol cans.

The estimation of GHG emissions from non-energy sources is often difficult, because they are widespread and diverse. The difficulties in the allocation of GHG emissions between fuel combustion and industrial processes arise when by-product fuels or waste gases are transferred from the manufacturing site and combusted elsewhere in different activities. The largest source of emissions in the IPPU sector emissions in South Africa is from the production of iron and steel.

4.1.1 Overview of shares and trends in emissions

Major GHGs generated by the IPPU sector include CO_2, N_2O, CH_4 and PFCs. The main emissions sources for this category are as follows:

- Manufacture of mineral products, mainly cement;
- Manufacture of chemical products, such as nitric acid and adipic acid; and
- Metal production, mainly iron and steel.

The performance of the economy is the key driver for trends in the IPPU sector. The South African economy is directly related to the global economy, mainly through exports and imports. South Africa officially entered an economic recession in May 2009; which was the first in 17 years. Until the global economic recession affected South Africa in the late 2008, the economic growth was stable and consistent. According to Statistics South Africa, the GDP increased annually by 2.7%, 3.7%, 3.1%, 4.9%, 5.0%, 5.4%, 5.1% and 3.1% between 2001 and 2008, respectively. However in the third and fourth quarters of 2008, the economy experienced enormous recession, and this continued into the first and second quarters of 2009. As a result of the economic recession, GHG emissions during that same period decreased enormously almost across all categories in the IPPU sector.

In 1990 IPPU GHG emissions accounted for 8.9% of South Africa's total GHG emissions (excl. *Land*), whereas in 1994 and 2000 it contributed 8.0% and 6.5%, respectively. When analyzing the recalculated IPPU sector emissions for the year 2000, there has been a decrease of 2.7% when compared to 1990. Between 2000 and 2010 there was a further 1.1% decrease.

The GHG emissions in the IPPU sector fluctuated during the ten year reporting period (Figure 4.1:). In 2001 the IPPU sector emissions decreased by 4.4 % when compared to the previous year, followed by a 6.0% increase in 2002. Between 2003 and 2006 there was a 10.3% increase in GHG emissions, mainly due to a robust economic growth which led to an increased demand in products.

A dramatic decline of 19.7% occurred between 2006 and 2009, where emissions dropped from 34 190 Gg CO_2eq in 2006 to 27 458 Gg CO_2eq in 2009. This decrease in GHG emissions was mainly due to the global economic recessions and the electricity crisis that occurred during that period resulting in a decline in the demand of products.

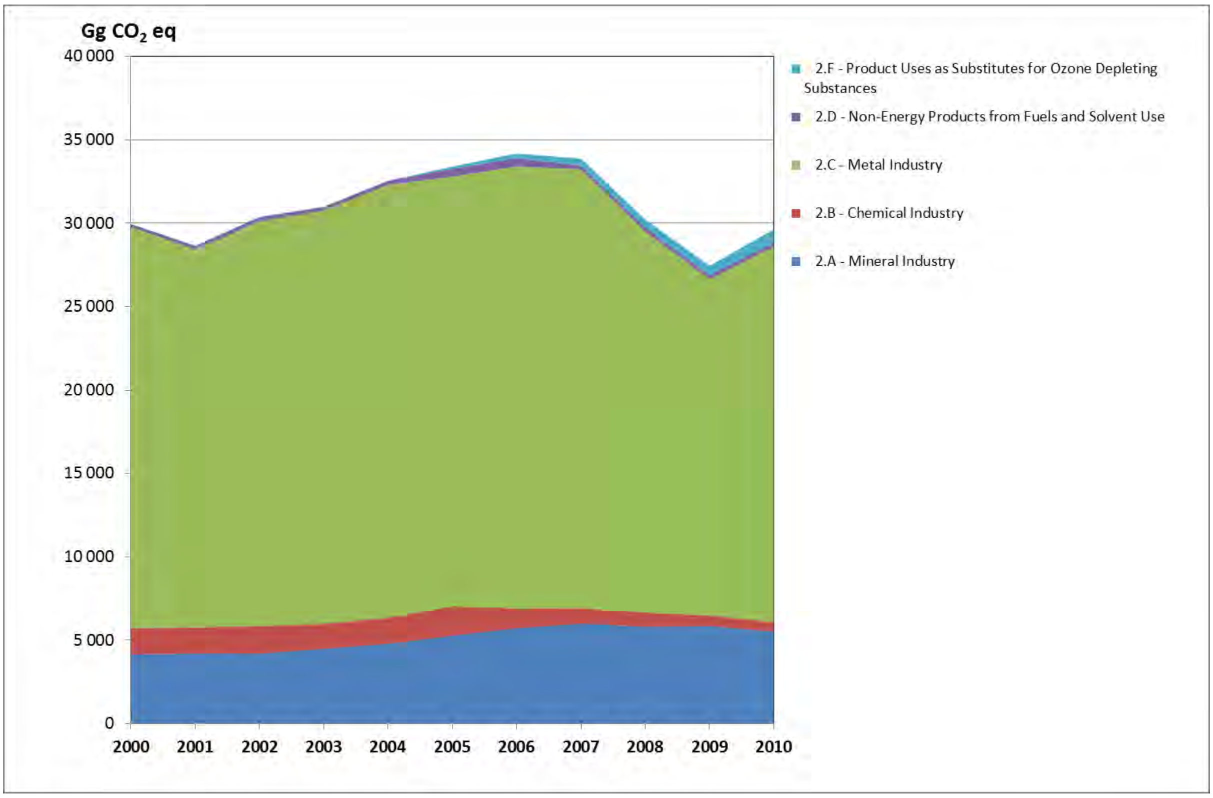

Figure 4.1: Sector 2 IPPU: Trend and emission levels of source categories, 2000 – 2010.

IPPU sector emissions in 2010 were estimated at 29 635 Gg CO_2eq, with an increase of 7.9% when compared to 2009. The economy was starting to recover from the global recession which occurred the previous year, therefore leading to increased emissions. Another reason for the increase in GHG emissions in the year 2010 was that South Africa hosted the 2010 world cup, and as a result an increase in demand for commodities was experienced.

The main source of emissions in the IPPU sector was the Metal Industries, which contributed between 73.5% and 80.3% over the period 2000 to 2010. The biggest contributor to the Metal Industry emissions was the Iron and Steel industry (60.9%). CO_2 emissions constitute between 89.2% and 91.6% of the total IPPU emissions between 2000 and 2010, while PFCs contribute between 7.2% and 8.2% (Figure 4.2:).

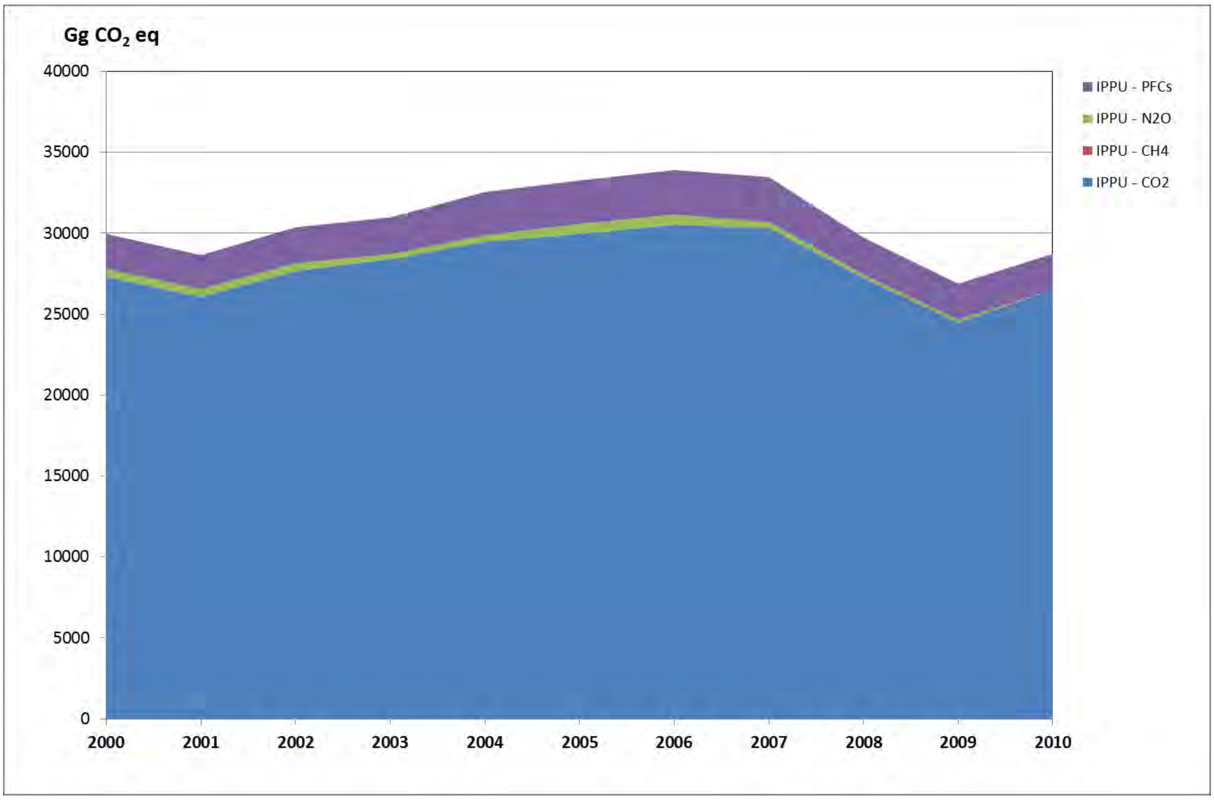

Figure 4.2: Sector 2 IPPU: Trends and emission levels of the various greenhouse gases, 2000 – 2010.

4.1.2 Key sources

The major key category in the IPPU sector was the emissions from *Iron and Steel Production*. The other key categories, which were also identified in the previous inventory (DEA, 2009) were *Ferroalloys production*, and *Cement production* (see Table 1.3, Table 1.4). In the Trend Assessment *Cement Production* was not shown as a key category, however it showed four additional key categories in the IPPU sector, namely, *Refrigeration and Air conditioning, Nitric Acid Production, Aluminium production* and *Ammonia Production*.

4.1.3 Completeness

The IPCC guidelines recommend that the national GHG inventory should include all relevant categories of sources, sinks and gases. The completeness of inventories refers to completeness of all gases, completeness of sources and sinks categories, completeness of geographical coverage and completeness in the coverage of the years in the time series.

In the compilation of the GHG emissions inventory it is important to minimize omissions and also avoid double counting of emissions. Therefore it is imperative to ensure that all the sources which have been identified are allocated to the appropriate sources. In the compilation of GHG emissions from the IPPU, it is important that all significant GHG emissions from non-energy uses of fossil fuels are reported, without any double counting. The sum of these emissions included (a) fuels used as feedstock in the chemical industry, (b) fuels used as reductants in the metal industry, (c) fuel products oxidized during use (partly or fully; direct emissions or emissions of carbon containing non-CO_2 gases (NMVOC, CO and CH_4) oxidized in the atmosphere).

In the completion of this inventory the main challenge was lack of activity data or costs associated with gathering the activity data. It is *good practice* to include all the sources of GHG emissions in a country, if actual emission quantities have not been estimated or is not reported then it should be transparent in the inventory report. This inventory is not complete as it does not include all categories and gases listed in the IPCC guidelines. The reasons for not including some categories are provided in Table 4.1. Identifying the categories which have not been included in the inventory will give direction on the disproportionate amount of effort required in the collection of data in this sector. The structure is based on the naming and coding of the 2006 IPCC guidelines and the Common Reporting Format (CRF) used by the UNFCCC.

Table 4.1: Sector 2 IPPU: Classification of categories of emissions excluded from this inventory.

Category	Definition of category	Justification for exclusion
2A Mineral Industry	2A4 Other Process Uses of Carbonates	Not Estimated (NE): Emissions occur but have not been estimated or reported because of lack of data.
2B Chemical Industry	2B3 Adipic Acid Production	Not Occurring (NO): An activity or process does not exist within a country.
	2B4 Caprolactam, Glyoxal and Glyosylic Acid Production	Not Occurring (NO): An activity or process does not exist within a country.
	2B7 Soda Ash Production	Not Occurring (NO): An activity or process does not exist within a country.
	2B9 Fluorochemical Production	Not Occurring (NO): An activity or process does not exist within a country.
2C Metal Industry	2C4 Magnesium Production	Not Occurring (NO): An activity or process does not exist within a country.
2E Electronics	2E1 Integrated Circuit or Semi-conductor 2E2 TFT flat panel display 2E3 Photovoltaics 2E4 Heat transfer fluid	Not Estimated (NE): Emissions and/or removals occur but have not been estimated or reported.
2H Other	2H1 Pulp and Paper Industry 2H2 Food and Beverages industry	Not Estimated (NE): Emissions and/or removals occur but have not been estimated or reported.

4.2 Mineral production [2A]

4.2.1 Source category description

GHG emissions from *Mineral production* is divided into five sub-categories; cement production, lime production, glass production, process uses of carbonates, and other mineral products processes. Mineral products emissions are mainly process related GHG emissions resulting from the use of carbonate raw materials. For this inventory report this source sub-category included cement production, lime production and glass production.

4.2.1.1 Cement production [2A1]

The South African cement industry's plants vary widely in age, ranging from five to over 70 years (DMR, 2009). The most common materials used for cement production are limestone, shells, and chalk or marl combined with shale, clay, slate or blast furnace slag, silica sand, iron ore and gypsum. For certain cement plants, low-grade limestone appears to be the only raw material feedstock for clinker production (DMR, 2009). Portland cement with a clinker content of >95% is described by the class CEM I. CEM II cements can be further grouped depending on their clinker content into categories A (80 – 94%) and B (65 – 79%). Portland cement contains other puzzolanic components such as blast furnace slag, micro silica, fly ash and ground lime stone. CEM III cements are lower in the clinker content and are also further split into subgroups: A (35 – 64% clinker) and B (20 – 34% clinker). The cement production plants produce Portland cement and blended cement products such as CEM I, and more recently CEM II and CEM III. Cement produced in South Africa is sold locally and to other countries in the Southern region such Namibia, Botswana, Lesotho and Swaziland.

The main GHG emission in cement production is CO_2 emitted through the production of clinker, an intermediate stage in the cement production process. Non-carbonate materials may also be used in cement production, which reduce the amount of CO_2 emitted. However the amounts of non-carbonate materials used are generally very small and not reported in cement production processes in South Africa. An example of non-carbonate materials would be impurities in primary limestone raw materials. It is estimated that the 50% of cement demand goes to residential building market (SAMI, 2009); therefore any changes in the interest rates that affect the residential market will affect cement sales.

4.2.1.2 Lime production [2A2]

Lime is the most widely used chemical alkali in the world. Calcium oxide (CaO or quicklime or slacked lime) is sourced from calcium carbonate ($CaCO_3$), which occurs naturally as limestone ($CaCO_3$) or dolomite ($MgCO_3$). CaO is formed by heating limestone at high temperatures to decompose the carbonates (IPCC, 2006, 2.19) and produce CaO. This calcination reaction produces CO_2 emissions. Lime kilns are typically rotary-type kilns, which are long, cylindrical, slightly inclined and lined with refractory material. At some facilities, the lime may be subsequently reacted (slaked) with water to produce hydrated lime.

In South Africa the market for lime is divided into pyrometallurgical and chemical components. Hydrated lime is divided into three sectors: chemical, water purification and other sectors (DMR, 2010). Quicklime and hydrated lime contributed an average of 92% and 8% respectively (DMR Report R85/2010). Lime has wide applications such as neutralizing and coagulating agent in chemical, hydrometallurgical and water treatment processes and a fluxing agent in pyrometallurgical processes. Pyrometallurgical quicklime sales have been increasing whilst the demand for quicklime in the chemical industry are decreasing (DMR, 2010).

4.2.1.3 Glass production [2A3]

There are many types of glass and compositions used commercially, however the glass industry is divided into four categories: containers, flat (window) glass, fibre glass and speciality glass. When other materials (including metal) solidify, they become crystalline, whereas glass (a super cool liquid) is non-crystalline. The raw materials used in glass production are sand, limestone, soda ash, dolomite, feldspar and saltcake. The major glass raw materials which emit CO_2 during the melting process are limestone ($CaCO_3$), dolomite $Ca,Mg(CO_3)_2$ and soda ash (Na_2CO_3). Glass makers do not produce glass only from raw materials, but they use a certain amount of recycled scrap glass (cullet). The chemical composition of glass are Silica(72%), Iron Oxide (0.075%), Alumina (0.75%), Magnesium oxide (2.5%), sodium oxide (14.5%), potassium oxide (0.5%), sulphur trioxide (0.25%) and calcium oxide (7.5%) (PFG glass, 2010).

4.2.2 Overview of shares and trends in emissions

The cumulative GHG emissions from the mineral industry for the reporting period 2000 to 2010 was equivalent to 55 959 Gg CO_2eq. Emissions increased by 38% between 2000 and 2006 (5 718 Gg CO_2 eq), after which emissions slowly declined (by 3.6%) until 2010 (Figure 4.3). Over the 10 year period the emissions from the Mineral Industries increased by 33.2%. The most significant GHG emission sources were cement production (contributing 79% of total GHG emissions), followed by lime production (19%). GHG emissions from glass production accounted for only 2% of the total emissions.

4.2.2.1 Cement production [2A1]

The GHG emissions from cement production increased linearly throughout the reporting period, from 3 347 Gg CO_2eq in 2000 to 4 186 Gg CO_2eq in 2010. Cement production in South Africa increased significantly from the period 2000 to 2007 as a result of economic growth. In 2008 there was a 2.3% decrease in emissions and an 8% decline in 2010. In 2009 the South African economy entered into recession and the GDP for the country decreased by 1.8% in that year. Cement demand in the residential market and construction industry in 2009/2010 decreased due to higher interest rates, increase in inflation rates and the introduction of the National Credit Act (SAMI, 2009/2010). Another reason for the decrease in GHG emissions in 2008 is that projects with an estimated value of R4 billion and R6 billion were postponed or cancelled until September 2008 as a result of electricity supply constraints (Cement and Concrete Institute, 2008). In 2009 GHG emissions from cement production increased by 13% as a result of the preparation of the 2010 World Cup which increased a demand in infrastructure.

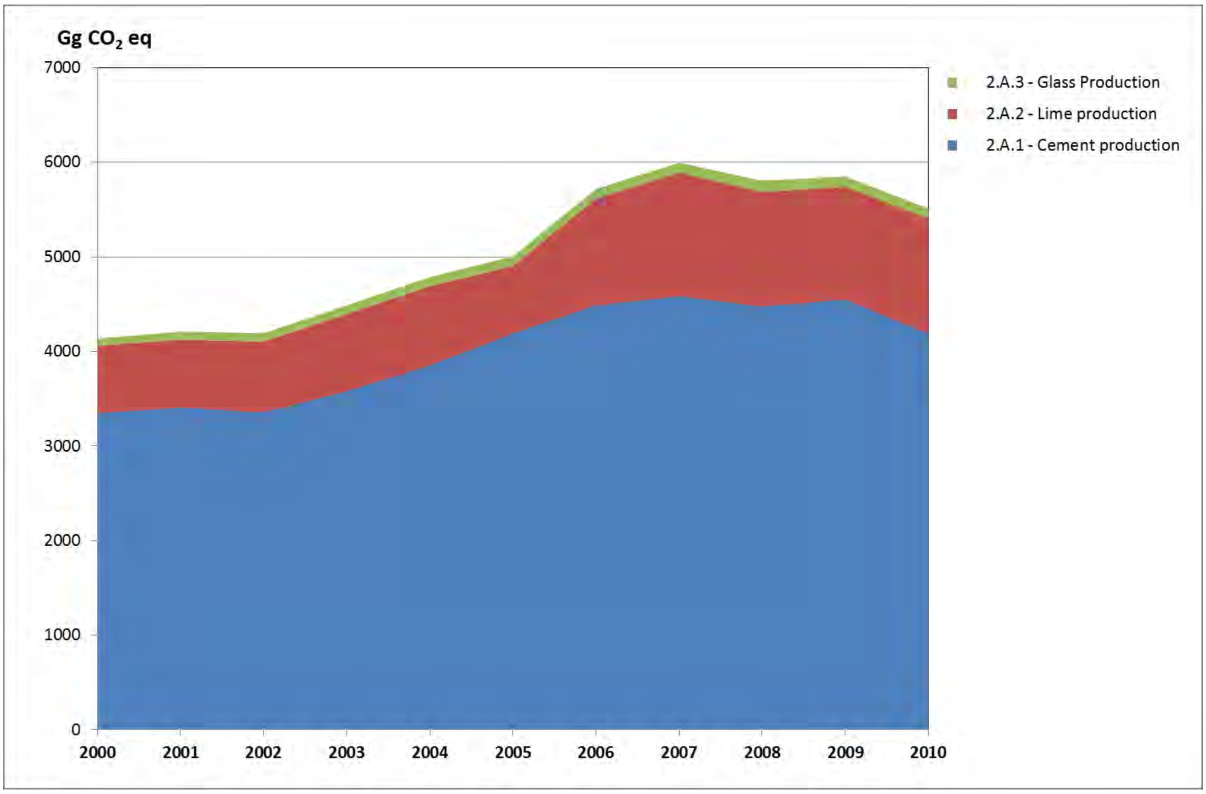

Figure 4.3: Sector 2 IPPU: Trend and emission levels in the Mineral Industries, 2000 – 2010.

4.2.2.2 Lime production [2A2]

The demand for lime production in South Africa is mainly linked to developments and investments in steel and metallurgical industries (DMR Report R85/2010). South Africa's local production has been declining in the past few years because of a decline is lime substitution, better efficiencies and the shrinking market. On the other hand, the GHG emissions from lime production have been increasing constantly from the year 2000 to 2006. The Iron and Steel industry is the largest consumer of lime in South Africa accounting for 56% of the total consumption followed by non-ferrous and environmental accounting for 20% and 10% respectively (DMR Report R85/2010). In the year 2006, the local steel industry increased its productivity (DMR Report R85/2010), and the GHG emissions from lime production increased by 13% and 10% in 2005 and 2006, respectively. The total cumulative estimation of GHG emissions from lime production for the period 2000 to 2010 was 10 616 Gg CO_2eq.

The fluctuations in lime production were directly linked to developments and investments in steel and metallurgical industries. In 2009 the lime industry declined as a result of the economic recession hence in that year GHG emissions from lime production decreased by 1.8%. Overall the GHG emissions from this category have increased by 71% between 2000 and 2010 which is mainly due to increased infrastructure projects and the 2010 world cup preparation.

4.2.2.3 Glass production [2A3]

South Africa's glass production emissions increased consistently from the year 2001 to 2005 and again in 2007 to 2008. In the year 2009 and 2010 GHG emissions from glass production declined by 6.6% and 5.3% respectively. This decline in emissions was mainly because of the global economic crisis which affected the glass manufacturing market. The glass manufacturing market is largely influenced by consumer behaviour and consumer spending; therefore any negative changes in the economy will affect the glass manufacturing industry. The total cumulative estimation of GHG emissions from glass production for the period 2000 to 2010 was 1 074 Gg CO_2eq.

4.2.3 Data sources

4.2.3.1 Cement production [2A1]

Data on cement production in South Africa was obtained from the cement production industry (Table 4.2). According to the Cement & Concrete Institute, cement demand has declined in South Africa between 2008 and 2010. With the decline in domestic demand of cement due to economic recession and the electricity crisid, the cement production industry had to reduce production. In 2009 Sephaku cement entered the cement production market and it was approximated to bring about 1.2 Mt of production capacity into the market (SAMI, 2009/2010).

Table 4.2: Sector 2 IPPU: Activity data for Cement, Lime and Glass Production, 2000 – 2010.

	Cement Production	Quicklime	Hyrdated lime	Total Glass Produced	Recycled Glass
			(tonnes)		
2000	8 499 906	891 480	77 520	561 754	189 958
2001	8 703 965	896 080	77 920	624 156	202 228
2002	8 857 304	935 640	81 360	667 110	225 379
2003	9 430 206	1 021 200	88 800	702 008	245 360
2004	10 129 856	1 047 880	91 120	726 644	247 184
2005	11 384 313	1 221 760	106 240	775 839	264 023
2006	11 979 671	1 410 360	122 640	808 328	299 475
2007	12 921 686	1 632 080	141 920	858 382	333 443
2008	12 766 382	1 514 320	131 680	978 488	391 618
2009	12 379 638	1 486 720	129 280	993 784	444 947
2010	11 355 458	1 521 166	132 275	1 009 043	489 621

4.2.3.2 Lime production [2A2]

The DMR publishes data on limestone and dolomite production in South Africa on the South Africa's Mineral Industry publication (SAMI, 2009/2010) (Table 4.2). The SAMI provides a breakdown on limestone demand; 80% of the limestone demand goes to cement manufacturing and the remaining 20% goes to metallurgical, agricultural and other. There was no data provided for lime production, therefore it was assumed that the 'other' in the breakdown of limestone demand goes to lime production.

4.2.3.3 Glass production [2A3]

Data on glass production (Table 4.2) was obtained from the glass production industry.

4.2.4 Methodology

4.2.4.1 Cement production [2A1]

As a key emission source, cement production requires higher-tier level emission estimation; The Tier 2 method stipulates that if sufficient country-specific data on the calcium oxide (CaO) content of clinker and inputs of non-carbonate CaO sources are available, a country-specific CO_2 emission factor for clinker should be calculated. This was, however, not possible due to the lack of plant-specific data. A Tier 1 approach was used to estimate emissions. Activity data was obtained from the cement production industry, and the IPCC default emission factors were used to estimate the total emissions. The country-specific clinker fraction for the period 2000 – 2010 ranged between 69% - 76% (Table 4.3).

Table 4.3: Sector 2 IPPU: Clinker fraction for the period 2000 – 2010.

	Clinker fraction
2000	0.76
2001	0.75
2002	0.73
2003	0.73
2004	0.73
2005	0.72
2006	0.73
2007	0.71
2008	0.70
2009	0.71
2010	0.69

EMISSION FACTORS

For the calculation of GHG emissions in cement production, CO_2 emission factors were sourced from the 2006 IPCC guidelines. It was assumed that the CaO composition (one Tonne of clinker) contains 0.65 tonnes of CaO from $CaCO_3$. This carbonate is 56.03% of CaO and 43.97% of CO_2 by weight (IPCC, 2006, p. 2.11). The emission factor for CO_2 , provided by IPCC 2006 Guidelines, is 0.52 tonnes CO_2 per tonne clinker.

4.2.4.2 Lime production [2A2]

The production of lime involves various steps, which include quarrying of raw materials, crushing and sizing, calcining the raw materials to produce lime, and (if required) hydrating the lime to calcium hydroxide. The Tier 1 approach was used for the calculation of GHG emissions from lime production. This report estimated the total lime production based on the aggregate national value of the quantity of limestone produced, using the breakdown of the types of lime published in the SAMI (2009/2010) report. Based on the IPCC's default method, an emission factor that assumes 85% to 15% ratio of limestone to dolomite was used.

EMISSION FACTORS

For the calculation of GHG emissions in lime production, GHG emission factors were sourced from the 2006 IPCC guidelines. In South Africa data was acquired for high calcium lime which has a range of 93 – 98% CaO content and hydraulic lime which has a range of 62 – 92 % CaO. The GHG emission factor for high-calcium lime (0.75 tonnes CO2/tonne CaO) and hydraulic lime (0.59 tonnes CO_2 per tonne CaO) were used for Quicklime and Hydrated lime, respectively (IPCC 2006 Guidelines).

4.2.4.3 Glass production [2A3]

The Tier 1 approach was used to determine estimates of the GHG emissions from glass production. The default IPCC emission factor was used and the cullet ratio for the national level glass production was also determined. Activity data was provided by the glass production industry.

EMISSION FACTORS

For the calculation of GHG emissions from glass production, the emission factor (0.2 tonnes CO_2 per tonne glass) was sourced from the 2006 IPCC guidelines based on typical raw material mixture to national glass production statistics. A typical soda-lime batch might consist of sand (56.2 weight percent), feldspar (5.3 %), dolomite (9.8 %), limestone (8.6 %) and soda ash (20.0 %). Based on this composition, one metric tonne of raw materials yields approximately 0.84 tonnes of glass, losing about 16.7 % of its weight as volatiles, in this case virtually entirely CO_2 (IPCC, 2006).

4.2.5 Uncertainty and time-series consistency

4.2.5.1 Cement production [2A1]

According to the 2006 IPCC Guidelines, if a 95% clinker fraction in Portland cement is assumed then the uncertainty is in the range of 2–7%.

4.2.5.2 Lime production [2A2]

The only available data for lime production was sourced from the South African Mineral Industry; therefore there was no comparison of data across different plants. According to the IPCC 2006 Guidelines, the uncertainty of the activity data for a tier 1 emission estimation methodology is within the range of 4–8%.

4.2.5.3 Glass production [2A3]

The only available data for glass production was sourced from the glass production industry; therefore there was no comparison of data across different plants. The uncertainty associated with use of the Tier 1 emission factor and cullet ratio is significantly high with +/- 60% (IPCC, 2006, Vol 3).

4.2.6 Source specific QA/QC and verification

No source specific QA/QC has been conducted for this source category. For cement production facility-level activity data submitted by facilities was compared with data published by the cement association as well as data reported in the South African Minerals Industry (SAMI). A comparison was made between facility level data and the SAMI data and it was evident that there are discrepancies between the two sources of data. To give a few examples; for the year 2000, SAMI reported the total cement production as 3 742 126 tonnes and industry reported the production for the same year as 6 436 640 tonnes; for the year 2009 SAMI reported production as 5 027 293 tonnes and the industry reported the production as 8 749 099 tonnes. These differences lead to increased uncertainty and the reasons for the discrepancies need to be further investigated before the next inventory. Corrections were made in facility level data to ensure that emissions are categorised according to IPCC categorization.

4.2.7 Source-specific recalculations

4.2.7.1 Cement production [2A1]

Recalculations have been performed for year 2000 emission estimates. Revised cement production statistics on clinker production, imports and exports were replaced by facility level data. The default fraction of clinker in cement sourced from the IPCC guidelines was also replaced by country-specific clinker fraction data supplied by the cement industry.

4.2.7.2 Lime production [2A2]

No specific recalculations were performed for this source category.

4.2.7.3 Glass production [2A3]

This is the first time that emission estimates from glass production have been estimated, hence no recalculations have been performed for this source-category.

4.2.8 Source-specific planned improvements and recommendations

4.2.8.1 Cement production [2A1]

An improvement would be the collection of activity data from all cement production plants in South Africa. The activity data has to include the CaO content of the clinker and the fraction of this CaO from carbonate. According to the 2006 IPCC Guidelines, it is *good practice* to separate CaO from non-carbonate sources (e.g. slag and fly ash) and CaO content of the clinker when calculating emissions. It is evident that there are discrepancies between the cement production data from industry and the cement production data published by the Department of Mineral Resources, as a recommendation the DMR should work with the cement production industry to ensure accuracy and consistency between the two data sources.

4.2.8.2 Lime production [2A2]

It is recommended that activity data be collected from all lime production plants in South Africa. Another improvement would be the development of country-specific emission factors.

4.2.8.3 Glass production [2A3]

Determining country-specific emission factors is recommended for the improvement of emission estimates from this category. One of the largest sources of uncertainty in the emissions estimate (Tier 1 and Tier 2) for glass production is the cullet ratio. The amount of recycled glass used can vary across facilities in a country and in the same facility over time. The cullet ratio might be a good candidate for more in-depth investigation.

4.3 Chemical industry [2B]

This category estimates GHG emissions from the production of both organic and inorganic chemicals in South Africa. The chemical industry in South Africa is mainly developed through the gasification of coal because the country has no significant oil reserves. The reporting of GHG emissions from the chemical production processes included ammonia production, nitric acid production, carbide production and titanium dioxide. The chemical industry in South Africa contributes approximately 5% to the GDP and 23% of its manufacturing sales. The chemical products in South Africa can be divided into four categories which are base chemicals, intermediate chemicals, chemical end-products and speciality end-products. Chemical products include ammonia, waxes, solvents, plastics, paints, explosives and fertilizers.

4.3.1 Source category description

4.3.1.1 Ammonia production [2B1]

Ammonia production is the most important nitrogenous material produced and is a major industrial chemical. According to the 2006 IPCC guidelines (p.3.11), Ammonia gas can be used directly as a fertilizer, in heat treating, paper pulping, nitric acid and nitrates manufacture, nitric acid ester and nitro compound manufacture, explosives of various types and as a refrigerant.

4.3.1.2 Nitric Acid production [2B2]

Nitric acid is a raw material which is used mainly in the production of nitrogenous-based fertilizer. According to the 2006 IPCC guidelines (p.3.19), during the production of nitric acid, nitrous oxide is generated as an unintended by-product of high temperature catalytic oxidation of ammonia.

4.3.1.3 Carbide production [2B5]

Carbide production can result in GHG emissions such as CO_2 and CH_4. According to the 2006 IPCC guidelines (p.3.39) calcium carbide is manufactured by heating calcium carbonate (limestone) and subsequently reducing CaO with carbon (e.g. petroleum coke).

4.3.1.4 Titanium Dioxide production [2B6]

Titanium dioxide (TiO_2) is a white pigment that is mainly used in paint manufacture, paper, plastics, rubber, ceramics, fabrics, floor covering, printing ink and other uses. According 2006 IPCC guidelines (p. 3.47), there are three processes in titanium dioxide production that results to GHG emissions namely: a) titanium slag production in electric furnaces; b) synthetic rutile production using Becher process and c) rutile TiO_2 production through chloride route.

4.3.1.5 Carbon black [2B8f]

Carbon black is produced from petroleum-based or coal-based feed stocks using the furnace black process (IPCC, 2006). Primary fossil fuels in the carbon black production include natural gas, petroleum and coal. The use of these fossil fuels may involve the combustion of hydrocarbon content for heat rising and the production of secondary fuels (IPCC, 2006, P.3.56). GHG missions from the combustion fuels obtained from feed stocks should be allocated to the source category in the IPPU Sector, however, where the fuels are not used within the source category but are transferred out of the process for combustion elsewhere these emissions should be reported in the appropriate energy Sector source category (IPCC, 2006, p. 3.56). Commonly the largest percentage of carbon black is used in the tyre and rubber industry, and the rest used as pigment in applications such as ink and carbon dry cell batteries.

4.3.2 Trends in emissions

The Chemical Industries contributed a total of 13 792 Gg CO_2eq over the period 2000 to 2010. Emissions from this category fluctuated considerably over the 10 year period, with a maximum of 1771 Gg CO_2eq in 2005 and a minimum of 570 Gg CO_2eq in 2010 (Figure 4.4). Overall there was a 63.9% decline in GHG emissions from this category over the 10 years.

The increases in 2002, 2004 and 2005 were mainly due to the changes in emissions from Nitric Acid Production. Ammonia production also contributed to the increase in 2004. There was a 58.9% decrease in emissions from Ammonia production between 2005 and 2006, and a decrease of 42.5% between 2008 and 2009. The largest consumers of ammonia included the industrial, mining, transport, agriculture and public health sectors. Emissions from Carbide Production were small, but increased by 162% from 2 Gg CO_2eq in 2000 to 5.2 Gg CO_2eq in 2010 with the major increase (125%) occurring in 2002. Total GHG emissions from Titanium Dioxide Production decreased from 438 Gg CO_2eq in 2000 to 159 Gg CO_2eq in 2010, while Carbon Black emissions remained fairly constant over the same period with a maximum of 162 Gg CO_2eq in 2002 to 134 Gg CO_2eq in 2008. Overall the GHG emissions from carbon black production have decreased by 3.1% for the period 2000 to 2010.

In 2000 the emissions were made up of 31.7% from Ammonia Production, 31.6% from Nitric Acid Production and 27.8% from Titanium Dioxide Production, with <9% from Carbide Production and Carbon Black. However, in 2010 the contribution from Carbon Black increased to 23.6%, and Ammonia production decreased to 29.3%. The contribution from Nitric Acid production decreased by 30%.

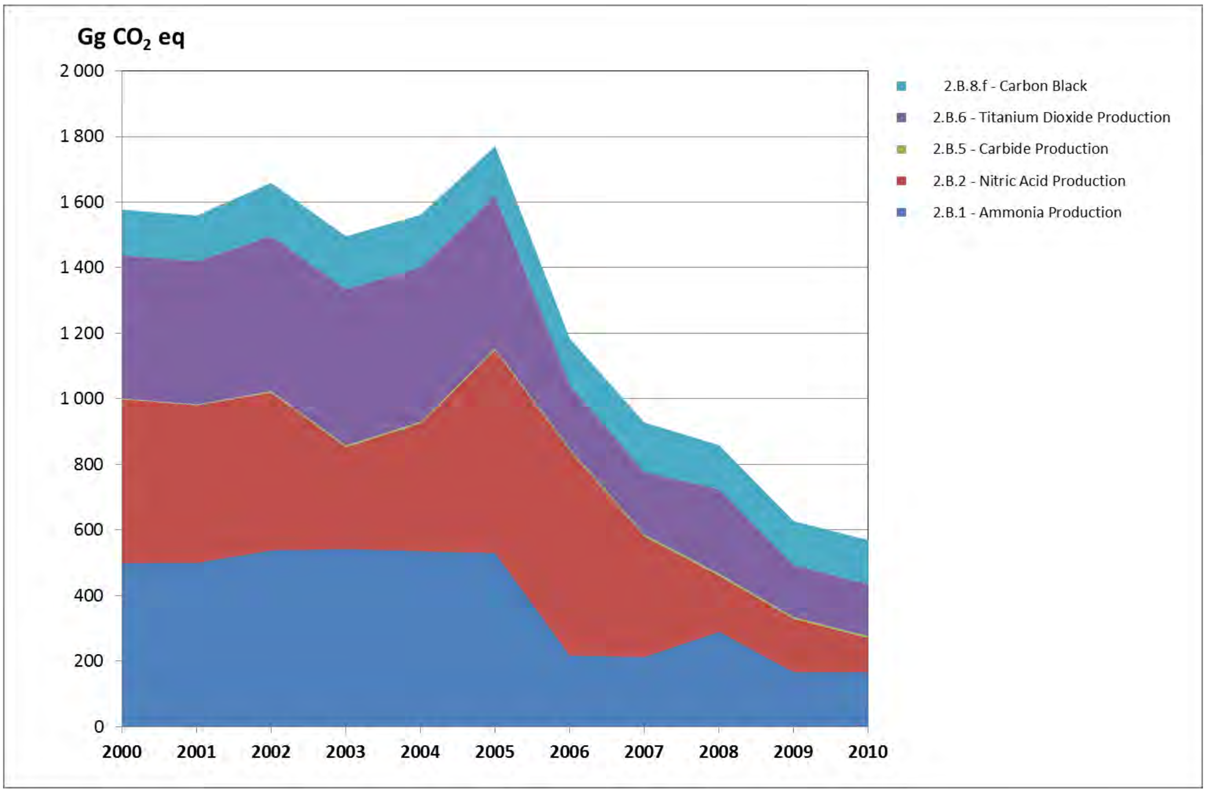

Figure 4.4: Sector 2 IPPU: Trend and emission levels in the Chemical Industries between 2000 and 2010.

4.3.3 Data sources

4.3.3.1 Ammonia production [2B1]

Activity data from ammonia production were not provided, but rather the total emission estimates were obtained from the ammonia production plants. The emissions were calculated based on actual process balance analysis. The total GHG emissions for the year 2000 were not provided for; therefore it was assumed that the GHG emissions for the year 2001 were similar to the GHG emissions for the year 2000.

4.3.3.2 Nitric Acid production [2B2]

The amount of nitric acid emission released was sourced from the nitric acid production plants (Table 4.4). The GHG emissions were calculated based on a combination of emission factors and process material balance analysis. Sasol emissions were added to the total emissions using the emission factor approach.

EMISSION FACTORS

For the calculation of GHG emissions from nitric acid production the N_2O emission factor of 2.0 kg N_2O per tonne nitric acid was sourced from the 2006 IPCC guidelines. This excluded Sasol emission estimates which are based on a mass-balance approach.

Table 4.4: Sector 2 IPPU: Total Nitric Acid emissions for 2000 to 2010.

	Nitric Acid Emissions (tonnes N_2O)
2000	1 686
2001	1 624
2002	1 627
2003	1049
2004	1 319
2005	2 088
2006	2114
2007	1244
2008	581
2009	550
2010	354

4.3.3.3 Carbide production [2B5]

The Carbide production values were sourced from the carbide production plants (Table 4.5) and emissions were calculated based on actual process balance analysis.

EMISSION FACTORS

For the calculation of GHG emissions from carbide production, the IPCC 2006 CO_2 emission factor (1.090 tonnes CO_2 per tonne carbide production) was used.

4.3.3.4 Titanium Dioxide production [2B6]

The titanium dioxide emissions data was sourced from the titanium dioxide production plants. Emission estimates are based on a mass-balance approach.

Table 4.5: Sector 2 IPPU: Carbide and Carbon Black production for 2000 to 2010.

	Carbide Production	Carbon Black
	(tonnes)	
2000	1 817	52 891
2001	1 818	52 917
2002	4 091	61 862
2003	4 345	61 464
2004	3 842	60 976
2005	4 886	57 662
2006	4 572	54 071
2007	4 850	57 686
2008	4 869	51 187
2009	4 765	51 212
2010	4 768	51 238

4.3.3.5 Carbon black [2B8f]

Carbon black activity data was sourced directly from industry (Table 4.5).

EMISSION FACTORS

For the calculation of GHG emissions from carbon black production, the IPCC 2006 default CO_2 and CH_4 emission factors were used (p. 3.80). It was assumed that the carbon black production is produced through the furnace black process.

4.3.4 Methodology

4.3.4.1 Ammonia production [2B1]

GHG emission estimates from Ammonia production were obtained through the Tier 3 approach, using production data and relevant emission factors. The GHG emissions from this category were calculated based on actual process balance analysis. The emission factors will not be provided, for the reason that there is only one company that produces ammonia and therefore the total consumption is confidential.

4.3.4.2 Nitric Acid production [2B2]

A Tier 3 approach was used for the calculation GHG emissions from nitric acid production, using production data and relevant emission factors. The GHG emissions in this category were calculated based on actual process balance analysis.

4.3.4.3 Carbide production [2B5]

Emission estimates for Carbide production were obtained by using the Tier 1 approach. Default IPCC 2006 emission factors were used. The GHG emissions from carbide production were estimated from activity data on petroleum coke consumption, which is in line with the 2006 IPCC guidelines.

4.3.4.4 Titanium Dioxide production [2B6]

The Tier 1 approach was used for calculating GHG emissions from titanium dioxide production, using 2006 IPCC default emission factors. It was assumed that in South Africa TiO_2 is produced through the process of rutile TiO_2 production through by means of the chloride route.

4.3.4.5 Carbon black [2B8f]

Tier 1 was the main approach used in calculating GHG emissions from Carbon Black Production, using production data and relevant emission factors. IPCC 2006 default emission factors were used in all GHG emission estimations.

4.3.5 Uncertainty and time-series consistency

4.3.5.1 Ammonia production [2B1]

According to the 2006 IPCC guideline (p. 3.16), the plant level activity data required for the Tier 3 approach are the total fuel requirement classified by fuel type, CO_2 recovered for downstream use or other applications and ammonia production. It is recommended that uncertainty estimates are obtained at the plant level, which should be lower than the uncertainty values associated with the IPCC default emission factors.

4.3.5.2 Nitric Acid production [2B2]

According to the 2006 IPCC guidelines (p. 3.24) the plant level activity data required for the Tier 3 approach include production data disaggregated by technology and abatement system type. According the 2006 IPCC guidelines (p. 3.24), default emission factors have very high uncertainties because two reasons which are a) N_2O may be generated in the gauze reactor section of nitric acid production as an unintended reaction by-product; b) the exhaust gas may or may not be treated for NO_x control and the NO_x abatement system may or may not reduce the N_2O concentration of the treated gas. The uncertainty measures of default emission factors are +/- 2%. For the uncertainty estimates of the country specific emission factors it is *good practice* that the uncertainty values are lower than the default emission factors.

