GHG INVENTORY FOR SOUTH AFRICA

2000 - 2010

environmental affairs
Department:
Environmental Affairs
REPUBLIC OF SOUTH AFRICA

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

On behalf of:
Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
of the Federal Republic of Germany

GHG NATIONAL INVENTORY REPORT

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November 2014

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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.

ACKNOWLEDGEMENTS

Many people and institutes were involved in the compilation of the updated National Inventory Report (DEAT, 2009). 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 (NWU), DEA, Department of Agriculture, Forestry and Fisheries (DAFF), GeoTerraImage (GTI), and the Agriculture Research Council (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.

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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*
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An independent reviewer was appointed to assess the quality of the inventory, determine the conformity of the procedures which were followed for the compilation of this inventory and to identify areas of improvements.

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ABREVIATIONS

AFOLU	*Agriculture, Forestry and Other Land Use*
AGB	*Above ground biomass*
BECF	*Biomass expansion and conversion factor*
BEF	*Biomass expansion factor*
C	*Carbon*
C2F6	*Carbon hexafluoroethane*
CF4	*Carbon tetrafluoromethane*
CFC	*Chlorofluorocarbons*
CH4	*Methane*
CO2	*Carbon dioxide*
CO2eq	*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*
FOLU	*Forestry and Other Land Use*
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*
SF6	*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*
WRI	*World Resource Institute*

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 IPCC 2006 Guidelines. 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 FOLU[1]) to be energy industries (solid fuels), road transportation, manufacturing industries and construction (solid fuels) and energy industries (liquid fuels); while the trend assessment (base year being 2000) indicated them to be other sectors (solid fuels), energy industries (solid fuels), other emissions from energy production, and iron and steel production. If the land sector is included then forest land remaining forest land becomes the 4th key category in the level assessment and land converted to grassland becomes the most important key category in the trend assessment. Further details are provided in section 1.3.3 with full results given in Appendix 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 National Atmospheric Emission Inventory System (NAEIS) will play a major role in managing reporting and processing of data. Due to their complex emission estimating methods, emission sectors such as agriculture, forestry, land use and waste are to be estimated outside the NAEIS. The NAEIS will in turn, ingest the outputs of models used in these sectors so that it can generate a national emissions profile (Figure A).

1 FOLU is the Forestry and Other Land Use component of AFOLU. It includes the land and the harvested wood products sub-categories of the AFOLU sector.

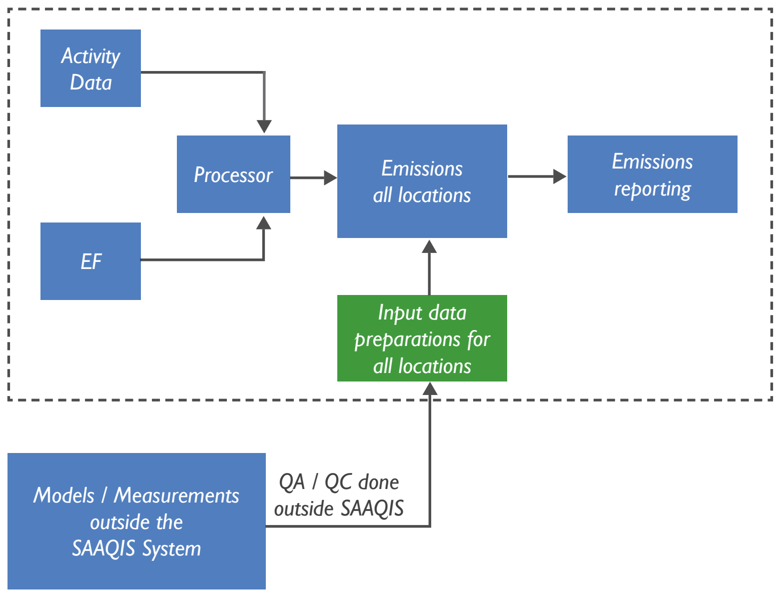

Figure A: Information flow in NAEIS.