4.3.5.3 Carbide production [2B5]

The total GHG emissions were sourced from the specific carbide production plants therefore there was no comparison of data across different plants. The default emission factors are generally uncertain because industrial scale carbide production processes differ from the stoichiometry of theoretical chemical reactions (IPCC, 2006, p. 3.45). According to the IPCC 2006 Guidelines (p. 3.45), the uncertainty of the activity data that accompanies the method used here is approximately 10%.

4.3.5.4 Titanium Dioxide production [2B6]

The total GHG emissions were sourced from the specific titanium dioxide production plants therefore no comparison of data across different plants was made. According to the IPCC 2006 Guidelines (p. 3.50), the uncertainty of the activity data that accompanies the method used here is approximately 5%.

4.3.5.5 Carbon black [2B8f]

The activity data was sourced from disaggregated national totals; therefore quality control measures were not applied. According to the IPCC 2006 Guidelines, the uncertainty of the activity data that accompanies the method used here is in the range of -15% to +15% for CO_2 emission factors and between -85% to +85% for CH_4 emission factors.

4.3.6 Source-specific QA/QC and verification

4.3.6.1 Chemical Industry [2B]

No source-specific QA/QC were performed for the Chemical Industry. However, activity data and material balance data was verified with industry sectors.

4.3.7 Source-specific recalculations

No source-specific recalculations were performed in this source-category.

4.3.8 Source-specific planned improvements and recommendations

For Ammonia, Nitric Acid, Carbide and Titanium production it is recommended that country specific emission factors be determined and reported. This would allow efficient quality assurance and control of the emission factors used. There is high uncertainty on many of the default emission factors so having country-specific emission factors would reduce this uncertainty. Development of country-specific emission factors and/or moving to a material approach will improve emission estimates for the Carbon Black source-category.

4.4 Metal industry [2C]

This subcategory relates to emissions resulting from the production of metals. Processes covered for this inventory report included the production of iron and steel, ferroalloys, aluminium, lead, and zinc. Estimates were made for emissions of CO_2 from the manufacturing of all the metals, CH_4 from ferroalloy production, and perfluorocarbons (CF_4 and C_2F_6) from aluminium production.

4.4.1 Source category description

4.4.1.1 Iron and steel production [2C1]

Iron and Steel production results in the emissions of CO_2, CH_4 and N_2O). According to the 2006 IPCC guidelines (p. 4.9), the iron and steel industry broadly consists of primary facilities that produce both iron and steel; secondary steelmaking facilities; iron production facilities; and offsite production of metallurgical coke. According to the world steel association (2010) South Africa is the 21st largest crude steel producer in the world. The range of primary steel products and semi-finished products manufactured in South Africa include billets, blooms, slabs, forgings, light-, medium- and heavy sections and bars, reinforcing bar, railway track material, wire rod, seamless tubes, plates, hot- and cold-rolled coils and sheets, electrolytic galvanised coils and sheets, tinplate and pre-painted coils and sheets. The range of primary stainless steel products and semi-finished products manufactured in South Africa include slabs, plates and hot- and cold-rolled coils and sheets.

4.4.1.2 Ferroalloys production [2C2]

Ferroalloy refers to concentrated alloys of iron and one or more metals such as silicon, manganese, chromium, molybdenum, vanadium and tungsten. Ferroalloy plants manufacture concentrated compounds that are delivered to steel production plants to be incorporated in alloy steels. Ferroalloy production involves a metallurgical reduction process that results in significant carbon dioxide emissions (IPCC, 2006, p. 4.32). South Africa is the world's largest producer of chromium and vanadium ores and the leading supplier of their alloys (SAMI, 2009). South Africa is also the largest producer of iron and manganese ores and an important supplier of ferromanganese, ferrosilicon and silicon metal (SAMI, 2009).

4.4.1.3 Aluminium production [2C3]

According to the 2006 IPCC guidelines aluminium production is done through the Hall-Heroult electrolytic process. In this process, electrolytic reduction cells differ in the form and configuration of the carbon anode and alumina feed system.

The most significant process emissions are (IPCC, 2006, p. 4.43):

- Carbon dioxide (CO_2) emissions from the consumption of carbon anodes in the reaction to convert aluminium oxide to aluminium metal;
- Perfluorocarbons (PFCs) emissions of CF_4 and C_2F_6 during anode effects. Also emitted are smaller amounts of process emissions, CO, SO_2, and NMVOC. SF_6 is not emitted during the electrolytic process and is only rarely used in the aluminium manufacturing process, where small quantities are emitted when fluxing specialized high magnesium aluminium alloys.

4.4.1.4 Lead production [2C5]

According to the 2006 IPCC guidelines there are two primary processes for the production of lead bullion from lead concentrates:

- Sintering/smelting (which consists of sequential sintering and smelting steps and constituents approximately 7% of the primary production.
- Direct smelting which eliminates the sintering step and is mainly 22% of the primary lead production.

4.4.1.5 Zinc production [2C6]

According to the 2006 IPCC guidelines there are three primary processes for the production of zinc:

- Electro – thermic distillation, this is a metallurgical process that combines roasted concentrate and secondary zinc products into sinter, that is combusted to remove zinc, halides, cadmium and other impurities. The reduction results in the release of non-energy CO_2 emissions.
- Pyrometallurgical process, this process involves the utilization of Imperial Smelting furnace, which allows for the simultaneous treatment of zinc and zinc concentrates. The process results in the simultaneous production of lead and zinc and the release of non-energy CO_2 emissions.
- Electrolytic, this process is a hydrometallurgical technique. During this process, zinc sulphide is calcinated, resulting in the production of zinc oxide. The electrolytic process does not result in non-energy CO_2 emissions.

4.4.2 Overview of shares and trends in emissions

Emissions from the Metal Industry totalled 265 801 Gg CO_2eq between 2000 and 2010. The major contributor over this period was the Iron and Steel Industry (60.9%), followed by Ferroalloy Production (23.1%) and Aluminium Production (15.2%) (Figure 4.5). Almost two thirds of the total GHG emissions (in Gg CO_2eq) from Aluminium production were due to PFC emissions.

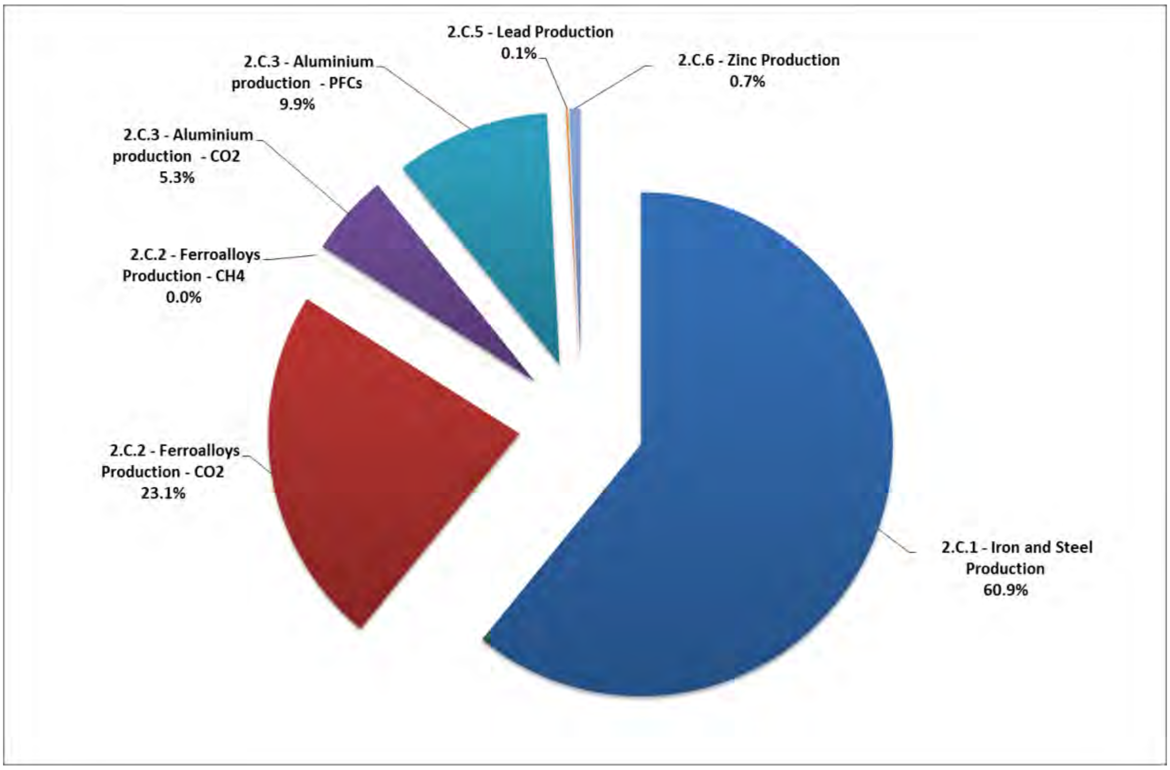

Figure 4.5: Sector 2 IPPU: Percentage contribution from the various industries and gases to the total accumulated GHG emissions from the Metal Industries between 2000 and 2010.

Total emissions declined between 2000 and 2001, then showed a slow increase until 2006, with a sharp decline (23.3%) between 2007 and 2009 (Figure 4.6). This decrease was evident in the three major contributing industries, with a 38.5% reduction from the Ferroalloy Industry and a 16.4% decrease in emissions from the Aluminium Producers over this period. There was also a reduction in emissions from the Iron and Steel Industry, however the decline began in 2005, with a decrease of 23.8% between 2005 and 2009. These declines could be attributed to reduced production caused by electricity supply challenges and decreased demand following the economic crisis that occurred during this period. In 2010 total GHG emissions from the Metal Industries increased by 11.6% from 200 175 Gg CO_2eq in 2009 to 22 522 Gg CO_2eq in 2010. This was due mainly to an increase in emissions from the Ferroalloy industries (54.7%). Although emissions from Zinc Production were relatively small, their emissions decreased by 60.8% between 2009 and 2010.

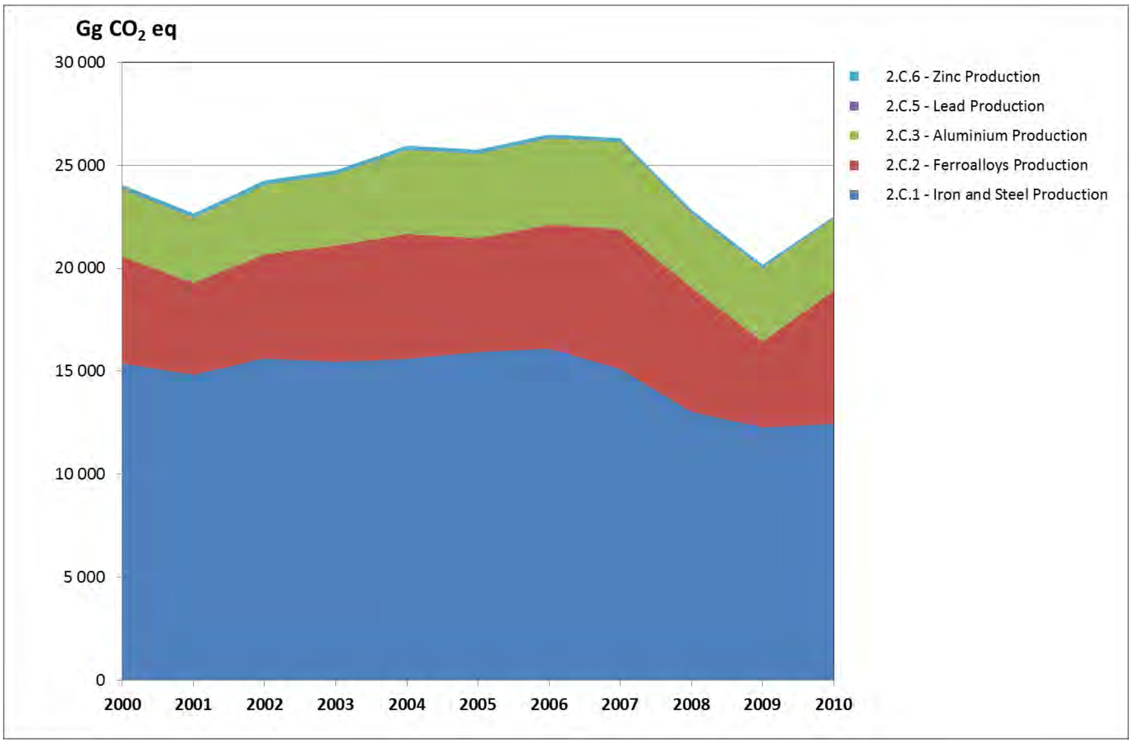

Figure 4.6: Sector 2 IPPU: Trend and emission levels in the Metal Industry, 2000 – 2010.

During 2003/04 South Africa's lead mine production declined by 6.2%, as did the emissions, due mainly to the depletion of a part of the Broken Hill ore body at Black Mountain mine, which contained a higher grade ore (SAMI, 2005). During 2004/05 zinc production decreased by 6.3% due to the closure of Metorex's Maranda operation in July 2004 (SAMI, 2004) and emissions declined by 3.6% over this period. In the year 2009, GHG emissions from zinc production increased by 1.1%, and this was attributed to new mine developments that occurred in the country such as the Pering Mine and the Anglo American (Black Mountain and Gamsberg Project) (SAMI, 2009).

Over the 10 year period emissions from Iron and Steel, Lead and Zinc production declined (19.1%, 32.8%, and 68.1% respectively), while emissions increased by 24.6% and 8.5% from the Ferroalloy and Aluminium Industries, respectively.

4.4.3 Data sources

Metal industry emission estimates were based on data from two main sources: the South Africa Iron and Steel Institute (SAISI 2008) provided data for iron and steel production, while production data for all the other metals were obtained from South Africa's Mineral Industry (DME, 2001b).

4.4.3.1 Iron and steel production [2C1]

The South African Iron and Steel Institute provided data for iron and steel production (Table 4.6).

4.4.3.2 Ferroalloy, Aluminium, Lead and Zinc Production

The source of activity data for these categories was sourced from South Africa's Mineral Industry (Table 4.6).

4.4.4 Methodology

4.4.4.1 Iron and steel production [2C1]

The Tier 2 approach was used to calculate the GHG emissions from iron and steel production as country-specific emission factors were used. An important assumption was made with regards to the activity data used for iron and steel emission estimation. The separation between energy and process emissions emanating from the use of coke was not done. This was due to lack of disaggregated information on coke consumption. Hence, energy related emission from Iron and Steel production are included in this source category.

EMISSION FACTORS

Country-specific emission factors were sourced from one of the Iron and Steel Companies in South Africa (Table 4.7) and these were based on actual process analysis at the respective plants. The country-specific emission factors for Electric Arc Furnace and Sinter Production are slightly higher than the IPCC default value, while that for Direct Reduced Iron Production is more than twice the default factor (Table 4.7). Differences in feedstock material and origin results in higher emission factors compared to the IPCC default emission factor values which assume consistent feedstock condition across countries.

4.4.4.2 Ferroalloys production [2C2]

The Tier 1 approach was used to calculate the GHG emissions from ferroalloys production, using production data and relevant IPCC default emission factors (Table 4.8).

4.4.4.3 Aluminium production [2C3]

The Tier 1 approach was used to calculate the GHG emissions from aluminium production, using production data and relevant IPCC default emission factors (Table 4.9). For aluminium production, it was assumed that the activity data is mainly for primary aluminium only, without any re-smelting.

Table 4.6: Sector 2 IPPU: Activity data for the various Metal Industries, 2000 – 2010.

		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Iron and Steel Production	Basic Oxygen Furnace production (tons)	4 674 511	4 849 655	5 051 936	5 083 168	4 949 693	5 255 831	5 173 676	4 521 461	4 504 275	3 953 709	4 366 727
	Electric Arc Furnace (tons)	3 724 914	3 861 133	3 997 352	4 301 301	4 455 875	4 137 292	4 429 648	4 464 344	3 671 687	3 530 223	3 250 035
	Pig Iron Production (not converted into steel) (tons)	705 872	706 225	706 578	706 931	733 761	735 378	739 818	705 428	460 746	429 916	584 452
	Direct Reduced Iron (DRI) Production (tons)	1 552 553	1 220 890	1 340 976	1 542 008	1 632 767	1 781 108	1 753 585	1 735 914	1 177 925	1 339 720	1 120 452
	Tata Steel production (tons)	0	0	0	0	0	0	0	0	45	115	106
Ferroalloy Production	Chromium Alloys (tons)	2 574 000	2 141 000	2 351 000	2 813 000	3 032 000	2 802 000	3 030 000	3 561 000	3 269 000	2 346 000	3 607 000
	Manganese Alloys (7% C) (tons)	596 873	523 844	618 954	607 362	611 914	570 574	656 235	698 654	502 631	274 923	529 300
	Manganese Alloys (1% C) (tons)	310 400	259 176	315 802	313 152	373 928	275 324	277 703	327 794	259 014	117 683	260 700
	Sillicon Alloys (Assume 65% Si) (tons)	108 500	107 600	141 700	135 300	140 600	127 000	148 900	139 600	134 500	110 400	128 760
	Silicon Metal (tons)	40 600	39 400	42 500	48 500	50 500	53 500	53 300	50 300	51 800	38 600	45 240
Aluminium Production	Prebake	586 868	573 285	623 778	629 668	778 067	784 638	800 668	808 630	788 859	811 324	808 795
	Soderberg	89 572	85 973	82 749	89 037	88 644	86 529	90 082	91 334	22 722	0	0
	CWPB	586 868	573 285	623 778	629 668	778 067	784 638	800 668	808 630	788 859	811 324	808 795
	SWPB	9 980	9 763	9 192	10 084	9 784	10 002	9 974	9 925	804	0	0
	VSS	79 592	76 210	73 557	78 952	78 860	76 527	80 108	81 409	21 917	0	0
Lead Production	Lead (tons)	75 300	51 800	49 400	39 900	37 500	42 200	48 300	41 900	46 400	49 100	50 600
Zinc Production	Zinc (tons)	113 000	110 000	113 000	113 000	112 000	108 000	101 000	97 000	91 000	92 000	36 100

Table 4.7: Sector 2 IPPU: Comparison of the country-specific emission factors for Iron and Steel Production and the IPCC 2006 default values (Source: Iron and Steel Company; IPCC 2006 Guidelines).

Type of Fuel	CO_2 Emission factor (tones CO_2 per tonne iron and steel)	
	Country-specific	IPCC 2006 default
Basic Oxygen Furnace	1.46	1.46
Electric Arc Furnace	1.1	0.08
Pig Iron Production (not converted into steel)	1.35	1.35
Direct Reduced Iron (DRI) Production	1.525	0.7
Sinter Production	0.34	0.2

Table 4.8: Sector 2 IPPU: Emission factors for Ferroalloy Production (Source: 2006 IPCC Guidelines).

Ferroalloy Type	CO_2	CH_4
	(tonnes per ferroalloys tonne production)	
Ferrosilicon (45%) Si	2.5	n/a
Ferrosilicon (65%) Si	3.6	1
Ferrosilicon (75%) Si	4	1
Ferrosilicon (90%) Si	4.8	1.1
Ferromanganese (7% C)	1.3	n/a
Ferromanganese (1% C)	1.5	n/a
Silicomanganese	1.4	n/a
Silicon metal	5	1.2

Table 4.9: Sector 2 IPPU: Emission factors for Aluminium Production (Source: 2006 IPCC Guidelines).

Aluminium Type	CO_2	CF_4	C_2F_6
	(kg CO_2 per aluminium tonne production)	(kg CH_4 per aluminium tonne production)	
Prebake	1.6	n/a	n/a
Soderberg	1.7	n/a	n/a
CWPB	n/a	0.4	0.04
SWPB	n/a	1.6	0.4
VSS	n/a	0.8	0.04

4.4.4.4 Lead production [2C5]

Emissions from Lead production were estimated using a Tier 1 approach. The emission factor of 0.52 tonnes CO_2 per tonne lead was sourced from the 2006 IPCC guidelines. In the calculation of lead production, it was assumed that that lead production was 80% Imperial Smelting Furnace and 20% direct smelting.

4.4.4.5 Zinc production [2C6]

Emissions from Zinc Production were calculated with the Tier 1 approach, using activity data and the IPCC 2006 default emission factor of 1.72 tonnes CO_2 per tonne zinc.

4.4.5 Uncertainty and time-series consistency

The necessary quality control measures were used to minimise estimation errors. The tier 1 approach for metal production emission estimates generates a number of uncertainties. For example, the IPCC 2006 Guidelines explain that applying Tier 1 to default emission factors for iron and steel production may have an uncertainty of ± 25%. The same range of uncertainty is associated with the tier 1 approach for ferroalloy production emission factors.

4.4.6 Source-specific QA/QC and verification

No specific QA/QC were performed in this source-category.

4.4.7 Source-specific recalculations

Recalculations have been performed in the Iron and Steel sub-category for the year 2000 due to the availability of new country-specific emission factors. No further recalculations were performed in this source-category.

4.4.8 Source-specific planned improvements and recommendations

As with most other subcategories, completeness of data is urgently needed for metal production activities. Other improvements would be ensuring that accurate activity data are collected and country specific emission factors are determined.

4.5 Non-energy use of fuels and solvent use [2D]

4.5.1 Source-category description

Non-energy use of fuels and solvents includes lubricants and paraffin wax. The use of solvents can result in evaporative emissions of various non-methane volatile organic compounds, which can be oxidized and released into the atmosphere. According to the 2006 IPCC guideline (p. 5.16) white spirit is used as an extraction solvent, cleaning solvent, degreasing solvent and as a solvent in aerosols, paints, wood preservatives, varnishes and asphalt products. Lubricants are used in industrial and transportation applications. Lubricants are divided into two types, namely motor and industrial oils; and greases which differ in physical characteristics. Paraffin wax use includes products such as petroleum jelly, paraffin waxes and other waxes (saturated hydrocarbons). Paraffin waxes are used in applications such as candles, corrugated boxes, paper coating, board sizing, food production, wax polishes, surfactants (as used in detergents) and many others (IPCC, 2006, p.5.11).

4.5.2 Overview of shares and trends in emissions

Total GHG emissions from the *Non-energy Products from Fuels and Solvent Use* fluctuated between 196 Gg CO_2eq and 250 Gg CO_2eq in 2000 to 2004 and 2007 to 2010, with a peak in emission occurring in 2006 (Figure 4.7). Emissions from Lubricant Use contributed over 96% to the total emissions from this category.

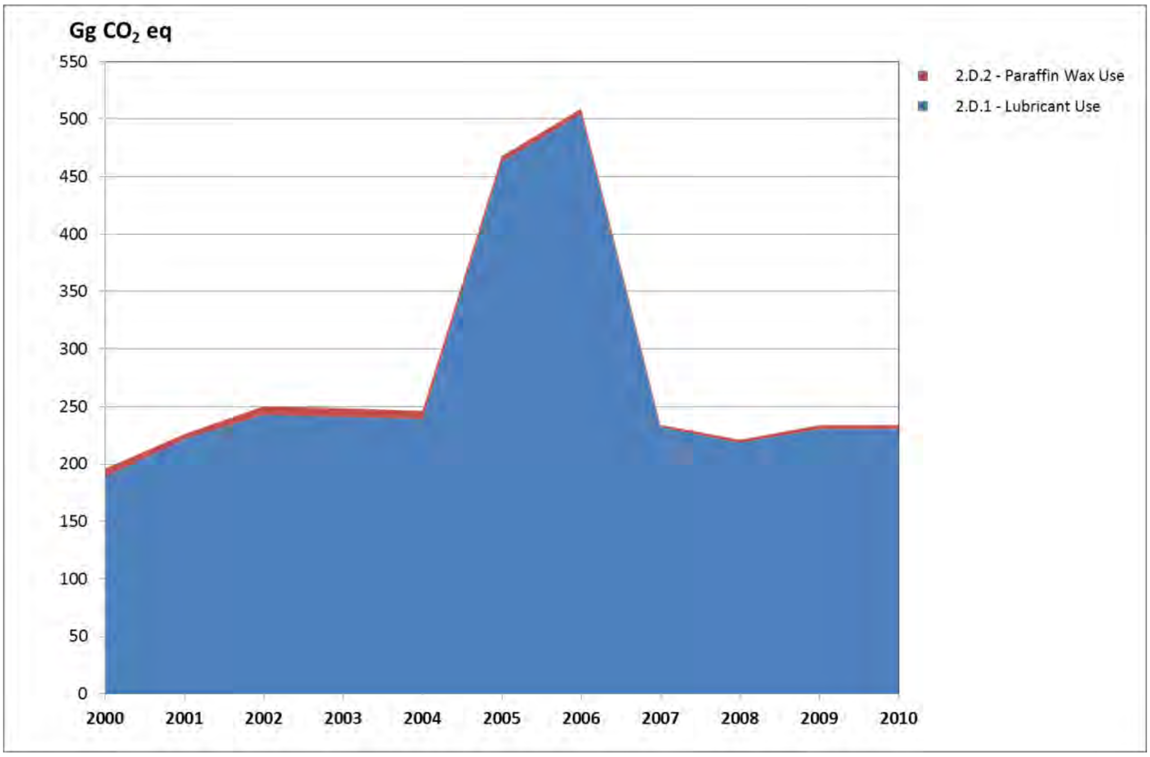

Figure 4.7: Sector 2 IPPU: Trends and emission levels from the Non-energy Products from Fuels and Solvent Use category, 2000 – 2010.

4.5.3 Data sources

The source of activity data for solvents was the energy balance tables that are published annually by the DoE (Table 4.10).

Table 4.10: Sector 2 IPPU: Total fuel consumption in the Non-energy use of Fuels and Solvent Use category, 2000 – 2010.

	Fuel consumption (TJ)	
	Lubricants	Paraffin Wax
2000	12 851	507
2001	15 092	314
2002	16 560	506
2003	16 430	521
2004	16 295	490
2005	31 549	350
2006	34 391	324
2007	15 818	141
2008	14 891	182
2009	15 706	231
2010	15 715	231

4.5.4 Methodology

Emissions for this category were estimated using a Tier 1 approach. In line with the 2006 IPCC guidelines (p.5.9) it was assumed that 90% of the mass of lubricants is oil and 10% of the mass is grease.

EMISSION FACTORS

The IPCC 2006 default emission factor for lubricating oils, grease and lubricants (0.2 tonnes CO_2 per TJ product) was used in the calculation of emissions from Lubricant and Paraffin Wax use.

4.5.5 Uncertainty and time-series consistency

The default ODU (Oxidised During Use) factors available in the IPCC guidelines are very uncertain, as they are based on limited knowledge of typical lubricant oxidation rates. Expert judgment suggests using a default uncertainty of 50%. The carbon content coefficients are based on two studies of the carbon content and heating value of lubricants, from which an uncertainty range of about ±3 % was estimated (US-EPA-2004). According to the IPCC guidelines much of the uncertainty in emission estimates is related to the difficulty in determining the quantity of non-energy products used in individual countries. For this a default of 5% may be used in countries with well-developed energy statistics and 10-20 % in other countries, based on expert judgement of the accuracy of energy statistics.

4.5.6 Source-specific QA/QC and verification

No source specific QA/QC was performed for this source category.

4.5.7 Source-specific recalculations

Emissions from non-energy use of fuels and solvents have been estimated for the first time and hence no recalculations were done for this source category.

4.5.8 Source-specific planned improvements and recommendations

Energy balances remain the source of activity data for this source-category and therefore no source-specific improvements are planned in the future. However, improvements in data collection for energy balances will reduce uncertainty in fuel use data.

4.6 Production uses as substitutes for ozone depleting substances [2F]

The Montreal Protocol on Substances that Deplete the Ozone Layer (a protocol to the Vienna Convention for the Protection of the Ozone Layer) is an international treaty designed to protect the ozone layer by phasing out the production of numerous substances believed to be responsible for ozone depletion. The hydrofluorocarbons (HFCs), and to a limited extent Perfluorocarbons (PFCs), are serving as alternatives to Ozone Depleting Substances (ODS) being phased out under this protocol. According to the 2006 IPCC guidelines current application areas of HFCs and PFCs include refrigeration and air conditioning; fire suppression and explosion protection; aerosols; solvent cleaning; foam blowing; and other applications (equipment sterilisation, for tobacco expansion applications, and as solvents in the manufacture of adhesives, coating and inks).

4.6.1 Overview of shares and trends in emissions

Total CO_2eq emissions from HFC's increased by 4.95% between 2005 (134.4 Gg CO_2eq) and 2010 (799.9 Gg CO_2eq) (Figure 4.8). There was no available data for the years prior to 2005. HFC-134a is the biggest contributor (68% to 93%), with HFC-143a contributing between 9% and 18% from 2005 to 2010.

4.6.2 Data sources

Activity data for ODS substitutes was sourced from the ODS database which is managed by the DEA. The ODS database registers imports and exports of ODS substances and their replacements. This data is sufficient to follow the Tier 1 methodology which requires national statistics on inflows and outflows of ODS replacement substances.

4.6.3 Methodology

The Tier 1 approach was used for the estimation of emissions from substitutes for ODS substance. The calculation of GHG emissions was done through a calculator that was provided by the IPCC. It was assumed that the equipment life time was 15 years and the emission factor from installed base was 15%. These assumptions were based on the defaults from the 2006 IPCC guidelines.

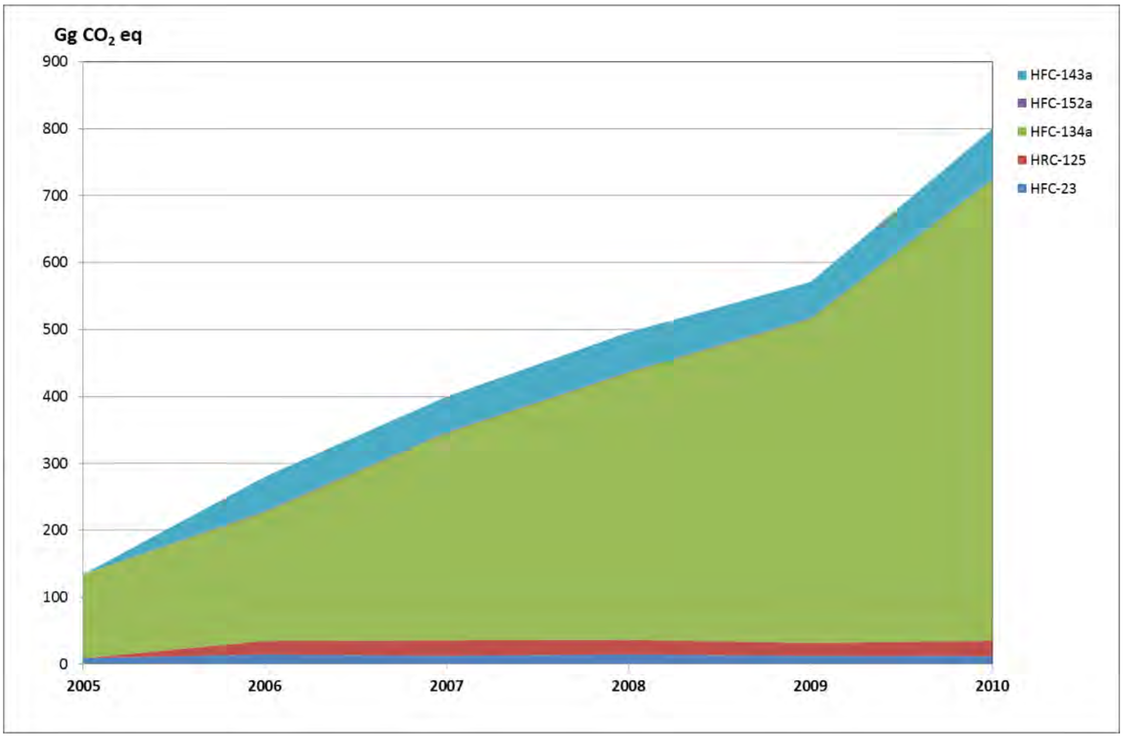

Figure 4.8: Sector 2 IPPU: Trends and emission levels of HFC's, 2005 – 2010.

4.6.4 Uncertainty and time-series consistency

There may be a wide range of other applications and therefore it is not possible to give default uncertainties for these sources. However, procedures should be put in place to assess levels of uncertainty in accordance with the practices outlined in Volume 1 Chapter 3 of the IPCC Guidelines.

4.6.5 Source-specific QA/QC and verification

Source-specific quality control is performed by the ODS database manager. The data submitted by ODS substance distributors is confirmed with the International Trade Administration Commission (ITAC) who is responsible for issuing import/export permits. In addition, the yearly import/export ODS figures are compared with import/export data obtained from the South African Revenue Services (SARS).

4.6.6 Source-specific recalculations

Emissions from this source category have been estimated for the first time and therefore there have been no recalculations.

4.6.7 Source-specific planned improvements and recommendations

According to the IPCC guidelines, it is *good practice* to estimate emissions from ODS replacement use by end-use sector (e.g. foam blowing, refrigeration etc). Future improvements would involve collection of data at sector level such that default emission factors can be applied at sectoral level.

5 AGRICULTURE, FORESTRY AND OTHER LAND USE

5.1 Overview of the sector

This section includes all emissions from the Agriculture, Forestry and Other Land Use (AFOLU) sector. Based on the IPCC 2006 guidelines the following categories are included in the emission estimates:

- Livestock
    - Enteric fermentation (IPCC section 3A1)
    - Manure management (IPCC section 3A2)
- Land
    - Forest land (IPCC section 3B1)
    - Cropland (IPCC section 3B2)
    - Grassland (IPCC section 3B3)
    - Wetlands (IPCC section 3B4)
    - Settlements (IPCC section 3B5)
    - Other land (IPCC section 3B6)
- Aggregate sources and non-CO_2 emissions on land
    - Biomass burning (IPCC section 3C1)
    - Liming (IPCC section 3C2)
    - Urea application (IPCC section 3C3)
    - Direct N_2O emission from managed soils (IPCC section 3C4)
    - Indirect N_2O emission from managed soils (IPCC section 3C5)
    - Indirect N_2O emission from manure management (IPCC section 3C6)

Emissions from fuel combustion in this sector are not included here as these fall under *Agriculture/Forestry/Fisheries* (see section 3.3.6) in the Energy sector. Categories not included in this report are 'Rice cultivation' (3C7), and 'Other' (3C8, 3D2), as they are not applicable to SA. Furthermore the category 3D1 on "Harvested Wood Products" has also not been included due to insufficient data. The Land Use component includes only *Land remaining Land* section and not the *Land converted to Other Lands* due to large uncertainties and insufficient data. This section also does not include the soil component as this requires information over a 20 year period (IPCC 2006 default time period) and information did not extend this far back.

Emissions from Buffalo have not been included in the *Enteric fermentation* and *Manure management* sections due to a lack of data. Buffalo data, as well as other wildlife, should be collected and emissions calculated for use in future inventories as these emissions could are estimated to contribute a further 10% to enteric emissions (Do Toit et al. 2013).

Manure management includes all emissions from confined, managed animal waste systems. Methane emissions from livestock manure produced in the field during grazing are included under *Manure management* (3A2), however the N_2O emissions from this source are included under category 3C4 *Direct N_2O emissions from managed soils*. This is in accordance with IPCC 2006 Guidelines. Methane emissions from managed soils are regarded as non-anthropogenic and are, according to the guidelines, not included.

Losses of CO_2 emissions from biomass burning for Forest land are included under *Losses due to disturbance* in the Forest land section (3B1) and not in the Biomass burning (3C1) section. Section 3C1 deals with non-CO_2 emissions from biomass burning in all land use types.

5.2 GHG Emissions from the AFOLU sector

5.2.1 Overview of shares and trends in emissions

The AFOLU sector was a source of CO_2 (Table 5.1). The source fluctuated over the 10 year period, but overall there appeared to be an increasing trend. The main cause of this was the decline in the Land CO_2 sink over the 10 years. The 2000 estimate in this inventory was 0.24% lower (19 974 Gg CO_2eq) than the previous inventory estimate of 20 022 Gg CO2eq (NIR, 2009) and the change was attributed to (a) improved methodologies in the Livestock category, (b) the use of different land cover map, and (c) inclusion of woodlands in Forest land. The land sub-sector data was also updated and included CO_2 losses from fires in Forest lands.

Table 5.1: Sector 3 - AFOLU: Trends in emissions and removals (Gg CO_2eq) from AFOLU sector, 2000 – 2010.

	3 - Agriculture, Forestry, and Other Land Use	*3.A - Livestock*	*3.B – Land*	*3.C - Aggregate sources and non-CO_2 emissions sources on land*
2000	19 974	*30 502*	*-19 557*	*9 030*
2001	23 525	*30 509*	*-16 170*	*9 186*
2002	21 968	*28 703*	*-16 917*	*10 183*
2003	18 249	*28 086*	*-18 709*	*8 872*
2004	23 128	*28 085*	*-13 882*	*8 924*
2005	31 184	*28 351*	*-6 017*	*8 851*
2006	31 789	*27 870*	*-5 314*	*9 233*
2007	28 011	*27 163*	*-8 400*	*9 248*
2008	32 127	*27 945*	*-5 340*	*9 522*
2009	23 294	*27 430*	*-13 335*	*9 199*
2010	33 717	*28 279*	*-3 837*	*9 274*

Total GHG emissions from Livestock declined by 7.3%, from 30 502 Gg CO_2eq in 2000 to 28 279 Gg CO_2eq in 2010. The decline was attributed mainly to the decline in cattle, sheep and goat populations. Between 1990 and 2000 there was a 25% decline, although the recalculations and updated methodology accounts for 21% of this, as the previous inventory estimated emissions in 2000 to be 38 716 Gg CO_2eq (NIR, 2009). Emissions from Aggregated and non-CO_2 emission sources fluctuated annually between a low of 8 885 Gg CO_2eq (2005) and a high of 10 183 Gg CO_2eq (2002). The fluctuation was driven mainly by changes in biomass burning. A comparison with the previous inventory was difficult as many sections in this category were not included in the previous inventory and they were not grouped together under *Aggregated and non-CO_2 emission sources*. The previous inventory only included biomass burning emissions (1 865 Gg CO_2eq) and indirect N_2O emissions from managed soils (17 427 Gg CO_2eq), however the emissions from these two sub-categories alone are much higher than all the *Aggregated and non-CO_2 emission sources* estimated in the current inventory. The Land component is estimated to be a sink, varying between 3 837and 19 557 Gg CO_2eq (Table 5.1), however the possible soil carbon sink has not been included due to a lack of data. Annual fluctuations were due mostly to changes in carbon losses by wood harvesting and disturbance.

In all years it was the CH_4 emissions that dominate the AFOLU sector (Figure 5.1) and 95.8% (average over 10 years) of the CH_4 came from *Enteric fermentation*. The contribution from N_2O fluctuated annually but was less than 20% (average of 16.2%) in all years.

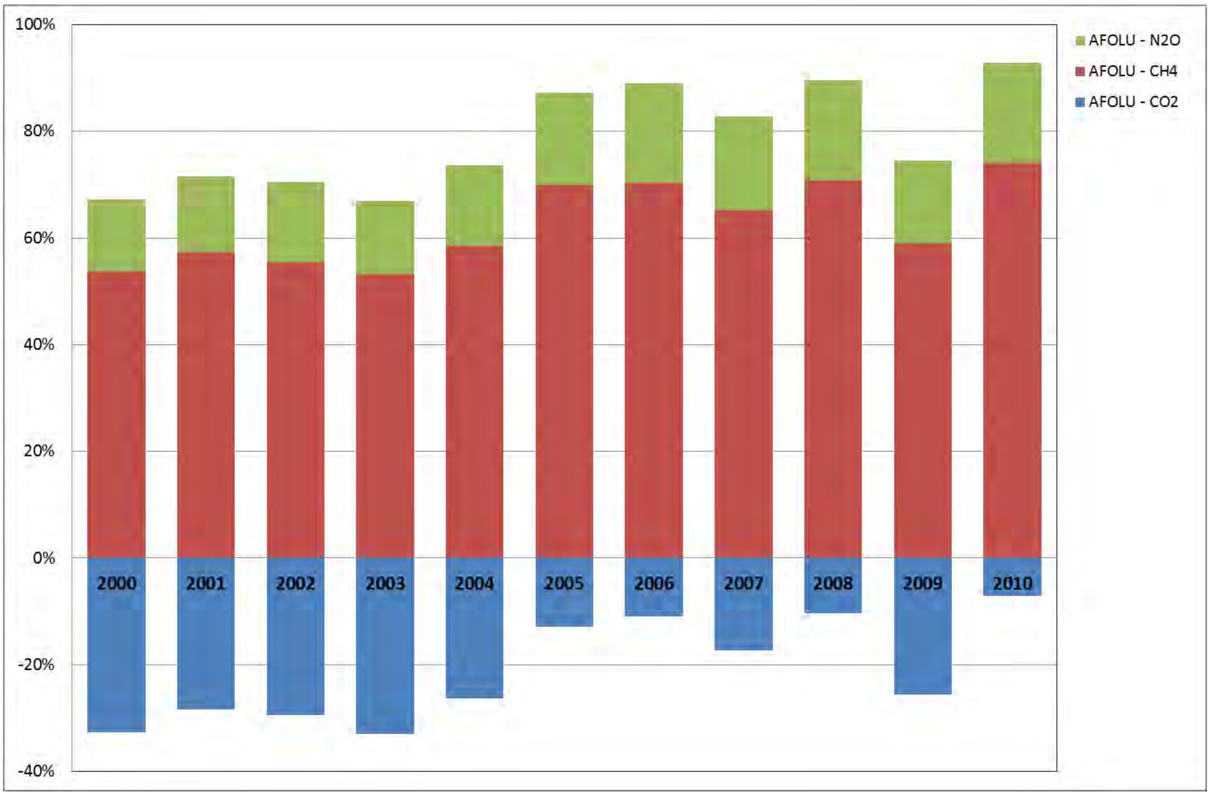

Figure 5.1: Sector 3 AFOLU: Percentage contribution of the various GHG to the total AFOLU inventory, 2000 – 2010.

5.2.2 Key sources

A Level and Trend key category analysis including the AFOLU sector was carried out on the 2010 data, and using 2000 as the base year (Appendix B). These showed that the key categories in this sector are *Enteric fermentation*, *Forest land remaining Forest land* and, to a lesser extent, indirect N_2O from managed soils.

5.2.3 Recalculations

The Agricultural category of this inventory included a greater disaggregation of the livestock population. Also, the enteric and manure management CH_4 emission factors were calculated using a different methodology and data from the previous inventory and were based on a recent study (Du Toit et al., submitted). Due to these updated activity data and emission factors the livestock emission in 2000 were recalculated.

In terms of the Land category there were several changes and recalculations which are discussed in further detail in section 5.4:

- New land use maps were developed for 2000 to 2010;
- Woodlands/Savannas and Thickets were incorporated into Forest land;
- Updated carbon data was included;
- Carbon losses from fires was incorporated into Forest lands;
- Burnt area data was updated for the new land use maps;
- Land converted to Forest land (in the form of plantations) was excluded; and
- CH_4 emissions from wetlands were excluded.

The biomass carbon data for 2000 were recalculated based on these changes. The Land use category is far from complete and needs further data validation and data collection so that Croplands, land conversions, the soil and a complete DOM component can be included.

5.3 Livestock [3A]

5.3.1 Overview of shares and trends in emissions

The GHG emissions from livestock produced a total accumulated amount of 312 922 Gg CO_2eq between 2000 and 2010. Overall livestock emissions have declined by 7.3% over the same period from 30 501 Gg CO_2eq in 2000 to 28 280 Gg CO_2eq in 2010 (Figure 5.2). There was a decline of 7.9% between 2001 and 2004, with an increase of 1%, 2.9% and 3.1% in 2005, 2008 and 2010 respectively. The enteric fermentation emissions were closely linked to the cattle population numbers (see section 5.3.3.3). Enteric fermentation accounted for an average of 96.8% of the GHG emissions from livestock, while the rest was from manure management (with an even split between the contribution from CH_4 and N_2O). Emissions from manure management show a decreasebetween 2000 (901 Gg CO_2eq) and 2003 (843 Gg CO_2eq), then increased all the way through to 2010 (980 Gg CO_2eq). This pattern was closely linked to the swine and poultry population as much of the manure from those livestock is managed, whereas for cattle (except feedlots), sheep and goats the manure is deposited in the pastures and is not managed.

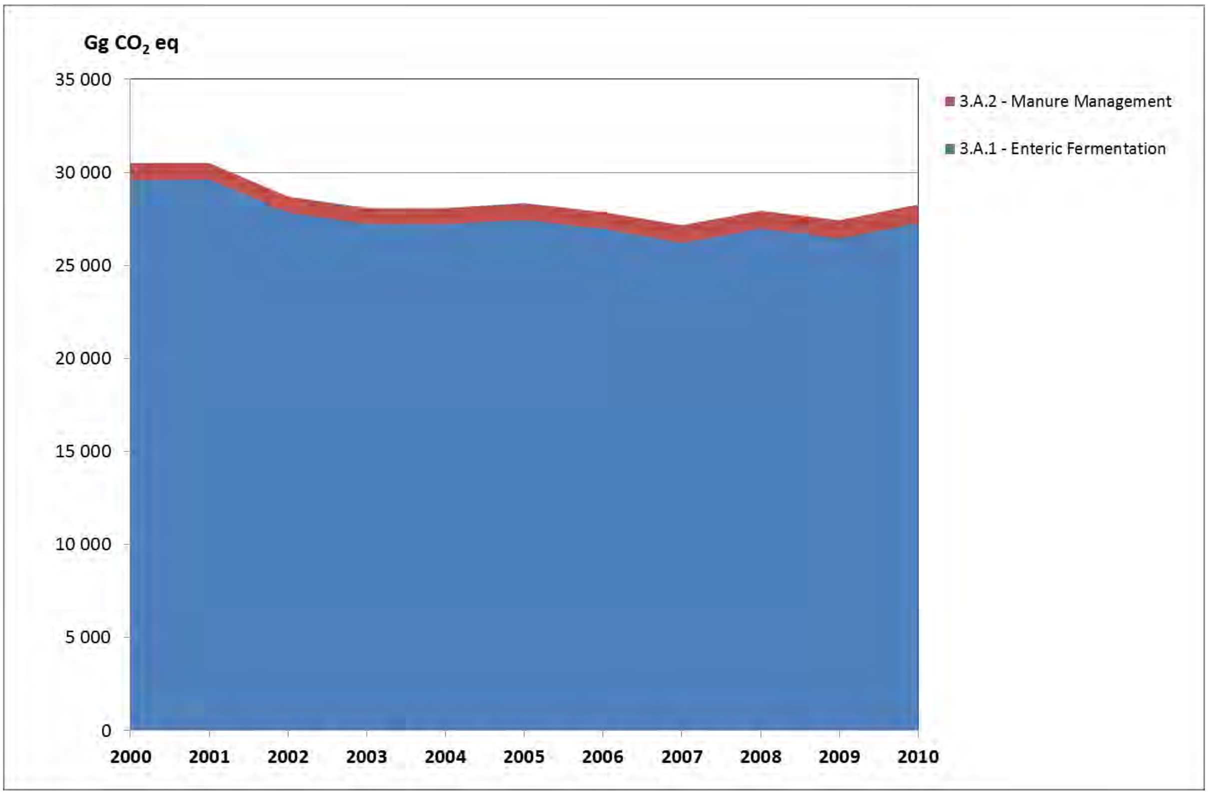

Figure 5.2: Sector 3 AFOLU: Trends in GHG emissions from the livestock category, 2000 – 2010.

5.3.2 Overview of trends in activity data

The total livestock population increased by 5.4% between 2000 and 2010, and this was mainly due to an increase in the poultry industry. If poultry numbers were excluded then there was a general decline (of 7.9%) in the remaining livestock population over the 10 year period (Figure 5.3). Commercial beef cattle population has declined from 7.7 million in 2000 to 7.3 million in 2010, and the communal beef cattle have also declined from 5 million in 2000 to 4.7 million in 2010. The dairy cattle population declined between 2000 and 2004, but then increased again between 2005 and 2010. Sheep and goat populations have also declined slightly, while swine populations have increased over the 10 year period. Poultry numbers showed a slight decline between 2000 and 2003, but then increased to 2007 after which they remained fairly stable. Generally the commercial population numbers were higher than the communal numbers, except for goats as the communal goat population was twice that of the commercial population.

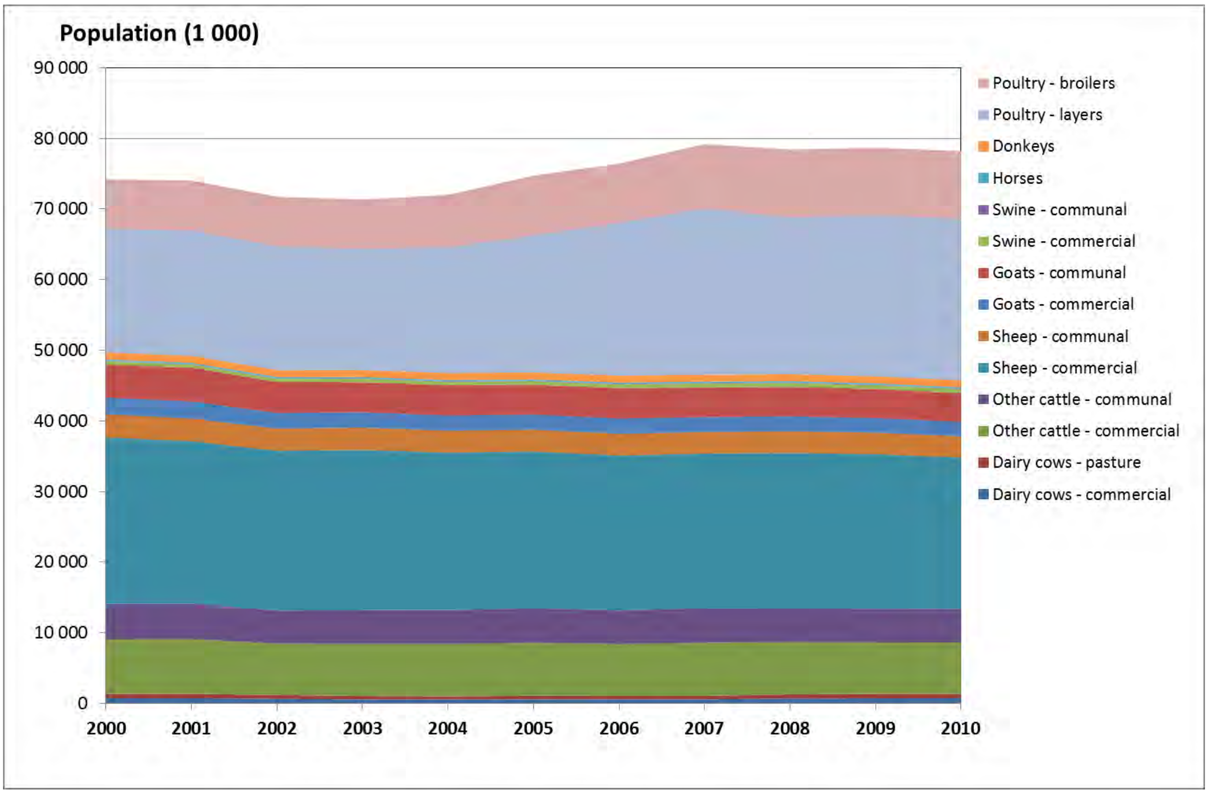

Figure 5.3: Sector 3 AFOLU - Livestock: Trends in livestock population numbers, 2000 – 2010.

5.3.3 Enteric fermentation [3A1]

5.3.3.1 Source-category description

Methane is the main greenhouse gas produced from agricultural livestock production. Livestock contributes about 18% of the global GHG emissions, and as much as 37% of anthropogenic methane, mostly from enteric fermentation by ruminants (Chhabra *et al.*, 2009). CH_4 from enteric fermentation is produced in herbivores as a by-product of the digestive process by which carbohydrates are broken down by methanogenic bacteria and protozoa into simple molecules for absorption into the blood-stream (Baggot *et al.*, 2006; IPCC, 1997; IPCC, 2006). CH_4 from enteric fermentation is released mainly through eructation and normal respiration, and a small quantity as flatus (Bull *et al.*, 2005; Chhabra *et al.*, 2009). The amount of CH_4 produced and emitted by an individual animal depends primarily on the animal's digestive system and the amount and type of feed it consumes (IPCC, 1997; Garcia-Apaza *et al.*, 2008). South Africa's animal data are divided into three main groups according to their different methane producing ability, namely ruminants (cattle, sheep, goats), pseudo-ruminants (horses, donkeys) and monogastric animals (pigs) (DAFF, 2009).

Camels and llamas do not occur in South Africa. The emissions from Buffalo and other game animals were not included here due to insufficient activity data. Enteric fermentation from CH_4 emissions from poultry are not estimated as the amount produced is negligible. Other countries do not estimate the emissions from poultry either.

5.3.3.2 Overview of shares and trends in emissions

Enteric fermentation emissions from livestock declined by 7.8% between 2000 (29 601 Gg CO_2eq) and 2010 (27 299 Gg CO_2eq) (Figure 5.4:), mainly due to a decline in population numbers. There was a slight increase in emissions in 2005 (0.9%), 2008 (2.9%) and 2010 (3.2%). These increases are due attributed to an increase in the number of mature cows and heifers in these years (Figure 5.5). Mature cows and heifers have a higher emission factor than calves (Table 5.3) due to a well-developed gut. Cattle are the largest contributors to the enteric fermentation emissions (81.8% in 2010), with 12.6% from dairy cattle (Figure 5.6). Following this are the contributions from sheep (13.8% in 2010) and goats (3.2%).

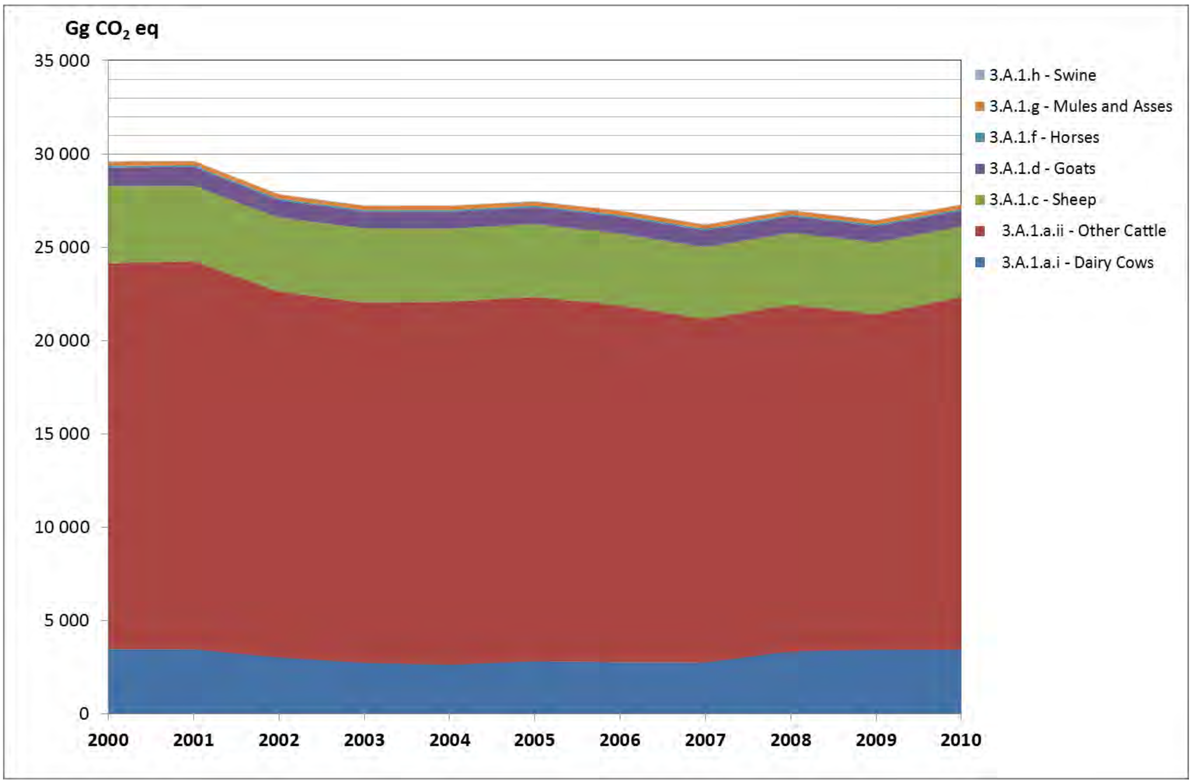

Figure 5.4: Sector 3 AFOLU - Livestock: Trend and emission levels of enteric fermentation emissions in the livestock categories, 2000 – 2010.

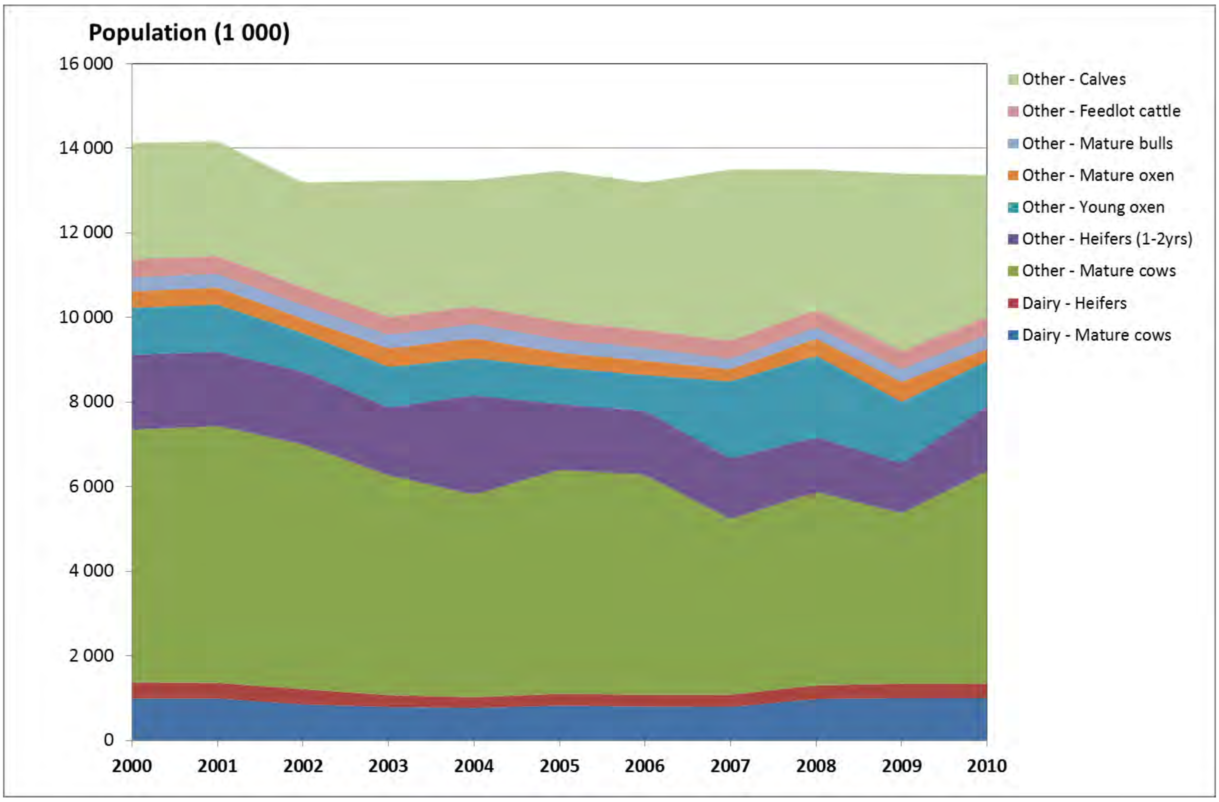

Figure 5.5: Sector 3 AFOLU - Livestock: Trend in cattle herd composition, 2000 – 2010.

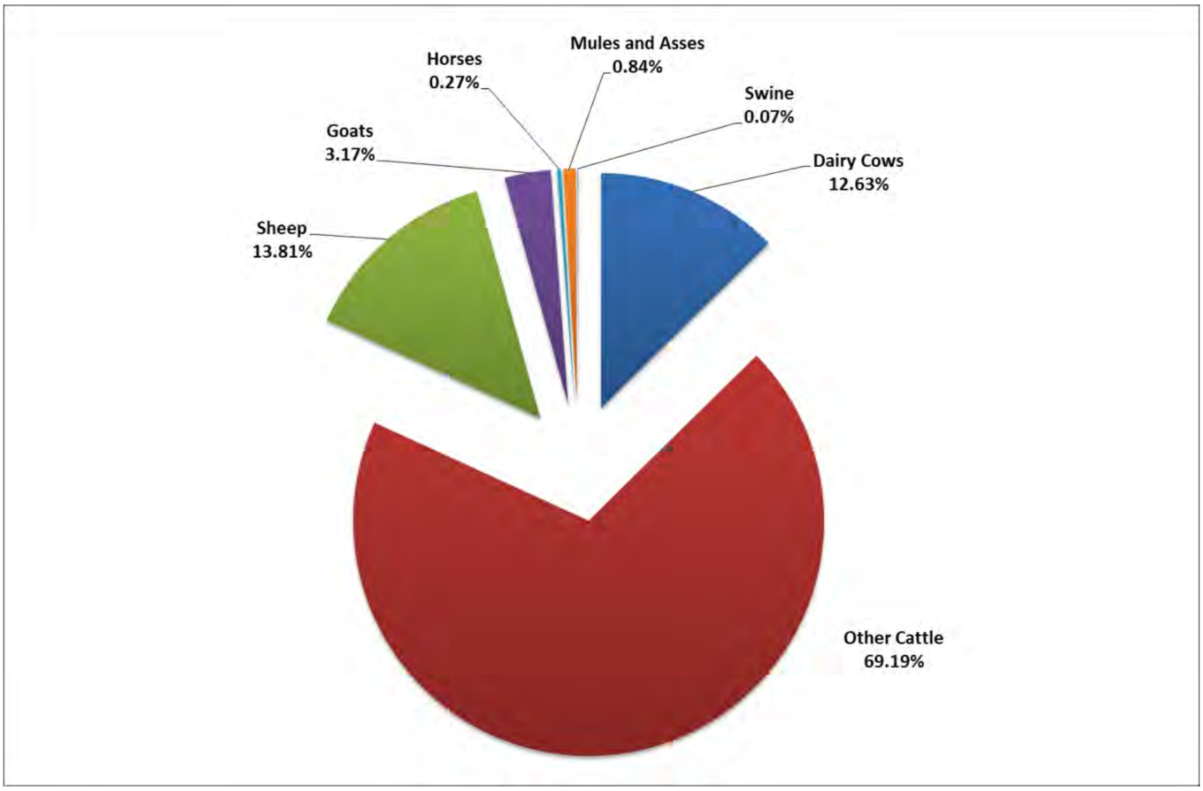

Figure 5.6: Sector 3 AFOLU – Livestock: Contribution of the livestock categories to the enteric fermentation emissions in 2010.

5.3.3.3 Data sources

LIVESTOCK CATEGORIZATION AND POPULATION NUMBERS

The first step in estimating CH_4 emissions from enteric fermentation and CH_4 and N_2O emissions from manure management involves dividing the farmed animal population into the livestock categories and sub-categories. The livestock categories and sub-categories used in this inventory update are shown in Table 5.2.

Cattle, sheep, goat and pig population data were obtained from the Abstracts of Agricultural Statistics 2012. The commercial population numbers for these animals has a consistent time-series dating back to 1970. To further divide the livestock into the additional sub-categories (for dairy, sheep, goats and swine), the herd composition given in Du Toit et al. (submitted) was applied to these numbers. It was assumed that the population split remained constant between 2000 and 2010. Du Toit et al. (submitted) obtained data from the individual livestock industries. The swine population numbers were calculated from the slaughterings given in the Abstracts of Agricultural Statistics, assuming one sow will produce 20 piglets per year. Once the sow numbers were determined, then the herd structure of Du Toit et al. (submitted) was applied.

The total communal population number for cattle, sheep and goats was obtained from an average of the quarterly census numbers which have been recorded from 2000 onwards (available from DAFF; http://www.daff.gov.za/ accessed on 12 Aug 2010). The communal livestock numbers were given as a total so to determine the amount in each livestock sub-category the same ratio as that of commercial livestock was assumed.

Table 5.2: Sector 3 AFOLU – Livestock: Livestock categories used in the determination of livestock emissions.

Main category		**Dairy cattle**	**Other cattle**	**Sheep**	**Goats**	**Swine**	**Horses**	**Mules and asses**
Sub-category	Commercial (or TMR for dairy cattle)	Lactating cow	Bulls	Non-wool ewe	Buck	Boars		
		Lactating Heifer	Cows	Non-wool ram	Doe	Sows		
		Dry cow	Heifers	Non-wool lamb	Weaner/kid	Pre-wean piglets		
		Pregnant heifers	Ox	Wool ewe	Angora	Cull pigs		
		Heifers >1 yr	Young ox	Wool ram	Milk goat	Replacement pigs		
		Heifers 6-12 mths	Calves	Wool lamb		Baconers		
		Heifers 2-6months				Porkers		
		Calves < 2 months						
	Communal (or pasture based for dairy cattle)	Lactating cow	Bulls	Ewe	Buck	Boars		
		Lactating Heifer	Cows	Ram	Doe	Sows		
		Dry cow	Heifers	Lamb	Weaner/kid	Pre-wean piglets		
		Pregnant heifers	Ox			Cull pigs		
		Heifers >1 yr	Young ox			Replacement pigs		
		Heifers 6-12 mths	Calves			Baconers		
		Heifers 2-6months				Porkers		
		Calves < 2 months						

Annual feedlot cattle numbers were only available for the years 2008 – 2010 (Feedlot Association of SA), so an average of 420 000 (http://www.safeedlot.co.za/index.asp?Content=90; accessed 10 June 2013; personal communication with Dave Ford, Executive Director, SA Feedlot Association) was used for each year between 2000 and 2010. The number of cattle in feedlots fluctuates by at most 20 000 around this number and this number is not expected to change much over a 10 year period (Dave Ford, Executive Director, SA Feedlot Association).

Data on horse and donkey populations in South Africa are very scarce. Census data obtained from DAFF (Selebogo Leshoro, DAFF) showed there were 20 588 horses in 2002 and 21 431 in 2007. However a detailed report by Simalenga *et al*. (2002) indicated the horse population to be 180 000, while the donkey population was at 1 million. This was based on 1995 data. FAO data (http://faostat.fao.org/site/573/default.aspx#ancor; accessed on 12 Aug 2010) gives a value of 270 000 for horses and 164 000 mules/asses in South Africa, and these numbers have remained constant over the last 5 years. The data varies quite widely, however it was decided that the numbers from Simalenga *et al*. (2002) would be used as these are the most detailed and were used in the 2004 inventory (DAFF, 2010). The only difference was that in order to include some annual variation the annual horse population increase (average of 0.8%) shown by the linear trend through the DAFF census data was applied to the horse numbers from Simalenga *et al*. (2002), assuming that the number of 180 000 was from 1995. None of the data indicates any change in the donkey numbers over a 6 year period so it was assumed that the donkey population numbers remained constant at 1 million between 2000 and 2010.

LIVE WEIGHT DATA

The live weight data of the various livestock categories and sub-categories was taken from Du Toit et al. (submitted) (Table 5.3). In some cases there were more detailed sub-categories, so in these cases values were averaged to get the values for the livestock sub-categories used in this inventory.

IMPLIED METHANE EMISSION FACTORS

South Africa has identified enteric fermentation as a key source category, therefore tier 2 methods were used to determine enteric fermentation emissions from the major livestock categories. The emission factors (EF) were taken from Du Toit et al. (submitted) (Table 5.3) who developed country specific methodologies based on the country specific methods developed by Australia and described in detail in their National Inventory Reports (ANIR, 2010). In the 2004 agricultural inventory (DAFF, 2010) it was determined that the emissions factors for South African livestock were similar to those of Australia, a country which has similar climatic conditions. This was one of the reasons for adopting the Australian methodology. The IEF takes into account the climate, feed digestibility and energy intake of the various livestock. Du Toit et al. (submitted) calculated the emission factors for the year 2010. In this inventory, we assumed that the emission factors remained constant between 2000 and 2010. IPCC 2006 default emission factors were used for horses and donkeys.

Table 5.3: Sector 3 AFOLU – Livestock: Livestock weights, implied methane emission factors and IPCC 2006 default emission factors.

Livestock category	Livestock sub-category	Weight (kg)	$EF_{enteric}$ (kg head^{-1} year^{-1})	IPCC default EF	
				Africa	Oceania
Dairy – TMR	Lactating cows	590	142.74	40	81
	Lactating heifers	503	136.72		
	Dry cows	590	80.41		
	Pregnant heifers	394	67.66		
	Heifers > 1 year	322	62.63		
	Heifers 6 – 12 months	172	42.12		
	Heifers 2 – 6 months	55	22.50		
	Calves	35	21.51		
Dairy – pasture	Lactating cows	540	137.02	40	81
	Lactating heifers	438	124.99		
	Dry cows	540	83.37		
	Pregnant heifers	333	61.78		
	Heifers > 1 year	254	52.63		
	Heifers 6 – 12 months	142	37.11		
	Heifers 2 – 6 months	54	24.49		
	Calves	36	20.02		
Other cattle - commercial	Bulls	733	112.63	31	60
	Cows	475	92.64		
	Heifers	365	75.89		
	Ox	430	89.44		
	Young ox	193	51.64		
	Calves	190	51.58		
	Feedlot	335	58.87		
Other cattle - communal	Bulls	462	83.83	31	60
	Cows	360	73.09		
	Heifers	292	62.51		
	Ox	344	72.56		
	Young ox	154	41.58		
	Calves	152	40.92		
Sheep – commercial	Non-wool ewe	55	8.27	5	8
	Non-wool ram	83	12.27		
	Non-wool lamb	30	4.58		
	Wool ewe	55	8.18		
	Wool ram	103	15.77		
	Wool lamb	29	4.39		
Sheep – communal	Ewe	44	5.91	5	8
	Ram	74	10.29		
	Lamb	23	3.35		
Goats – commercial	Buck	103	15.68	5	5
	Doe	67	10.04		
	Weaner/kid	60	9.16		
	Angora	26	4.16		
	Milk goat	45	6.88		
Goats – communal	Buck	72	9.60	5	5
	Doe	47	6.30		
	Weaner/kid	21	3.10		
Swine – commercial	Boars	300	1.89	1	1.5
	Sows	325	3.12		
	Pre-wean piglets	9	0.43		
	Cull pigs	325	1.72		
	Replacement pigs	135	2.41		
	Baconers	90	0.99		
	Porkers	70	0.51		
Swine – communal	Boars	240	1.55	1	1.5
	Sows	260	2.50		
	Pre-wean piglets	7	0.34		
	Cull pigs	260	1.40		
	Replacement pigs	108	1.93		
	Baconers	90	0.79		
	Porkers	70	0.41		
Horses		595	18.00	18	18
Mules and asses		250	10.00	10	10

COMPARISON OF IMPLIED METHANE EF WITH IPCC DEFAULTS

A comparison of implied methane emission factors (IEF) and IPCC default factors is shown in Table 5.4. The IEF's were seen to be in the same range as the Oceania or developed country emission factors as opposed to the Africa or developing country default factors. This was not unexpected. The reasons for these differences were evaluated by investigating the IPCC 2006 default productivity data used to calculate the default emission factors. The milk production in SA in 2010 was 14.5 kg day^{-1}, which is much higher than the 1.3 kg day^{-1} given for Africa (**Error! Not a valid bookmark self-reference.**). The cattle weights in RSA were much higher than those given for the African default. For example, the weight of dairy cows in this study was between 333 kg and 590 kg, which were much higher than the value 275 kg given for Africa. The pregnancy and DE percentages in this study were also higher than those used in the calculation of the default IPCC values.

Table 5.4: Sector 3 AFOLU – Livestock: Comparison between the productivity data used and EF calculated in this inventory and the IPCC 2006 Guideline default values.

Livestock category	Parameter	Value used in this study (2010)	IPCC 2006 default values (Table 10.11, 10A.1, 10A.2)		
			Africa	Oceania	Western Europe
Dairy cattle	Milk production (kg head^{-1} yr^{-1})	6,015	475	2,200	6,000
	Milk production (kg day^{-1})	14.5	1.3	6	16.4
	Cattle weight (kg)	333 – 590 (heifer - mature cow)	275 (mature cow)	500	600
	Pregnancy (%)	58	67	80	90
	DE%	76	60	60	70
Other cattle	Cattle weight (kg)	Communal: 360 – 462 (cow - bull); Commercial: 475 – 733 (cow - bull)	200 – 275 (cow - bull)	400 – 450 (cow - bull)	400 – 600 (bulls)
	Pregnancy	24 – 49	33	67	No value given
	DE%	55 - 80	55	55	60 – 65

5.3.3.4 *Methodology*

The proportion of intake that is converted into methane is dependent on both the characteristics of the animal, feed and the amount eaten. Given the heterogeneity of available feed types within South Africa it was considered important to use methodologies that could reflect such differences, developed under similar conditions as in Australia. A detailed description of the methods, data sources and emission factors is found in Du Toit et al. (submitted), and are summarized below.

Emissions from enteric fermentation are calculated from activity data on animal numbers and the appropriate emission factor:

CH_4 emission = ΣEF*i* (kg CH_4 animal^{-1}) * [number of animals for livestock category *i*] (*Eq.5.1*)

DAIRY CATTLE [3A1ai]

Emission factors for the various sub-categories of dairy cattle were taken from Du Toit et al. (submitted). These EF's were calculated using a Tier 2 approach following the equation:

$$EF = ((Y/100) * GEI * 365)/ F \qquad (Eq.5.2)$$

Where:
EF = Emission factor in kg CH_4 animal^{-1} year^{-1};
Y = % of GEI yielded as CH_4 (calculated from equation in Blaxter and Clapperton, 1965);
GEI = gross energy intake (MJ head^{-1} day^{-1});
F = 55.22 MJ (kg CH_4)$^{-1}$ (Brouwer, 1965).

The gross energy intake (GEI) is the sum of the intake converted into energy terms assuming a gross energy content of 18.4 MJ kg^{-1}. An average daily milk production (14.5 kg day^{-1}) was sourced from LACTO data (2010). Further details of how the various factors were calculated are provided in Du Toit et al. (submitted).

OTHER CATTLE [3A1aii]

The emission factors for commercial and communal cattle were taken from Du Toit et al. (submitted). These EF's were calculated following an equation developed by Kurihara *et al*. (1999) to calculate the total daily methane production for animals grazing in tropical pastures:

$$EF = ((34.9 \times I – 30.8)/ 1000) \times 365 \qquad (Eq.\ 5.3)$$

Where:
EF = methane emission factor (kg CH_4 animal^{-1} year^{-1})
I = Feed intake (kg day^{-1})

The feed intake (I) was calculated from live weight and live weight gain data following the equation of Minson and McDonald (1987). An additional intake for milk production was incorporated where a feed adjustment value of 1.3 was used during the calving season and 1.1 during the following season. Further details provided in Du Toit et al. (submitted).

Feedlot beef cattle

Feedlot enteric methane emission factors were taken from du Toit et al. (in press) who based their calculations on intake of specific diet components using an equation developed by Moe and Tyrrell (1979):

$$EF = (3.406 + 0.510SR + 1.736H + 2.648C) \times 365 \qquad (\textit{Eq.5.4})$$

Where:
SR = intake of soluble residue (kg day^{-1});
H = intake of hemicellulose (kg day^{-1});
C = intake of cellulose (kg day^{-1}).

Soluble residue intake, hemicellulose intake and cellulose intake were calculated from feedlot diet analysis (ANIR, 2009) and average DM intake taken as 8.5 kg DM per day (South African feedlot association and industry experts).

Total annual methane production (EF, kg CH_4 $head^{-1}$ $year^{-1}$) was calculated as:

$$EF = (Y / F) \times 365 \qquad (\textit{Eq.5.5})$$

Where:
F = 55.22 MJ (kg CH_4 $)^{-1}$ (Brouwer, 1965)

The total feedlot calculations are based on the assumption that an animal will stay in the feedlot for approximately 110 days (3 cycles per year).

SHEEP [3A1c]

Sheep CH_4 emission factors were taken from Du Toit et al. (submitted) which are based on the equations of Howden et al. (1994):

$$EF = (I \times 0.0188 + 0.00158) \times 365 \qquad (\textit{Eq.5.6})$$

Where:
EF = emission factor (kg CH_4 $head^{-1}$ $year^{-1}$);
I = Feed intake (kg DM day^{-1}).

The actual feed intake by sheep was calculated from the potential feed intake (determined by body size and the proportion of the diet that was able to be metabolised by the animal), relative intake (based on dry matter availability) and an additional intake for milk production.

GOATS [3A1d]

The CH_4 emission factors for the various goat sub-categories were taken from Du Toit et al. (submitted). These calculations followed the same methodology as for sheep. Goats are browsers they are also selective feeders and will select for quality. It was assumed that lactating milk goats will receive a higher quality diet with a DMD of 70% throughout the year.

SWINE [3A2h]

CH_4 emission factors for the pig sub-categories were taken from Du Toit et al. (submitted) which were based on the methodology described in the Australian National Inventory (ANIR, 2009):

$$EF = I \times 18.6 \times 0.007 / F \qquad (Eq.5.7)$$

Where:
EF = emission factor (kg CH_4 head^{-1} year^{-1})
I = Feed intake (kg DM day^{-1});
F = 55.22 MJ (kg CH_4)$^{-1}$ (Brouwer, 1965);
18.6 = MJ GE per kg feed DM.

A methane conversion factor of 0.7% was used in calculation for pigs based on the ANIR (2009). Further details are provided in Du Toit et al. (submitted).

HORSES AND DONKEYS [3A1f AND 3A1g]

The contribution of horses and donkeys to the total methane emissions was relatively small, and given the lack of data on methane production from these animals, a complex methodology, incorporating relationships between feed intake and methane production, is inappropriate. Therefore the emissions from horses and donkeys were based on the Tier 1 methodology and IPCC default emission factors.

5.3.3.5 Uncertainty and time-series consistency

Uncertainty for enteric fermentation was estimated to be in the order of 5%. Time-series consistency was ensured by using consistent methods for the 10 year period, as well as for the recalculations in 2000.

5.3.3.6 Source-specific QA/QC and verification

Population data was obtained for a 40 year period for cattle, sheep, goats and pigs and trends were checked and there were no sudden changes in the data. For poultry a 10 year trend was monitored. Population numbers were also checked against the numbers from the individual livestock organizations for the year 2010. These numbers were found to vary slightly, however the variation for all livestock except pigs was smaller than the uncertainty on the national population numbers, therefore the national numbers were used because of the long time period of the data. It also assists with the time-series consistency if the same source of data is used throughout. The pig data may need to be investigated further in the future as there seemed to be a greater discrepancy between the national numbers and SAPPO's numbers than for the other livestock.

Implied emission factors were compared to the IPCC default factors (Section 5.3.3.3). No actual measurements have been made on methane emissions from livestock in South Africa, so no direct comparisons can be made.

5.3.3.7 Source-specific recalculations

Disaggregated livestock population numbers, along with updated methane emission factors and liveweights for each sub-category were incorporated into this inventory, so recalculations for the year 2000 were completed using the same methodology.

5.3.3.8 Source-specific planned improvements and recommendations

There are no planned improvements, however it is recommended that in future annual emission factors, incorporating changes in feed quality and milk production, be calculated instead of assuming a constant emission factor.

5.3.4 Manure management [3A2]

5.3.4.1 Source-category description

Manure management includes storage and treatment of manure, before using it as farm manure or burning as fuel. Methane (CH_4) and nitrous oxide (N_2O) are produced during different storage and treatment stages of manure. The term 'manure' includes both dung and urine produced by livestock.

Camels and llamas do not occur in SA and were therefore not included in the report. There is a fair amount of Buffalo in RSA, however, wildlife were not included in the emission estimates due to a lack of data. The majority of manure in RSA is produced and left in the pastures while grazing. In accordance with IPCC Guidelines, N_2O emissions from the manure left in pastures and daily spread are not taken into account in this source category (Manure management), but are included in the source category for managed soils.

5.3.4.2 Overview of shares and trends in emissions

Manure management produced a total of 980 Gg CO_2 eq in 2010, which increased from the 901 Gg CO_2 eq produced in 2000. Methane emissions accounted for an average of 49.6% of the manure emissions over the 10 year period. The largest contributor to the CH_4 emissions were the dairy cattle (40.9% - 52.5%), closely followed by swine (35.6% - 46.8%) (Figure 5.7). The contribution of CH_4 from dairy cattle manure management declined over the period 2000 to 2010 by 0.2%, while the contribution from swine manure increased by 15.3%. In terms of the N_2O emissions from manure management, beef manure from feedlots contributed an average of 59% and poultry 36.5% (Figure 5.8). The contribution from poultry increased from 145 Gg CO_2eq to 192 Gg CO_2eq (32.6%) between 2000 and 2010. Even though the contribution from swine was less than 5% there was a 15% increase in their contribution to the N_2O emissions from manure management.

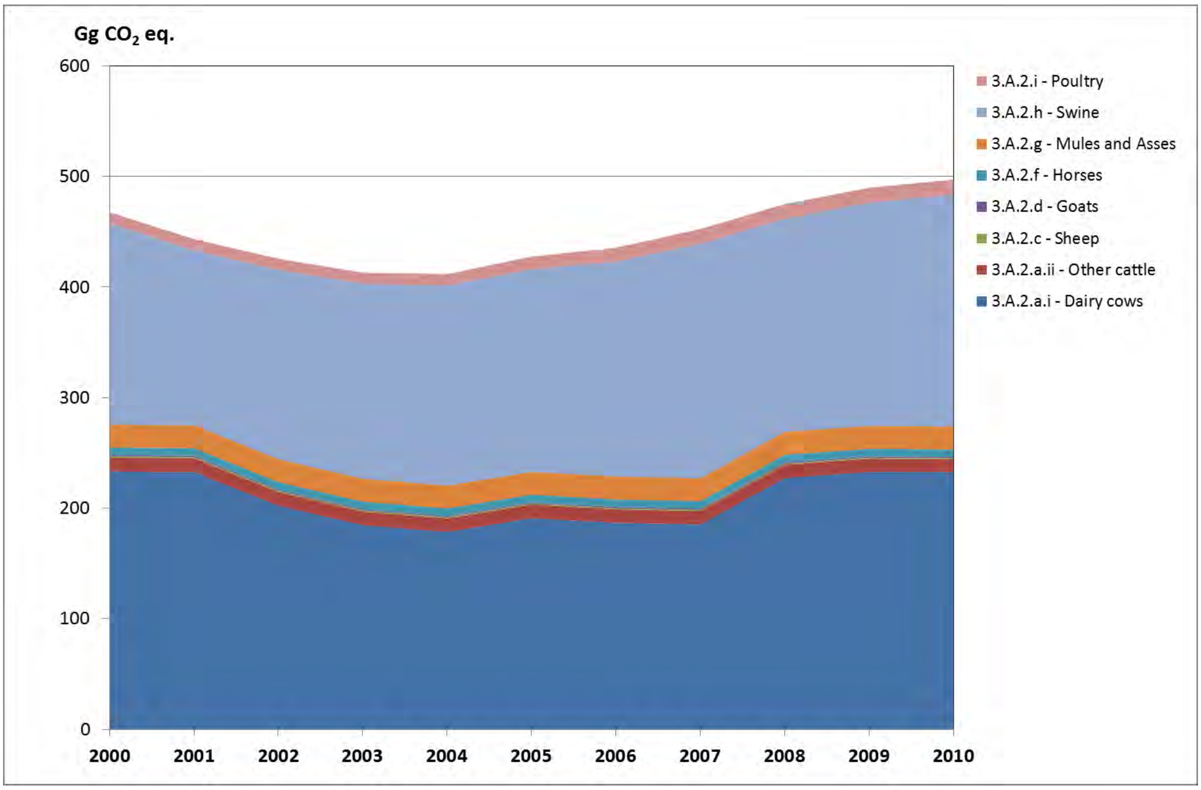

Figure 5.7: Sector 3 AFOLU – Livestock: Manure Management CH_4 trend and emission levels from source categories, 2000 – 2010.

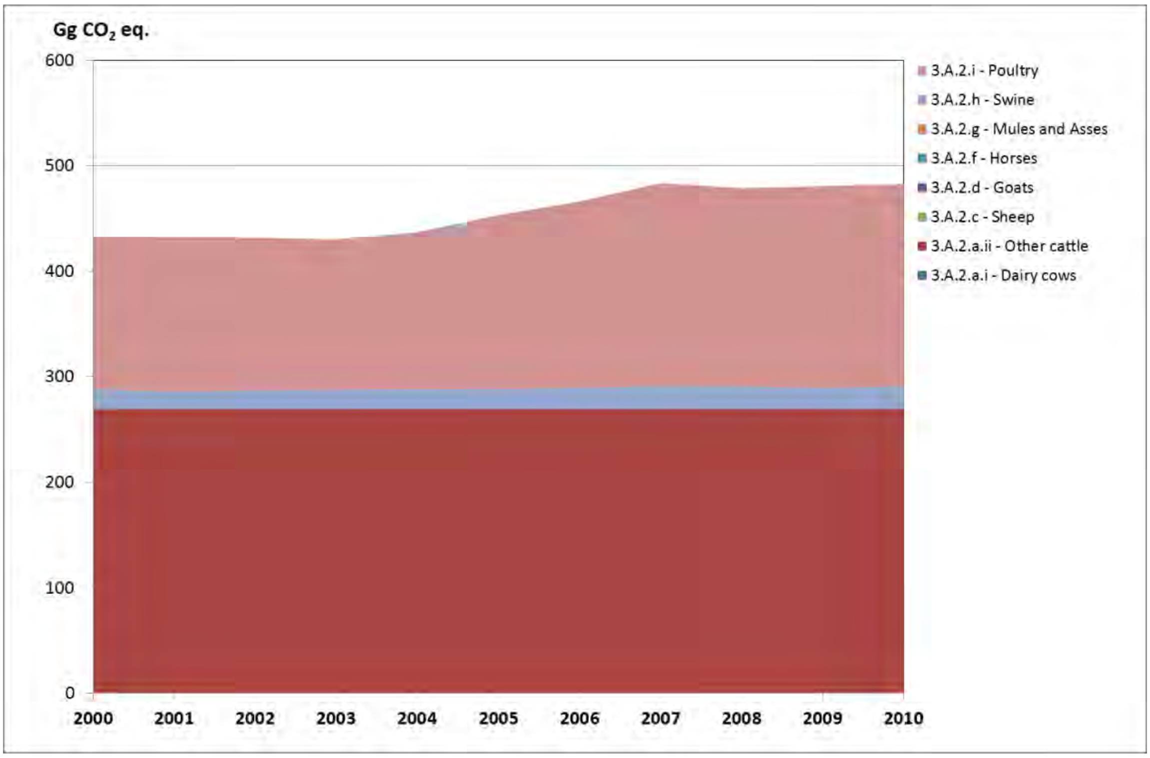

Figure 5.8: Sector 3 AFOLU – Livestock: Manure Management N_2O trend an emission levels from source categories, 2000 – 2010.