DEA is responsible for the co-ordination and management of all climate change-related information, including mitigation, adaption, monitoring and evaluation, and GHG inventories. 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. Figure B gives an overview of the institutional arrangements for the compilation of the 2000 – 2010 GHG emissions inventory.

Organisation of report

This report follows a standard NIR format in line with the United Nations Framework Convention on Climate Change (UNFCCC) Reporting Guidelines. 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, methodology, data sources, recalculations, uncertainty and time-series consistency, QA/QC and planned improvements and recommendations.

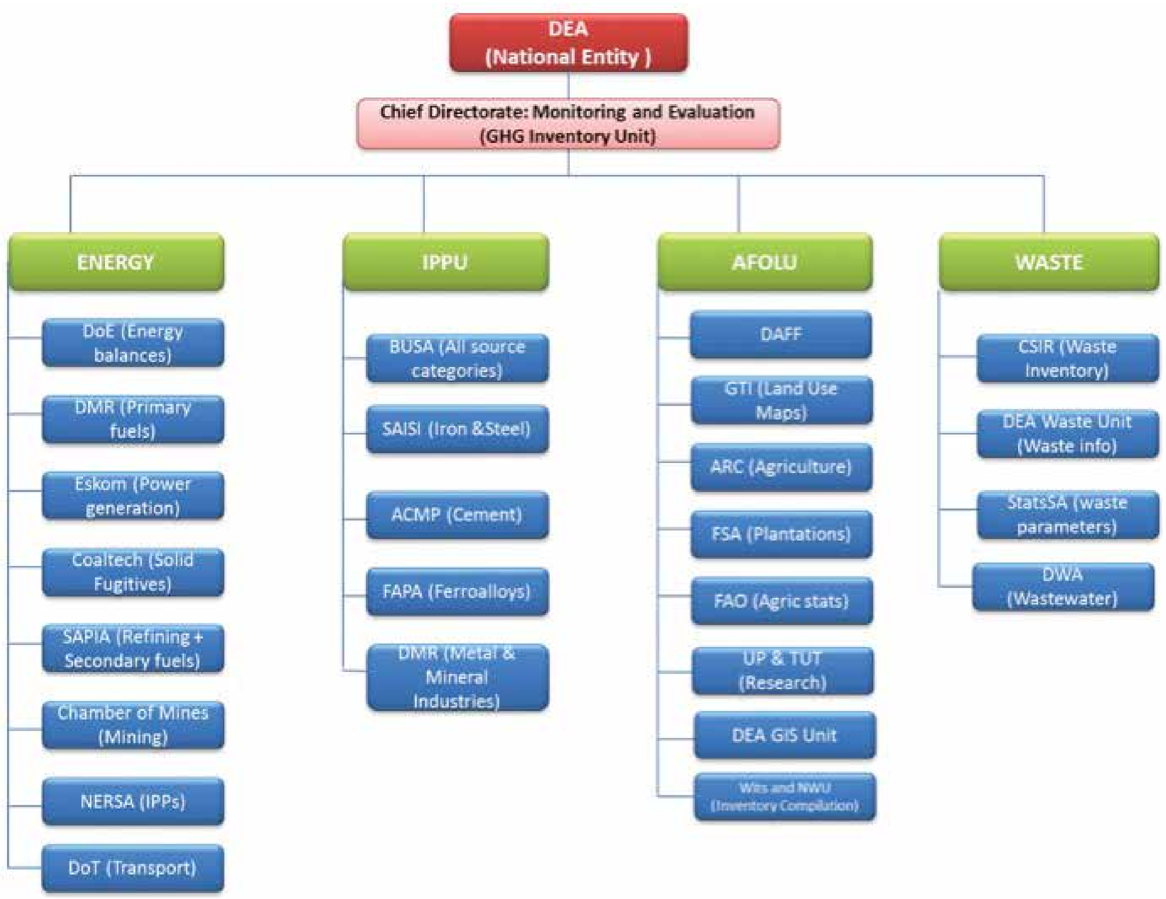

Figure B: Institutional arrangements for the compilation of the 2000 – 2010 inventories.