5.3.4.3 Data sources

Population numbers and the Typical Animal Mass (TAM) are provided in Table 5.3. Poultry were also included in the manure management emission calculations. The number of layer and broiler (life cycle of 38 days) chickens between 2000 and 2010 were obtained from the SA Poultry Association (Magda Prinsloo, SA Poultry Association Statistician).

MANURE MANAGEMENT SYSTEMS

For dairy cattle it is only the manure from lactating cows and heifers that is managed (Table 5.5), as the rest of the herd is kept in the pasture so manure is deposited in the pasture, range and paddock (Du Toit et al., submitted). All other cattle, sheep, goats, horses and donkeys are considered range-fed and therefore all manure gets deposited in the field and is not managed. All of swine manure is managed either as lagoon, liquid/slurry, drylot and daily spread (du Toit et al., in press; Table 5.5). All cattle feedlot manure and poultry manure is managed as drylot.

Table 5.5: Sector 3 AFOLU – Livestock: Manure management system usage (%) for different livestock categories, 2000 – 2010 (Source: DAFF, 2010; du Toit et al., in press).

Livestock Category	Sub-category	Lagoon	Liquid /slurry	Drylot	Daily spread	Compost	Pasture
Dairy Cattle	TMR - lactating cows/heifers	10	0.5	0	1	0	88.5
	Pasture - lactating cows/heifers	3	0	0	7	0	90
	All other	0	0	0	0	0	100
Other Cattle	Feedlot cattle	0	0	100	0	0	0
	Commercial	0	0	0	0	0	100
	Communal	0	0	0	0	0	100
Sheep	Commercial	0	0	0	0	0	100
	Communal	0	0	0	0	0	100
Goats	Commercial	0	0	0	0	0	100
	Subsistence	0	0	0	0	0	100
Horses		0	0	0	0	0	100
Donkeys		0	0	0	0	0	100
Pigs	Commercial	92	1.5	5	1.5	0	0
	Communal	0	0	50	50	0	0
Poultry	Layers	0	0	100	0	0	0
	Broilers	0	0	100	0	0	0

CH_4 ACTIVITY DATA AND EMISSION FACTORS

Volatile solids (VS) for cattle, sheep, goats, pigs and poultry were calculated using methods from the ANIR (2009) and are discussed in section 5.2.2.4 below. The Africa default VS values were used for horses and donkeys (IPCC 2006, Tables 10A.4-10A.9). Methane conversion factors (MCF) were obtained from the IPCC 2006 guidelines. All other activity data were obtained from Du Toit et al. (submitted).

Emission factors for cattle, sheep, goats, swine and poultry (Table 5.6) were taken from Du Toit et al. (submitted) and the methods are described below in section 5.3.3.4. In some cases there were additional livestock subcategories in Du Toit et al. (submitted) and here the values were averaged to obtain an emission factor for that livestock category. IPCC 2006 Africa default values were used for horses and donkeys.

Table 5.6: Sector 3 AFOLU – Livestock: Implied CH_4 manure emission factors for the various livestock compared to the IPCC 2006 default factors and the Australian EF's (Source: Du Toit et al., submitted; IPCC 2006 Guidelines; ANIR, 2009).

Livestock category	Livestock sub-category	EF$_{manure}$ (kg head^{-1} year^{-1})	IPCC default EF (kg head^{-1} year^{-1})		Australia EF (kg head^{-1} year^{-1})
			Africa	Oceania	
Dairy – TMR	Lactating cows	15.780	1	29	8.8
	Lactating heifers	15.760			
	Dry cows	1.470			
	Pregnant heifers	1.240			
	Heifers > 1 year	1.190			
	Heifers 6 – 12 months	0.750			
	Heifers 2 – 6 months	0.370			
	Calves	0.210			
Dairy – pasture	Lactating cows	6.730	1	29	8.8
	Lactating heifers	6.530			
	Dry cows	1.110			
	Pregnant heifers	0.880			
	Heifers > 1 year	0.780			
	Heifers 6 – 12 months	0.580			
	Heifers 2 – 6 months	0.400			
	Calves	0.320			
Other cattle – commercial	Bulls	0.022	1	2	0.04
	Cows	0.018			
	Heifers	0.016			
	Ox	0.018			
	Young ox	0.012			
	Calves	0.012			
	Feedlot	0.870			2.91
Other cattle – communal	Bulls	0.017	1	2	0.04
	Cows	0.015			
	Heifers	0.013			
	Ox	0.015			
	Young ox	0.010			
	Calves	0.010			
Sheep – commercial	Non-wool ewe	0.002	0.15	0.28	0.002
	Non-wool ram	0.003			
	Non-wool lamb	0.001			
	Wool ewe	0.002			
	Wool ram	0.005			
	Wool lamb	0.001			
Sheep – communal	Ewe	0.002	0.15	0.28	0.002
	Ram	0.003			
	Lamb	0.001			
Goats – commercial	Buck	0.017	0.17	0.2	
	Doe	0.011			
	Weaner/kid	0.009			
	Angora	0.004			
	Milk goat	0.006			
Goats – communal	Buck	0.011	0.17	0.2	
	Doe	0.008			
	Weaner/kid	0.004			
Swine – commercial	Boars	16.470	1	13 – 24	23
	Sows	27.130			
	Pre-wean piglets	3.740			
	Cull pigs	14.970			
	Replacement pigs	20.960			
	Baconers	20.960			

	Porkers	17.960			
Swine – communal	Boars	0.370	1	13 – 24	23
	Sows	0.605			
	Pre-wean piglets	0.080			
	Cull pigs	0.335			
	Replacement pigs	0.460			
	Baconers	0.460			
	Porkers	0.400			
Horses		1.640	1.64	2.34	
Mules and asses		0.900	0.9	1.1	
Poultry	Layers	0.018		0.03	0.04
	Broilers	0.018		0.02	

Comparison of Implied manure EF's to and IPCC defaults

A comparison of the implied manure emission factors with IPCC default values is given in Table 5.6. For dairy cattle the IEF were slightly higher than the Africa default, but still much lower than the Oceania default EF. Swine IEF were much higher than the Africa default values, and the commercial swine IEF were much closer to the Oceania default values. Implied EF's for all other livestock were an order of magnitude lower than the Africa default value, however the IEF's were within the same range as the EF used by Australia (Table 5.6).

N_2O ACTIVITY DATA AND EMISSION FACTORS

Nitrogen excretion rates (N_{rate}) were obtained from the Africa default values (IPCC 2006, Table 10.19) while the annual N excretion for livestock N_{ex} was estimated using Equation 10.30 from the guidelines (IPCC, 2006). The Typical Animal Mass (TAM) for the various livestock categories is given in Table 5.3. The manure management system usage data (Table 5.5) was used to produce the fraction of total annual nitrogen excretion for each livestock category managed in the various manure management systems.

IPCC 2006 default N_2O emission factors were used for the various manure management systems (IPCC 2006, Table 10.21).

5.3.4.4 Methodology

Methane production from manure management of dairy cattle, beef cattle and feedlot cattle were calculated based on the approach of the IPCC (2006) using a combination of default IPCC and country specific input values. Methane production is likely to be negligible in manure of range-kept livestock due to the high temperatures and high solar radiation which would dry manure rapidly. Due to the similarity in environmental and climatic conditions, the Australian methodology was used to calculate the manure emission factor (MEF) of range-kept cattle in environments with an average temperature of 21°C. This was determined to be 1.4×10^{-5} kg CH_4 (kg DM manure)$^{-1}$ based on Gonzalez-Avalos and Ruiz-Suarez (2001).

CH_4 EMISSIONS FROM ANIMAL MANURE

Dairy cattle [3A2ai]

Methane emissions from manure originate from the organic fraction of the manure (volatile solids). Manure CH_4 emissions were taken from Du Toit et al. (submitted). A tier 2 approach was used and the emissions (kg head^{-1} year^{-1}) were determined using the equation:

$$EF = (VS \times B_o \times MCF \times p) \times 365 \qquad (Eq.5.8)$$

Where:
B_o = emissions potential (0.24 m^3 CH_4 (kg VS)$^{-1}$; IPCC, 2006);
MCF = integrated methane conversion factor – based on the proportion of the different manure management systems;
p = density of methane (0.662 kg m^{-3})

Using the MCF from the IPCC 2006 Guidelines for the various manure management systems the integrated MCF for lactating dairy cattle in TMR based production systems was calculated as 10% and 1% for all other classes of dairy cattle. In pasture based production systems the integrated MCF for lactating cattle was calculated as 4.57% and 1% for all other classes of cattle. Volatile solids (VS, kg head^{-1} day^{-1}) were calculated according to ANIR (2009) as:

$$VS = I \times (1 - DMD) \times (1 - A) \qquad (Eq.5.9)$$

Where:
I = dry matter intake calculated as described above;
DMD = dry matter digestibility expressed as a fraction;
A = ash content of manure expressed as a fraction (assumed to be 8% of faecal DM, IPCC 2006 Guidelines).

Other cattle, sheep and goats [3A2aii, 3A2c and 3A2d]

Methane emissions from manure (kg head^{-1} year^{-1}) of all categories of beef cattle, sheep and goats were taken from Du Toit et al. (submitted) who followed the methods used in the Australian inventory (ANIR, 2009):

$$EF = (I \times (1 - DMD) \times MEF) \times 365 \qquad (Eq.\ 5.10)$$

Where:
I = Intake as calculated under enteric emissions (section 5.3.3.4);
MEF = manure emissions factor (kg CH_4 (kg DM manure)$^{-1}$).

Feedlot cattle

The IPCC default methane conversion factor (MCF) for drylot (1.5%) was used. The volatile solid production for feedlot cattle was estimated based on data developed under the enteric methane emission calculations. The volatile solid production and methane emission factor was calculated as for dairy cattle (Eq. 5.9), but assuming a DMD of 80% for feedlot diets and a B_0 of 0.17 m^3 CH_4 (kg VS)$^{-1}$ (IPCC, 2006).

Swine [3A2h]

Commercial pig production systems in South Africa are housed systems and a large proportion of manure and waste is managed in lagoon systems. The CH_4 emission factors for pig manure (kg head^{-1} year^{-1}) were taken from Du Toit et al. (submitted) which followed the equations provided in ANIR (2009):

$$EF = (VS \times B_o \times MCF \times p) \times 365 \qquad \textit{(Eq. 5.11)}$$

Where:
VS = volatile solid production (kg head^{-1} year^{-1});
B_o = emissions potential (0.45 m^3 CH_4 (kg VS)$^{-1}$) (IPCC 2006);
MCF = integrated methane conversion factor calculated from IPCC 2006 MCF for each manure management system;
P = density of methane (0.622 kg m^{-3}).

Du Toit et al. (submitted) calculated the volatile solid production from South African pigs by using the following equation provided in the IPCC 2006 Guidelines:

$$VS = [GE \times (1 - (DE\%/100)) + (UE \times GE)] \times [(1 - ASH)/18.45] \qquad \textit{(Eq. 5.12)}$$

Where:
VS = volatile solid excretion (kg VS day^{-1});
GE = Gross energy intake (MJ day^{-1});
DE% = digestibility of feed (%);
(UE x GE) = urinary energy expressed as a fraction of GE. Typically 0.02GE for pigs (IPCC 2006);
ASH = Ash content of manure (17%, Siebrits, 2012);
18.45 = conversion factor for dietary GE per kg of DM (MJ kg^{-1}).

Poultry [3A2i]

As for the other manure CH_4 emission factors, the poultry emission factors were taken from Du Toit et al. (submitted). Those were calculated according to Equation 5.8, using an integrated MCF of 1.5% (IPCC 2006). Volatile solid production from poultry production systems were calculated using the same equation as for dairy cattle (Eq. 5.9), but assuming a dry matter intake of 0.11 kg day^{-1}, a DMD of 80% and an ash content of 8% of faecal DM (ANIR, 2009). Further details provided in Du Toit et al. (submitted).

N_2O EMISSIONS FROM ANIMAL MANURE

Du Toit et al. (submitted) calculated nitrogen excretion from the various livestock categories using crude protein inputs and storage, and from this the output of nitrogen in faeces and urine (following the methodology provided in ANIR, 2009). Unfortunately there was insufficient data to extend these calculation from 2010 to the period 2000 – 2009, therefore a Tier 1 approach was used as in the 2004 Agricultural inventory (DAFF, 2010). N_2O emissions from manure management are not a key source of emissions so the Tier 1 methodology is sufficient.

Direct N_2O emissions from manure management were calculated from animal population data, activity data and manure management system data using Equation 10.25 and 10.30 from the IPCC 2006 Guidelines.

5.3.4.5 Uncertainty and time-series consistency

UNCERTAINTY

Data on manure management storage systems under different livestock categories are lacking, with estimates being based on expert opinion and information from the various livestock industries. The uncertainty on the default B_o estimates is ±15%. For VS the uncertainty is ± 20% for dairy cattle, ± 35% for other cattle and ± 25% for pigs. Country average temperatures were used and this leads to inaccuracies in the estimates. To reduce this uncertainty, the percentage of animal populations, and thus manure management systems, in different temperature zones needs to be determined so that a more specific MCF can be used and a weighted average emission factor can be determined. The uncertainty on the default emission factors for horses, mules and asses is ± 30%. The default N_{rate} values were used for Africa and these had an uncertainty of ±50%. The drylot emission factor has an uncertainty of a factor of 2.

TIME-SERIES CONSISTENCY

Time-series consistency is ensured by the use of consistent methods and full recalculations in an event of any method refinement.

5.3.4.6 Source-specific QA/QC and verification

Methane emission factors were compared to IPCC default values (Table 5.6), as well as those used in the Australian inventory. No direct measurements of methane emissions from manure have been made in South Africa so the calculated values could not be verified, only compared to default values.

Default values were used to determine the N_2O emissions from manure management so no data comparisons were made.

5.3.4.7 *Source-specific recalculations*

Full recalculations for enteric fermentation and manure management emissions were done for the year 2000 as the emission factors, and the methods for calculating them, have been changed.

5.3.4.8 *Source-specific planned improvements and recommendations*

No specific improvements are planned however it is suggested that in order to improve the accuracy and reduce the uncertainty of the manure management emission data it would be important to improve the monitoring of manure management systems. The other improvement would be to obtain information on the percentage of animal populations in different temperature zones, or even provincial data, so that a more accurate weighted average emission factor can be determined.

N_2O emission data from manure management systems would also be improved if N excretion rates for cattle in SA were determined so that actual data could be used instead of the value calculated using IPCC 2006 default values. Du Toit et al. (in press) provided a methodology and emission factors for 2010, so this could perhaps be incorporated into the next inventory.

5.4 Land [3B]

5.4.1 Overview of the sub-sector

This chapter describes the inventory for the Land Use and Land Use Change sector for South Africa. It covers the sources and sinks of the above- and below-ground CO_2 emissions from the land categories. The N_2O emissions from the land sector were estimated in the *Aggregated and non-CO_2 emission sources on land* section and CH_4 emissions from wetlands were not included as these were estimated to contribute very little (<1%%) to the overall GHG emissions (NIR, 2009). This inventory only includes the biomass carbon component as the soil carbon requires a 20 year historical land use data set to determine what land uses have occurred on a particular piece of land and this data was not available. The soil carbon component will therefore need to be included in future inventories. All other emissions in the Land category were assumed to be negligible.

According to the maps developed in section 5.4.5 (GeoTerraImage, 2013) the land cover in South Africa is dominated by woodland/savanna (~30%) and grasslands (~20%). Natural forests are very small in South Africa covering less than 0.5% of the land area, while settlements occupy approximately 1.5% (SA 2nd NC, 2011, GeoTerraImage, 2013). Agricultural activities cover about 7% of the land area, with maize and wheat being the dominant annual crops by area. Perennial crops (orchards, viticulture, sugar cane) contribute about 8% towards the cropland land area. Plantations are based on non-native trees, dominant species being *Eucalyptus grandis,* and they cover about 1.1% of the land area (FSA, 2012).

Classifying the South African soils into the 6 main types provided by IPCC shows that the high activity clay mineral soil dominate (>60%) (Moeletsi et al., 2013). This soil type consists of lightly to moderately weathered soils, dominated by 2:1 silicate clay minerals, including vertisols, mollisols, calcareous soils, shallow soils and various others. The other two main soil types are the sandy mineral soil and low activity clay mineral soil. Sandy minerals predominate over the Northern Cape, Northwest and Western Cape. The low activity clay soils are found mainly in the warmer, higher rainfall areas, such as KwaZulu-Natal and Mpumalanga. Organic soils are considered negligible.

Long term (1920 – 1999) climate data for South Africa were used to categorize the climate into the IPCC climate classes, and over 95% of South Africa is categorised under the warm temperate dry climate class. There are a few very small patches over the Limpopo ranges, along the KwaZulu-Natal coast, some parts of Mpumalanga and patches over Western Cape, which fall into the warm, temperate moist class. The other exception is the cool, temperate, dry regions in the ranges of the Eastern Cape that are close to Lesotho.

5.4.2 Overview of shares and trends

5.4.2.1 Land cover trends

Over the 10 year period annual and perennial crops together are estimated to increase by 11.9%, while semi-commercial/subsistence crops show an increase of 43.7% (Figure 5.9). On the other hand, indigenous forests, woodlands/savannas, and karoo vegetation are estimated to decline by 14.3%, 3.1% and 40% respectively. There is a sharp decline in the succulent karoo vegetation between 2000 and 2005, and this is due to a large land area change to Other land. Other lands increase in area by 57.2%. This conversion does not affect the outcome of this inventory as carbon stock changes in *Grasslands* and *Other lands* are assumed to be zero, however this area change needs to be investigated and validated in future before all the land use change data is incorporated into the inventory (see section 5.4.5.4).

5.4.2.2 Trends in CO_2

The Land sector was estimated to be a net sink of CO_2. All land was classified as Land remaining Land due to high uncertainties in the land conversion data and insufficient activity data.

Forest land (3B1) comprised emissions and removals from the above and below ground carbon pool of *Forest land remaining Forest land* for the sub-categories plantations, natural forests, thickets, and Woodland/savannas. Carbon stock changes due to wood harvesting, fuelwood consumption, and disturbance (including fires) were all included. A deadwood component was also included. The Forest land category was estimated to have constituted a net sink for CO_2 in all years between 2000 and 2010. The sink was estimated to vary between 3 837 Gg CO_2 and 19 557 Gg CO_2 over the 10 year period (Area per category was estimated using a wall-to-wall approach where the entire land surface of South Africa is classified into one of the 6 land class. Land areas were determined from the maps described in section 5.4.5.

In this inventory emissions and removals from land conversions were not included as the land conversion data from the new land use maps developed for this inventory had a high uncertainty and some of the land changes were smaller than the uncertainty. Further investigation and validation of these land changes need to occur before they are incorporated into the inventory. The IPCC Guidelines (IPCC, 2006, p. 3.11) indicates that if there is insufficient data to support land conversions then all emissions and removals must be reported under the *Land remaining in the same land* use category. Using this approach may over- or under-estimate emissions from that particular land category, however a complete inventory will tend to counter-balance this with emissions and removals from another *land remaining land* category.

). All Forest land was classified as *Forest land remaining Forest land* (see section5.4.3) therefore CO_2 from Land converted to Forest land was not estimated.

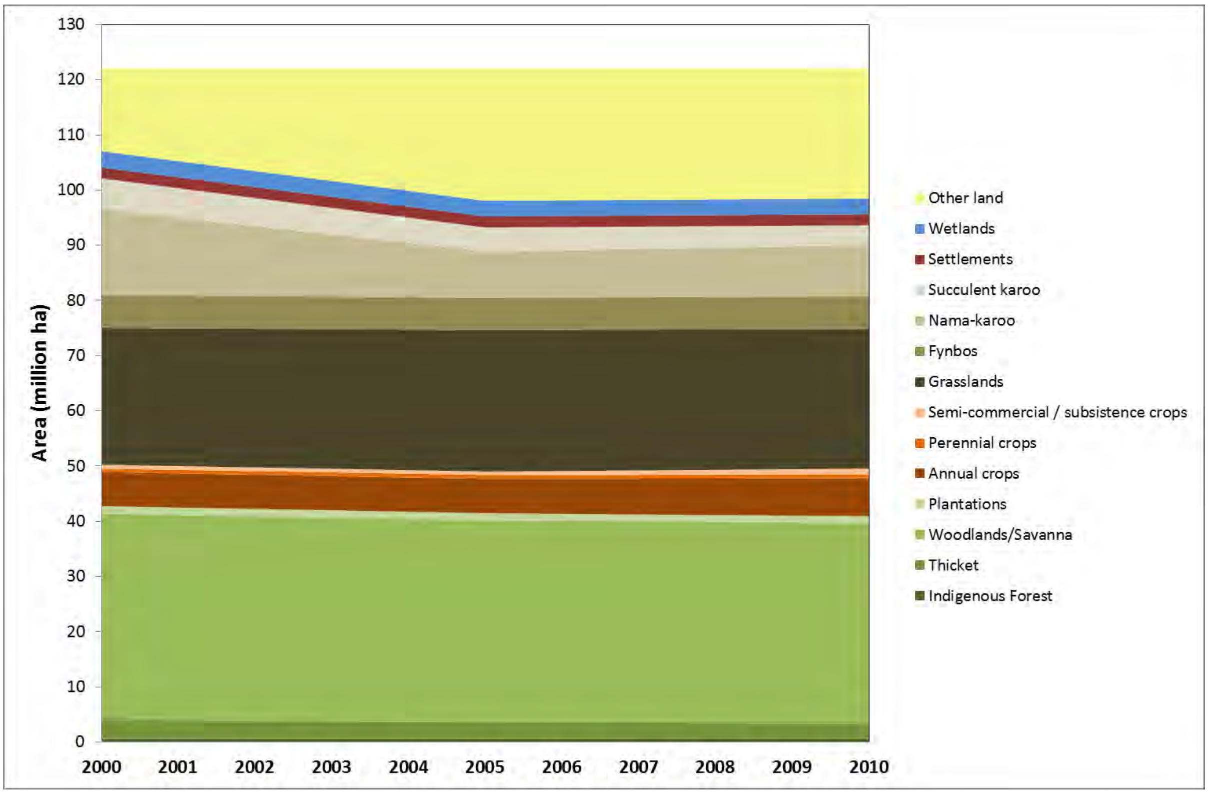

Figure 5.9: Sector 3 AFOLU – Land: Trend in land cover between 2000 and 2010 (GeoTerraImage, 2013).

Croplands (3B2) comprised emissions and removals from the biomass carbon pool in *Croplands remaining Croplands*, but these lands were assumed to be in balance and therefore have no emissions or removals. Emissions from Lands converted to Croplands were not estimated.

Grasslands (3B3) comprised emissions and removals from the biomass carbon pool for *Grasslands remaining Grasslands*, which includes grasslands, fynbos, nama karoo and succulent karoo. As with Croplands, *Grassland remaining Grasslands* was assumed to have no net emissions or removals. Emissions from Land converted to Cropland were not estimated.

Wetlands (3B4) were estimated not to have any emissions or removals of CO_2.

Settlements (3B5) comprised of *Settlements remaining Settlements*, which do not have any CO_2 emissions or uptakes. The Settlements category included mines.

Other lands (3B6) were similar to Settlements in that *Other lands remaining Other lands* were assumed to have zero CO_2 change.

Harvested Wood Products were not included in this inventory due to a lack of historical data.

Table 5.7: Sector 3 AFOLU – Land: Trends in carbon stock changes and CO_2 emissions from Forest lands, 2000 – 2010.

Forest land	**Carbon stocks (Gg C)**			**Net CO_2 emissions (Gg CO_2)**
	Increase	***Decrease***	***Net change***	
2000	33 185	27 851	5 334	-19 557.0
2001	33 071	28 661	4 410	-16 170.3
2002	32 865	28 251	4 614	-16 917.4
2003	32 779	27 677	5 102	-18 708.9
2004	32 405	28 619	3 786	-13 881.6
2005	32 101	30 460	1 641	-6 017.0
2006	31 817	30 367	1 450	-5 314.5
2007	31 706	29 415	2 291	-8 399.9
2008	31 597	30 141	1 456	-5 339.5
2009	31 627	27 990	3 637	-13 334.6
2010	31 482	30 435	1 047	-3 836.7

5.4.3 Methods

South Africa followed the Tier 1 approach of the IPCC 2006 Guidelines to determine the effects of Land use and Land use change on the GHG inventory. The gain-loss method was used where the inventory data was subdivided into the appropriate pools and land use types.

The inventory comprises the 6 land classes recommended by IPCC: Forest land, Grassland, Cropland, Settlements, Wetlands and Other. Due to the diverse nature of South Africa’s vegetation, the 6 land classes had several subdivisions (Table 5.8) and these divisions are further explained in section 5.4.4.

Area per category was estimated using a wall-to-wall approach where the entire land surface of South Africa is classified into one of the 6 land class. Land areas were determined from the maps described in section 5.4.5.

In this inventory emissions and removals from land conversions were not included as the land conversion data from the new land use maps developed for this inventory had a high uncertainty and some of the land changes were smaller than the uncertainty. Further investigation and validation of these land changes need to occur before they are incorporated into the inventory. The IPCC Guidelines (IPCC, 2006, p. 3.11) indicates that if there is insufficient data to support land conversions then all emissions and removals must be reported under the *Land remaining in the same land* use category. Using this approach may over- or under-estimate emissions from that particular land category, however a complete inventory will tend to counter-balance this with emissions and removals from another *land remaining land* category.

Table 5.8: Sector 3 AFOLU – Land: The six IPCC land classes and the South African sub-categories within each land class.

IPCC Land Class	SA Sub-category
Forest Land	Natural Forests Plantations (Eucalyptus, Softwoods, Acacia, Other sp.) Thicket Woodland/savannas
Cropland	Annual commercial crops Perennial crops (viticulture, orchards) Annual semi-commercial/subsistence crops Sugarcane
Grassland	Grassland Fynbos Nama karoo Succulent karoo
Settlements	Settlements Mines
Wetlands	Wetlands Waterbodies
Other Lands	Bare ground Other

Annual carbon stock changes were estimated using the process-based (Gain-Loss) approach where gains are attributed to growth and losses are due to decay, harvesting, burning, disease, etc. For *land remaining in the same land-use category* annual increases in biomass carbon stocks were estimated using Equation 2.9 of the IPCC 2006 Guidelines, where the mean annual biomass growth was estimated using the Tier 1 Approach of equation 2.10 in the IPCC 2006 Guidelines. The annual decrease in carbon stocks dues to biomass losses were estimated from equations 2.11 to 2.14 and 2.27 of the IPCC 2006 Guidelines.

If an IPCC default factor was require the climate zone often plays a part in the selection process. For the purpose of this inventory all land classes were assumed to be within the warm temperate dry climate category as this is the dominant category for South Africa based on long term climate data (Moeletsi et al., 2013).

The AFOLU inventory for South Africa is incomplete due to a lack of data. There was insufficient data to include the soil carbon component. IPCC requires a 20 year historical land use data set to determine the full impacts of soil carbon changes. South Africa does not have a 20 year data set and so soil carbon changes were also excluded from this inventory. A more complete DOM component, quantifying all inputs and outputs to this pool, also needs to be included in the future.

5.4.4 Land category definitions

5.4.4.1 *Forest land*

The Forest land category included all land with woody vegetation consistent with thresholds used to define Forest Land in the national greenhouse gas inventory. It also included systems with a vegetation structure that currently fall below, but in situ could potentially reach the threshold values used by a country to define the Forest Land category. According to the Kyoto Protocol and the Marrakesh Accord, a forest is defined as having a minimum area of 0.05 - 1.0 hectares with tree crown cover (or equivalent stocking level) of more than 10 - 30%, with trees with the potential to reach a minimum height of 2-5 metres at maturity in situ. A forest may consist either of closed forest formations where trees of various storeys and undergrowth cover a high proportion of the ground or open forest. Young natural stands and all plantations which have yet to reach a crown density of 10-30% or tree height of 2-5 metres are included under forest.

The FAO defines indigenous forests as forests with a tree canopy cover of more than 10%, trees should be able to reach a height of 5 m and an the forest area must be greater than 0.5ha. Under this definition indigenous forests include woodlands which have a tree canopy cover of 10 – 70%. In the Global Forest Resources Assessment Report for South Africa (GFRASA, 2005) forests include (a) forests with a tree canopy cover >70%, (b) forest and woodlands which have a tree cover of between 10% to 70%, and (c) plantations. This report therefore classifies all woodlands and savannas under Forest land. The previous inventory differed in that it separated out the woody savannas from other woodlands by their geographical distribution, and excluded woody savannas from Forest lands.

A further addition to Forest land in this inventory was thickets. Typically thickets are not classed as Forest lands as the trees do not reach the height requirement. In the GFRASA (2005) they were classified as Other woodlands, however for the purpose of this inventory, Thickets were classed as Forest land since they are more like forests than grasslands.

The following vegetation sub-categories were therefore included within the Forest land:

- Natural forests:
    - The 2000 Inventory (NIR, 2009) and GFRASA (2005) define an indigenous forest as all wooded areas with over 70% tree canopy. Indigenous forest is a multi-strata

    community with interlocking canopies composed of canopy sub-canopy shrub and herb layers. The canopy is composed mainly of self-supporting single stemmed woody plants over 5 m in height. These are essentially indigenous species growing under natural or semi-natural conditions although some areas of self-seeded exotic species may be included. The category excludes planted forests and woodlots;

- Plantations:
    - All areas of systematically planted man-managed tree resources and composed of primarily exotic species including hybrids. This category includes all plantations from young to mature which have been established for commercial timber production seedling trials or woodlots (Thompson, 1999; GeoTerraImage, 2013);
    - It includes clear-felled stands;
    - It excludes all non-timber based plantations, as well as orchards.
- Thickets:
    - The vegetation is typically a short, evergreen, compact, continuous canopy of short trees, shrubs, succulents, forbs, bulbs and vines (Low and Rebelo, 1996). It is vegetation that replaces forest where a degree of fire protection is still evident but rainfall is too low;

- Savannas and woodlands:
    - All wooded areas with a tree canopy between 10% and 70% typically consisting of a single tree canopy layer and a grass layer (SSA, 2004). The canopy of Woodland is composed mainly of self-supporting single stemmed woody plants over 5 m in height of essentially indigenous species growing under natural or semi-natural conditions (which may include some areas of self-seeded exotic species). Planted forests and woodlots are therefore excluded.

5.4.4.2 Cropland

This category included cropped land and agro-forestry systems where the vegetation structure falls below the thresholds used for the Forest Land category. The sub-categories in Croplands were:

- Annual commercial crops:
    - Annuals; cultivated with crops with a growing cycle of under 1 year, which must be newly sown or planted for further production after harvesting; not only small grain crops such as beets, wheat, and soy bean but also bi-annuals that are destroyed at harvesting, such as cassava and yams; bananas are transitional to the permanent crops category;
- Perennial crops:
    - Perennials; cultivated with long-term crops that do not have to be replanted for several years after each harvest; harvested components are not timber but fruits, latex, and other products that do not significantly harm the growth of the planted trees or shrubs: orchards, vineyards, rubber and oil palm plantations, coffee, tea, sisal, etc. In this inventory the perennial crops were further divided into orchards and viticulture;
- Sugar cane:

    - Commercial sugar cane fields; perennial crop which is harvested after 15 to 18 months. This crop is kept separate due to the unique biomass burning activities which occur in these fields;
- Semi-commercial or subsistence crops:
    - Those that do not meet the threshold for annual commercial crops and are found in and around local housing areas.

5.4.4.3 Grassland

The Grassland category included range and pasture lands that were not considered Cropland. The category also included all grassland from wild lands to recreational areas as well as agricultural and silvi-pastural systems, consistent with national definitions. Both planted and natural grasslands were included in this category. "Natural grassland" is all areas of grassland with less than 10% tree and/or shrub canopy cover and more than 0.1% total vegetation cover. This class is dominated by grass-like non-woody rooted herbaceous plants which are essentially indigenous species growing under natural or semi-natural conditions. "Planted grassland‟ is defined in the same way except that it is grown under human-managed (including irrigated) conditions for grazing hay or turf production or recreation. Planted grassland can be either indigenous or exotic species.

Grasslands also included the following categories which have a woody component but they do not meet the requirements of a forest:

- Fynbos:
    - This biome is classified on the basis of climate (winter rainfall), corresponding life-form patterns (regeneration after fire) and major natural disturbances (intense fires). The altitudinal range is from sea level to 1,100 m, which spans various geological substrates. Fynbos comprises evergreen heathlands and shrublands, in which Protea, Erica (fine leafed low shrubs) and Restio (leafless tufted grass-like plants) species dominate. Trees are rare and grasses comprise a relatively small part of the biomass;
- Nama-karoo:
    - This biome is dominated by steppe type vegetation, comprising a mixture of shrubs, dwarf shrubs, and annual and perennial grasses (Palmer and Ainslie, 2002).
- Succulent karoo
    - comprises mainly of shrubs (0.5-1.5m) and dwarf shrubs (<0.5m) with succulent leaves and stems (Palmer and Ainslie, 2002). There are many species in two families (i.e. Mesembryanthecaceae and Crassulaceae), several unique taxa (species of the genus *Pachypodium*) and growth forms (leaf and stem succulents). The nutrient deficient soils are also dominated by slow growing and stress tolerant evergreen shrubs such as *P. paniculata* and *H. integrifolium* and large leaf succulent shrubs such as *R. caroli*.

5.4.4.4 Settlement

Settlements are defined as all developed land, including transportation infrastructure and human settlements of any size, unless they are already included under other categories. They essentially comprise all formal built-up areas in which people reside on a permanent or near-permanent basis identifiable by the high density of residential and associated infrastructure. Includes both towns villages and where applicable the central nucleus of more open rural clusters. This category also includes mines.

5.4.4.5 Wetlands

Wetlands are areas of land that are covered or saturated by water for all or part of the year and that do not fall into the Forest Land, Cropland, Grassland or Settlements categories. They include reservoirs as a managed sub-division and natural rivers and lakes as unmanaged sub-divisions. Wetlands include two sub-divisions:

- Waterbodies:
    - Areas occupied by (generally permanent) open water. The category includes both natural and man-made waterbodies that are either static or flowing and fresh brackish and salt-water conditions (Thompson, 1999). This category includes features such as rivers, major reservoirs, farm-level irrigation dams, permanent pans lakes and lagoons;
- Wetlands:
    - Natural or artificial areas where the water level is permanently or temporarily at (or very near) the land surface typically covered in either herbaceous or woody vegetation cover. The category includes fresh brackish and salt-water conditions (Thompson, 1999). Examples include pans (with non-permanent water cover) and reed-marsh or papyrus-swamp. Dry pans are included in this category unless they are permanently dry. This category also includes peatlands which are wetlands in which the annual generation of dead organic matter exceeds the amount that decays.

5.4.4.6 Other land

This category includes bare soil, rock, ice, and all land areas that did not fall into any of the other five categories. It allowed the total of identified land areas to match the national area, where data were available.

5.4.4.7 Managed and unmanaged lands

According to the IPCC definition of the AFOLU sector, anthropogenic GHG emissions and removals take place on ‘managed land’. Most land in SA is managed to some degree so all land classes were included in the biomass growth and loss calculations.

5.4.5 Representation of Land areas

Land cover classes were based on wall-to-wall land cover maps developed for the years 2001, 2005 and 2010. Coarse resolution MODIS time series satellite data was used to model the various land-cover classes in each assessment year, in conjunction with high resolution geographic masks of specific land-cover types.

The MODIS dataset was sourced from the Remote Sensing Research Unit (Meraka Institute, CSIR, Pretoria). The MODIS time series imagery represents summarised biomass data for each 32-day period within the period 2001 – 2010. Biomass was represented by the Enhanced Vegetation Index (EVI) dataset. Using the EVI time series dataset it was possible to model and therefore identify on a cell-by-cell basis, for example areas that show continuously or periodically high or low vegetation cover, either in all years and all seasons, or in specific years or seasons. High resolution geographic masks were used to define known areas of specific land-cover types as mapped in independent provincial (and other) land-cover mapping projects. These high resolution reference land-cover datasets cover the full extent of the country, but not in terms of a single standardised time-frame, having been compiled through unrelated, independent projects undertaken between 2000 and 2010. Each land-cover type is modelled separately and the outputs are then merged into a final multi-class land-cover for that specific assessment year, using prescribed orders of dominance. A detail description of the methodology used to develop the maps, as well as the order in which each of the land cover classes are merged is given in a GeoTerraImage report (2013). This report also includes a summary list of the source image data used to generate the geographic masks.

The maps were developed for the specific purpose of this inventory. The sum of all land use categories is constant over the 10 year period. The reason for using the coarser resolution MODIS data was so as to create a consistent time series of maps that can be compared over time.

The IPCC has a default transition period of 20 years as that is how long it is estimated for the soil carbon stock changes to reach the new soil carbon levels. However, South Africa does not have a 20 year historical land cover data set, so in this inventory the soil carbon stocks were excluded from the inventory. For biomass purposes it was assumed that prior to 2000 there were no land use changes. The maps developed for this inventory will serve as a base for future land cover maps so that by 2020 this assumption can be corrected and so that the soil component can be included.

5.4.5.1 Land cover and modelling grid resolution

The MODIS EVI modelling was based on 500 x 500 m pixels, while the geographic masks were based on 30m resolution pixels (derived independently from either Landsat or SPOT imagery).

5.4.5.2 Land matrix approach

The IPCC provides detailed guidelines for the three approaches to spatial data use (IPCC 2006, Vol. 4, Chapter 3.3.1):

- Approach 1 identifies the total area for each category of land use within a country, but does not provide detailed information on conversions between different categories of land use;
- Approach 2 incorporates Approach 1, but introduces the tracking of conversions between land use categories; and
- Approach 3 extends the information available from Approach 2 by allowing land use conversions to be tracked in a spatially explicit way.

The 2000 inventory mainly used approach 1, due to limited data on land use change over time, but it applied approach 2 to some categories where there were more data. That was a significant improvement on the 1994 inventory. The maps developed for this inventory did allow for an approach 2 with stratification (IPCC 2006 guidelines) to represent areas of land cover and change, and to develop the Land cover change matrix. However these land cover changes were often smaller than the uncertainty and some conversions do not occur therefore corrections need to be made. For these reasons, land conversions were not included in this inventory but can be incorporated in future when a quality check and verification process has been completed on this data. Therefore in this inventory approach 1 was used, as was the case in the 2000 inventory.

5.4.5.3 Limitations of the modelling approach

Due to the difference in resolution of the MODIS EVI modelling (500 x 500 m pixels) and the geographic masks (30 m resolution pixels) it is quite feasible that spatial misrepresentations were introduced within the final land-cover outputs since the area for the single cover class allocated to each 500 x 500 km cell is rounded up to the nearest 0,5 km^2 regardless of the actual extent of that cover type (i.e. geographic mask) within the 500 x 500 m cell. That may be further exacerbated by the sequence in which the individual cover classes are overlaid / merged during compilation of the final land-cover product.

5.4.5.4 QA/QC and verification

The land cover maps were developed as a desk-top only modelling exercise, the results of which are directly dependent on the validity and accuracy of the modelling data inputs, theoretical assumptions and associated modelling rules. As such no statistical verification of final land-cover change detection accuracy can or has been be provided. The DEA has produced a report detailing a stratified sampling approach which can be used to validate these, and future, land cover maps and these plans should be carried out over the next few years. This data can then be incorporated into future inventories.

For the purpose of this inventory some broad comparisons were made with available data sets so as to provide some quality check on the data. Note that it is difficult to make direct comparisons as in most cases different classifications were used. The following results were found:

- Plantation area was overestimated. Plantation area was compared with data from FSA and the plantation area was overestimated, due to the fact that plantations were high on the hierarchical overlay sequence (GeoTerraImage, 2013) and was therefore often given preference over other land classes. The FSA data indicated that the area of plantations is approximately half that provided by the maps in this inventory. Comparing the 2000 area data with the NLC2000 areas the plantation area overestimation is less than this (about 25%). Either way this is significant and needs to be further investigated in future inventories, however it should also be kept in mind that the natural forests and plantations cover a very small area. In the inventory and the calculation of the carbon stock changes corrections were made for the overestimation of the plantation area (discussed in section 5.4.7.1).
- Cropland area was underestimated. The Cropland area was compared to FAO data and the NLC2000 data and both seem to indicate that the cropland area in this inventory was slightly underestimated. However it should be noted that direct comparison is difficult as all data sources have slightly different categories. Comparing the sugar cane area with the area from the Agricultural Abstracts (Abstracts of Agricultural Statistics, 2012) it is evident that the sugar cane area was underestimated (by about 18% to 45% depending on the year), which is consistent with the other findings. This underestimation in Cropland area could partly be caused by the overestimation on the plantation area. The GFRASA (2012) provides a value of 14 753 248 ha for cultivated land (this is however for 1995), but this is almost twice the area provided in this inventory.
- Natural forests, Grassland, Wetland and Settlement categories appeared to be within a similar range to the areas provided in the NLC2000 map. For Grasslands, the area was 24 308 870 ha in 2000 in this inventory, which is similar to the 25 759 325 ha given in the NLC2000 map and other estimates of 24 – 26 million ha (Engelbrecht et al., 2004; van der Merwe and Scholes, 1998; GFRASA, 2005). Natural forest area was estimated at 557 484 ha and Settlements at 1 968 225in 2000, which is similar to the 527 048 ha and 1 832 725 ha in the NLC2000, respectively.
- The savanna, woodland and shrubland categories were very difficult to assess due to the different classifications used. If all of these vegetation types (Woodland/savanna, thickets, fynbos, karoo vegetation) are grouped together then the total area reported here was slightly lower (67 474 976 ha) than the NLC2000 data (72 466 577ha).
- Other lands appear to be overestimated (15 008 199 ha) when compared to the NLC2000 data set (995 300 ha). The land change matrix showed large conversions between Other land and the fynbos and karoo vegetation (and vice versa) so it may be there is some misclassification in these classes which needs further investigation. This conversion does not impact the outcome of this inventory as Grasslands and Other lands are assumed to be in balance and therefore have no annual carbon stock change.

Further validation and verification is required in the future, preferably from field data, so that these maps can be improved.

5.4.5.5 Time-series consistency

It is important that there is a consistent time-series in the preparation of land-use category and conversion data so that any artefact from method change is not included as an actual land-use conversion. When using land-use data it is important to harmonize definitions between the existing independent data sources; ensure that data acquisition methods are reliable and well documented; ensure the consistent application of category definitions between time periods; prepare uncertainty estimates; and ensure that the national land area is consistent across the inventory time-series. This inventory has tried to address these issues.

The MODIS data set was used specifically to address the time-series consistency issue. One of the biggest problems with the AFOLU sector was that the source land cover maps vary greatly in the method used to derive them and also in the categorization of the land and this made it very difficult to track changes over time. For example, in the previous inventory for 2000 it was very difficult to track land use change because of the different methodologies and different scales of the two National Land Cover data sets (NLC1996 and NLC2000). The resolution from MODIS is coarse but it is one of the few available data sets that could be obtained for the full period of this inventory and provides a wall-to-wall map which can be compared from year to year. Furthermore the same land type classifications were used throughout the 10 year period. The data acquisition and methodology used to produce the land cover maps used in this inventory have been well documented (GeoTerraImage, 2013).

5.4.6 Recalculations

There were several changes and thus recalculations for the Land use sector since the last inventory:

- New land cover maps:
  - These were developed specifically for this inventory to cover the period 2000 – 2010. The previous inventory made use of the NLC2000.
- Reclassification of land classes:
  - In the previous inventory Forest land included plantations, indigenous forests, and woodlands (excluding savannas). Additional land classes were created for savannas, arid shrublands and fynbos/shrublands. In this inventory the sub-categories were slightly different and were named as Woodland/savanna, fynbos, nama-karoo and succulent-karoo. All woodlands (including savannas) as well as thickets were included under Forest land, while fynbos, nama karoo and succulent karoo were classified under Grasslands.
  - Land classified as mines and quarries was incorporated into the Settlements category, as opposed to Other lands as in the previous inventory.
- Wetland emissions:
  - The previous inventory included CH_4 emissions from wetlands, but these are excluded in this inventory as these emissions are not a key category and contribute less than 1% to the overall AFOLU inventory (NIR, 2009).