ES2 Summary of national emission and removal trends

In 2010 the total GHG emissions in South Africa were estimated to be at 544 314 CO_2eq (excl. FOLU) (Table A). Emissions (excl. FOLU) increased by 21.1% between 2000 and 2010. There is a decrease of 0.4% and 2.3% between 2004-2005 and 2007-2008, respectively. Including FOLU, which are estimated to be net carbon sinks, the total GHG emissions in 2010 are reduced to 518 239 Gg CO_2eq (Table A). Emissions including FOLU showed a decrease of 21.9% over the 10 years from 425 219 Gg CO_2eq in 2000. The decline in 2005 (0.4%) and 2008 (2.3%) are still evident. CO_2 and CH_4 emissions (excl. FOLU) increased by 24.3% and 12.4% respectively between 2000 and 2010, while N_2O and PFC emissions showed a decline of 7.0% and 85.9% respectively over the same period. HFC's were only included from 2005 and have increased more than 6 fold over the 5 year period.

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

	Energy	IPPU	AFOLU (excl. FOLU)	AFOLU (incl. FOLU)	Waste	Total (excl. FOLU)	Total (incl. FOLU)
	(Gg CO_2 eq)						
2000	337 382	44 907	54 775	30 497	12 434	449 498	425 219
2001	337 300	45 472	54 762	29 854	13 122	450 657	425 748
2002	345 892	47 416	53 143	28 054	13 789	460 240	435 151
2003	369 834	47 665	51 488	28 514	14 477	483 464	460 490
2004	386 309	48 472	51 663	31 984	15 179	501 623	481 944
2005	379 315	49 946	51 127	34 971	15 907	496 295	480 140
2006	386 082	51 537	51 386	25 982	16 649	505 654	480 251
2007	414 350	49 716	50 219	23 500	17 409	531 694	504 975
2008	405 769	45 284	51 483	24 184	18 170	520 707	493 407
2009	414 039	42 833	50 370	20 760	18 989	526 231	496 621
2010	428 368	44 351	51 789	25 714	19 806	544 314	518 239

ES3 Overview of source and sink category emission estimates and trends

The energy sector contributed 75.1% to the total GHG inventory (excl. FOLU) in 2000 and this increased to 78.7% in 2010 (Table A). There was a general increase in the energy sector contribution; however slight declines were evident in 2001, 2005 and 2006. The AFOLU (excl. FOLU) is the second largest contributor, followed closely by IPPU. AFOLU (excl. FOLU) contributed 12.2% in 2000 and declined to 9.5% in 2010, while in 2000 IPPU contributed 10.0% and this declined to 8.1% in 2010. The IPPU sector showed a slight increase in contribution to the total in 2002 and 2006, while the AFOLU (excl. FOLU) showed a decline each year except in 2008 when there was a slight increase. The waste sector showed a steady increase in contribution from 2.8% in 2000 to 3.7% in 2010. Including the FOLU component into the AFOLU sector decreased the total GHG emissions to 518 239 Gg CO_2eq in 2010.

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. Emissions from this source category shall be included in the next inventory submission covering the period 2000-2012;
- CO_2, CH_4 and N_2O from spontaneous combustion of coal seams due to unavailability of data and estimation methodologies. New research work on sources of emissions from this category shall be used to report in the next inventory submission.
- CH_4 emissions from abandoned mines due to unavailability of data and estimation methodology. New research work on sources of emissions from this category shall be used to report emissions in the next inventory submission;
- CO_2, CH_4 and N_2O emissions from water-borne navigation. Fuel consumption for this source-category is included elsewhere. Accurate quantification of fuel consumption attributed to water-borne navigation will be undertaken in 2015 and a progress report will be included in the next inventory submission.
- other process use of carbonates due to lack of activity data;
- Electronics industry due to lack of activity data. A study will be undertaken in 2015 to understand emissions from this source category;
- Ozone Depleting Substance replacements for fire protection and aerosols;
- other product manufacture and use;