- Activity data:
    - some updated activity factors were incorporated into this inventory.

The more specific recalculations done within each land class are discussed in detail under the specific sections below.

5.4.7 Forest land [3B1]

5.4.7.1 Forest land remaining Forest land [3B1a]

SOURCE-CATEGORY DESCRIPTION

This section deals with the sources and sinks of CO_2 caused by changes in woody biomass stocks in Forest land. The category included natural forests, plantations, thickets, and Woodland/savannas. As in the previous inventory the plantations were sub-divided into Eucalyptus sp., Softwood sp., Acacia (wattle) and Other plantation sp.. Softwoods were further divided into sawlogs and pulp as the growth and expansion factors of those two types of plantations differed. The majority of the *Eucalyptus* plantations are used for pulp and only a small amount of area allocated to *Eucalyptus* so the difference was assumed to be negligible. All *Eucalyptus* plantations were therefore grouped together in one category.

Changes in biomass include wood removal, fuelwood collection, and losses due to disturbance. Wood removal was only included for Plantations, while fuel wood collection was estimated for all Forest land sub-categories. In Plantations disturbance from fires and other disturbances was included, while for all other sub-categories only disturbance from fire was included due to a lack of data on other disturbances. It should be noted that only CO_2 emissions from fires were included in this section as all other non-CO_2 emissions were included under section 3C1. Also all emissions from the burning of fuelwood for energy or heating purposes were reported as part of the energy sector.

The Tier 1 assumption for dead wood and litter (Dead Organic Matter) pools for all land-use categories is that their stocks are not changing over time if the land remains within the same land-use category. The dead wood pool could, therefore be assumed to be zero, however, in South Africa a lot of the fuelwood collected comes from the dead wood pool. If the dead wood pool is not included then the carbon losses from the live biomass will be overestimated because of the large fuel wood removals. A dead wood component was therefore included in this inventory, as was done in the previous inventory (NIR, 2009).

METHODOLOGY

The land cover maps developed in section 5.4.5 overestimated the plantation area (see section 5.4.5.4 for more detail). This would lead to an overestimation in the carbon gains of Forest lands, therefore a correction was made. The area of plantations was taken to be that provided by FSA (2012). Plantations are generally scattered in the Woodland/savanna and Grassland areas, so the excess plantation area (i.e. the difference between the map area and the FSA data) was divided evenly between the savannah/woodland and Grassland categories..

Removals and emissions of CO_2 from changes in woody biomass are estimated using the Tier 1 Gain-Loss Method in the 2006 IPCC Guidelines. The gains in biomass stock growth were calculated using the following equations (Equation 2.9 and 2.10 from IPCC 2006 Guidelines):

$$\Delta CG = \sum(A_i * G_{TOTALi} * CF_i) \qquad \textit{(Eq. 5.13)}$$

where

$$G_{TOTALi} = \Sigma[G_{Wi} * (1+R+DW)] \qquad \textit{(Eq. 5.14)}$$

And:

A_i = Area of forest category i remaining in the same land-use category
G_{Wi} = Average annual above-ground biomass growth for forest category i (t dm ha^{-1} a^{-1})
R_i = Ratio of below-ground biomass to above-ground biomass for forest category i (t dm below-ground biomass (t dm above-ground biomass)$^{-1}$)
DW = ratio of dead wood to above-ground biomass for forestry category i (t dead wood dm (t dm above-ground biomass)$^{-1}$)
CF_i = Carbon fraction of dry matter for forest category i (t C (t dm)$^{-1}$)

The losses were calculated for three components:

- Loss of carbon from wood removals;
- Loss of carbon from fuelwood removals; and
- Loss of carbon from disturbance.

Loss of carbon from wood removals was calculated for Plantations only as follows (Equation 2.12 IPCC 2006 Guidelines):

$$L_{wood\text{-}removals} = [H * BCEF_R * (1+R) * CF \qquad \textit{(Eq. 5.15)}$$

Where:
H = annual wood removals (m^3 yr^{-1})
BCEF = biomass conversion and expansion factor for conversion of removals in merchantable volume to total biomass removals (including bark), (t biomass removed (m^3 of removals)$^{-1}$)
R = ratio of below-ground biomass to above-ground biomass (t dm below-ground (t dm above-ground)$^{-1}$).
CF = Carbon fraction of dry matter (t C (t dm)$^{-1}$)

Loss of carbon from fuelwood removals was calculated using the following equation (Equation 2.13 of IPCC 2006 Guidelines):

$$L_{fuelwood} = [FG_{trees} * BCEF_R * (1+R) + FG_{part} * D] * CF \qquad \textit{(Eq. 5.16)}$$

where
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})
$BCEF_R$ = biomass conversion and expansion factor for conversion of removals in merchantable volume to biomass removals (including bark), (t biomass removal (m^3 of removals)$^{-1}$)
R = ratio of below-ground biomass to above-ground biomass (t dm below-ground (t dm above-ground)$^{-1}$)
D = basic wood density (t dm m^{-3})
CF = carbon fraction of dry matter (t C (t dm)$^{-1}$)

Finally, the loss of carbon from disturbance in plantations was calculated following IPCC Equation 2.14:

$$L_{disturbances} = A_{disturbance} * B_W * (1+R) * CF * fd \qquad \textit{(Eq. 5.17)}$$

where
$A_{disturbance}$ = area affected by disturbances (ha yr^{-1})
B_W = average above-ground biomass of areas affected by disturbance (t dm ha^{-1})
R = ratio of below-ground biomass to above-ground biomass (t dm below-ground (t dm above-ground)$^{-1}$).
CF = carbon fraction of dry matter (t C (t dm)$^{-1}$)
fd = fraction of biomass lost in disturbance; a stand-replacing disturbance will kill all (fd = 1) biomass while an insect disturbance may only remove a portion (e.g. fd = 0.3) of the average biomass C density

For Woodland/savannas the loss of carbon from disturbance (fires only) was calculated using the biomass burning equation (IPCC 2006, equation 2.27, p. 2.42):

$$L_{fire} = A * M_B * C_f * G_{ef} * 10^{-3} * (12/44) \qquad (\textit{Eq. 5.18})$$

Where
L_{fire} = mass of carbon emissions from fire (t C);
A = area burnt (ha)
M_B = mass of fuel available for combustion (t ha^{-1})
C_f = combustion factor
G_{ef} = emission factor (g CO_2 (kg dm burnt)$^{-1}$)

This ensured that the disturbance estimates were consistent with the biomass burning estimates.

The total carbon flux (ΔC) was then calculated as follows (IPCC 2006 Equations 2.7 and 2.11):

$$\Delta C = \Delta CG - L_{wood\text{-}removals} - L_{fuelwood} - L_{disturbances} \qquad \textit{(Eq. 5.19)}$$

DATA SOURCES

The land areas for *Forest land remaining forest land* were obtained from the land use maps discussed in section 5.4.5, while the plantation data was obtained from FSA (2012).

Biomass gains

Annual biomass growth data for plantations was calculated from FSA (2012) data by assuming the system is in equilibrium and therefore the amount harvested per area is approximately equal to the mean annual increment (MAI). An average value over the 10 year period was obtained for each plantation category. These values were then multiplied by the Dovey and Smith (2005) dry matter conversion factors (0.39 for softwood; 0.5 for *Eucalyptus*; 0.65 for *Acacia*; 0.51 for Other sp.) to obtain the increment in t dm ha^{-1}. The harvested data is given as m^{3} ha^{-1} yr^{-1} and that was converted to whole tree dry matter by using the ratios provided in Dovey and Smith (2005) (0.52 for softwoods; 0.65 for *Eucalyptus*; 0.91 for *Acacia*; 0.68 for Other sp.). The annual biomass growth values range between 3.5 and 8.3 t dm ha^{-1} yr^{-1} which are slightly lower than the Africa values for tropical and subtropical dry systems (Table 4.10, IPCC 2006 Guidelines, p. 4.59).

For forests, an annual above ground biomass growth value of 0.8 t dm ha^{-1} yr^{-1} was used as Midgley and Seydack (2006) reported that growth was 1% of AGB. The AGB was taken to be 81 t dm ha^{-1} (IPCC GPG, 2003). Data for thickets were limited and variable. Carbon sequestration rates of some thicket species have been estimated to be between 1.2 and 5.1 t C ha^{-1} yr^{-1} (2.4 to 10.2 t dm ha^{-1} yr^{-1}) (Aucamp and Howe, 1979; Mills and Cowling, 2006; Van der Vyver, 2011). Since data is limited a conservative approach was taken by using an IPCC default value. Thickets have been suggested to be more akin to mesic forest ecosystems (Mills et al., 2005), therefore the default value for African forests (1.8 t dm ha^{-1} yr^{-1}) was selected for thickets (IPCC 2006 Guidelines, Table 4.9). Further research into thicket growth rates should be conducted so that uncertainty can be reduced and a country-specific value used.

For Woodland/savannas a value of 0.523 t dm ha^{-1} yr^{-1} was used in the previous inventory (NIR, 2009), however the source of the data could not be traced. This value appeared to be conservative as the literature shows values of between 0.9 – 2.6 t ha^{-1} yr^{-1} (4% AGB, savannas) and 1.2 – 3.4 t ha^{-1} yr^{-1} (3-4% AGB, miombo woodland) (Scholes and Walker, 1993; Wessels, et al., 2013; Chidumayo, 1993; CHAPOSA, 2002; Malimbwi and Zahabu, 2009). In this inventory a value of 0.9 t ha^{-1} yr^{-1} was used which is the lower range value of the IPCC Africa default value (IPCC 2006 Guidelines, Table 4.9).

A root to shoot ratio of 0.24 for Woodland/savannas and forests taken from the GFRASA (2005), as was the 0.34 for Acacia and Other plantation species. For Eucalyptus and softwoods the value of 0.15 was taken from Christie and Scholes (1995) and is consistent with the values used in the previous inventory (NIR, 2009). Thickets were determined to have a ratio of 0.63 (Mills et al., 2005).

The IPCC 2006 default value of 0.47 t C per t dm^{-1} was used for the carbon fraction of dry matter of all Forest lands.

The ratios of dead wood to above-ground biomass for the various land classes were determined from the GFRASA (2005) data (0.18 for plantations, 0.17 for forests and Woodland/savannas and 0.2 for thickets). In the previous inventory a value of 0.14 was used, however this is the ratio of dead wood to total live biomass.

Losses due to wood harvesting

Loss of carbon due to wood harvesting was only calculated for plantations using the FSA data (FSA, 2012). The annual data for wood harvested and losses due to disturbance were used for the years 2000 to 2010. The biomass expansion and conversion factors (BECF) for plantation species were calculated from the data in Dovey and Smith (2005) and are in the range of 0.52 - 0.91 t biomass removed (m^3 of removals)$^{-1}$. These are in the same range as the values used in the 2000 inventory.

Losses due to fuelwood removal

Fuelwood removal was estimated for all sub divisions within the Forest land class. For plantations FSA provides annual data on wood removed for firewood/charcoal. For the natural woodlands and shrublands data at a national scale is limited. Data were obtained from GFRASA (2005) which estimated that a total of 12 000 000 m^3 of biofuel were consumed in 2000. This was an increase from what was consumed in 1990, but data suggests that fuel wood consumption is stabilizing and may even decline in the future (Damm and Triebel, 2008). For this reason a constant value of 12 000 000 m^3 yr^{-1} was used throughout the 10 year inventory period. There is very little information on how this amount is split between the various vegetation types, therefore the whole amount was assumed to be taken from Woodland/savannas with no removal from forests and thickets.

For forests a BECF value of 1.58 t biomass removed (m^3 of removals)$^{-1}$ was calculated from the GFRASA (2005). For thickets and savannas/woodlands the same data source was used and a value of 2.9 t biomass removed (m^3 of removals)$^{-1}$ was calculated. This is higher than the 0.72 provided in the previous inventories but is similar to the IPCC default value of 2.1 t biomass removed (m^3 of removals)$^{-1}$. It also falls in the middle of the range of the IPCC default values provided for pines and hardwoods (growing stock levels of <20 m^3) in temperate regions (Table 4.5, IPCC 2006 Guidelines).

Losses due to disturbance

The only disturbance losses that were estimated for all Forest land classes were those from fire, but for plantations the loss due to other disturbances was also included. The FSA provides data on the area damaged during fire and other disturbances. For the year 1979 to 2000 FSA also recorded whether the plantations in the disturbed area were slightly damaged, seriously damage (in terms of timber sold) or seriously damaged in that there was a total loss of vegetation. The data were used to determine the weighted average fraction of biomass lost in the disturbance (by assuming a slight damage had a fd = 0.3 and serious damage with total loss had a fd = 1) for each plantation type. These averages were kept constant over the 10 year period. The above ground biomass (B_W) for the various plantation types were determined from Forestry SA data and Dovey and Smith (2005) ratios to be 60 t dm ha^{-1} for *Eucalyptus* sp.; 75 t dm ha^{-1} for Softwood sawlogs; 74 t dm ha^{-1} for softwood pulp; 43 t dm ha^{-1} for *Acacia* and 28 t dm ha^{-1} for other species.

The area of Woodland/savannas systems that were disturbed by fires was determined from MODIS burnt area (discussed in detail in section 5.5.2.4). Natural forests and thickets were assumed not to burn. The M_B and C_f factors were taken from the previous inventory (NIR, 2009) and are discussed further in section 5.5.2. A G_{ef} of 1650 g CO_2 (kg dm burnt)$^{-1}$ was taken from the IPCC guidelines.

5.4.7.2 Uncertainties and time-series consistency

UNCERTAINTIES

Much of the uncertainty associated with the land component relates to the mapping and area of each land type and these are discussed in section 5.4.5.3. The statistics from FSA have a high confidence rating (80%) with an uncertainty range from -11% to 3% based on a comparison with the RSA yearbook (NIR, 2009). Uncertainty on a lot of the activity data for the other vegetation sub-categories was difficult to estimate due to a lack of data. Uncertainty would, however, be higher than that for the Forestry industry. Uncertainty of above ground biomass growth increment in natural forests could not be determine but for thickets default factor was used and this has a range of 0.6 – 3.0 t dm ha^{-1} yr^{-1}. The uncertainty in BCEF could not be determined however IPCC 2006 Guidelines suggests that it can reach up to 30%. The range in the root to shoot ratios for forests and woodlands was not provided, however the default values have a range of 0.28 – 0.68; while thicket ratios had a variance of about 5%.

The uncertainty on the burnt area, M_B and C_f factors is discussed in section 5.5.2.5.

The Forest land category covers a wide span of vegetation types, from closed forests to open woodlands, and so the variation on the activity data was large and requires more vigorous analysis to determine the uncertainty. It is suggested that a more detailed uncertainty analysis be done on the data in the next inventory.

TIME-SERIES CONSISTENCY

The same sources of data and land cover maps were used throughout the 10 year period so as to provide a consistent time-series of data.

5.4.7.3 Source-specific QA/QC and verification

The land area in the land cover maps were compared to other data sets (section 5.4.5.4). The activity data was compared to literature and to default values where ever possible.

5.4.7.4 Source-specific recalculations

In this inventory the biomass pools for savannas and thickets were also included in the Forest land. Updates to some of the plantation activity data were incorporated. Carbon losses due to fire disturbance in Woodland/savannas were included in Forest land and not in the biomass burning section. The AGB value for plantations in the previous inventory was corrected as an error was found. The other change is that in the previous inventory the forestry data for 1980 was used, whereas in this inventory the data for the associated year was used. The ratios for deadwood to AGB were corrected in this inventory.

Land converted to Forest land was not included in this inventory as the land conversion data had a high uncertainty and needs to be verified before being used in the inventory estimates. In the previous inventory land converted to plantations was reported and was calculated using FSA data. Carbon gains and losses for *Lands converted to Forest lands* were calculated in the same way as the *Forest land remaining Forest land* so essentially in this inventory all the Forest land data are included under *Forest land remaining Forest land*. The *Lands converted to Forest lands* category only really has implications for the soil carbon pool. Furthermore, the calculations from the previous inventory were found to have errors in this section (incorrect value input for above-ground biomass growth in *Pinus*, and the carbon fraction). There may also have been some double counting as it is not clear if the area of land converted to plantations was subtracted from the total area of timber plantations in the *land remaining land* section. The other issue is that in the previous inventory the area of plantations under *Acacia* sp. was shown to decline, thus Forest land was being converted to another land use. It was assumed that this plantation area was converted to abandoned land and there was zero carbon change. That however, would be incorrect as the loss of carbon from the removal of wood needs to be accounted for and would essentially need to be reported under the land category into which the forest land was converted.

5.4.7.5 Category-specific planned improvements

Besides adding in the land conversion and soil data, it would be an improvement to include information on the various age class categories, specifically in natural forests and plantations. It is also important that more information be gathered on the carbon flows in and out of the DOM pool so that a more complete DOM component can be included in the next inventory.

5.4.8 Cropland [3B2]

5.4.8.1 Cropland remaining cropland [3B2a]

SOURCE CATEGORY DESCRIPTION

This section deals with the sources and sinks of CO_2 caused by changes in biomass stocks in Croplands. Croplands include annual commercial crops, annual semi-commercial or subsistence crops, orchards, viticulture and sugar cane.

METHODOLOGY

Tier 1 method is to multiply the land area of perennial woody cropland by a net estimate of biomass accumulation from growth and subtract losses associated with harvest, gathering or disturbance. Losses are estimated by multiplying a carbon stock value by the area of cropland on which perennial woody crops were harvested. According to IPCC the change in biomass is only estimated for perennial woody crops because for annual crops the increase in biomass stocks in a single year is assumed to equal the biomass losses from harvest and mortality in that same year. Tier 1 assumes that all carbon in perennial woody biomass removed is emitted in the year of removal; and perennial woody crops accumulate carbon for an amount of time equal to a nominal harvest/maturity cycle. However if we assume an average value of the annually harvested area over the entire harvest cycle of the perennial crop, the annual change in carbon stocks in biomass can also be taken to be zero (IPCC 2006 Guidelines, p. 5.7). So the change in carbon stocks for Croplands remaining Croplands was zero as the systems were in balance.

The Tier 1 default assumption is that there is no change in below-ground biomass of perennial trees or crops in agricultural systems (IPCC 2006 Guidelines, p. 5.10). There are no default values and so below-ground biomass was assumed to be zero.

As with Forest lands the DOM and soil carbon pools were excluded due to a lack of data. The CO_2 emissions from biomass burning in Croplands does not have to be reported, as the carbon released during combustion is assumed to be reabsorbed by the vegetation during the next growing season.

DATA

The areas of the various Croplands were obtained from the updated land use maps developed by GTI (2013) and are discussed in detail in section 5.4.5.

5.4.8.2 Uncertainties and time-series consistency

UNCERTAINTIES

The main uncertainties were associated with the area estimates of the Croplands and this is discussed in section 5.4.5.

TIME-SERIES CONSISTENCY

The same sources of data and land cover maps were used throughout the 10 year period so as to provide a consistent time-series of data.

5.4.8.3 Source-specific recalculations

In the previous inventory for 2000 Croplands were estimated to be a sink of 7 730 Gg CO_2. This value was however taken from the 1990 inventory and was not included in this inventory as the activity data and methodology for calculating these carbon changes needs to be updated since the origin of the data is unclear.

5.4.8.4 Category-specific planned improvements

It is essential the land conversions in Croplands be incorporated as this is where all the carbon stock changes occur. Furthermore, the ARC-ISCW recently collected detailed information on the various different types of crops and the tillage and irrigation practices on these croplands (Moeletsi et al., 2013). Much of this information will have an impact on the soil carbon changes in Croplands. This inventory does not include the soil component and the ARC data has not yet been incorporated into this inventory, so it is suggested that it be incorporated into future inventories.

5.4.9 Grassland [3B3]

5.4.9.1 Grassland remaining Grassland [3B3a]

SOURCE CATEGORY DESCRIPTION

Grassland remaining Grassland includes all grasslands, managed pastures and rangelands. The IPCC does recommend separating out the improved grassland, however there was insufficient information at the national scale to enable this division so all grasslands were classified together. In this inventory the fynbos, nama karoo and succulent karoo were also included under Grasslands. This section deals with emissions and removals of CO_2 in the biomass carbon pool as there was insufficient data to determine the DOM and soil carbon pools. The emission of CO_2 from biomass burning was not reported since they are largely balanced by the CO_2 that is reincorporated back into biomass via photosynthetic activity.

METHODOLOGY

A Tier 1 approach assumes no change in biomass in Grassland remaining Grassland as carbon accumulation through plant growth is roughly balanced by losses through grazing, decomposition and fire.

DATA

The areas of the various categories of Grasslands were obtained from the updated land use maps developed by GTI (2013) and are discussed in detail in section 5.4.5.

5.4.9.2 Uncertainty and time-series consistency

UNCERTAINTIES

The main uncertainties were associated with the area estimates of the Grassland categories (discussed in section 5.4.5.3).

TIME-SERIES CONSISTENCY

The same sources of data and land cover maps were used throughout the 10 year period so as to provide a consistent time-series of data.

5.4.9.3 Source-specific recalculations

No recalculations were necessary.

5.4.9.4 Category-specific planned improvements

All Grassland conversions need to be included in future. Otherwise no specific improvements are planned for this category; however estimates could be improved if a sub-category for improved grasslands is included. Soil carbon and DOM data still need to be included for this section.

5.4.10 Wetlands [3B4]

5.4.10.1 Wetlands remaining Wetlands [3B4a]

SOURCE CATEGORY DESCRIPTION

Waterbodies and Wetlands are the two sub-divisions in the Wetland category and these are defined in section 5.4.4.5. Peatlands are included under wetlands, and due to the resolution of the mapping approach used, the area of Peatlands could not be distinguished from the other wetlands, therefore they were grouped together.

METHODOLOGY

As in the previous inventory, emissions from peatlands were ignored as the peatland area in SA is insignificant. The CH_4 emissions from wetlands were excluded as they were estimated to be insignificant. The previous inventory indicated the emissions to be 0.04% of the total CO_2 eq emissions and this is an overestimation as the flooded area was taken to be the total area of waterbodies (NIR, 2009). Waterbodies would only include a small component of flooded land. Furthermore Otter and Scholes (2000) showed that emissions only occur from shallow water, which again would reduce the area of the flooded land which is likely to emit CH_4. Therefore emissions from wetlands were assumed to be negligible.

DATA

The area of wetlands and waterbodies were obtained from the updated land use maps developed by GTI (2013) and are discussed in detail in section 5.4.5.

5.4.10.2 Uncertainty and time-series consistency

UNCERTAINTIES

The main uncertainties were associated with the area estimates of the Wetland categories (discussed in section 5.4.5.3).

TIME-SERIES CONSISTENCY

The same sources of data and land cover maps were used throughout the 10 year period so as to provide a consistent time-series of data.

5.4.10.3 Source-specific recalculations

In the previous inventory for 2000 CH_4 emissions from wetlands was calculated, however this was not included in this inventory as the resulting emissions were show to contribute less than 0.04% to the total CO_2 eq. emissions for 2000 and this was an over estimate. The Wetland category therefore did not contribute any emissions to the emission inventory.

5.4.11 Settlements [3B5]

5.4.11.1 Settlements remaining Settlements [3B5a]

SOURCE CATEGORY DESCRIPTION

Settlements include all formal built-up areas, in which people reside on a permanent or near-permanent basis. It includes transportation infrastructure as well as mines. The population of South Africa in 2010 is just over 50 million (Statistics SA, 2010), with the urban population increasing from 52% to 62% over the past two decades (2nd National Communications, 2011). The surface area of settlements provided by the land cover map developed for this inventory was 2 002 077 ha (1 822 753 ha settlements and 179 324 ha under mines). This number was slightly higher than the 1 832 725 ha used in the previous 2000 inventory; however the increase was expected due to a growing population.

METHODOLOGY

The Tier 1 approach assumes no change in carbon stocks in above ground biomass in Settlements remaining Settlements. Therefore this category did not contribute any emissions or removals to the overall inventory.

DATA

The area of Settlements was obtained from the updated land use maps developed by GTI (2013) and are discussed in detail in section 5.4.5.

5.4.11.2 Uncertainties and time-series consistency

UNCERTAINTIES

The main uncertainties were associated with the area estimates of Settlements and this is discussed in section 5.4.5.3.

TIME-SERIES CONSISTENCY

The same sources of data and land cover maps were used throughout the 10 year period so as to provide a consistent time-series of data.

5.4.11.3 Source-specific recalculations

No recalculations were necessary.

5.4.11.4 Category-specific planned improvements

There are no planned improvements for this category, particularly since it is not a key category, however carbon stock changes could be improved if land conversions and country-specific data on biomass in Settlements could be included.

5.4.12 Other land [3B6]

5.4.12.1 Other land remaining Other land [3B6a]

SOURCE CATEGORY DESCRIPTION

Other land includes bare soil, rock, and all other land areas that do not fall into the other land classes. The Tier 1 method assumes no change in carbon stocks in this category, so growth and loss are in balance.

DATA

The area of Other lands was obtained from the updated land use maps developed by GTI (2013) and are discussed in detail in section 5.4.5.

5.4.12.2 Uncertainties and time-series consistency

UNCERTAINTIES

The main uncertainties were associated with the area estimates of Other lands and this is discussed in section 5.4.5.3.

TIME-SERIES CONSISTENCY

The same sources of data and land cover maps were used throughout the 10 year period so as to provide a consistent time-series of data.

5.4.12.3 Source-specific recalculations

No recalculations were necessary.

5.4.12.4 Category-specific planned improvements

No specific improvements are planned for this category other than to include the land conversions.

5.5 Aggregated sources and non-CO_2 emission sources on land [3C]

5.5.1 Overview of shares and trends in emissions

Aggregated and non-CO_2 emission sources on land produced a total of 101 522 Gg CO_2 eq over the 10 year period. This fluctuated between a low of 8 851 Gg CO_2eq in 2005 and a high of 10 183 Gg CO_2eq in 2002. 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. Indirect N_2O emissions from managed soil were the biggest contributor to this category, producing between 36.6% (2010) and 43.0% (2000) of the total annual aggregated and non-CO_2 emissions. This was followed by direct N_2O emissions from managed soils (24.6% - 28.6%) and biomass burning (1.6% - 2.6%) (Figure 5.10).

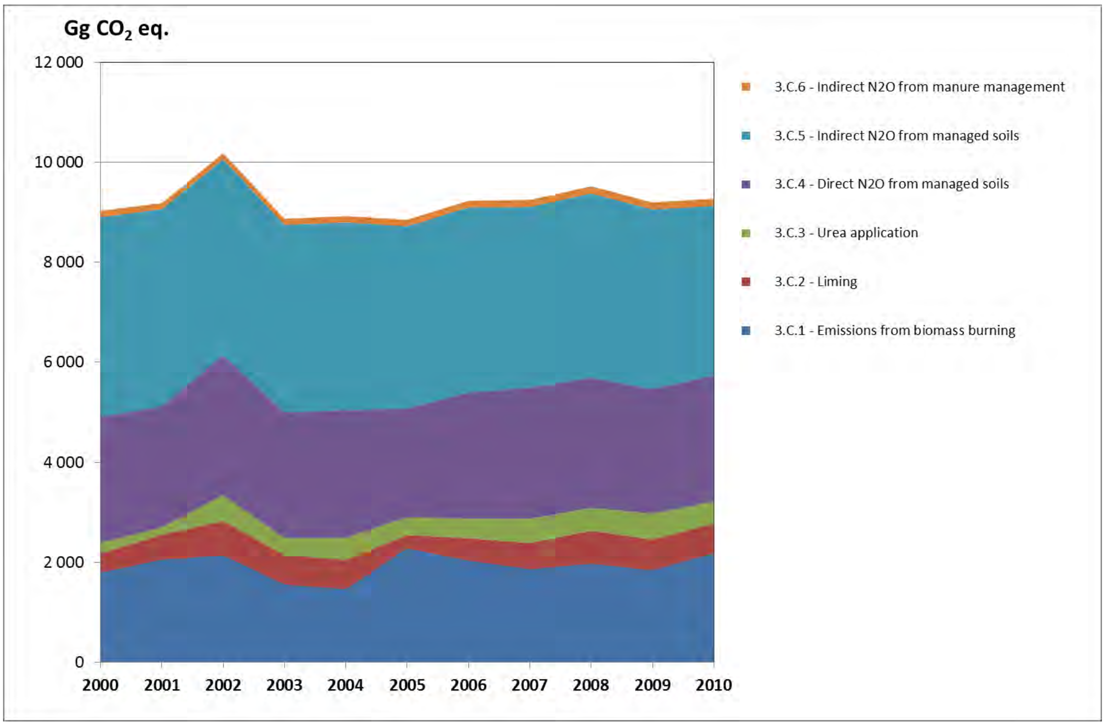

Figure 5.10: Sector 3 AFOLU – Aggregated and non-CO_2 sources: Trend and emission levels, 2000 – 2010.

5.5.2 Biomass burning [3C1]

5.5.2.1 *Source category description*

Biomass burning is an important ecosystem process in southern Africa, with significant implication for regional and global atmospheric chemistry and biogeochemical cycles (Korontzi *et al.,* 2003). According to the National Inventory Report (NIR, 2009) fire plays an important role in South African biomes where grassland, savanna and fynbos fires maintain ecological health. Savanna and grassland environments produce fine fuels which dry out rapidly when there is no rain and human ignition and fire management is pervasive throughout Africa (Archibald *et al.,* 2009). Under ideal conditions, when organic materials are burned, the oxidation process takes place resulting in the release of carbon dioxide and water vapour. In addition to carbon dioxide, the burning of biomass results in the release of other GHGs or precursor of GHGs that originate from incomplete combustion of the fuel. The key greenhouse gases are CO_2, CH_4, and N_2O; however, NO_x, NH_3, NMVOC and CO are also produced and these are precursors for the formation of GHG in the atmosphere (IPCC, 2006).

Although the IPCC guidelines only require the calculation of emissions from savanna burning, South Africa reports emissions of non-CO_2 gases (CH_4, CO, N_2O and NO_x) from all land categories, as explained in the 2000 inventory (NIR, 2009). The burning of biomass is classified into the six land-use categories defined in the 2006 guidelines, namely Forest Land, Cropland, Grassland, Wetlands, Settlements and Other Land. The IPCC guidelines suggest that emissions from savanna burning should be included under the Grassland category, however since, in this inventory savannas and woodlands have been classified as Forest land their emissions were dealt with under Forest land.

Although burning of croplands might be limited, burning has been shown to occur on cultivated land (Archibald *et al.*, 2010), mainly due to the spread of fires from surrounding grassland areas. The Croplands category was sub-divided into Annual and Perennial crops and there was also a sub-division for Sugarcane as the residue burning in this crop is still an acceptable practice in South Africa (Hurly et al., 2003).

The CO_2 net emissions should be reported when CO_2 emissions and removals from the biomass pool are not equivalent in the inventory year. For grasslands and croplands the annual CO_2 removals (through growth) and emissions (whether by decay or fire) are in balance. CO_2 emissions are therefore assumed to be zero for Grasslands and Croplands.

Non-CO_2 emissions from biomass burning in all land categories were dealt with in this section. For Forest land the CO_2 emissions from biomass burning were not included in this section but rather in the Forest land section (see section 5.4.7).

5.5.2.2 Overview of shares and trends in emissions

Biomass burning contributed between 1 466 Gg CO_2 eq (2004) and 2 282 Gg CO_2eq (2005) to the overall emissions in the AFOLU sector. Of this about 64% was CH_4 and 36% N_2O. Biomass burning was at its lowest in the years 2003, 2004 and 2009. These annual fluctuations were related to the estimated amount of burnt area each year. Grasslands contributed the most to biomass burning emissions (47.1% - 61.7%), followed by Forest lands (22.8% - 38.7%) and then Croplands contributing around 14% (Figure 5.11). In the previous inventory (NIR, 2009) Grasslands contributed about 68% and Forest lands only 28%, compared to the 53.9% and 30.3%, respectively, in the year 2000 in this inventory. This change was likely due to the incorporation of the savannas into the Forest land category in this inventory, as in the previous inventory they were classified into the Grasslands section in the Biomass burning section. The burning in Croplands differs significantly between this inventory and the previous one. Some differences could be due to differences in land use categorization and mapping scales, however this difference needs to be investigated further in the future. Comparative data was hard to come by so making a good assessment of this cropland burning was difficult and requires a more detailed investigation in the future.

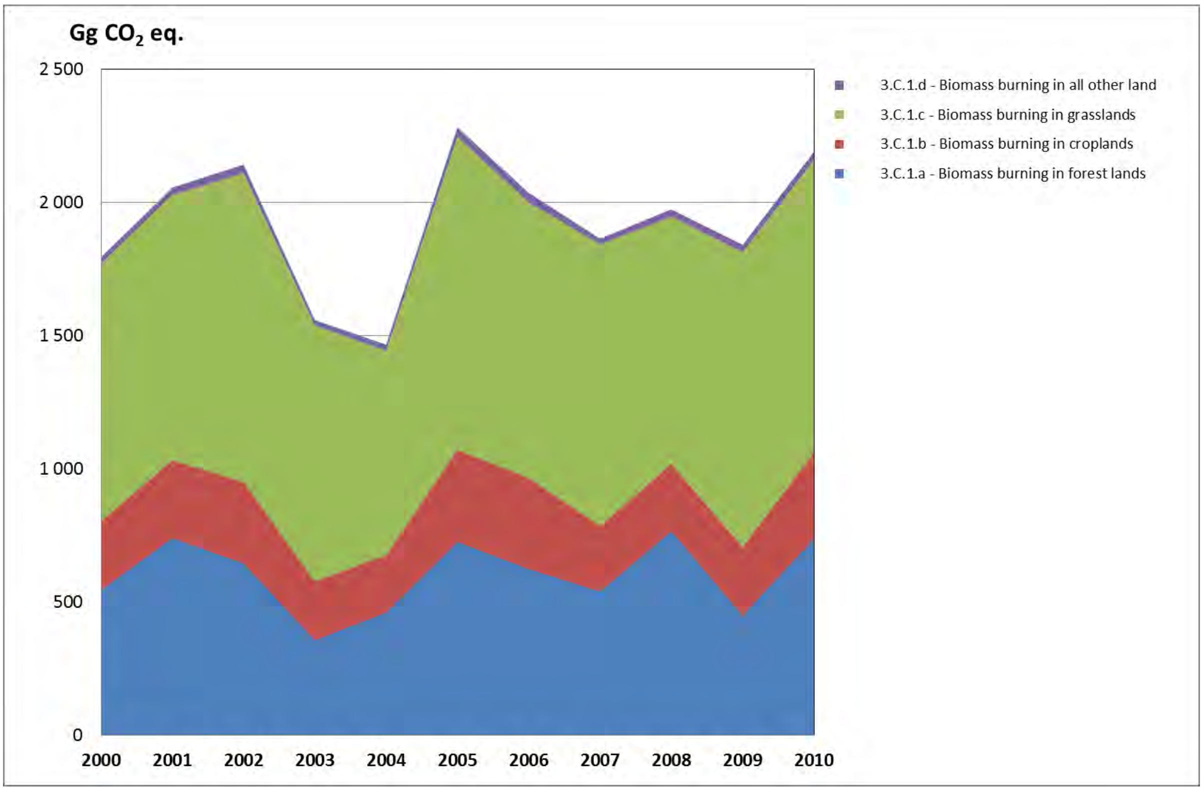

Figure 5.11: Sector 3 AFOLU – Biomass burning: Contribution of the various land categories to the biomass burning emissions, 2000 – 2010.

5.5.2.3 Data sources

BURNT AREA DATA

Annual burnt area maps were produced from the MODIS monthly burnt area product for each year of the inventory (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 Albers Equal Area projection. 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 land cover maps developed and discussed in section 5.4.5 to determine the area burnt in each land class. The 2000 – 2004 burnt area was intersected with the 2001 land cover map, while the 2005 – 2010 burnt area maps was overlaid on the 2010 land cover map.

Due to the scale of the land cover and burnt area maps some corrections were made to incorrect burnt area allocations. For plantations the area burnt was taken from the FSA data rather than the burnt area maps so as to remain consistent with the data used in the Forest land section (i.e. removals due to disturbance). The difference between the MODIS burnt area data and the FSA data was equally divided (either added or subtracted depending on the data) into the Woodland/savanna and Grassland burnt area.

Natural forests and thicket patches are scattered throughout the Woodland and Grassland categories, but they themselves don't generally burn. However due to the scale of the land cover and burnt area data some burnt area was allocated to these land classes. This burnt area was assumed to be due to burning in neighbouring Grasslands or Savannas, so as in the previous inventory (NIR, 2009) this was corrected for. Similarly a small amount of burnt area was also assigned to Settlements, Waterbodies and Otherlands. All the burnt area from Natural forests, Thickets, Settlements, and Waterbodies was taken away from these categories and added equally to the Grassland and Woodland/savanna category. The Other land burnt area was equally added to the Grassland, Woodland/savanna and Fynbos categories. The resultant percentage burnt area in each land class is shown in Table 5.9.

Table 5.9: Sector 3 AFOLU – Biomass burning: Percentage area burnt within each land class, 2000 – 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 / Savanna	3.76	5.33	4.64	2.20	3.03	5.23	4.31	2.84	4.62	3.14	5.48
Plantations	1.52	1.28	1.24	2.11	2.12	1.68	2.25	5.58	5.63	1.55	1.24
Annual crops	6.15	6.30	7.23	5.15	4.99	7.66	7.68	4.32	4.90	4.82	5.75
Permanent crops (orchard)	0.80	1.33	1.18	0.81	0.62	1.11	1.11	1.61	2.16	0.99	2.03
Permanent crops (viticulture)	0.91	0.39	0.39	0.52	0.09	0.38	0.73	0.30	0.09	0.60	0.26
Annual semi-commercial / subsistence crops	8.96	15.91	11.17	8.86	9.43	18.50	13.90	17.77	12.09	12.08	15.26
Sugarcane	0.66	1.04	1.22	1.45	0.89	1.85	0.97	1.25	1.99	1.39	2.49
Settlements	0	0	0	0	0	0	0	0	0	0	0
Wetlands	6.12	7.27	8.13	5.20	5.93	9.02	8.81	5.56	6.95	7.05	7.84
Grasslands	9.94	10.54	11.28	9.39	7.48	11.64	10.53	10.58	8.89	9.74	10.61
Water bodies	0	0	0	0	0	0	0	0	0	0	0
Fynbos	0.92	0.66	1.50	1.14	0.89	1.19	0.82	0.99	1.20	2.17	1.40
Nama Karoo	0.05	0.04	0.06	0.13	0.09	0.10	0.03	0.10	0.18	0.07	0.16
Succulent Karoo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.04
Other lands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

MASS OF FUEL AVAILABLE FOR COMBUSTION

The values for fuel density were sourced from the 2000 inventory (NIR, 2009), except for Croplands where a value of 7.0 t ha^{-1} was taken from the 2004 Agricultural Inventory (DAFF, 2010).

COMBUSTION FACTOR

The combustion factors (C_f) were taken from the 2000 GHG inventory (NIR, 2009).

EMISSION FACTORS

Emission factors were also sourced from the 2000 GHG inventory (NIR, 2009).

5.5.2.4 Methodology

The Tier 2 methodology was applied, with the emissions from biomass burning being calculated using the following equation (Equation 2.27 from IPCC 2006 Guidelines):

$$L_{fire} = A * M_B * Cf * G_{ef} * 10^{-3} \qquad (Eq. 5.20)$$

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

5.5.2.5 Uncertainty and time-series consistency

UNCERTAINTY

The MODIS burnt area products have been shown to identify about 75% of the burnt area in Southern Africa (Roy and Boschetti, 2009a & b). The MCD45 product produces a finer resolution (500 m) than the other products (1 km) and uses a more sophisticated change-detection process to identify a burn scar (Roy et al., 2005). It also provides ancillary data on the quality of the burn scar detection. The MCD45 product has been shown to have the lowest omission and commission errors compared to the L3JRC and GlobCarbon products (Anaya and Chuvieco, 2012). Much of the uncertainty lies with the land cover maps (Section 5.4.5.3) due to the scale of the maps and so some corrections for misclassified pixels were made. The area burnt under sugarcane was highly uncertain, as no published data was available. Since the values for fuel density, combustion fraction and emission factors were taken from the 2000 GHG inventory the uncertainties discussed in section 5.5.1.6 of the 2000 inventory (NIR, 2010) still applies to this data set.

TIME-SERIES CONSISTENCY

The MODIS burnt area product was used for all 10 years to maintain consistency. There may be a slight variation in the data for the first five years and second five years since the 2 land cover maps (2001 and 2010) were used. The land cover maps are, however, consistent with each other as they are both derived from MODIS data and have the same vegetation categories.

5.5.2.6 Source-specific QA/QC

The burnt area data derived in this inventory was compared to the data from the previous inventory (NIR, 2009) (Table 5.10) using the data from the same years (i.e. 2000 – 2007). While the values are in a similar range, the percentage burnt area in Grasslands and Wetlands is much higher in this inventory. Differences are attributed to the different land cover maps that were used in the two inventories.

Table 5.10: Sector 3 AFOLU – Biomass burning: Comparison of burnt area percentage (mean with SD in brackets) with previous inventory, 2000 – 2007.

Vegetation class	Burnt area (%)	
	NIR (2009)	This inventory
Arid shrubland	0.02 (0.01)	0.01 (0.04)
Plantations	1.71 (0.42)	1.91 (1.33)
Fynbos	0.93 (0.26)	0.92 (0.23)
Grassland	8.79 (1.12)	10.76 (1.25)
Savanna	3.8 (1.07)	4.04 (1.10)
Wetlands	3.57 (0.62)	6.69 (1.44)

In terms of the amount of fuel burnt and the combustion factors, South Africa is one of the leaders in research on biomass burning. The methods used to derive the data were very comprehensive and locally relevant.

5.5.2.7 Source-specific recalculations

Biomass burning emissions were recalculated for the year 2000 using the new land cover maps developed in this inventory. This provided a slightly different burnt area for each land class. This was done so as to maintain consistency with the land areas used in the Land section of this report. The mass of fuel available for combustion in Croplands was taken from a more recent source and this value was higher than that used in the previous inventory. Therefore these emissions were also recalculated.

5.5.2.8 Source-specific planned improvements and recommendations

There are no planned improvements for this category.

5.5.3 Liming and urea application [3C2 and 3C3]

5.5.3.1 *Source category description*

Liming is used to reduce soil acidity and improve plant growth in managed systems. Adding carbonates to soils in the form of lime (limestone or dolomite) leads to CO_2 emissions as the carbonate limes dissolve and release bicarbonate.

Adding urea to soils during fertilization leads to a loss of CO_2 that was fixed in the industrial production process. Similar to the soil reaction following the addition of lime, bicarbonate that is formed evolves into CO_2 and water.

5.5.3.2 *Overview of shares and trends in emissions*

The CO_2 from liming showed a high annual variability, with the highest emissions being in 2002 (684 Gg CO_2) and the lowest in 2005 (267 Gg CO_2) (Figure 5.12). The variation was directly linked to the limestone and dolomite consumption (Figure 5.13). The CO_2 emissions from Urea application showed a similar annual variability (Figure 5.12). Urea application produced an accumulated amount of 4 297 Gg CO_2 between 2000 and 2010, with the lowest emissions (147 Gg) occurring in 2001 and highest (519 Gg) in 2002 and 2009. There was a sharp decline in emissions from both liming and urea application in 2005.