- Dead organic matter (DOM) pools due to insufficient data;
- Land converted to other lands due to a lack of data. A study to update the land sector is being conducted next year, which will allow the incorporation of this sub-category;
- 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, emissions and removals from land conversions have been incorporated and carbon storage in HWP is reported. 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 (excl. FOLU) was 449 497 Gg CO_2eq which is 2.9% lower than the estimate provided in the 2000 National Inventory (Table B). The updated emission data lead to a decrease in the estimates from the Energy sector, while the estimates for the IPPU, AFOLU (excl. FOLU) and Waste sectors increased. The changes made to the *land* and HWP components of the AFOLU sector produced total GHG emission estimates which are 3.9% lower 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. FOLU)	AFOLU (incl. FOLU)	Waste	Total (excl. FOLU)	Total (incl. FOLU)
	(Gg CO_2eq.)						
Initial 2000 estimates	380 988	32 081	40 582	20 022	9 393	463 044	442 484
Recalculated 2000 estimates	337 382	44 907	54 775	30 497	12 434	449 497	425 219
Difference	43 606	12 826	-14 193	-10 475	-3 041	13 547	17 265
% impact to national emissions total (excl. FOLU)	-9.42	2.77	3.07	2.26	0.66		
% impact to national emissions total (incl. FOLU)	-9.85	2.90	3.21	2.37	0.69		

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. In response to this, DEA has initiated a new programme called the National Greenhouse Gas Improvement Programme (GHGIP). The GHGIP comprise a series of sector-specific projects that are targeting improvements in activity data, country-specific methodologies and emission factors used in the most significant sectors. Table C and Table D summarize some of the projects that are under implementation as part of the GHGIP.

Table C: DEA driven GHGIP projects

Sector	Baseline	Nature of methodological improvement	Partner	Completion date
Power Generation [Implications for other sectors]	Using IPCC default emission factors	Development of country-specific CO2, CH4 and N2O emission factors	ESKOM, Coal-tech, Fossil-fuel foundation, GIZ	December 2015
Iron &Steel	Using a combination of IPCC default and assumptions based on material flows	Shift towards a material balance approach	Mittal Steel, South African Iron & Steel Institute (SAISI)	June 2015
Transport Sector [Implications for other sectors]	Using IPCC default emission factors	Development of country-specific CO2, CH4 and N2O emission factors	SAPIA	December 2015
Gas-To-Liquids (GTL)	Not accounting for all emission sources. Material balance approach needs a review	Detailed life-cycle emissions analysis coupled with material balance approach	PETROSA	March 2015
Coal-To-Liquids (CTL)	Allocation of emissions not transparently done, not accounting for all emissions	Improved allocation of emissions, life-cycle emissions analysis	SASOL	March 2015
Ferro-alloy production	Using a combination of IPCC default and assumptions based on material flows	Shift towards a material balance approach	Xstrata, Association of Ferroalloy produces	March 2015
Aluminium Production	Using IPCC default emission factors	Shift towards a material balance approach	BHPBilliton	December 2014
Petroleum Refining	Not accounting for all emission sources. Data time series inconsistencies	Completeness – provide sector specific guidance document for this sector. Improve completeness and allocation of emissions	SAPIA in collaboration with all refineries	December 2014

Table D: Donor funded GHGIP projects

Project	Partner	Objective	Outcome	Timelines
Development of a formal GHG Inventory National System	Norwegian Embassy	Helping South Africa develop its national system	SA GHG inventories are compiled annually	2014-2016
Stationary Combustion EFs	GIZ, Eskom (Power Utility)	To develop emissions factors for stationary combustion using the Power generation sector as a pilot	Emissions from key sectors based on country-specific information	2014-2015
Land Cover mapping	DFID-UK	To develop land-use maps for 2-time steps [1990, 2013]	Land-use change matrix developed for 36 IPCC land use classes to detect changes.	2014-2015
Waste-sector data improvement project	African Development Bank (AFDB)	To improve waste-sector GHG emissions estimates and addressing data gaps	Waste Sector GHG inventory is complete, accurate and reflective of national circumstances	2015-2016
Compliance with SA Statistical Quality Assurance Framework (SASQAF)	Statistics South Africa	Align GHG Inventory national system with the SASQAF to ensure quality of the inventory	The national GHG inventory and its compilation processes endorsed through the SASQAF evaluation	2014-2016
National Forest Assessment (NFA)	African Development Bank (AFDB); Department of Agriculture, Forestry and Fishing (DAFF)	Piloting of the NFA to map and assess resource demands for a wall-to-wall based NFA	A resource demand analysis based on NFA pilot that informs	2015-2016