5.5.3.3 *Methodology*

A Tier 1 approach of the IPCC 2006 guidelines was used to calculate annual C emissions from lime application (Equation 11.12, IPCC 2006) and CO_2 emissions from urea fertilization (Equation 11.13, IPCC 2006).

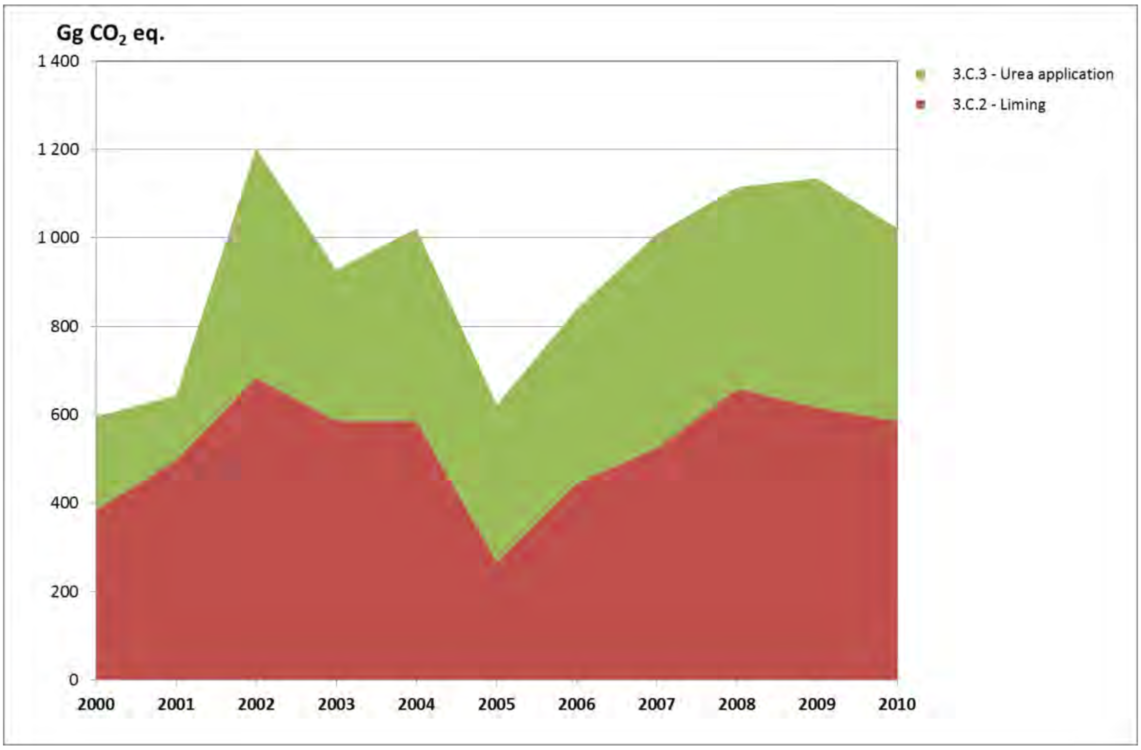

Figure 5.12: Sector 3 AFOLU – Aggregated sources: Trends and emission levels from liming and urea application, 2000 – 2010.

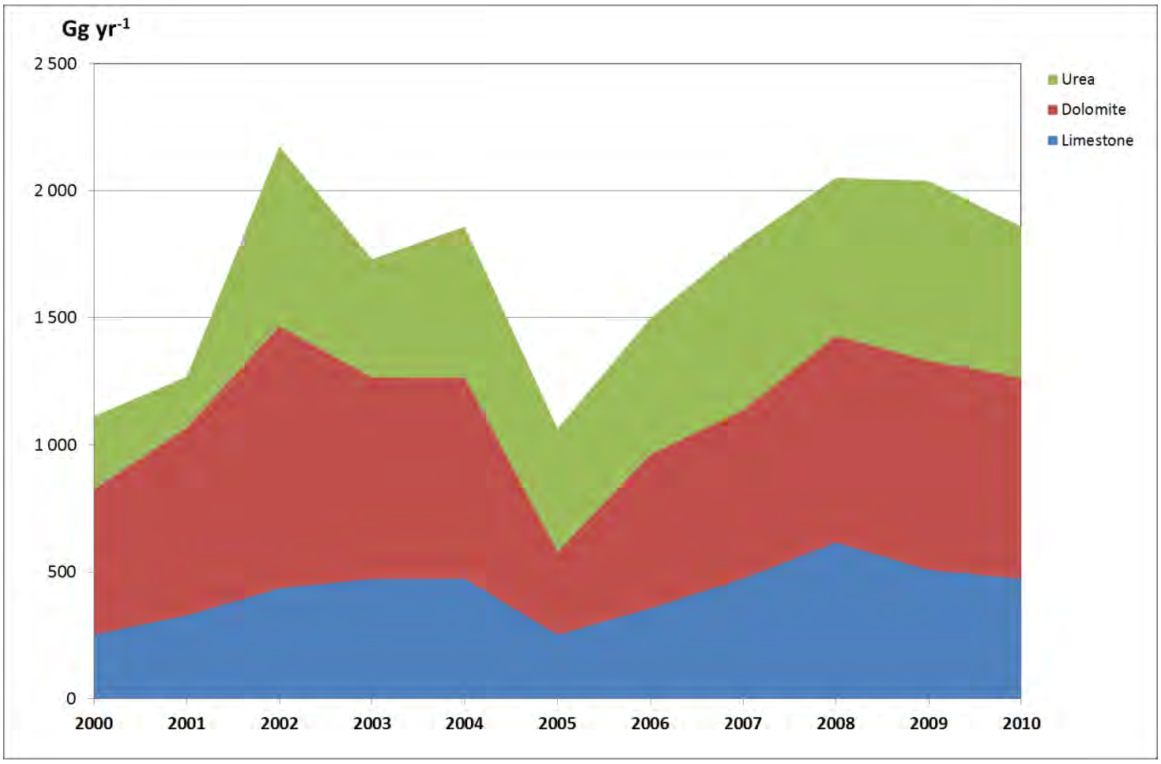

Figure 5.13: Sector 3 AFOLU – Aggregated sources: Annual amount of lime and urea applied to soils, 2000 – 2010.

5.5.3.4 Data sources

The amount of limestone and dolomite applied was obtained from the Fertilizer Society of South Africa and reported in Otter (2011). Data for 2010 was not available so an amount was estimated as described in DAFF (2010). The amount of urea used was assumed to be the amount imported into SA (FAOSTAT; http://faostat.fao.org/site/575/default.aspx#ancor; accessed on 02/2013) (Figure 5.13).

EMISSION FACTORS

The IPCC default emission factors of 0.12 t C (t limestone)$^{-1}$; 0.13 t C (t dolomite)$^{-1}$; and 0.2 t C (t urea)$^{-1}$ were used to calculate the CO_2 emissions.

5.5.3.5 Uncertainty and time-series consistency

UNCERTAINTY

The dolomite and limestone default emission factors have an uncertainty of -50% (IPCC 2006 Guidelines, p. 11.27). In terms of urea application it was assumed that all urea imported was applied to agricultural soils and this approach may lead to an over- or under-estimate if the total imported is not applied in that particular year. However, over the long-term this bias should be negligible (IPCC, 2006). As for the liming emission factors, the urea emission factor also has an uncertainty of -50% (IPCC 2006 Guidelines, p. 11.32).

TIME-SERIES CONSISTENCY

For liming the same source of activity data was used for 2000 to 2009, and for 2010 numbers were estimated based on this data so as to try and maintain the time-series consistency. The same activity data source for urea was applied to all 10 years.

5.5.3.6 Source-specific QA/QC and verification

Quality control of the activity data was limited for this section as very little comparative data was available.

5.5.3.7 Source-specific recalculations

Emissions from liming and urea application were not included in the previous inventory, so this report provides the first set of emission data for 2000 for this category. Therefore no recalculations were necessary.

5.5.3.8 Source-specific planned improvements and recommendations

At this stage there are no improvements planned for CO_2 emissions from liming and urea application, however more accurate urea application data would improve the emission estimates.

5.5.4 Direct N_2O emissions from managed soils [3C4]

5.5.4.1 Source category description

Agricultural soils contribute to greenhouse gases in three ways (Desjardins *et al*., 1993):

- CO_2 through the loss of soil organic matter. This is a result of land use change, and is therefore dealt with in the Land sector and not in this section;
- CH_4 from anaerobic soils. Anaerobic cultivation such as rice paddies is not practised in South Africa, and therefore CH_4 emissions from agricultural soils are not included in this inventory;
- N_2O from fertilizer use and intensive cultivation. This is a significant fraction of non-carbon emissions from agriculture and is the focus of this section of the inventory.

The IPCC (2006) identifies several pathways of nitrogen inputs to agricultural soils that can result in direct N_2O emissions:

- Nitrogen inputs:
  - Synthetic nitrogen fertilizers;
  - Organic fertilizers (including animal manure, compost and sewage sludge);
  - Crop residue (including nitrogen fixing crops);
- Soil organic matter lost from mineral soils through land-use change (dealt with under the Land sector);
- Organic soil that is drained or managed for agricultural purposes (also dealt with under the Land sector); and
- Animal manure deposited on pastures, rangelands and paddocks.

5.5.4.2 Overview of shares and trends in emissions

Direct N_2O emissions from managed soils produced an accumulated total of 27 738 Gg CO_2eq between 2000 and 2010. Emissions fluctuated annually with 2002 having the highest and 2005 the lowest emissions of 2 137 Gg CO_2eq (Figure 5.14). The variation was due to the fluctuation in synthetic fertilizer use, while emissions from organic amendments (manure inputs, compost and sewage sludge) and crop residues did not change significantly over the 10 year period. The greatest contributor to the direct N_2O emissions was emissions from the use of synthetic fertilizers which contributed an average of 77.2% (74.3% - 79.2%) over the 10 year period.

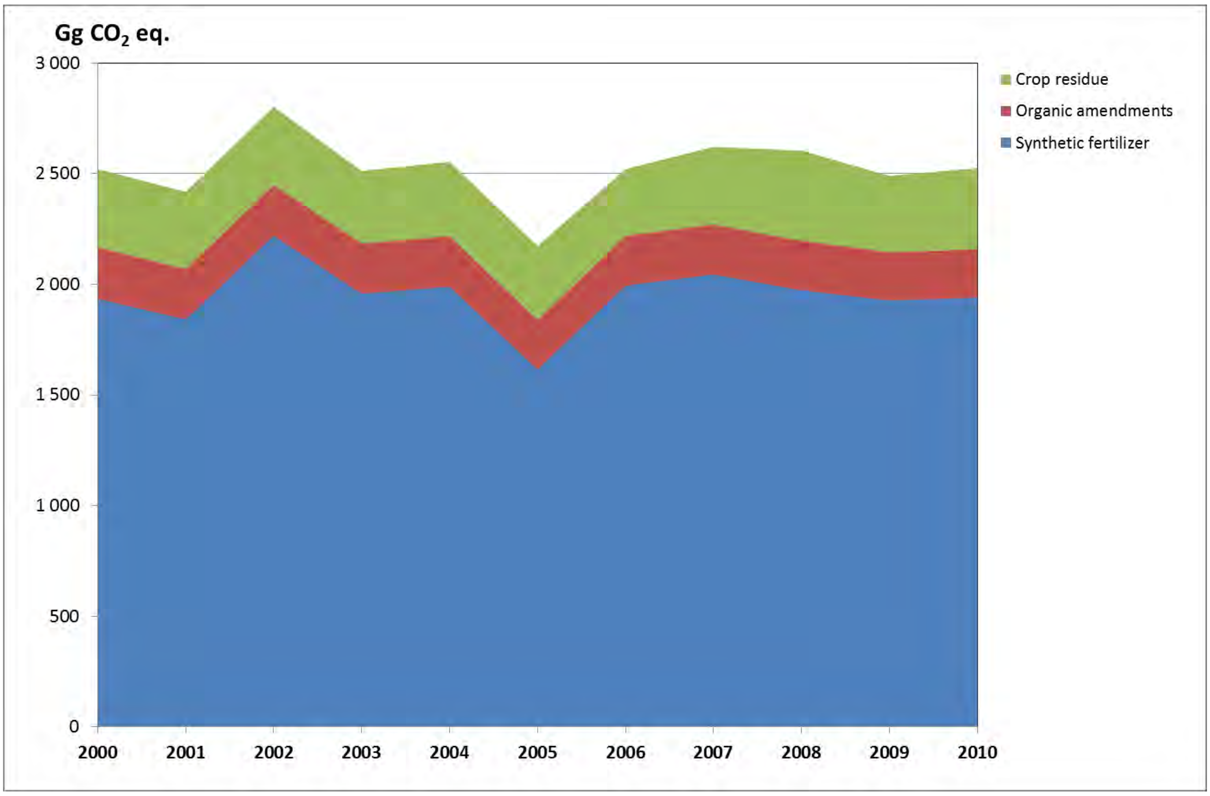

Figure 5.14: Sector 3 AFOLU – Direct N_2O: Trend and emission levels of direct N_2O from managed soils, 2000 – 2010.

5.5.4.3 Methodology

The N_2O emissions from managed soils were calculated by using the Tier 1 method from the IPCC 2006 Guidelines (Equation 11.1). As in the 2004 agricultural inventory (DAFF, 2010), the contribution of N inputs from F_{SOM} (N mineralization associated with loss of SOM resulting from change of land use or management) and F_{OS} (N from managed organic soils) were assumed to be minimal and were therefore excluded from the calculations. Furthermore, since there are no flooded rice fields in South Africa these emissions were also excluded. The simplified equation for direct N_2O emissions from soils is therefore as follows:

$$N_2O_{Direct}\text{-}N = N_2O\text{-}N_{N\ inputs} + N_2O\text{-}N_{PRP} \quad \text{[Eq 5.21]}$$

Where:

$$N_2O\text{-}N_{N\ inputs} = [(F_{SN} + F_{ON} + F_{CR}) * EF_1] \quad \text{[Eq 5.22]}$$

$$N_2O\text{-}N_{PRP} = [(F_{PRP,CPP} * EF_{3PRP,CPP}) + (F_{PRP,SO} * EF_{3PRP,SO})] \quad \text{[Eq 5.23]}$$

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_{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.

Most of the country specific data was obtained from national statistics from the Department of Agriculture (Abstracts of Agricultural Statistics, 2012), and supporting data was obtained through scientific articles, guidelines, reports or personal communications with experts as discussed below.

NITROGEN INPUTS

Synthetic fertilizer use (F_{SN}) was recorder by the Fertilizer Society of South Africa, but organic nitrogen (F_{ON}) and crop residue (F_{CR}) inputs needed to be calculated. F_{ON} is composed of N inputs from managed manure (F_{AM}), compost and sewage sludge. F_{AM} includes inputs from manure which is managed in the various manure management systems (i.e. lagoons, liquid/slurries, or as drylot, daily spread, or compost). The amount of animal manure N, after all losses, applied to managed soils or for feed, fuel or construction was calculated using Equations 10.34 and 11.4 in the IPCC 2006 guidelines.

The amount of compost used on managed soils each year was calculated in the same way as in the 2004 inventory (DAFF, 2010). The synthetic fertilizer input changed each year, while the rest of the factors were assumed to remain unchanged over the 10 year period.

Application of sewage sludge to agricultural land is common practice in South Africa; however, no national data of total production of sewage sludge for South Africa exists, therefore estimates were made from wastewater treatment plant data (DAFF, 2010). To estimate total sewage sludge production, a list of wastewater treatment plants (WWTP) was obtained from the Department of Water Affairs (DWA, 2009) and an average capacity for each province was used to calculate the volume of wastewater treated in South Africa each year. Supporting references show that 0.03% of wastewater typically could be precipitated as sewage sludge (0.1% of wastewater is solids, of which 30% is suspended) (Environment Canada, 2009; Van der Waal, 2008). Snyman *et al.* (2004) reported several end uses for sewage sludge and from this it was estimated that about 30% is for agricultural use. Due to limited data, for the years 2000 to 2004 the amount of sewage sludge used for agriculture was kept constant. The 2004 report (DAFF, 2010) did however indicated that this amount was probably an over-estimate as the use of sewage sludge for agricultural purposes has reduced significantly over the last 5 years due to contamination. There are no figures on how much this has been reduced by, so an estimated 15% reduction each year between 2004 and 2010 was assumed.

Actual data for crop residue left on land was not available so the amount was calculated as described in DAFF (2010). The principal biological nitrogen fixing (BNF) crops in South Africa are soybeans, groundnuts and lucerne. The addition of N through BNF crops were included in the default values for crop residue calculations.

NITROGEN INPUTS FROM URINE AND DUNG

Manure deposited in pastures, rangelands and paddocks include all the open areas where animal excretions are not removed or managed. This fraction remains on the land, where it is returned to the soil, and also contributes to GHG emissions. In South Africa the majority of animals spend most or part of their lives on pastures and rangelands. The annual amount of urine and dung N deposited on pasture, range or paddock and by grazing animals (F_{PRP}) was calculated as in the 2004 inventory using Equation 11.5 in the IPCC 2006 guidelines (Chapter 11, Volume 4).

5.5.4.4 Activity data

Nitrogen inputs into the managed soils fluctuated annually, with synthetic fertilizers being the dominant inputs (Figure 5.15).

SYNTHETIC FERTILIZER INPUTS (F_{SN})

National consumption data for N fertilizer for 2000 to 2009 was obtained from the Fertilizer Society of South Africa (http://www.fssa.org.za) and reported in Otter (2011). Data for 2010 were estimated using the 2000 – 2009 data (Otter, 2011).

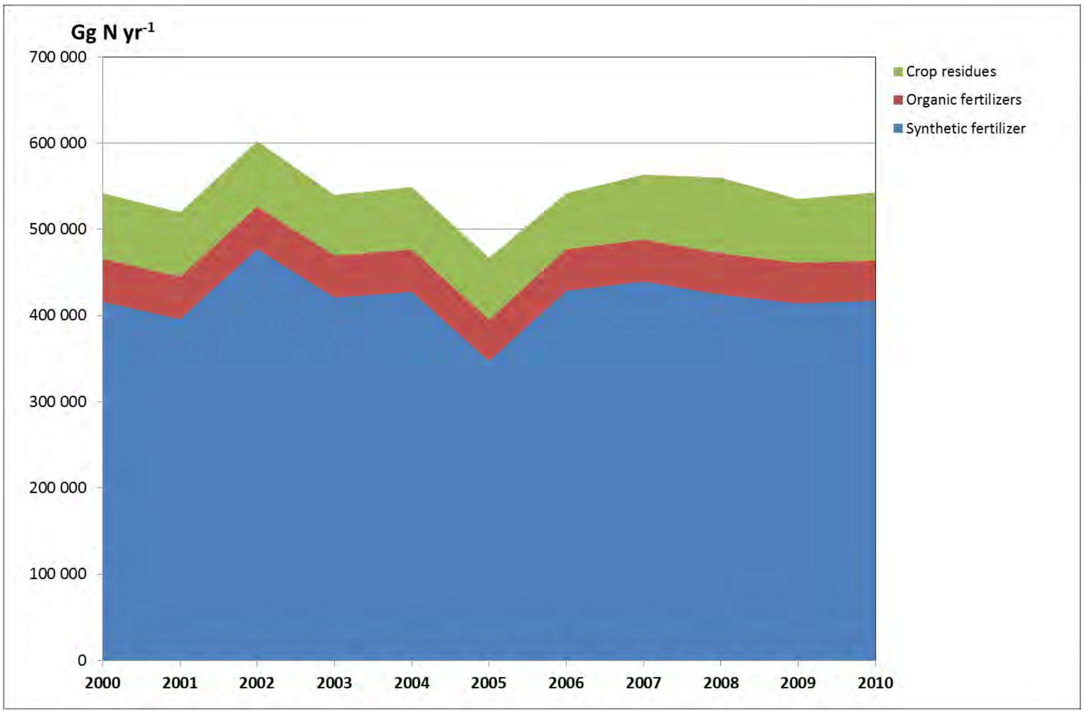

Figure 5.15: Sector 3 AFOLU – Direct N_2O: Nitrogen inputs to managed soils, 2000 – 2010.

ORGANIC NITROGEN INPUTS (F_{ON})

Managed manure inputs (F_{AM})

The calculation of F_{AM} required the following activity data:

- population data (section 5.3.3.3);
- N_{ex} data (section 5.3.4.3);
- manure management system usage data (section 5.3.4.3);
- amount of managed manure nitrogen that is lost in each manure management system ($Frac_{LossMS}$). IPCC 2006 default values were used here (Table 10.23, Chapter 10, Volume 4 , IPCC 2006);
- amount of nitrogen from bedding. There was no data available for this so the value was assumed to be zero; and
- the fraction of managed manure used for feed, fuel, or construction. Again there was insufficient data and thus F_{AM} was not adjusted for these fractions (IPCC 2006 guidelines, p. 11.13).

Compost

To estimate N inputs from compost the F_{SN} data was used. It was estimated that a total of 5% of all farmers use compost. Compost is seldom, if ever, used as the only nutrient source for crops or vegetables. It is used as a supplement for synthetic fertilizers, and it is estimated that farmers would supply about a third (33%) of nutrient needs through compost. All of this was taken into account when estimating N inputs from compost (details provided in DAFF (2010)).

Sewage sludge

Waste water treatment data was obtained from DWA (2009) and the end users of sewage sludge were determined from Snyman *et al.* (2004). Calculations follow those described in DAFF (2010).

NITROGEN INPUTS FROM CROP RESIDUE (F_{CR})

Actual data for crop residue left on land was not available so the amount was calculated as described in DAFF (2010) using the following activity data:

- crop production data from the Abstract of Agricultural Statistics (2012). For some of the crops the data was for a split year (i.e. July 2005/June 2006), while others it was for a year January to December. In order to standardize the data it was assumed that the production was evenly split between the two years and thus production per full year (January to December) was calculated. For dry peas production declined until there was no reported data between 2007 and 2010 so dry pea production was assumed to be zero for these years. The same applied to lentil production between 2006 and 2010. Rye production data was not recorded between 2003 and 2009, but the data for these years was calculated by fitting a linear regression to the data collected since 1970.

- IPCC 2006 default values for above- and below-ground residues. In the absence of IPCC default values, external references were used to calculate the biomass by using harvest index of crops;
- above-ground biomass removal from grazing and burning. As in the previous inventory it was assumed that all below-ground plant material remains in the soil, and that most (80%) above-ground plant material is removed by grazing. Removal of above-ground biomass includes grazing (for all field crops) and burning (assumed only to occur with sugarcane).

NITROGEN INPUTS FROM MANURE DEPOSITED BY LIVESTOCK ON PASTURES, RANGELANDS AND PADDOCKS (F_{PRP})

The activity data required for this calculation were population data (section 5.3.3.3), N_{ex} data (section 5.3.4.3) and the fraction of total annual N excretion for each livestock species that is deposited on PRP.

5.5.4.5 Emission factors

The IPCC 2006 default emission factors (Chapter 11, Volume 4, Table 11.1) were used to estimate direct N_2O emissions from managed soils. EF_1 was used to estimate direct N_2O-N emissions from F_{SN}, F_{ON} and F_{CR} N inputs; while EF_{3PRP} was used to estimate direct N_2O-N emissions from urine and dung N inputs to soil from cattle, poultry and pigs (CPP), and sheep and other animals (SO).

The IPCC 2006 default EF's for pasture, range and paddock were thought to be over-estimated for South Africa as grazing areas in South Africa are mostly in the drier parts of the country where water content is low. Even though the N is available as a potential source of N_2O, this is not the most likely pathway. The 2004 inventory (DAFF, 2010) suggests that emissions from PRP are probably more towards the lower range of the default values provided by IPCC (2006).

5.5.4.6 Uncertainty and time-series consistency

UNCERTAINTY

The uncertainty ranges for EF_1, $EF_{3PRP,CPP}$ and $EF_{3PRP,SO}$ are 0.003 – 0.03, 0.007 – 0.06, and 0.003 – 0.03 respectively (IPCC 2006 Guidelines, Table 11.1).

The uncertainty on the amount of compost applied was high due to the high variability across the region. No quantitative data was available so estimates were based on expert opinion. Most estimates indicated a use of 20% animal manure in producing compost, while some indicated as much as 80%. Most vegetable production is estimated to use compost for about 33% of the nutrient requirements. The data could be improved if more information on organic matter use in agriculture was available.

Sewage sludge use in agriculture is also uncertain due to a lack of actual data. In this inventory data from 72 WWTP was used as representative of all 1,697 WWTP in SA. A calculated value based on estimated capacity ranges for wastewater treatment was used to determine the total quantity of sewage sludge produced. Ranges of WWTP capacity, varied between 1,776 ML and 8,580 ML per day, with an average of 5,177 ML per plant. The end use of sewage sludge could also be improved. It was estimated that 30% of total sewage sludge is used in the agricultural sector, but this number could vary between 10 – 80%. The N content for sludge, from the 72 WWTP data, varied between 1.5% and 6.5%. The average of 3.8% was used in the calculations.

The main source of data for crop residue was the Abstract of Agricultural Statistics (2012), and one of the main limitations was that it only included commercial crops, and not subsistence agriculture. For the rest of the calculation, the default values were mostly used, or estimates of the fraction of crop removal. These estimates were often area-specific but applied on a broad scale. In future each province or area could be documented separately to give more accurate data input.

TIME-SERIES CONSISTENCY

The same data sources and emission factors were used for the 10 year period so as to maintain the time-series consistency over the inventory period.

5.5.4.7 Source-specific QA/QC and verification

It was difficult to verify a lot of the data in this section due to there being very limited data available to cross check the numbers against.

5.5.4.8 Source-specific recalculations

The previous inventory did not account for direct N_2O emissions, therefore the numbers in this report are new and no recalculations were necessary.

5.5.4.9 Source-specific planned improvements

No source-specific improvements are planned but suggestions are given as to how estimates could be improved in future. The major component of N_2O emissions from managed soils was from the inputs of animal manure and manure deposited on pasture, range and paddock. As with the CH_4 emissions from manure management, the manure management system usage data needs to be better quantified in order to improve the accuracy of these emission numbers. Quantitative data on compost and sewage sludge usage in the agricultural sector would also lead to an improvement of the emission data.

5.5.5 Indirect N_2O emissions from managed soils [3C4]

5.5.5.1 Source category description

Indirect emissions of N_2O-N can take place in two ways: i) volatilization of N as NH_3 and oxides of N, and the deposition of these gases onto water surfaces, and ii) through runoff and leaching from land where N was applied (IPCC, 2006). Due to limited data a Tier 1 approach was used to calculate the indirect N_2O emissions.

5.5.5.2 Overview of shares and trends in emissions

The total accumulated amount of indirect N_2O lost over the period 2000 to 2010 was estimated at 41 002 Gg CO_2eq. There was a decreasing trend over this period with losses due to atmospheric deposition of N volatilised from managed soils decreasing by 16.2% and losses due to leaching and runoff declining by 13.8% (Figure 5.16). Indirect N_2O losses due to leaching and runoff accounted for 56.7% of the indirect emissions.

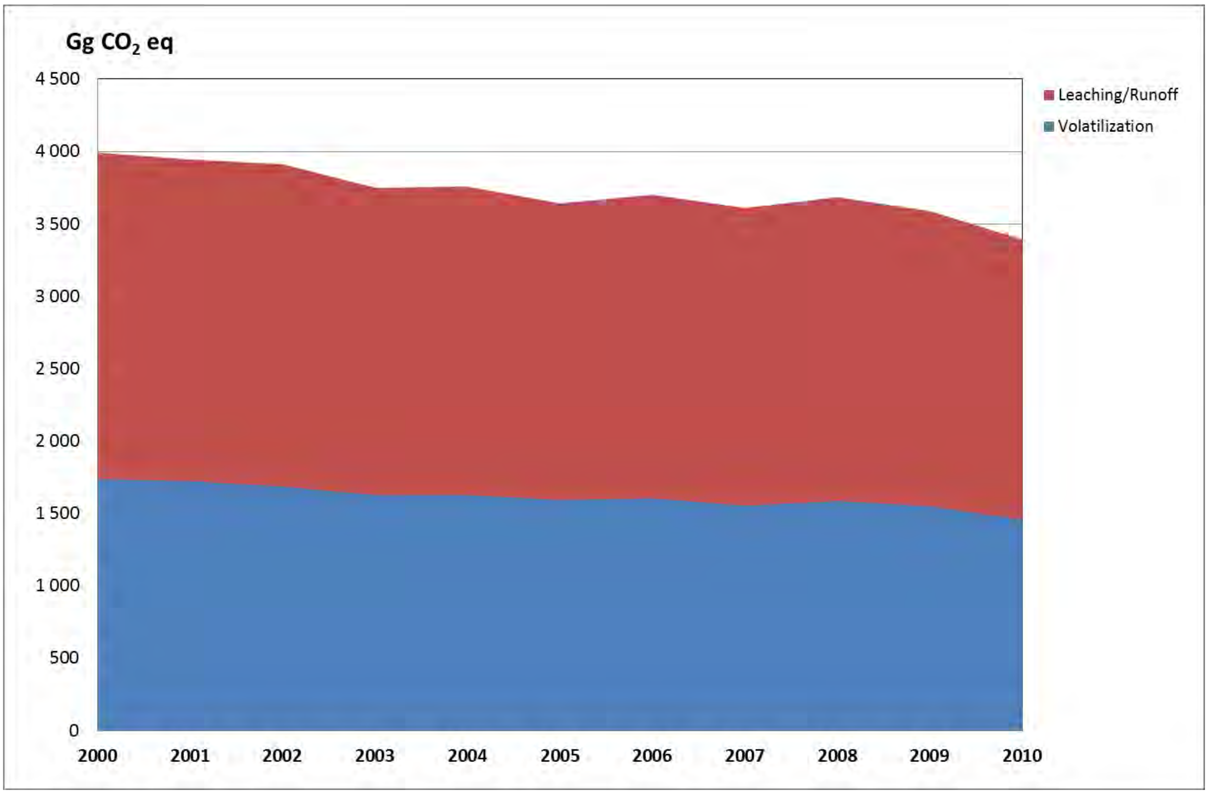

Figure 5.16: Sector 3 AFOLU – Indirect N_2O: Trend and emission level estimates of indirect N_2O losses from managed soils, 2000 – 2010.

5.5.5.3 Source data

The values for F_{SN}, F_{ON}, F_{PRP}, F_{CR}, and F_{SOM} were taken from section 5.5.4.4 of this report. The emission (EF_4 and EF_5), volatilization ($Frac_{GASF}$ and $Frac_{GASM}$) and leaching ($Frac_{LEACH-(H)}$) factors were all taken from the IPCC 2006 default table (Table 11.3, Chapter 11, Volume 4, IPCC 2006).

5.5.5.4 Methodology

A Tier 1 approach was used to estimate the indirect N_2O losses from managed soils. The annual amount of N_2O-N produced from atmospheric deposition of N volatilized from managed soils ($N_2O_{(ATD)}$-N) was calculated using IPCC 2006 Equation 11.9; while Equation 11.10 was used to estimate the annual amount of N_2O-N produced from leaching and runoff of N additions to managed soils ($N_2O_{(L)}$-N) (Chapter 11, Volume 4, IPCC 2006).

5.5.5.5 Uncertainty and time-series consistency

UNCERTAINTY

There is uncertainty in the activity data, nevertheless emission factor uncertainty is likely to dominate. The uncertainty ranges on EF_4 and EF_5 are 0.002 – 0.05, and 0.0005 – 0.025 respectively. For $Frac_{GASF}$, $Frac_{GASM}$ and $Frac_{LEACH-(H)}$ the uncertainty ranges are 0.03 – 0.3, 0.05 – 0.5 and 0.1 – 0.8 respectively (IPCC 2006 Guidelines, Table 11.3, p. 11.24).

TIME-SERIES CONSISTENCY

The same data sources were used throughout the 10 year period so as to reduce uncertainties due to inconsistent data sources.

5.5.5.6 Source-specific QA/QC and verification

No source-specific QA/QC and verification procedures were carried out in this section.

5.5.5.7 Source-specific recalculations

No volatilization values were indicated in the 1990 inventory, but the leaching/runoff value was twice as high in the 1990 inventory. This is mainly because of the change in the default emission factor for leaching/runoff. In 1990 the default factor was 0.025 but in this inventory, as in the 2004 inventory, this factor was reduced to 0.0075. Values for 2004 were recalculated in this report as the inputs from pasture, range and paddock have changed due to a change in the manure management usage numbers. In the previous 2000 inventory (NIR, 2009) the indirect N_2O loss from managed soils was estimated at 17 427 Gg CO_2 eq which is four times the estimate in this inventory. The previous inventory did not provide any details on how this estimate was obtained or where the value came from so the exact reason for the decrease in this inventory is impossible to assess.

5.5.5.8 Source-specific planned improvements and recommendations

No specific improvements have been planned for this source.

5.5.6 Indirect N_2O emissions from manure management [3C6]

5.5.6.1 Source category description

Indirect N_2O losses from manure management due to volatilization were calculated using the Tier 1 method. Throughout the world data on leaching and runoff losses from various management systems is extremely limited, and therefore there are no IPCC 2006 default values and no Tier 1 method. The equation given in the IPCC 2006 guidelines can only be used where there is country-specific information on the fraction of nitrogen loss due to leaching and runoff from manure management systems available, i.e. there is only a Tier 2 method. There was insufficient data for SA to do the Tier 2 calculation so there is no estimate for manure management N losses due to leaching and runoff.

5.5.6.2 Overview of shares and trends in emissions

The amount of manure N lost due to volatilized NH_3 and NO_x was calculated as described in the IPCC 2006 Guideline default equations and emission factors. The total accumulated loss in N_2O from manure was estimated at 1 474 Gg CO_2eq between 2000 and 2010. The annual variation was low and there was an increasing trend from 127 Gg CO_2eq in 2000 to 145 Gg CO_2eq in 2010 (Table 5.11).

Table 5.11: Sector 3 AFOLU – Indirect N_2O: Indirect emissions of N_2O (Gg CO_2eq) due to volatilization from manure management between 2000 and 2010.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Indirect N_2O	127	124	124	124	127	130	136	145	145	145	145

5.5.6.3 Methodology

The IPCC 2006 Guideline Tier 1 approach was used to estimate N_2O losses due to volatilization from manure management.

5.5.6.4 Data sources

The amount of manure N lost due to volatilized NH_3 and NO_x was calculated using Equation 10.26 (IPCC, 2006). This requires N_{ex} data (section 5.3.4.3), manure management system data (section 5.3.4.3), and default fractions of N losses from manure management systems due to volatilization ((IPCC 2006, Table 10.22) (Table 5.12).

EMISSION FACTORS

A default emission factors for N_2O from atmospheric deposition of N on soils and water surfaces (given in IPCC 2006 guidelines as 0.01 kg N_2O-N (kg NH_3-N + NO_x-N volatilized)$^{-1}$) was used to calculate indirect N_2O emissions due to volatilization of N from manure management (Equation 10.27, IPCC 2006).

Table 5.12: Sector 3 AFOLU – Indirect N_2O: Default values used for N loss due to volatilization of NH_3 and NO_x from manure management (%). The value in the brackets indicates the range.

Livestock Category	Lagoon	Liquid /slurry	Drylot	Daily spread	Compost
Dairy Cattle	35 (20-80)	40 (15-45)	20 (10-35)		30 (10-40)
Commercial Beef Cattle			30 (20-50)		45 (10-65)
Subsistence Cattle			30 (20-50)		45 (10-65)
Sheep			25 (10-50)		
Goats			25 (10-50)		
Horses					
Donkeys					
Pigs	40 (25–75)	48 (15-60)	25 (10-50)	45 (10-65)	25 (15-30)
Poultry			55 (40-70)		55 (40-70)

Columns that have no data are not required as there is no manure management in this division for this livestock.

5.5.6.5 Uncertainty and time-series consistency

UNCERTAINTY

The uncertainty on N losses from manure management systems due to volatilization was high because of the wide ranges on default values (see Table 5.12) and uncertainty on manure management system usage (section 5.3.4.5). The uncertainty range on EF_4 is 0.002 – 0.05 (IPCC 2006 guidelines, Table 11.3).

TIME-SERIES CONSISTENCY

The same data sources and emission factors were used throughout the 10 year period to ensure time-series consistency.

5.5.6.6 Source-specific QA/QC and verification

There was no previous data to compare the values with, making quality control very difficult, so no source-specific QA/QC was done on this category.

5.5.6.7 Source-specific recalculations

The data was recalculated for 2004 due to the change in the manure management system usage given in this report. Indirect N_2O emissions from manure management were not provided in the 2000 inventory so the calculations in this inventory provide the first estimates for 2000 from this source.

5.5.6.8 Source-specific planned improvements

The indirect N_2O emissions from manure management form a very small component of the overall N_2O emission budget and so there are no immediate plans to improve this section.

6 WASTE SECTOR

6.1 Overview of sector

Climate change remains one of the most significant challenges defining the human history over the last few decades due to greenhouse gases (GHG) emissions mainly from anthropogenic sources. Among the sectors that contribute to the increasing quantities of GHG into the atmosphere is the Waste sector. This report highlights the GHG emissions into the atmosphere from managed landfills and wastewater treatment systems in South Africa estimated using the IPCC 2006 guidelines.

The national inventory of South Africa comprises 2 sources in the Waste Sector:

- 4A Solid waste disposal; and
- 4D Wastewater treatment and discharge.

The results were derived by either using available data or estimated based on the accessible surrogate data sourced from the scientific literature. For the waste sector, among the chief limitations of quantifying the GHG emissions from different waste streams was the lack of periodically updated national inventory on: the quantities of organic waste deposited in well managed landfills, the annual recovery of methane from landfills, quantities generated from anaerobically decomposed organic matter from wastewater treated, and per capita annual protein consumption in South Africa.

To contextualize the findings presented herein, and provide a sound basis for interpreting them – the assumptions used in estimating the 2000 GHG emissions from waste sector were adopted (NIR, 2009). In this respect, the entire set of assumptions will not be reproduced in this report. However, even though a large percentage of the GHG emissions from waste sources are expected to come from managed solid waste landfills and wastewater treatment systems, future inventories should comprehensively address completeness in this sector by quantifying emissions from the following sources: emissions from open burning of waste as it also has potential impacts to the air quality management; emissions from biological treatment of organic waste where a clear and unambiguous link with agricultural practices merit to explicitly made in future inventories; and emissions of GHG from incineration of solid waste and biological waste.

6.2 Overview of shares and trends in emissions

The total estimated GHG emissions from the waste sector were projected to increase by 59.8% from 11 748 Gg CO_2eq in 2000 to 18 773 Gg CO_2eq in 2010 (Figure 6.1). The annual increase declined from 5.63% to 4.31% between these years. Emissions from solid waste disposal dominated (Figure 6.1) with its contribution to the total GHG emissions from the Waste sector increasing steadily from 76.77% in 2000 to 82.75% in 2010. Two reasons were likely to account for that increase: firstly, that could have been due to the exponential growth of the emissions from the solid waste in managed landfills as the FOD methodology has an in-built lag-effect of delaying the decomposition of solid waste before the generating methane emissions. As a result, the reported emissions in a given year are likely to be due to solid waste disposed of over the previous 10 to 15 years. Secondly, in South Africa the expected growth in the provision of sanitary services with respect to collecting and managing of solid waste streams in managed landfills to meet the growing demand for improved service delivery is likely to increase the emissions in the coming years. Within this context, the quantities of solid waste resulting into managed landfills are likely to increase by more than 5% annually applied as the maximum limit in this study. This, and viewed in the context of the current scenario marked by low or none capture of methane in numerous landfills in addition to low percentages of recycled organic waste, justifies projection of considerable increases of GHG emissions from solid waste sources. Intervention mechanisms designed towards reducing GHG emissions from solid waste are likely to yield significant reduction in the waste sector.

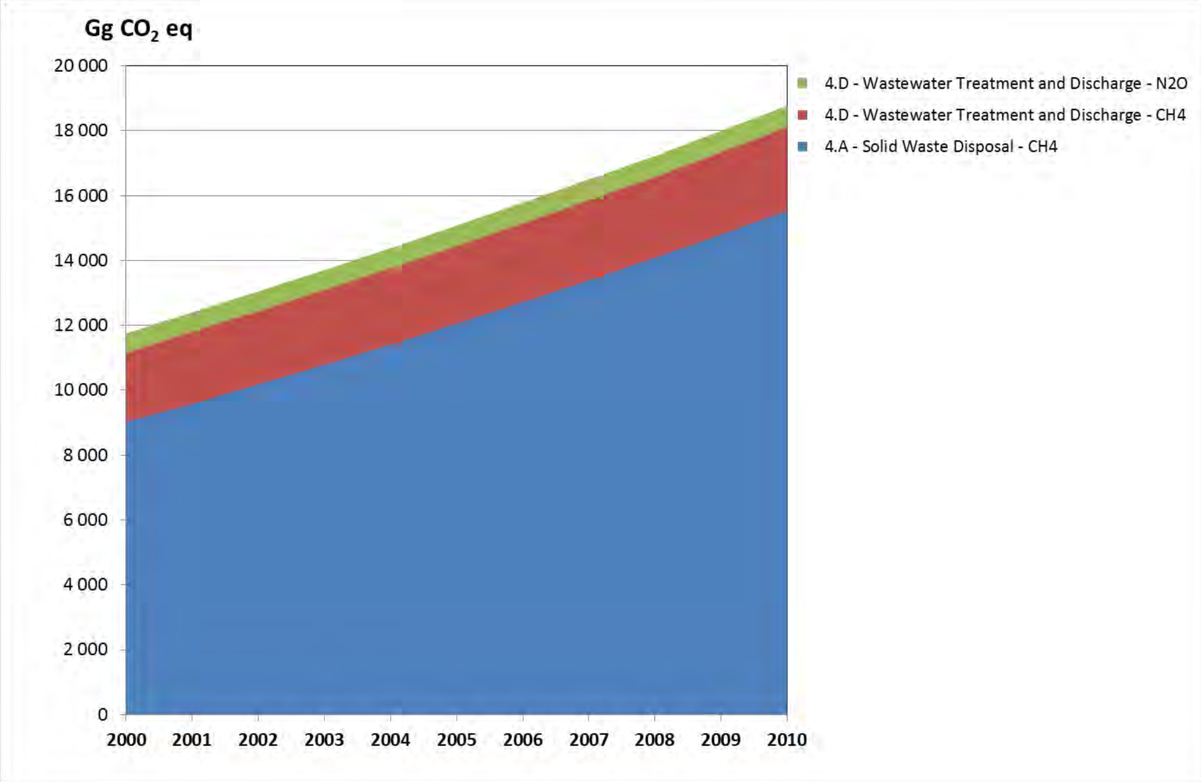

Figure 6.1: Sector 4 Waste: Trends and emission levels of source categories, 2000 – 2010.

6.3 Solid waste disposal on land [4A]

6.3.1 Source category description

In 2000 it was estimated that the disposal of solid waste contributed less than 2% of the total GHG emissions in South Africa, mainly through emissions of methane from urban landfills (NIR, 2009). Waste streams deposited into managed landfills in South Africa comprise waste from households, commercial businesses, institutions, and industry. In this report only the organic fraction of the waste in solid disposal sites was considered as other waste stream components were assumed to generate insignificant quantities in landfills. Furthermore only GHG's generated from managed disposal landfills in South Africa were included, as data on unmanaged sites is not documented and the sites are generally shallow.

6.3.2 Overview of shares and trends in emissions

The total accumulated GHG emissions from Solid Waste disposal between 2000 and 2010 was estimated at 133 579 Gg CO_2 eq, increasing from 9 019 Gg CO_2 eq in 2000 to 15 535 Gg CO_2 eq in 2010 (Figure 6.1 above). This is an increase of 72.3% over the 10 year period.

6.3.3 Methodology

The First Order Decay (FOD) model was used to estimate GHG from this source category for the period 2000 to 2000 using the input activity data comprising of: waste generation rates, income per capita, annual waste generation and population growth rates, emission rates, half-lives of bulk waste stream (default value for the half-live is 14 years), rate constants, methane correction factor (MCF), degradable carbon fraction (DCF) in addition to other factors described in Vol. 5, Ch. 3 of the IPPC Guidelines (IPPC, 2006). Notably, due to the lack of published specific activity data for many of these parameters in South Africa, the default values suggested in the IPCC guidelines were applied.

For the FOD methodology, the model required historical data with at least three to five half-lives. Therefore, the activity data used comprised of waste quantities disposed of into managed landfills from 1950 to 2010 covering a period of about 70 years (satisfying the condition for a period of five half-lives). Population data was sourced from United Nations population statistics (UN, 2012), while for industrial waste the GDP values (in $) between 1970 and 2010 were sourced from IEA (2012).

Among the chief limitations of the FOD methodology is that even after the activity data improved considerably in the coming years, the limitations of data or lack thereof of previous years will still introduce a considerable degree of uncertainty. On the other hand, the estimated waste generations for South Africa derived based on this study from previous years till 1950 will remain useful in future estimations of GHG in this country as it will aid in taking into account the half-life approach.

No detailed analysis of the methane recovery from landfills was accounted for between 2000 and 2010 as this aspects merits careful consideration during full evaluation of the GHG under this period. As noted in the previous inventory (DEA, 2009), the recovery of methane from landfills commenced in large-scale post 2000 with some sites having lifespan of about 21 years (DME, 2008). To address these data limitations, the Department of Environmental Affairs has implemented the National Climate Change Response Database which captures mitigation and adaptation projects which provide valuable data for future GHG estimations from landfills. This tool will be used in the future in the identification and implementation of methane recovery projects in the country. However, presently there is limited publicly accessible data on the quantities of methane recovered annually from managed landfills in South Africa.

6.3.4 Uncertainty and time-series consistency

6.3.4.1 Uncertainty

Uncertainty in this category was due mainly to the lack of data on the characterization of landfills, as well as knowledge of the quantities of waste disposed in them over the medium to long term. An uncertainty of 30% is typical for countries which collect waste generation data on a regular basis (IPCC 2006 Guidelines, Table 3.5). Another cause of uncertainty is that methane production is calculated using bulk waste because of a lack of data on waste composition and so uncertainty is more than a factor of two (NIR, 2009). For the purpose of the bulk waste estimates the whole of South Africa is classified as a dry temperate climate zone, even though some landfills are located in dry tropical climatic conditions. Other uncertainties are the fraction of MSWT sent to SWDS (more than a factor of two), DOCf (±20%), MCF (-10%-0%), F (±5%), methane recovery (can be as much as ±50%) and the oxidation factor (IPCC 2006 Guidelines, Table 3.5).

6.3.4.2 Time-series consistency

The First Order Decay (FOD) methodology as applied in the South African case for estimating methane emissions from solid waste requires a minimum of 48 years' worth of historical waste disposal data. However, waste disposal statistics are not available. In addition, periodic waste baseline studies do not build time-series data. Hence, population statistics sourced from the UN secretariat provided consistent time series activity data for solid waste disposal.

6.3.5 Source-specific QA/QC and verification

A review of the waste sector emission estimates has been performed by experts from various universities. The review resulted in major changes to emission estimates. For example, assumptions about the percentage of waste that lends in waste disposal sites, GDP values for estimating emissions from industrial waste as well as waste generation rates were all reviewed. Verification focused on waste generation rates, population statistics and GDP values using StatsSA datasets and DEA's waste baseline study.

6.3.6 Source-specific recalculations

No source-specific recalculations were performed for this category. This was due to the propagation of the FOD methodology employed in the 2000 GHG inventory published in 2009.

6.3.7 Source-specific planned improvements

The most challenging task of estimating GHG emissions in South Africa was the lack of specific activity and emissions factor data. As a result, estimations of GHG emissions from both the solid waste and wastewater sources were largely computed using default values suggested in IPCC 2006 guidelines, and consequently causing potential large margins of error. Therefore, several recommendations are suggested towards improving the activity and emission factors data particularly in South Africa. These include: (i) to advance data capturing particularly on the quantities of waste disposed of into managed and unmanaged landfills. Other activity that merits improvement are the MCF and rate constants owing to their impact on the computed methane emissions from landfills; and (ii) improvement in reporting of economic data (e.g. annual growth) according to different population groups in respect to the actual growth for a given year. The assumption that the GDP growth is evenly distributed (using computed mean) under all different populations groups is highly misleading, and leads to exacerbated margins of error. On the other hand, if such data is accessible, it should be used in future inventories as means of reducing the error margins.

6.4 Wastewater treatment and discharge [4D]

6.4.1 Source category description

Wastewater treatment contributes to anthropogenic emissions, mainly methane (CH_4) and nitrous oxide (N_2O). The generation of CH_4 is due to anaerobic degradation of organic matter in wastewater from domestic, commercial and industrial sources. The organic matter can be quantified using Biological Oxygen Demand (BOD) values.

Wastewater can be treated on site (mostly industrial sources), or treated in septic systems and centralised systems (mostly for urban domestic sources), or disposed of untreated (mostly in rural and peri-urban settlements). Most domestic wastewater CH_4 emissions are generated from centralised aerobic systems that are not well managed, or from anaerobic systems (anaerobic lagoons and facultative lagoons), or from anaerobic digesters where the captured biogas is not completely combusted.

Unlike in the case of solid waste, organic carbon in wastewater sources generates comparatively low quantities of CH_4. This is because even at very low concentrations, oxygen considerably inhibits the functioning of the anaerobic bacteria responsible for the generation of CH_4.

N_2O is produced from nitrification and denitrification of sewage nitrogen, which results from human protein consumption and discharge.

The Revised 1996 IPCC Guidelines (IPCC 1997) included one equation to estimate emissions from wastewater and another to estimate emissions from sludge removed from wastewater. This distinction was removed in the 2006 IPCC Guidelines (IPCC 2006, Vol.5, p 6.9), so both emissions are now calculated by the same equation.

In South Africa, most of the wastewater generated from domestic and commercial sources is treated through Municipal Wastewater Treatment Systems (MWTPs).

For wastewater generated by industrial processes, the IPCC 2006 Guidelines list the industry categories which use large quantities of organic carbon that generate wastewater (IPCC 2006 Vol.5, p.6.22). The IPCC 2006 Guidelines require the development of consistent data for estimating emissions from wastewater in a given industrial sector (IPCC 2006, Vol.5, p 6.22). Once an industrial sector is included in an inventory, it should be included in all future inventories.

The South African data on industrial categories with high organic content are very limited. Some data exist on wastewater in sectors such as vegetables, fruits and juices, and the wine industry, but these are available only for a specific year, making it impossible to extrapolate such statistics accurately over any period. Therefore in this inventory, only CH_4 emissions from domestic sources are presented. However wastewater from commercial and industrial sources discharged into sewers is accounted for, so the term “domestic wastewater” in this inventory refers to the total wastewater discharged into sewers from all sources. This is achieved by employing the default IPCC Methane Correction Factor (MCF) of 1.25 used to account for commercial and industrial wastewater. It is highly likely that the MCF value for South African ranges between 1.2 and 1.4.

Domestic and commercial wastewater CH_4 emissions mainly originate from septic systems and centralised treatment systems such as MWTPs. Because of the lack of national statistics on the quantities of BOD generated from domestic and commercial sources in South Africa annually, the yearly estimates were determined using the IPPC 2006 default Tier 1 method.

6.4.2 Overview of shares and trends in emissions

Domestic and commercial waste water treatment and discharge were estimated to produce a total accumulated emission of 33 078 Gg CO_2 eq between 2000 and 2010. The CH_4 emissions accounted for approximately 79% of total emissions (Table 6.1), with a slight increase (1.72%) in the contribution from 2000 to 2010. In 2010 CH_4 emissions totalled 2 581 Gg CO_2 eq, while N_2O emissions contributed 657 Gg CO_2 eq (Table 6.1).

The urban low income population had the highest total contribution of methane emissions. Results suggest that for South Africa to reduce the methane emissions to the atmosphere from wastewater sources, directed interventions such as increasing the low income urban population served by closed sewer treatment systems is critical. This is because closed server treatment systems are suitable for potential capturing of generated methane emissions as they are localized and closed – unlike in the case of open latrines and sewer systems currently serving approximately 60% of the low urban income population group in South Africa.

Table 6.1: Sector 4 Waste: CH_4 and N_2O emissions from domestic and industrial wastewater treatment, 2000 – 2010.

	Wastewater Treatment and Discharge CH_4 emissions	Wastewater Treatment and Discharge N_2O emissions	Total GHG emission
		(Gg CO_2eq)	
2000	2 139.3	590.4	**2 729.7**
2001	2 226.7	591.9	**2 818.6**
2002	2 269.8	600.2	**2 870.0**
2003	2 314.2	608.5	**2 922.7**
2004	2 354.1	616.9	**2 971.0**
2005	2 398.3	625.2	**3 023.5**
2006	2 436.0	631.8	**3 067.7**
2007	2 472.8	637.8	**3 110.6**
2008	2 492.3	640.6	**3 132.9**
2009	2 543.4	650.4	**3 193.8**
2010	2 581.1	656.7	**3 237.7**

6.4.3 Methodology

6.4.3.1 Domestic wastewater treatment and discharge

The projected methane emissions from the wastewater follow the same methodology described in the 2000 National GHG Inventory Report (NIR, 2009). The estimated methane emissions reported are from domestic and commercial sources of wastewater because the IPPC guidelines of 2006 have no different set of equations or differentiated computational approaches for both sources as previously stipulated in 1996 IPCC guidelines. It should be noted that the data on quantities of wastewater from specific industrial sources with high organic content are largely lacking in South Africa, and therefore, the projected values in this report are assumed to be due to domestic and industrial sources treated in municipal wastewater treatment systems.

To be consistent, the specific category data described in section 6.4.1 of the National GHG Inventory Report (NIR, 2009) and its underlying assumptions were adopted. For example, in determining the total quantity of kg BOD yr^{-1}, the South African population was sourced from the projections reported by the United Nations population statistics (UN 2010), the same population distribution trends between the rural and urban settlements, default average South Africa BOD production value of 37 g $person^{-1}$ day^{-1}. Though generally it is good practice to express BOD product as a function of income, however, this information is not readily available in South Africa, and therefore, could not be included in our model. In this case, a correction factor of 1.25 was applied in order to take into account the industrial wastewater treated in sewer treatment systems.

The emissions factors for different wastewater treatment and discharge systems were taken from the 2000 inventory (Table 6.2) as was the data on distribution and utilization of different treatment and discharge systems (Table 6.3).

Table 6.2: Sector 4 Waste: Emission factors for different wastewater treatment and discharge systems (Source: NIR, 2009).

Type of treatment or discharge	Maximum CH_4 producing capacity (BOD) (kg CH_4/kg BOD)	CH_4 correction factor for each treatment system (MCF)	Emission factor (kg CH_4/kg BOD)
Septic system	0.6	0.5	0.30
Latrine – rural	0.6	0.1	0.06
Latrine - urban low income	0.6	0.5	0.30
Stagnant sewer (open and warm)	0.6	0.5	0.30
Flowing sewer	0.6	0.0	0.00
Other	0.6	0.1	0.06
None	0.6	0.0	0.00

Table 6.3: Sector 4 Waste: Distribution and utilization of different treatment and discharge systems (Source: NIR, 2009).

Income group	Type of treatment or discharge pathway	Degree of utilization (Tij)
Rural	Septic tank	0.10
	Latrine – rural	0.28
	Sewer stagnant	0.10
	Other	0.04
	None	0.48
Urban high-income	Sewer closed	0.70
	Septic tank	0.15
	Other	0.15
Urban low-income	Latrine - urban low	0.24
	Septic tank	0.17
	Sewer (open and warm)	0.34
	Sewer (flowing)	0.20
	Other	0.05

6.4.3.2 Domestic wastewater N_2O emissions

The default values provided by the IPCC guidelines were used in estimating the potential growing trends of nitrous oxide (N_2O) emissions from the wastewater treatment systems. This was due to the lack of specific activity data for South Africa. For instance, a default value for per capita protein consumption of 27.96 kg yr^{-1} was applied in the model.

6.4.4 Uncertainties and time-series consistency

6.4.4.1 *Uncertainties*

An analysis of the results for the methane emissions suggest that the likely sources of uncertainties may be due to the input data. These include uncertainties associated with South Africa population estimates provided by the United Nations, the presumed constant country BOD production of about 37 g person^{-1} day^{-1} from 2001 to 2020, and the lack of data on the distribution of wastewater treatment systems in South Africa. It is recommended that, in future inventories, a detailed study on the input parameters merits careful consideration to minimize the uncertainty level. In turn, this approach would improve the reliability of the projected methane estimates from wastewater sources.

6.4.4.2 *Time-series consistency*

Time-series consistency was achieved by using population datasets obtained from the UN secretariat. Assumptions about wastewater streams were assumed to be constant over the 10-year time series and default IPCC emission factors used.

6.4.5 Source-specific QA/QC and verification

Internal and external reviews of this source category were included in the review of solid waste disposal. Hence changes on population statistics, percentage split of wastewater pathways, total organics in wastewater and methane correction factors were all reviewed.

6.4.6 Source-specific recalculations

One correction was made to the calculations since the 2000 inventory. In the previous inventory individual TOW (total organics in wastewater) values for each income group were used to calculate a CH_4 emission from each income group which were then summed together to obtain the total emissions. Whereas in this inventory the total TOW (of all the income groups) was used in the emission calculation. This correction was made following equation 6.1 in the IPCC 2006 Guidelines.

6.4.7 Source-specific planned improvements

The most challenging task of estimating GHG emissions in South Africa was due to lack of specific activity and emissions factor data. As a result, estimations of GHG from both the solid waste and wastewater sources were largely computed using default values suggested in IPCC 2006 guidelines, and consequently causing potential large margins of error. Therefore, several recommendations are suggested towards improving the activity and emission factors data particularly in South Africa.

These include: (i) to advance data capturing particularly on the quantities of waste disposed of into managed and unmanaged landfills. Other activity that merits improvement are the MCF and rate constants owing to their impact on the computed methane emissions from landfills; and (ii) improvement in reporting of economic data (e.g. annual growth) according to different population groups in respect to the actual growth for a given year. The assumption that the GDP growth is evenly distributed (using computed mean) under all different populations groups is highly misleading, and leads to exacerbated margins of error. On the other hand, if such data is accessible, it should be used in future inventories as means of reducing the error margins.

7 REFERENCES

Abstract of Agricultural Statistics, 2012. Department of Agriculture, Forestry and Fisheries, Pretoria, RSA.

Abstracts of Agricultural Statistics, 2012. Department of Agriculture, Forestry and Fisheries, Pretoria, RSA. Can be downloaded from www.daff.gov.za.

Airports Company South Africa (ACSA) 2013: Passenger travel Statistics. http://www.acsa.co.za/home.asp?pid=137. [Accessed April 2013]

Anaya, J.A. and Chuvieco, E., 2012. Accuracy Assessment of Burned Area Products in the Orinoco Basin, *Photogrammetric Engineering & Remote Sensing*, 78: 53 – 60.

Anglo American 2011: The South African Iron and Steel Value Chain. http://www.angloamericankumba.com/ [Accessed July 2012]

ANIR, 2009. Australian national greenhouse accounts: National inventory report. Department of climate change and energy efficiency, Commonwealth of Australia, Canberra, ACT.

Anton Eberhard 2009: *South African Coal: market, investment and policy challenges*. South African coal paper, University of Cape Town.

Archibald, S., Roy, D.P., Van Wilgen, B.W, Scholes, R.J., 2010. What limits fire? An examination of the drivers of burnt area in southern Africa. *Global Change Biology*.

Archibald, S., Scholes, R.J., Roy, D., Roberts, G. and Boscheti, L., 2009. Southern African fire regimes as revealed by remote sensing. African Journal of Ecology.

Association of Cementitious Material Producers 2009: *Cement Manufacturing Process.* http://www.acmp.co.za/cement_manufacturing_process.htm. [Accessed March 2013].

Aucamp, A.J. and Howe, L.G., 1979. The production potential of the Eastern Cape Valley Bushveld. *Proc. Grassl. Soc. S Afr.* 14: 115 – 117.

Baggott, S.L., Brown, L., Cardenas, L., Downes, M.K., Garnett, E., Hobson, M., Jackson, J., Milne, R., Mobbs, D.C., Passant, N., Thistlethwaite, G., Thomson, A. and Watterson, J., 2006. Greenhouse Gas Inventory, 1990 to 2004.

Bessinger, D 2000: *Cooling Characteristics of High Titania Slags, MSc dissertation*, University of Pretoria, Pretoria. http://upetd.up.ac.za/thesis/available/etd-07212006-102324 [Accessed 30 January 2013].

Bexley, J. 2013: *A perspective on the Glass Manufacturing Industry*. (Personal communication, February, 2013).

Blaxter, K.L. and Clapperton, J.L., 1965. Prediction of the amount of methane produced by ruminants. Brit. J. Nutr. 19: 511 – 522.

Boschetti, L., Roy, D., Hoffman, A.A. and Humber, M., 2012. MODIS Collection 5.1 burned area product – MCD45: User's guide version 3.

Brouwer, 1965. Report of sub-committee on constants and factors. In: Proceedings of the 3rd symposium on energy metabolism, pp. 441 – 443. K.L Blaxter (Edt). London: Academic Press.

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

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

Cement and Concrete Institute 2008: *Cement and Concrete Institute Review 2008.* http://www.cnci.org.za/Uploads/Overall_Review%202008.pdf. [Accessed October 2012].

CHAPOPSA, 2002. *Charcoal potential in southern Africa*. INCO_DEV: International cooperation with developing countries (1998 – 2002).

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

Chidumayo, E.N., 1993. *Response of miombo to harvesting: ecology and management*. Stockholm Environmental Institute, Stockholm.

Christie, S.I. and Scholes, R.J. 1995. Carbon storage in Eucalyptus and Pine plantations in South Africa. *Environmental Monitoring and Assessment,* 38: 231 – 241.

Cowling, R.M., Richardson, D.M. and Mustart, P.J., 1997. Fynbos. In: Cowling, R.M., Richardson, D.M. and Pierce, S.M. (eds), *Vegetation of Southern Africa*. Cambridge University Press, Cambridge, UK, pp 99 – 130.

DAFF, 2010. The South African Agricultural GHG Inventory for 2004. Department of Agriculture, Forestry and Fisheries, ISBN: 978-1-86871-321-9, DAFF, Pretoria, RSA.

Department Government Communication and Information System (GCIS) 2008: *South African Year Book on Transport 2007/2008.* http://www.gcis.gov.za/content/resource-centre/sa-info/yearbook/2009-10. [Accessed November 2012]

Department Government Communication and Information System (GCIS) 2009: *South African Year Book on Economy 2008/2009.* http://www.gcis.gov.za/content/resource-centre/sa-info/yearbook/2009-10. [Accessed November 2012]

Department Government Communication and Information System (GCIS) 2010: *South African Year Book on Energy 2009/2010.* http://www.gcis.gov.za/content/resource-centre/sa-info/yearbook/2009-10http://www.gcis.gov.za. [Accessed November 2012]

Department of Energy 2000: *Digest of South African Energy Statistics*. Pretoria.

Department of Energy 2005: *Energy Price Report. Directorate: Energy Planning and Development,* Pretoria.

Department of Energy 2005: *Digest of South African Energy Statistics*, Pretoria.

Department of Energy 2007: *Biofuels Industrial Strategy of the Republic of South Africa*, Pretoria. http://www.energy.gov.za/files/esources/petroleum/biofuels_indus_strat.pdf(2).pdf [Accessed October 2012].

Department of Energy 2009a: *Digest of South African Energy Statistics*, Pretoria.

Department of Energy 2009b: *Electrification Statistics*. Electrification Policy Development and Management Directorate, Pretoria.

Department of Energy 2010: South Africa National energy Balance (2000-2010). Pretoria, DOE. http://www.energy.gov.za/files/energyStats_frame.html

Department of Energy 2010: *South African Energy Synopsis 2010.* http://www.energy.gov.za [Accessed June 2012].

Department of Environmental Affairs (DEA) 2012: *Atmospheric Emissions Licenses*, Pretoria.

Department of Environmental Affairs 2009: *Greenhouse Gas Inventory South Africa 1990-2000.* Pretoria.

Department of Minerals and Energy 2000: *Hydrocarbons and Energy Planning Branch – Liquid Fuel,* Pretoria.

Department of Minerals and Energy 2001: *National Electrification Programme NEP.* Summary evaluation Report, Pretoria.

Department of Minerals and Energy 2002: *South African National Energy Database: Energy Prices*, Pretoria.

Department of Minerals and Energy 2008: *National Efficiency Strategy of the Republic of South Africa*, Report 32342, Pretoria.

Department of Minerals and Energy 2010: *Department of Minerals and Energy annual reports 2009/2010,* Pretoria.

Department of Minerals and Energy 2010: *Department of Minerals and Energy annual reports 2009/2010,* Pretoria.

Department of Minerals and Energy, Eskom, Energy Research Institute and University of Cape Town 2002: *Energy Outlook for South Africa 2002.* http://www.info.gov.za/view/DownloadFileAction [Accessed August 2012].

Department of Minerals and Resources 2001a: *Department of Minerals and Resources Annual Report 2001/2002.* Pretoria

Department of Minerals and Resources 2001b: *South Africa's mineral industry (SAMI) 2001/2002.* Pretoria

Department of Minerals and Resources 2004: *South Africa's mineral industry (SAMI) 2004/2005.* Pretoria

Department of Minerals and Resources 2005: *South Africa's mineral industry (SAMI) 2005/2006.* Pretoria

Department of Minerals and Resources 2006: *South Africa's mineral industry (SAMI) 2006/2007.* Pretoria

Department of Minerals and Resources 2006: *South African Ferroalloy Production Trends 1995-2004*. Directorate: Mineral Economics, Report 52/2006, Pretoria.

Department of Minerals and Resources 2008: *South Africa's mineral industry (SAMI) 2007/2008.* Pretoria

Department of Minerals and Resources 2010: *Lime Industry SA 2010*. Directorate: Mineral Economics, Report 85, Pretoria.

Department of Minerals and Resources 2010: *Operating and Developing Coal Mines in the Republic of South Africa 2010.* Directorate: Mineral Economics, Directory D2/2010, Pretoria.

Department of Minerals and Resources 2010*: Producers of Industrial Mineral Commodities in South Africa.* Directorate: Mineral Economics, Directory D11/2010, Pretoria.

Department of Minerals and Resources 2010: *South Africa's mineral industry (SAMI) 2009/2010.* Pretoria

Department of Minerals and Resources 2010: *Statistical Tables*, 1988 -2009. Directorate: Mineral Economics, Bulletin B1/2010, Pretoria.

Department of Minerals and Resources 2011: *Operating Mines and Quarries and Mineral Processing Plants in the Republic of South Africa, 2011*. Directorate: Mineral Economics, Directory D1/2011, Pretoria

Department of Transport 2001: *Statistics*, Pretoria. http://www.dot.gov.za [Accessed October 2012].

Department of Transport 2009: *Transport Statistics 2008*. Annual Transport Statistics Bulletin, Pretoria. http://www.dot.gov.za, [Accessed 11 July 2012].

Desjardins, R., Rochette, P., Pattey, E. and MacPherson, I., 1993. Measurements of Greenhouse Gas Fluxes using Aircraft and Tower-based Techniques. In: Harper, L.A., Mosier, A.R. and Duxbury, J.M. (eds), Agricultural ecosystems effects on trace gases and global climate change: proceedings of a symposium / sponsored by Divisions A-3 and S-3 of the American Society of Agronomy and Soil Science Society of America. ASA Special Publication Number 55, USA.

Dingaan, M.N.V and du Preez, P.J., 2013. Grassland communities of urban open spaces in Bloemfontein, Free State, South Africa. *Koedoe* 55: 1-8, http://www.koedoe.co.za, doi:10.4102/koedoe.v55i1.1075.

Donaldson, R.A., 2009. Season effects on the potential biomass and sucrose accumulation of some commercial cultivars of sugarcane, PhD Thesis, University of KwaZulu-Natal, Pietermaritzburg, RSA.

Donaldson, R.A., Redshaw, K.A., Rhodes, R. and Van Antwerpen, R., 2008. Season effects on productivity of some commercial South African sugarcane cultivars, 1: Biomass and radiation use efficiency. *Proc. S Afr. Sug. Technol. Ass*. 81: 517 – 527.

Dovey, S.B. and Smith, C.W., 2005. Simple ratios to estimate bark and branch biomass and nutrient contents of commercial plantations. ICFR Bulletin Series 13/2005, ICFR, Pietermaritzburg, RSA.

du Toit, C.J.L., van Niekerk, W.A. and Meissner, H.H., in press. Livestock greenhouse gas emissions inventory of South Africa, Part 1: Dairy cattle, beef cattle and feedlot cattle.

du Toit, C.J.L., van Niekerk, W.A. and Meissner, H.H., in press. Livestock greenhouse gas emissions inventory of South Africa, Part 2: Sheep, goats and game.

du Toit, C.J.L., van Niekerk, W.A. and Meissner, H.H., in press. Livestock greenhouse gas emissions inventory of South Africa, Part 3: Pigs, ostriches, equine and poultry.

DWA, 2009. Directorate: Resource Protection and Waste. Inventory of Waste Water Treatment Works, Department of Water Affairs, Pretoria, RSA.

Engelbrecht, A., Golding, A., Hietkamp, S. and Scholes, R.J., 2004. *The potential for sequestration of carbon dioxide in South Africa*. Council for Scientific and Industrial Research (CSIR), Pretoria, RSA.

Environment Canada, 2009. Municipal Waste Water sources and characteristics. http://www.atl.ec.gc.ca/epb/issues/wstewtr.html

Eskom 2005: *Eskom Annual Report 2005*. http://www.eskom.co.za/c/article/289/publications/ [Accessed February 2012]

Eskom 2007: *Eskom Annual Report 2007*. http://www.eskom.co.za/c/article/289/publications/ [Accessed February 2012]

Eskom 2008: *Eskom Annual Report 2008*. http://www.eskom.co.za/c/article/289/publications/ [Accessed February 2012]

Eskom 2010: *Eskom Annual Report* 2010. http://www.eskom.co.za/c/article/289/publications/ [Accessed February 2012]

Eskom 2011: *Eskom Annual Report 2011*. http://www.eskom.co.za/c/article/289/publications/ [Accessed February 2012]

FAOSTAT, 2012. Food and Agriculture Organization of the United Nations: Statistics. 2012. http://faostat.fao.org/site/605/default.aspx#ancor; accessed on 11/2012.

FSA, 2012. Forestry and FP Industry Facts, 1980 – 2011. Forestry South Africa.

FSSA, 2009. Fertilizer Society of South Africa, http://www.fssa.org.za.

Garcia-Apaza, E., Paz, O. and Arana, I., 2008. Greenhouse gas emissions from enteric fermentation of livestock in Bolivia: values for 1990–2000 and future projections. *Australian Journal of Experimental Agriculture*, 48 : 255–259.

GeoTerraImage (GTI) Pty Ltd., 2013. *Modelling of Land-Cover Change in South Africa (2001-2010) in Support of Green House Gas Emissions Reporting: Summary report and metadata*. Report (unpublished) compiled for Wits Commercial Enterprise, University of the Witwatersrand, Johannesburg, RSA,

GFRASA, 2005. *Global Forest Resources Assessment: Country Reports – South Africa*. FAO, Rome, Italy.

Gonzalez-Avalos, E. and Ruiz-Suarez, L.G (2001). Methane emission factors from cattle manure in Mexico. Biosecure Technology, 80(1): 63 – 71.

Hély, C., Dowty, P.R., Alleane, S., Caylor, K.K., Korontzi, S., Swap, R.J., Shugart, H.H. and Justice, C.O., 2003. Regional fuel load for two climatically contrasting years in southern Africa. *Journal of Geophysical Research*, 108.

Howden, S.M., White, D.H., McKeon, G.M., Scanlan, J.C and Carter J.O., 1994. Methods for Exploring Management Options to Reduce Greenhouse Gas Emissions from Tropical Grazing Systems, *Climatic Change*, vol 27 pp 49–70.

IPCC, 1997. Greenhouse Gas Inventory Reporting Instructions. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. UNEP, WMO, OECD and IEA, Bracknell United Kingdom.

IPCC, 2001. *IPCC Third Assessment Report (TAR): Climate Change 2001*. Cambridge: Intergovernmental Panel on Climate Change. Cambridge University Press.

IPCC, 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry.

IPCC, 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories.* The National Greenhouse Gas Inventories Programme, Eggleston H S, Buenida L, Miwa K, Ngara T, and Tanabe K, eds; Institute for Global Environmental Strategies (IGES). Hayama, Kanagawa, Japan.

Korontzi, S., Justice, C.O. and Scholes, R.J., 2003. Influence of timing and spatial extent of Savanna fires in Southern Africa on atmospheric emissions. *Journal of Arid Environments*, 54: 395 - 404.

Kurihara, M., Magner, T., Hunter, R.A. and McCrabb, G.J., 1999. Methane production and energy partition of cattle in the tropics. British J. Nutr. 81, 227 – 234.

LACTO data, 2010. Milk producers statistics, MPO, Pretoria. Vol 14 (1).

Lambers, H., Raven, J.A., Shaver, G.R. and Smith, S.E., 2008. Plant nutrient-acquisition strategies change with soil age*. Trends Ecol Evol* 23: 95–103.

Lloyd P.J.D 2001: The South African Petroleum Industry: A Review. Prepared for the Automobile Association of South Africa. Energy Research Institute: University of Cape Town.

Low, A.B. and Rebelo, A.G., 1996. Vegetation of South Africa, Lesotho and Swaziland, Department of Environmental Affairs and Tourism, Pretoria. 0-621-17316-9 ISBN.

Malimbwi, R.E. and Zahabu, E., 2009. The analysis of sustainable charcoal production systems in Tanzania. In: Simmone, S., Remedio, E. and Trossero, M.A. (eds), *Criteria and Indicators for Sustainable Woodfuels: Case studies from Brazil, Guyana, Nepal, Philippines and Tanzania*. FAO, Rome, Italy.

McGinn, S.M., Chen, D., Loh, Z., Hill, J., Beauchemin, K.A. and Denmead, O.T., 2008. Methane emissions from feedlot cattle in Australia and Canada. *Australian Journal of Experimental Agriculture*, 48: 183–185.

Midgley, J.J. and Seydack, A.H.W., 2006. No adverse signs of the effect of environmental change on tree biomass in the Knysna forest during the 1990s*. S A J Science* 102: 96-97.

Mills, A.J., Birch, S.C., Stephenson, J.D. and Bailey, R.V., 2012. Carbon stocks in fynbos, pastures and vineyards on the Agulhas Plain, South Africa: a preliminary assessment. *S A J Plant. Soil*, iFirst: 1-3.

Mills, A.J., Cowling, R.M., Fey, M.V., Kerley, G.I.H., Donaldson, J.S., Lechmere-Oertel, R.G., Sigwela, A.M., Skowno, A.L. and Rundel, P., 2005. Effects of goat pastoralism on ecosystem carbon storage in semiarid thicket, Easern Cape, South Africa. *Austral Ecology* 30: 797 – 804.

Milton, S.J., 1990. Above-ground biomass and plant cover in a succulent shrubland in the southern Karoo, South Africa*. S A J Bot*. 56: 587-589.

Milton, S.J., Yeaton, R., Dean, W.R.J. and Vlok, J.H.J., 1997. Succulent Karoo. In: Cowling, R.M., Richardson, D.M. and Pierce, S.M. (Eds.), *Vegetation of Southern Africa*. Cambridge: Cambridge University Press, Cambridge, UK.

Minson, D.J. and McDonald, C.K., 1987. Estimating forage intake from growth of cattle. Tropical grasslands, 21(3): 116 – 121.

Moe, P.W. and Tyrell, H.F., 1979. Methane production in dairy cows. J. Dairy Sci. 62: 1583 – 1586.

Moeletsi, M., Paterson, G.. Van Der Walt, M., Malherbe, J., Nape, M., Nkambule, V. and Malaka, S., 2013. ARC Contribution to ALU GHG Project, ARC-ISCW, unpublished report no. GW/A/2013/19, Pretoria, RSA.

National Electricity Regulator 2000: *Electricity Supply Statistics for South Africa.* http://www.ner.org.za. [Accessed July 2012].

National Electricity Regulator 2004: *Electricity Supply Statistics for South Africa.* http://www.ner.org.za. [Accessed July 2012].

National Electricity Regulator 2006: Electricity Supply Statistics for South Africa. http://www.ner.org.za. [Accessed July 2012].

National Energy Regulator of South Africa (NERSA) 2006: *2006 Electricity statistics for South Africa.* http://www.nersa.org.za [Accessed February 2012]

National Energy Regulator of South Africa (NERSA) 2008: 2008 Electricity statistics for South Africa. http://www.nersa.org.za [Accessed February 2012]

National Energy Regulator of South Africa (NERSA) 2008: The national electricity supply shortage and load shedding. http://www.eepublishers.co.za/article/nersa-enquiry-into-the-national-electricity-supply-shortage-and-load-shedding.html [Accessed February 2012]

NIR, 2009. Greenhouse Gas Inventory South Africa: 1990 – 2000. National Inventory report, Compiled under the UNFCCC, Department of Environmental Affairs and Tourism, Pretoria, RSA.

O'Connor, T.G. and Bredenkamp, G.J., 1997. Grassland. In: Cowling, R.M., Richardson, D.M. and Pierce, S.M. (eds), *Vegetation of Southern Africa*. Cambridge University Press, Cambridge, UK.

O'Connor, T.G., 2008. Influence of land use on phytomass accumulation in Highland Sourveld grassland in the southern Drakensberg, South Africa. *Afr. J. Range & Forage Sci*. 25: 17 – 27.

Otter, L. and Scholes, M., 2000. Methane sources and sinks in a periodically flooded South African savannah. *Glob. Biogeochem. Cycles*, vol 14: 97 – 111.

Palmer, T. and Ainslie, A., 2002. South Africa: FAO Country Profile – Country Pasture/Forage Resource Profile, Rome: FAO. http://www.fao.org/ag/agp/agpc/doc/counprof/southafrica/southafrica.htm ; accessed on 15/03/2013.

PFG Glass 2010: *Chemical composition of glass*. http://www.pfg.co.za/all-about-glass.aspx [Accessed February 2013]

Research Unit of Creamer Media (Pty) Ltd 2009: *South Africa's Steel Industry 2009*. Creamer media, Johannesburg.

Roy, D.P. and Boschetti, L., 2009a. Southern Africa validation of the MODIS, L3JRC and GlobCarbon burned-area products, *IEEE Transactions on Geoscience and Remote Sensing,* 47:DOI 10.1109/TGRS.2008.2009000.

Roy, D.P. and Boschetti, L., 2009b. Southern Africa validation of the MODIS, L3JRC and GlobCarbon Burned-Area Products, *IEEE Transactions on Geoscience and Remote Sensing*, 47(4):1–13.

Roy, D.P., Jin, Y., Lewis, P.E. and Justice, C.O., 2005. Prototyping a global algorithm for systematic fire-affected area mapping using MODIS time series data. Remote Sensing of Environment 97(2), pp.137-162

Scholes, R.J. and Walker, B.H., 1993. *An African Savanna: Synthesis of the Nylsvley study*. Cambridge University Press, Cambridge, UK.

Shackleton, C.M. and Scholes, R.J., 2011. Above ground woody community attributes, biomass and carbon stocks along a rainfall gradient in the savannas of the central lowveld, South Africa. *S A J Bot* 77: 184 -192.

Siebrits, F., 2012. Report to authors on pig diets in South Africa. Pretoria.

Simalenga, T.E., Joubert, A.B.D. and Hanekom, D., 2002. Agricultural Mechanization in South Africa: Status, Trend and Challenges, ARC-All, Pretoria.

Singh, J.S. and Joshi, M.C., 1979. Primary Production. Chapter 17 in: Coupland, R.T. (ed), *Grassland ecosystems of the world: Analysis of grasslands and their uses*. Cambridge University Press, Cambridge, UK.

Snyman, H.A., 2005. Influence of fire on root distribution, seasonal root production and root/shoot ratios in grass species in a semi-arid grassland of South Africa. *S A J Bot*. 71: 133-144.

Snyman, H.A., 2011. Root studies in a semi-arid climate. In: Grassroots, The Grassland Society of Southern Africa, http://www.grassland.org.za.

Snyman, H.G., Herselman, J.E. and Kasselman, G., 2004. *A metal content survey of South African Sewage Sludge and an Evaluation of Analytical Methods for their Determination in Sludge.* WRC Report No 1283/1/04. Water Research Commission, Pretoria, RSA.

South Africa Iron and Steel Institute (SAISI) 2009: *Local Sales of Iron and Crude Steel Production in South Africa*. http://www.saisi.co.za/localsales.php. [Accessed September 2012].

South Africa Iron and Steel Institute (SAISI) 2009: *Local Sales of Iron and Crude Steel Production in South Africa*. http://www.saisi.co.za/localsales.php. [Accessed September 2012].

South Africa Iron and Steel Institute (SAISI) 2012: *Iron and Crude Steel Production in South Africa*. http://www.saisi.co.za/ironsteelproduction.php. [Accessed September 2012].

South Africa Iron and Steel Institute (SAISI) 2012: *Overview of Iron and Crude Steel Production in South Africa.* http://www.saisi.co.za/primover.php. [Accessed September 2012].

South African Petroleum Industry Association (SAPIA), 2006: SAPIA Annual Report 2006. http://www.sapia.co.za. [Accessed September 2011].

South African Petroleum Industry Association (SAPIA), 2008: Petrol and Diesel in South Africa and the Impact on Air Quality. http://www.sapia.co.za. [Accessed September 2011].

South African Petroleum Industry Association (SAPIA), 2010: SAPIA Annual Report 2010. http://www.sapia.co.za. [Accessed September 2011].

South African Statistics Council 2006: South African Statistics Council Annual Report 2005/2006, Report 174/2006. http://www.statssa.gov.za/publications/StatsCouncilAnnualReport0506.pdf. [Accessed February 2012].

Standards South Africa (SSA), 2004. SANS 1877:2004 - A standard land-cover classification scheme for remote-sensing applications in South Africa. Edition 1. Pretoria, RSA.

Statistics South Africa 2006: *Statistics South Africa Annual Report 2005/2006.* http://www.statssa.gov.za/annual reports. [Accessed September 2012]

United Nations (UN) 2012: Population Division of the Department of Economic and Social Affairs of the Secretariat, World Population Prospects: http://esa.un.org/unpd/wpp/index.htm [Accessed April 2013]

Van den Berg, E.C., Plarre, C., Van den Berg, H.M. and Thompson, M.W., 2008. *The South African National Land-Cover 2000*. Agricultural Research Council-Institute for Soil, Climate and Water, Unpublished Report No. GW/A/2008/86.

Van der Merwe, M. and Scholes, R. J., 1998. *Greenhouse Gas Emissions Inventory of 1990 for South Africa, Phase 1*. Council for Scientific and Industrial Research (CSIR), Pretoria: National Research Foundation, RSA.

Van der Waal, C., 2008. *Guidelines for the Utilization and Disposal of Wastewater Sludge, Volume 1-5: Impact Assessment.* WRC Report No TT 370/08. Water Research Commission, Pretoria, RSA.

Van Dyk J.P. 2006: *An overview of the Zincor Process, Southern African Pyrometallurgy* 2006. South African Institute of Mining and Metallurgy, Johannesburg

Van Heerden, P.D.R., Donaldson, R.A., Watt, D.A. and Singels, A., 2010. Biomass accumulation in sugarcane: unravelling the factors underpinning reduced growth phenomena. *J Exp. Bot.*, June 13, 2010, p 1 – 11; doi:10.1093/jeb/erq144.

Wessels, K.J., Colgan, M.S., Erasmus, B.F.N., Asner, G.P., Twine, W.C., Mathieu, R., Aardt, J.A.N., Fisher, J.T. and Smit, I.P.J., 2013. Unsustainable fuelwood extraction from South African savannas. *Environ. Res. Lett*. 8: 1-10.

8 APPENDIX A: KEY CATEGORY ANALYSIS WITHOUT LAND SUB-SECTOR

8.1 Level assessment

IPCC Category code	IPCC Category	Greenhouse gas	2010 Ex,t (Gg CO2 Eq)	|Ex,t| (Gg CO2 Eq)	Lx,t	Cumulative Total of Column F
1.A.1	**Energy Industries - Solid Fuels**	**CARBON DIOXIDE (CO2)**	**324 244.750**	**324 244.750**	**0.560**	**0.560**
1.A.3.b	**Road Transportation**	**CARBON DIOXIDE (CO2)**	**42 515.180**	**42 515.180**	**0.073**	**0.633**
1.A.2	**Manufacturing Industries and Construction - Solid F**	**CARBON DIOXIDE (CO2)**	**35 142.521**	**35 142.521**	**0.061**	**0.694**
3.A.1	**Enteric Fermentation**	**METHANE (CH4)**	**27 299.456**	**27 299.456**	**0.047**	**0.741**
1.A.4	**Other Sectors - Solid Fuels**	**CARBON DIOXIDE (CO2)**	**27 024.858**	**27 024.858**	**0.047**	**0.788**
1.B.3	**Other emissions from Energy Production**	**CARBON DIOXIDE (CO2)**	**22 181.071**	**22 181.071**	**0.038**	**0.826**
1.A.4	**Other Sectors - Liquid Fuels**	**CARBON DIOXIDE (CO2)**	**17 589.759**	**17 589.759**	**0.030**	**0.856**
4.A	**Solid Waste Disposal**	**METHANE (CH4)**	**16 568.600**	**16 568.600**	**0.029**	**0.885**
2.C.1	**Iron and Steel Production**	**CARBON DIOXIDE (CO2)**	**12 448.402**	**12 448.402**	**0.021**	**0.906**
2.C.2	**Ferroalloys Production**	**CARBON DIOXIDE (CO2)**	**6 457.976**	**6 457.976**	**0.011**	**0.918**
2.A.1	**Cement production**	**CARBON DIOXIDE (CO2)**	**4 186.732**	**4 186.732**	**0.007**	**0.925**
1.A.1	**Energy Industries - Liquid Fuels**	**CARBON DIOXIDE (CO2)**	**4 051.679**	**4 051.679**	**0.007**	**0.932**
1.A.2	**Manufacturing Industries and Construction - Gaseo**	**CARBON DIOXIDE (CO2)**	**3 837.577**	**3 837.577**	**0.007**	**0.938**
1.A.3.a	**Civil Aviation**	**CARBON DIOXIDE (CO2)**	**3 657.685**	**3 657.685**	**0.006**	**0.945**
3.C.5	**Indirect N2O Emissions from managed soils**	**NITROUS OXIDE (N2O)**	**3 392.063**	**3 392.063**	**0.006**	**0.951**
4.D	Wastewater Treatment and Discharge	METHANE (CH4)	2 581.064	2 581.064	0.004	0.955
3.C.4	Direct N2O Emissions from managed soils	NITROUS OXIDE (N2O)	2 524.811	2 524.811	0.004	0.959
1.B.3	Other emissions from Energy Production	METHANE (CH4)	2 439.794	2 439.794	0.004	0.964
1.B.1	Solid Fuels	METHANE (CH4)	2 239.457	2 239.457	0.004	0.967
2.C.3	Aluminium production	PFCs (PFCs)	2 229.039	2 229.039	0.004	0.971
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	CARBON DIOXIDE (CO2)	1 901.986	1 901.986	0.003	0.975
1.A.1	Energy Industries - Solid Fuels	NITROUS OXIDE (N2O)	1 510.272	1 510.272	0.003	0.977
3.C.1	Emissions from biomass burning	METHANE (CH4)	1 364.948	1 364.948	0.002	0.980
2.C.3	Aluminium production	CARBON DIOXIDE (CO2)	1 294.072	1 294.072	0.002	0.982
2.A.2	Lime production	CARBON DIOXIDE (CO2)	1 218.917	1 218.917	0.002	0.984
1.A.5	Non-Specified - Liquid Fuels	CARBON DIOXIDE (CO2)	1 134.857	1 134.857	0.002	0.986
3.C.1	Emissions from biomass burning	NITROUS OXIDE (N2O)	824.786	824.786	0.001	0.987
2.F.1	Refrigeration and Air Conditioning	HFCs, PFCs	799.882	799.882	0.001	0.989
4.D	Wastewater Treatment and Discharge	NITROUS OXIDE (N2O)	656.668	656.668	0.001	0.990
1.B.2.a	Oil	CARBON DIOXIDE (CO2)	619.000	619.000	0.001	0.991
1.A.3.b	Road Transportation	NITROUS OXIDE (N2O)	610.517	610.517	0.001	0.992
3.C.2	Liming	CARBON DIOXIDE (CO2)	585.542	585.542	0.001	0.993
3.A.2	Manure Management	METHANE (CH4)	497.153	497.153	0.001	0.994
3.A.2	Manure Management	NITROUS OXIDE (N2O)	482.863	482.863	0.001	0.995
3.C.3	Urea application	CARBON DIOXIDE (CO2)	435.896	435.896	0.001	0.995
1.A.3.b	Road Transportation	METHANE (CH4)	314.038	314.038	0.001	0.996
1.A.3.c	Railways	CARBON DIOXIDE (CO2)	298.771	298.771	0.001	0.996
1.A.4	Other Sectors - Solid Fuels	NITROUS OXIDE (N2O)	249.720	249.720	0.000	0.997
2.D	Non-Energy Products from Fuels and Solvent Use	CARBON DIOXIDE (CO2)	233.875	233.875	0.000	0.997
1.A.4	Other Sectors - Biomass	NITROUS OXIDE (N2O)	167.721	167.721	0.000	0.998
2.B.1	Ammonia Production	CARBON DIOXIDE (CO2)	166.706	166.706	0.000	0.998
1.A.2	Manufacturing Industries and Construction - Solid Fuels	NITROUS OXIDE (N2O)	162.365	162.365	0.000	0.998
2.B.6	Titanium Dioxide Production	CARBON DIOXIDE (CO2)	158.506	158.506	0.000	0.998
3.C.6	Indirect N2O Emissions from manure management	NITROUS OXIDE (N2O)	146.348	146.348	0.000	0.999
2.B.8	Petrochemical and Carbon Black Production	CARBON DIOXIDE (CO2)	134.244	134.244	0.000	0.999
2.B.2	Nitric Acid Production	NITROUS OXIDE (N2O)	104.784	104.784	0.000	0.999
2.A.3	Glass Production	CARBON DIOXIDE (CO2)	103.931	103.931	0.000	0.999
1.A.4	Other Sectors - Biomass	METHANE (CH4)	97.743	97.743	0.000	0.999
1.A.1	Energy Industries - Solid Fuels	METHANE (CH4)	79.075	79.075	0.000	1.000
2.C.6	Zinc Production	CARBON DIOXIDE (CO2)	62.092	62.092	0.000	1.000
1.A.4	Other Sectors - Liquid Fuels	NITROUS OXIDE (N2O)	40.224	40.224	0.000	1.000
1.A.3.c	Railways	NITROUS OXIDE (N2O)	34.133	34.133	0.000	1.000
1.A.4	Other Sectors - Gaseous Fuels	CARBON DIOXIDE (CO2)	27.040	27.040	0.000	1.000
1.B.1	Solid Fuels	CARBON DIOXIDE (CO2)	26.594	26.594	0.000	1.000
2.C.5	Lead Production	CARBON DIOXIDE (CO2)	26.312	26.312	0.000	1.000
1.A.4	Other Sectors - Liquid Fuels	METHANE (CH4)	15.806	15.806	0.000	1.000
1.A.3.a	Civil Aviation	NITROUS OXIDE (N2O)	9.088	9.088	0.000	1.000
1.A.2	Manufacturing Industries and Construction - Solid Fuels	METHANE (CH4)	8.411	8.411	0.000	1.000
1.A.4	Other Sectors - Solid Fuels	METHANE (CH4)	6.468	6.468	0.000	1.000
2.B.5	Carbide Production	CARBON DIOXIDE (CO2)	5.197	5.197	0.000	1.000
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	NITROUS OXIDE (N2O)	4.419	4.419	0.000	1.000
2.C.2	Ferroalloys Production	METHANE (CH4)	4.210	4.210	0.000	1.000
1.A.1	Energy Industries - Liquid Fuels	NITROUS OXIDE (N2O)	3.720	3.720	0.000	1.000
1.A.3.a	Civil Aviation	METHANE (CH4)	3.531	3.531	0.000	1.000
1.A.5	Non-Specified - Liquid Fuels	NITROUS OXIDE (N2O)	2.908	2.908	0.000	1.000
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	NITROUS OXIDE (N2O)	2.025	2.025	0.000	1.000
1.A.1	Energy Industries - Liquid Fuels	METHANE (CH4)	1.893	1.893	0.000	1.000
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	METHANE (CH4)	1.718	1.718	0.000	1.000
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	METHANE (CH4)	1.573	1.573	0.000	1.000
1.A.5	Non-Specified - Liquid Fuels	METHANE (CH4)	1.130	1.130	0.000	1.000
1.A.3.c	Railways	METHANE (CH4)	0.385	0.385	0.000	1.000
2.B.8	Petrochemical and Carbon Black Production	METHANE (CH4)	0.071	0.071	0.000	1.000
1.A.4	Other Sectors - Gaseous Fuels	NITROUS OXIDE (N2O)	0.014	0.014	0.000	1.000
1.A.4	Other Sectors - Gaseous Fuels	METHANE (CH4)	0.011	0.011	0.000	1.000

8.2 Trend assessment

IPCC Category code	IPCC Category	Greenhouse gas	2000 Year Estimate Ex0 (Gg CO2 Eq)	2010 Year Estimate Ext (Gg CO2 Eq)	Trend Assessment (Txt)	% Contribution to Trend	Cumulative Total of Column G
1.A.4	**Other Sectors - Solid Fuels**	**CO2**	**5 578.194**	**27 024.858**	**0.043**	**0.274**	**0.274**
1.B.3	**Other emissions from Energy Production**	**CARBON DIOXIDE (CO2**	**26 658.563**	**22 181.071**	**0.024**	**0.152**	**0.426**
3.A.1	**Enteric Fermentation**	**METHANE (CH4)**	**29 601.077**	**27 299.456**	**0.021**	**0.132**	**0.558**
2.C.1	**Iron and Steel Production**	**CARBON DIOXIDE (CO2**	**15 385.781**	**12 448.402**	**0.015**	**0.093**	**0.651**
4.A	**Solid Waste Disposal**	**METHANE (CH4)**	**9 704.243**	**16 568.600**	**0.010**	**0.061**	**0.712**
1.A.1	**Energy Industries - Solid Fuels**	**CO2**	**256 361.413**	**324 244.750**	**0.009**	**0.055**	**0.766**
1.A.1	**Energy Industries - Liquid Fuels**	**CO2**	**4 715.484**	**4 051.679**	**0.004**	**0.025**	**0.792**
1.A.3.b	**Road Transportation**	**CARBON DIOXIDE (CO2**	**32 623.344**	**42 515.180**	**0.004**	**0.024**	**0.816**
1.A.4	**Other Sectors - Liquid Fuels**	**CO2**	**12 766.456**	**17 589.759**	**0.004**	**0.022**	**0.838**
3.C.5	**Indirect N2O Emissions from managed soils**	**NITROUS OXIDE (N2O)**	**3 992.526**	**3 392.063**	**0.003**	**0.022**	**0.860**
1.A.2	**Manufacturing Industries and Construction - Solid F**	**CO2**	**29 056.219**	**35 142.521**	**0.002**	**0.016**	**0.876**
1.A.3.a	**Civil Aviation**	**CARBON DIOXIDE (CO2**	**2 040.001**	**3 657.685**	**0.002**	**0.015**	**0.891**
1.A.2	**Manufacturing Industries and Construction - Gaseou**	**CO2**	**2 217.745**	**3 837.577**	**0.002**	**0.015**	**0.906**
2.F.1	**Refrigeration and Air Conditioning**	**HFCs, PFCs**	**0.000**	**799.882**	**0.002**	**0.011**	**0.916**
3.C.4	**Direct N2O Emissions from managed soils**	**NITROUS OXIDE (N2O)**	**2 520.340**	**2 524.811**	**0.002**	**0.011**	**0.927**
2.B.2	**Nitric Acid Production**	**NITROUS OXIDE (N2O)**	**499.056**	**104.784**	**0.001**	**0.007**	**0.934**
2.C.3	**Aluminium production**	**PFCs (PFCs)**	**2 156.756**	**2 229.039**	**0.001**	**0.006**	**0.941**
2.B.1	**Ammonia Production**	**CARBON DIOXIDE (CO2**	**499.854**	**166.706**	**0.001**	**0.006**	**0.947**
1.A.2	**Manufacturing Industries and Construction - Liquid F**	**CO2**	**1 186.104**	**1 901.986**	**0.001**	**0.006**	**0.953**
2.B.6	Titanium Dioxide Production	CARBON DIOXIDE (CO2)	437.617	158.506	0.001	0.005	0.958
1.B.3	Other emissions from Energy Production	METHANE (CH4)	2 226.032	2 439.794	0.001	0.005	0.963
2.A.2	Lime production	CARBON DIOXIDE (CO2)	714.347	1 218.917	0.001	0.004	0.967
1.A.4	Other Sectors - Biomass	N2O	369.642	167.721	0.001	0.004	0.971
1.B.1	Solid Fuels	METHANE (CH4)	1 978.881	2 239.457	0.001	0.003	0.974
1.B.2.a	Oil	CARBON DIOXIDE (CO2)	325.000	619.000	0.000	0.003	0.977
1.A.4	Other Sectors - Solid Fuels	N2O	51.457	249.720	0.000	0.003	0.980
2.C.6	Zinc Production	CARBON DIOXIDE (CO2)	194.360	62.092	0.000	0.002	0.982
3.C.3	Urea application	CARBON DIOXIDE (CO2)	211.493	435.896	0.000	0.002	0.985
1.A.4	Other Sectors - Biomass	CH4	215.417	97.743	0.000	0.002	0.987
3.C.2	Liming	CARBON DIOXIDE (CO2)	384.053	585.542	0.000	0.001	0.988
1.A.5	Non-Specified - Liquid Fuels	CO2	985.585	1 134.857	0.000	0.001	0.990
4.D	Wastewater Treatment and Discharge	METHANE (CH4)	2 139.345	2 581.064	0.000	0.001	0.991
3.A.2	Manure Management	METHANE (CH4)	467.679	497.153	0.000	0.001	0.992
4.D	Wastewater Treatment and Discharge	NITROUS OXIDE (N2O)	590.354	656.668	0.000	0.001	0.993
1.A.3.c	Railways	CARBON DIOXIDE (CO2)	176.580	298.771	0.000	0.001	0.994
2.C.3	Aluminium production	CARBON DIOXIDE (CO2)	1 091.261	1 294.072	0.000	0.001	0.995
3.A.2	Manure Management	NITROUS OXIDE (N2O)	432.808	482.863	0.000	0.001	0.996
2.B.8	Petrochemical and Carbon Black Production	CARBON DIOXIDE (CO2)	138.573	134.244	0.000	0.001	0.997
1.A.3.b	Road Transportation	NITROUS OXIDE (N2O)	463.046	610.517	0.000	0.000	0.997
3.C.1	Emissions from biomass burning	METHANE (CH4)	1 113.108	1 364.948	0.000	0.000	0.997
3.C.1	Emissions from biomass burning	NITROUS OXIDE (N2O)	680.320	824.786	0.000	0.000	0.998
2.C.5	Lead Production	CARBON DIOXIDE (CO2)	39.156	26.312	0.000	0.000	0.998
1.A.3.b	Road Transportation	METHANE (CH4)	267.585	314.038	0.000	0.000	0.998
3.C.6	Indirect N2O Emissions from manure management	NITROUS OXIDE (N2O)	128.131	146.348	0.000	0.000	0.999
1.A.1	Energy Industries - Solid Fuels	N2O	1 200.818	1 510.272	0.000	0.000	0.999
2.A.3	Glass Production	CARBON DIOXIDE (CO2)	74.376	103.931	0.000	0.000	0.999
1.A.4	Other Sectors - Gaseous Fuels	CO2	12.959	27.040	0.000	0.000	0.999
2.D	Non-Energy Products from Fuels and Solvent Use	CARBON DIOXIDE (CO2)	195.917	233.875	0.000	0.000	0.999
2.C.2	Ferroalloys Production	CARBON DIOXIDE (CO2)	5 181.335	6 457.976	0.000	0.000	0.999
1.A.3.c	Railways	NITROUS OXIDE (N2O)	20.174	34.133	0.000	0.000	0.999
2.A.1	Cement production	CARBON DIOXIDE (CO2)	3 347.053	4 186.732	0.000	0.000	1.000
1.A.2	Manufacturing Industries and Construction - Solid Fuels	N2O	134.245	162.365	0.000	0.000	1.000
1.A.4	Other Sectors - Solid Fuels	CH4	1.338	6.468	0.000	0.000	1.000
1.A.4	Other Sectors - Liquid Fuels	N2O	28.776	40.224	0.000	0.000	1.000
1.A.1	Energy Industries - Liquid Fuels	N2O	5.201	3.720	0.000	0.000	1.000
1.A.3.a	Civil Aviation	NITROUS OXIDE (N2O)	5.070	9.088	0.000	0.000	1.000
1.B.1	Solid Fuels	CARBON DIOXIDE (CO2)	23.500	26.594	0.000	0.000	1.000
2.B.5	Carbide Production	CARBON DIOXIDE (CO2)	1.981	5.197	0.000	0.000	1.000
1.A.4	Other Sectors - Liquid Fuels	CH4	11.354	15.806	0.000	0.000	1.000
1.A.1	Energy Industries - Liquid Fuels	CH4	2.410	1.893	0.000	0.000	1.000
1.A.3.a	Civil Aviation	METHANE (CH4)	1.970	3.531	0.000	0.000	1.000
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	N2O	2.752	4.419	0.000	0.000	1.000
1.A.1	Energy Industries - Solid Fuels	CH4	62.628	79.075	0.000	0.000	1.000
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	N2O	1.170	2.025	0.000	0.000	1.000
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CH4	0.909	1.573	0.000	0.000	1.000
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	CH4	1.070	1.718	0.000	0.000	1.000
2.C.2	Ferroalloys Production	METHANE (CH4)	3.616	4.210	0.000	0.000	1.000
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CH4	6.954	8.411	0.000	0.000	1.000
1.A.5	Non-Specified - Liquid Fuels	N2O	2.526	2.908	0.000	0.000	1.000
1.A.3.c	Railways	METHANE (CH4)	0.227	0.385	0.000	0.000	1.000
1.A.5	Non-Specified - Liquid Fuels	CH4	0.981	1.130	0.000	0.000	1.000
2.B.8	Petrochemical and Carbon Black Production	METHANE (CH4)	0.073	0.071	0.000	0.000	1.000
1.A.4	Other Sectors - Gaseous Fuels	N2O	0.007	0.014	0.000	0.000	1.000
1.A.4	Other Sectors - Gaseous Fuels	CH4	0.005	0.011	0.000	0.000	1.000

9 APPENDIX B: KEY CATEGORY ANALYSIS WITH THE LAND SUB-SECTOR

9.1 Level assessment

IPCC Category code	IPCC Category	Greenhouse gas	2010 Ex,t (Gg CO2 Eq)	|Ex,t| (Gg CO2 Eq)	Lx,t	Cumulative Total of Column F
1.A.1	**Energy Industries - Solid Fuels**	**CARBON DIOXIDE (CO2)**	**324 244.750**	**324 244.750**	**0.556**	**0.556**
1.A.3.b	**Road Transportation**	**CARBON DIOXIDE (CO2)**	**42 515.180**	**42 515.180**	**0.073**	**0.629**
1.A.2	**Manufacturing Industries and Construction - Solid Fue**	**CARBON DIOXIDE (CO2)**	**35 142.521**	**35 142.521**	**0.060**	**0.689**
3.A.1	**Enteric Fermentation**	**METHANE (CH4)**	**27 299.456**	**27 299.456**	**0.047**	**0.736**
1.A.4	**Other Sectors - Solid Fuels**	**CARBON DIOXIDE (CO2)**	**27 024.858**	**27 024.858**	**0.046**	**0.782**
1.B.3	**Other emissions from Energy Production**	**CARBON DIOXIDE (CO2)**	**22 181.071**	**22 181.071**	**0.038**	**0.820**
1.A.4	**Other Sectors - Liquid Fuels**	**CARBON DIOXIDE (CO2)**	**17 589.759**	**17 589.759**	**0.030**	**0.851**
4.A	**Solid Waste Disposal**	**METHANE (CH4)**	**16 568.600**	**16 568.600**	**0.028**	**0.879**
2.C.1	**Iron and Steel Production**	**CARBON DIOXIDE (CO2)**	**12 448.402**	**12 448.402**	**0.021**	**0.900**
2.C.2	**Ferroalloys Production**	**CARBON DIOXIDE (CO2)**	**6 457.976**	**6 457.976**	**0.011**	**0.911**
2.A.1	**Cement production**	**CARBON DIOXIDE (CO2)**	**4 186.732**	**4 186.732**	**0.007**	**0.919**
1.A.1	**Energy Industries - Liquid Fuels**	**CARBON DIOXIDE (CO2)**	**4 051.679**	**4 051.6788**	**0.007**	**0.926**
1.A.2	**Manufacturing Industries and Construction - Gaseous**	**CARBON DIOXIDE (CO2)**	**3 837.577**	**3 837.577**	**0.007**	**0.932**
3.B.1.a	**Forest land Remaining Forest land**	**CARBON DIOXIDE (CO2)**	**-3 836.740**	**3 836.740**	**0.007**	**0.939**
1.A.3.a	**Civil Aviation**	**CARBON DIOXIDE (CO2)**	**3 657.685**	**3 657.685**	**0.006**	**0.945**
3.C.5	**Indirect N2O Emissions from managed soils**	**NITROUS OXIDE (N2O)**	**3 392.063**	**3 392.063**	**0.006**	**0.951**
4.D	Wastewater Treatment and Discharge	METHANE (CH4)	2 581.064	2 581.064	0.004	0.955
3.C.4	Direct N2O Emissions from managed soils	NITROUS OXIDE (N2O)	2 524.811	2 524.811	0.004	0.960
1.B.3	Other emissions from Energy Production	METHANE (CH4)	2 439.794	2 439.794	0.004	0.964
1.B.1	Solid Fuels	METHANE (CH4)	2 239.457	2 239.457	0.004	0.968
2.C.3	Aluminium production	PFCs (PFCs)	2 229.039	2 229.039	0.004	0.971
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	CARBON DIOXIDE (CO2)	1 901.986	1 901.986	0.003	0.975
1.A.1	Energy Industries - Solid Fuels	NITROUS OXIDE (N2O)	1 510.272	1 510.272	0.003	0.977
3.C.1	Emissions from biomass burning	METHANE (CH4)	1 364.948	1 364.948	0.002	0.980
2.C.3	Aluminium production	CARBON DIOXIDE (CO2)	1 294.072	1 294.072	0.002	0.982
2.A.2	Lime production	CARBON DIOXIDE (CO2)	1 218.917	1 218.917	0.002	0.984
1.A.5	Non-Specified - Liquid Fuels	CARBON DIOXIDE (CO2)	1 134.857	1 134.857	0.002	0.986
3.C.1	Emissions from biomass burning	NITROUS OXIDE (N2O)	824.786	824.786	0.001	0.987
2.F.1	Refrigeration and Air Conditioning	HFCs, PFCs	799.882	799.882	0.001	0.989
4.D	Wastewater Treatment and Discharge	NITROUS OXIDE (N2O)	656.668	656.668	0.001	0.990
1.B.2.a	Oil	CARBON DIOXIDE (CO2)	619.000	619.000	0.001	0.991
1.A.3.b	Road Transportation	NITROUS OXIDE (N2O)	610.517	610.517	0.001	0.992
3.C.2	Liming	CARBON DIOXIDE (CO2)	585.542	585.542	0.001	0.993
3.A.2	Manure Management	METHANE (CH4)	497.153	497.153	0.001	0.994
3.A.2	Manure Management	NITROUS OXIDE (N2O)	482.863	482.863	0.001	0.995
3.C.3	Urea application	CARBON DIOXIDE (CO2)	435.896	435.896	0.001	0.995
1.A.3.b	Road Transportation	METHANE (CH4)	314.038	314.038	0.001	0.996
1.A.3.c	Railways	CARBON DIOXIDE (CO2)	298.771	298.771	0.001	0.996
1.A.4	Other Sectors - Solid Fuels	NITROUS OXIDE (N2O)	249.720	249.720	0.000	0.997
2.D	Non-Energy Products from Fuels and Solvent Use	CARBON DIOXIDE (CO2)	233.875	233.875	0.000	0.997
1.A.4	Other Sectors - Biomass	NITROUS OXIDE (N2O)	167.721	167.721	0.000	0.998
2.B.1	Ammonia Production	CARBON DIOXIDE (CO2)	166.706	166.706	0.000	0.998
1.A.2	Manufacturing Industries and Construction - Solid Fuels	NITROUS OXIDE (N2O)	162.365	162.365	0.000	0.998
2.B.6	Titanium Dioxide Production	CARBON DIOXIDE (CO2)	158.506	158.506	0.000	0.998
3.C.6	Indirect N2O Emissions from manure management	NITROUS OXIDE (N2O)	146.348	146.348	0.000	0.999
2.B.8	Petrochemical and Carbon Black Production	CARBON DIOXIDE (CO2)	134.244	134.244	0.000	0.999
2.B.2	Nitric Acid Production	NITROUS OXIDE (N2O)	104.784	104.784	0.000	0.999
2.A.3	Glass Production	CARBON DIOXIDE (CO2)	103.931	103.931	0.000	0.999
1.A.4	Other Sectors - Biomass	METHANE (CH4)	97.743	97.743	0.000	0.999
1.A.1	Energy Industries - Solid Fuels	METHANE (CH4)	79.075	79.075	0.000	1.000
2.C.6	Zinc Production	CARBON DIOXIDE (CO2)	62.092	62.092	0.000	1.000
1.A.4	Other Sectors - Liquid Fuels	NITROUS OXIDE (N2O)	40.224	40.224	0.000	1.000
1.A.3.c	Railways	NITROUS OXIDE (N2O)	34.133	34.133	0.000	1.000
1.A.4	Other Sectors - Gaseous Fuels	CARBON DIOXIDE (CO2)	27.040	27.040	0.000	1.000
1.B.1	Solid Fuels	CARBON DIOXIDE (CO2)	26.594	26.594	0.000	1.000
2.C.5	Lead Production	CARBON DIOXIDE (CO2)	26.312	26.312	0.000	1.000
1.A.4	Other Sectors - Liquid Fuels	METHANE (CH4)	15.806	15.806	0.000	1.000
1.A.3.a	Civil Aviation	NITROUS OXIDE (N2O)	9.088	9.088	0.000	1.000
1.A.2	Manufacturing Industries and Construction - Solid Fuels	METHANE (CH4)	8.411	8.411	0.000	1.000
1.A.4	Other Sectors - Solid Fuels	METHANE (CH4)	6.468	6.468	0.000	1.000
2.B.5	Carbide Production	CARBON DIOXIDE (CO2)	5.197	5.197	0.000	1.000
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	NITROUS OXIDE (N2O)	4.419	4.419	0.000	1.000
2.C.2	Ferroalloys Production	METHANE (CH4)	4.210	4.210	0.000	1.000
1.A.1	Energy Industries - Liquid Fuels	NITROUS OXIDE (N2O)	3.720	3.720	0.000	1.000
1.A.3.a	Civil Aviation	METHANE (CH4)	3.531	3.531	0.000	1.000
1.A.5	Non-Specified - Liquid Fuels	NITROUS OXIDE (N2O)	2.908	2.908	0.000	1.000
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	NITROUS OXIDE (N2O)	2.025	2.025	0.000	1.000
1.A.1	Energy Industries - Liquid Fuels	METHANE (CH4)	1.893	1.893	0.000	1.000
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	METHANE (CH4)	1.718	1.718	0.000	1.000
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	METHANE (CH4)	1.573	1.573	0.000	1.000
1.A.5	Non-Specified - Liquid Fuels	METHANE (CH4)	1.130	1.130	0.000	1.000
1.A.3.c	Railways	METHANE (CH4)	0.385	0.385	0.000	1.000
2.B.8	Petrochemical and Carbon Black Production	METHANE (CH4)	0.071	0.071	0.000	1.000
1.A.4	Other Sectors - Gaseous Fuels	NITROUS OXIDE (N2O)	0.014	0.014	0.000	1.000
1.A.4	Other Sectors - Gaseous Fuels	METHANE (CH4)	0.011	0.011	0.000	1.000

9.2 Trend assessment

IPCC Category code	IPCC Category	Greenhouse gas	2000 Year Estimate Ex0 (Gg CO2 Eq)	2010 Year Estimate Ext (Gg CO2 Eq)	Trend Assessment (Txt)	% Contribution to Trend	Cumulative Total of Column G
1.A.4	**Other Sectors - Solid Fuels**	**CO2**	**5 578.194**	**27 024.858**	**0.045**	**0.221**	**0.221**
1.B.3	**Other emissions from Energy Production**	**BON DIOXIDE (**	**26 658.563**	**22 181.071**	**0.028**	**0.138**	**0.359**
3.A.1	**Enteric Fermentation**	**METHANE (CH4**	**29 601.077**	**27 299.456**	**0.025**	**0.123**	**0.482**
3.B.1.a	**Forest land Remaining Forest land**	**BON DIOXIDE (**	**-19 557.151**	**-3 836.740**	**0.022**	**0.111**	**0.593**
1.A.1	**Energy Industries - Solid Fuels**	**CO2**	**256 361.413**	**324 244.750**	**0.018**	**0.088**	**0.680**
2.C.1	**Iron and Steel Production**	**BON DIOXIDE (**	**15 385.781**	**12 448.402**	**0.017**	**0.083**	**0.764**
4.A	**Solid Waste Disposal**	**METHANE (CH4**	**9 704.243**	**16 568.600**	**0.009**	**0.045**	**0.809**
1.A.2	**Manufacturing Industries and Construction - Solid**	**CO2**	**29 056.219**	**35 142.521**	**0.006**	**0.028**	**0.836**
1.A.1	**Energy Industries - Liquid Fuels**	**CO2**	**4 715.484**	**4 051.679**	**0.005**	**0.023**	**0.859**
3.C.5	**Indirect N2O Emissions from managed soils**	**ROUS OXIDE (N**	**3 992.526**	**3 392.063**	**0.004**	**0.020**	**0.879**
1.A.4	**Other Sectors - Liquid Fuels**	**CO2**	**12 766.456**	**17 589.759**	**0.002**	**0.012**	**0.891**
1.A.3.a	**Civil Aviation**	**BON DIOXIDE (**	**2 040.001**	**3 657.685**	**0.002**	**0.011**	**0.902**
1.A.2	**Manufacturing Industries and Construction - Gase**	**CO2**	**2 217.745**	**3 837.577**	**0.002**	**0.011**	**0.913**
3.C.4	**Direct N2O Emissions from managed soils**	**ROUS OXIDE (N**	**2 520.340**	**2 524.811**	**0.002**	**0.008**	**0.921**
2.F.1	**Refrigeration and Air Conditioning**	**HFCs, PFCs**	**0.000**	**799.882**	**0.001**	**0.006**	**0.927**
2.C.3	**Aluminium production**	**PFCs (PFCs)**	**2 156.756**	**2 229.039**	**0.001**	**0.006**	**0.933**
2.B.2	**Nitric Acid Production**	**ROUS OXIDE (N**	**499.056**	**104.784**	**0.001**	**0.006**	**0.939**
2.B.1	**Ammonia Production**	**BON DIOXIDE (**	**499.854**	**166.706**	**0.001**	**0.005**	**0.944**
1.B.3	**Other emissions from Energy Production**	**METHANE (CH4**	**2 226.032**	**2 439.794**	**0.001**	**0.005**	**0.949**
2.B.6	Titanium Dioxide Production	RBON DIOXIDE (C	437.617	158.506	0.001	0.005	0.954
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	CO2	1 186.104	1 901.986	0.001	0.004	0.958
1.B.1	Solid Fuels	METHANE (CH4)	1 978.881	2 239.457	0.001	0.004	0.961
1.A.4	Other Sectors - Biomass	N2O	369.642	167.721	0.001	0.003	0.965
2.A.2	Lime production	RBON DIOXIDE (C	714.347	1 218.917	0.001	0.003	0.968
1.A.3.b	Road Transportation	RBON DIOXIDE (C	32 623.344	42 515.180	0.001	0.003	0.971
2.C.2	Ferroalloys Production	RBON DIOXIDE (C	5 181.335	6 457.976	0.001	0.003	0.974
1.B.2.a	Oil	RBON DIOXIDE (C	325.000	619.000	0.000	0.002	0.976
2.C.6	Zinc Production	RBON DIOXIDE (C	194.360	62.092	0.000	0.002	0.978
4.D	Wastewater Treatment and Discharge	METHANE (CH4)	2 139.345	2 581.064	0.000	0.002	0.980
1.A.4	Other Sectors - Solid Fuels	N2O	51.457	249.720	0.000	0.002	0.982
1.A.4	Other Sectors - Biomass	CH4	215.417	97.743	0.000	0.002	0.984
3.C.3	Urea application	RBON DIOXIDE (C	211.493	435.896	0.000	0.002	0.986
2.A.1	Cement production	RBON DIOXIDE (C	3 347.053	4 186.732	0.000	0.002	0.988
1.A.5	Non-Specified - Liquid Fuels	CO2	985.585	1 134.857	0.000	0.002	0.989
2.C.3	Aluminium production	RBON DIOXIDE (C	1 091.261	1 294.072	0.000	0.001	0.991
3.A.2	Manure Management	METHANE (CH4)	467.679	497.153	0.000	0.001	0.992
4.D	Wastewater Treatment and Discharge	TROUS OXIDE (N2	590.354	656.668	0.000	0.001	0.993
3.C.2	Liming	RBON DIOXIDE (C	384.053	585.542	0.000	0.001	0.994
3.A.2	Manure Management	TROUS OXIDE (N2	432.808	482.863	0.000	0.001	0.995
3.C.1	Emissions from biomass burning	METHANE (CH4)	1 113.108	1 364.948	0.000	0.001	0.996
1.A.3.c	Railways	RBON DIOXIDE (C	176.580	298.771	0.000	0.001	0.996
3.C.1	Emissions from biomass burning	TROUS OXIDE (N2	680.320	824.786	0.000	0.001	0.997
2.B.8	Petrochemical and Carbon Black Production	RBON DIOXIDE (C	138.573	134.244	0.000	0.001	0.998
1.A.1	Energy Industries - Solid Fuels	N2O	1 200.818	1 510.272	0.000	0.001	0.998
1.A.3.b	Road Transportation	METHANE (CH4)	267.585	314.038	0.000	0.000	0.998
2.C.5	Lead Production	RBON DIOXIDE (C	39.156	26.312	0.000	0.000	0.999
2.D	Non-Energy Products from Fuels and Solvent Use	RBON DIOXIDE (C	195.917	233.875	0.000	0.000	0.999
3.C.6	Indirect N2O Emissions from manure management	TROUS OXIDE (N2	128.131	146.348	0.000	0.000	0.999
1.A.2	Manufacturing Industries and Construction - Solid Fuels	N2O	134.245	162.365	0.000	0.000	0.999
1.A.3.b	Road Transportation	TROUS OXIDE (N2	463.046	610.517	0.000	0.000	0.999
1.A.4	Other Sectors - Gaseous Fuels	CO2	12.959	27.040	0.000	0.000	1.000
1.A.3.c	Railways	TROUS OXIDE (N2	20.174	34.133	0.000	0.000	1.000
2.A.3	Glass Production	RBON DIOXIDE (C	74.376	103.931	0.000	0.000	1.000
1.A.4	Other Sectors - Solid Fuels	CH4	1.338	6.468	0.000	0.000	1.000
1.B.1	Solid Fuels	RBON DIOXIDE (C	23.500	26.594	0.000	0.000	1.000
1.A.1	Energy Industries - Liquid Fuels	N2O	5.201	3.720	0.000	0.000	1.000
1.A.4	Other Sectors - Liquid Fuels	N2O	28.776	40.224	0.000	0.000	1.000
2.B.5	Carbide Production	RBON DIOXIDE (C	1.981	5.197	0.000	0.000	1.000
1.A.3.a	Civil Aviation	TROUS OXIDE (N2	5.070	9.088	0.000	0.000	1.000
1.A.1	Energy Industries - Solid Fuels	CH4	62.628	79.075	0.000	0.000	1.000
1.A.1	Energy Industries - Liquid Fuels	CH4	2.410	1.893	0.000	0.000	1.000
1.A.4	Other Sectors - Liquid Fuels	CH4	11.354	15.806	0.000	0.000	1.000
1.A.3.a	Civil Aviation	METHANE (CH4)	1.970	3.531	0.000	0.000	1.000
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	N2O	2.752	4.419	0.000	0.000	1.000
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CH4	6.954	8.411	0.000	0.000	1.000
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	N2O	1.170	2.025	0.000	0.000	1.000
2.C.2	Ferroalloys Production	METHANE (CH4)	3.616	4.210	0.000	0.000	1.000
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CH4	0.909	1.573	0.000	0.000	1.000
1.A.5	Non-Specified - Liquid Fuels	N2O	2.526	2.908	0.000	0.000	1.000
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	CH4	1.070	1.718	0.000	0.000	1.000
1.A.5	Non-Specified - Liquid Fuels	CH4	0.981	1.130	0.000	0.000	1.000
1.A.3.c	Railways	METHANE (CH4)	0.227	0.385	0.000	0.000	1.000
2.B.8	Petrochemical and Carbon Black Production	METHANE (CH4)	0.073	0.071	0.000	0.000	1.000
1.A.4	Other Sectors - Gaseous Fuels	N2O	0.007	0.014	0.000	0.000	1.000
1.A.4	Other Sectors - Gaseous Fuels	CH4	0.005	0.011	0.000	0.000	1.000

10 APPENDIX C: SUMMARY TABLE FOR 2010

	Emissions (Gg)			Emissions CO2 Equivalents (Gg)			Emissions (Gg)			
Categories	**Net CO2 (1)(2)**	**CH4**	**N2O**	**HFCs**	**PFCs**	**SF6**	**NOx**	**CO**	**NMVOCs**	**SO2**
Total National Emissions and Removals	507 934.99	2 327.24	36.92	798.94	2 229.04	0.00	62.37	1 574.54	0.00	0.00
1 - Energy	484 253.33	226.57	9.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.A - Fuel Combustion Activities	461 426.66	23.12	9.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.A.1 - Energy Industries	328 296.43	3.52	5.11				0.00	0.00	0.00	0.00
1.A.2 - Manufacturing Industries and Construction	40 882.08	0.51	0.57				0.00	0.00	0.00	0.00
1.A.3 - Transport	46 471.64	13.82	2.21				0.00	0.00	0.00	0.00
1.A.4 - Other Sectors	44 641.66	5.22	1.55				0.00	0.00	0.00	0.00
1.A.5 - Non-Specified	1 134.86	0.05	0.01				0.00	0.00	0.00	0.00
1.B - Fugitive emissions from fuels	22 826.67	203.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.B.1 - Solid Fuels	26.59	97.37	0.00				0.00	0.00	0.00	0.00
1.B.2 - Oil and Natural Gas	619.00	0.00	0.00				0.00	0.00	0.00	0.00
1.B.3 - Other emissions from Energy Production	22 181.07	106.08	0.00				0.00	0.00	0.00	0.00
1.C - Carbon dioxide Transport and Storage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.C.1 - Transport of CO2	0.00						0.00	0.00	0.00	0.00
1.C.2 - Injection and Storage	0.00						0.00	0.00	0.00	0.00
1.C.3 - Other	0.00						0.00	0.00	0.00	0.00
2 - Industrial Processes and Product Use	26 496.96	0.19	0.35	798.94	2 229.04	0.00	0.00	0.00	0.00	0.00
2.A - Mineral Industry	5 509.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.A.1 - Cement production	4 186.73						0.00	0.00	0.00	0.00
2.A.2 - Lime production	1 218.92						0.00	0.00	0.00	0.00
2.A.3 - Glass Production	103.93						0.00	0.00	0.00	0.00
2.A.4 - Other Process Uses of Carbonates	0.00						0.00	0.00	0.00	0.00
2.A.5 - Other (please specify)	0.00	0.00	0.00				0.00	0.00	0.00	0.00
2.B - Chemical Industry	464.65	0.00	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.B.1 - Ammonia Production	166.71						0.00	0.00	0.00	0.00
2.B.2 - Nitric Acid Production			0.35				0.00	0.00	0.00	0.00
2.B.3 - Adipic Acid Production			0.00				0.00	0.00	0.00	0.00
2.B.4 - Caprolactam, Glyoxal and Glyoxylic Acid Production			0.00				0.00	0.00	0.00	0.00
2.B.5 - Carbide Production	5.20	0.00					0.00	0.00	0.00	0.00
2.B.6 - Titanium Dioxide Production	158.51						0.00	0.00	0.00	0.00
2.B.7 - Soda Ash Production	0.00						0.00	0.00	0.00	0.00
2.B.8 - Petrochemical and Carbon Black Production	134.24	0.00					0.00	0.00	0.00	0.00
2.B.9 - Fluorochemical Production				0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.B.10 - Other (Please specify)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.C - Metal Industry	20 288.85	0.18	0.00	0.00	2 229.04	0.00	0.00	0.00	0.00	0.00
2.C.1 - Iron and Steel Production	12 448.40	0.00					0.00	0.00	0.00	0.00
2.C.2 - Ferroalloys Production	6 457.98	0.18					0.00	0.00	0.00	0.00
2.C.3 - Aluminium production	1 294.07				2 229.04		0.00	0.00	0.00	0.00
2.C.4 - Magnesium production	0.00					0.00	0.00	0.00	0.00	0.00
2.C.5 - Lead Production	26.31						0.00	0.00	0.00	0.00
2.C.6 - Zinc Production	62.09						0.00	0.00	0.00	0.00
2.C.7 - Other (please specify)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.D - Non-Energy Products from Fuels and Solvent Use	233.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.D.1 - Lubricant Use	230.49						0.00	0.00	0.00	0.00
2.D.2 - Paraffin Wax Use	3.39						0.00	0.00	0.00	0.00
2.D.3 - Solvent Use							0.00	0.00	0.00	0.00
2.D.4 - Other (please specify)	0.00	0.00	0.00				0.00	0.00	0.00	0.00
2.E - Electronics Industry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.E.1 - Integrated Circuit or Semiconductor				0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.E.2 - TFT Flat Panel Display					0.00	0.00	0.00	0.00	0.00	0.00
2.E.3 - Photovoltaics					0.00		0.00	0.00	0.00	0.00

2.E.4 - Heat Transfer Fluid					0.00		0.00	0.00	0.00	0.00
2.E.5 - Other (please specify)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.F - Product Uses as Substitutes for Ozone Depleting Substances	0.00	0.00	0.00	798.94	0.00	0.00	0.00	0.00	0.00	0.00
2.F.1 - Refrigeration and Air Conditioning				798.94			0.00	0.00	0.00	0.00
2.F.2 - Foam Blowing Agents				0.00			0.00	0.00	0.00	0.00
2.F.3 - Fire Protection				0.00	0.00		0.00	0.00	0.00	0.00
2.F.4 - Aerosols				0.00			0.00	0.00	0.00	0.00
2.F.5 - Solvents				0.00	0.00		0.00	0.00	0.00	0.00
2.F.6 - Other Applications (please specify)				0.00	0.00		0.00	0.00	0.00	0.00
2.G - Other Product Manufacture and Use	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.G.1 - Electrical Equipment					0.00	0.00	0.00	0.00	0.00	0.00
2.G.2 - SF6 and PFCs from Other Product Uses					0.00	0.00	0.00	0.00	0.00	0.00
2.G.3 - N2O from Product Uses			0.00				0.00	0.00	0.00	0.00
2.G.4 - Other (Please specify)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.H - Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.H.1 - Pulp and Paper Industry	0.00	0.00					0.00	0.00	0.00	0.00
2.H.2 - Food and Beverages Industry	0.00	0.00					0.00	0.00	0.00	0.00
2.H.3 - Other (please specify)	0.00	0.00	0.00				0.00	0.00	0.00	0.00
3 - Agriculture, Forestry, and Other Land Use	-2 815.30	1 267.89	24.90	0.00	0.00	0.00	62.37	1 574.54	0.00	0.00
3.A - Livestock	0.00	1 208.55	1.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.A.1 - Enteric Fermentation		1 186.93					0.00	0.00	0.00	0.00
3.A.2 - Manure Management		21.62	1.63				0.00	0.00	0.00	0.00
3.B - Land	-3 836.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.B.1 - Forest land	-3 836.74						0.00	0.00	0.00	0.00
3.B.2 - Cropland	0.00						0.00	0.00	0.00	0.00
3.B.3 - Grassland	0.00						0.00	0.00	0.00	0.00
3.B.4 - Wetlands	0.00		0.00				0.00	0.00	0.00	0.00
3.B.5 - Settlements	0.00						0.00	0.00	0.00	0.00
3.B.6 - Other Land	0.00						0.00	0.00	0.00	0.00
3.C - Aggregate sources and non-CO2 emissions sources on land	1 021.44	59.35	23.27	0.00	0.00	0.00	62.37	1 574.54	0.00	0.00
3.C.1 - Emissions from biomass burning		59.35	2.79				62.37	1 574.54	0.00	0.00
3.C.2 - Liming	585.54						0.00	0.00	0.00	0.00
3.C.3 - Urea application	435.90						0.00	0.00	0.00	0.00
3.C.4 - Direct N2O Emissions from managed soils			8.53				0.00	0.00	0.00	0.00
3.C.5 - Indirect N2O Emissions from managed soils			11.46				0.00	0.00	0.00	0.00
3.C.6 - Indirect N2O Emissions from manure management			0.49				0.00	0.00	0.00	0.00
3.C.7 - Rice cultivations		0.00					0.00	0.00	0.00	0.00
3.C.8 - Other (please specify)		0.00	0.00				0.00	0.00	0.00	0.00
3.D - Other	-2 356.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.D.1 - Harvested Wood Products	-2 356.58						0.00	0.00	0.00	0.00
3.D.2 - Other (please specify)	0.00	0.00	0.00				0.00	0.00	0.00	0.00
4 - Waste	0.00	832.59	2.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.A - Solid Waste Disposal	0.00	720.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.B - Biological Treatment of Solid Waste	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.C - Incineration and Open Burning of Waste	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.D - Wastewater Treatment and Discharge	0.00	112.22	2.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.E - Other (please specify)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5 - Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.A - Indirect N2O emissions from the atmospheric deposition of nitrogen in NOx and NH3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.B - Other (please specify)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Memo Items (5)										
International Bunkers	2 563.63	0.11	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.A.3.a.i - International Aviation (International Bunkers)	2 563.63	0.11	0.02				0.00	0.00	0.00	0.00
1.A.3.d.i - International water-borne navigation (International bunkers)	0.00	0.00	0.00				0.00	0.00	0.00	0.00
1.A.5.c - Multilateral Operations	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00