ES5 Conclusions and recommendations

The 2000 to 2010 GHG emissions results revealed an increase in emissions from the energy and waste sectors, and a decline in emissions from the AFOLU agriculture sub-sector. IPPU emissions increased and declined again over the 10 years. 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 declining trend in the AFOLU sector. The energy sector in South Africa continued to be the main contributor of GHG emissions (>75%) and was found to be a key category each year, 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 highlighted as an important sector as it (excl. FOLU) has a contribution greater than the IPPU sector and *enteric fermentation* is one of the top ten key categories each year. It is also important that the estimates for the *land* component be improved as it is estimated to be a carbon sink. South Africa needs to produce a more complete picture of the sinks and sources in this sector (including HWP), and needs to develop a full 20 year historical land cover data set so that the soil carbon estimates can be improved. Activity data on the DOM pool is also required. 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 culturally-diverse developing country with 11 official languages. It 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 governments (infra-) structure, population growth, geography, economic growth, energy consumption, technology development, climate and soils, agriculture and land use management. South Africa is a contributor to global climate change and as a result has taken steps to formulate measures to mitigate and adapt to a changing climate.

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 a population (in 2013) of 52.98 million (Statistics SA, 2013). The population of South Africa grew by 11.54% from 2001 to 2010 and had a projected population growth rate of 0.5% for 2010 – 2015 (DEA, 2011). International immigration is currently the main driving force of South Africa's population growth (DEA, 2014). 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 is one of the most urbanised countries in Africa. It 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 24% of residents (DEA, 2014), followed by KwaZulu - Natal with 19.7%. The Northern Cape has the smallest population (2.2%) (Statistics SA, 2013). 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 more than 2 500 km from a desert border in the Northwest downwards to the Cape Agulhas, and then extends northwards to the Indian Ocean, to the border of Mozambique in the Northeast (GCSI, 2009). The country ranges from subtropical regions in the north east to desert in the North West. 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, where most of the central areas are 1 000m above sea level. The main geographical features are the Drakensberg Mountains in the east, the Great Escarpment in the north east and the great Karoo in the centre (DEA, 2014).

1.2.1.4 Economic and industry profile

The Republic of South Africa is deemed a developing country with well-developed mining, transport, energy, manufacturing, tourism, agriculture, commercial timber and pulp production, and service sectors. The national GDP was $248 million in 2007, which translated to a per capita GDP of R36 461 (DEA, 2011).

This increased to $380 billion (R2 835 087) in 2012 (Statistics SA, 2013). The growth in GDP slowed to 3.8% in 2008, which was lower than the annual growth rates of 4.6% to 5.6% between 2004 and 2007 (Table 1.1). 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 (Statistics SA, 2013). Agriculture, industry and service sectors account for 2.5%, 31.6% and 65.9% of the GDP in 2012, respectively.

Table 1.1: The GDP percentage growth in South Africa between 2000 – 2010 (source: Statistics SA, 2010).

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
GDP % growth	4.2	2.7	3.7	2.9	4.6	5.3	5.6	5.6	3.8	-1.7	3.1

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 (DEA, 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 (DEA, 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 - Natal.

The land cover in South Africa is dominated by shrublands (~40%), savanna woodlands (~33%) and grasslands (~27%) (DEA, 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 (DEA, 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 (DEA, 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 (DEA, 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 (DEA, 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 (DEA, 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 (DEA, 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 and reporting of the national GHG inventories, there are many other relevant agencies and ministries that play supportive roles in terms of data provision across relevant sectors (Figure B). 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 (Statistics SA) 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 1.2 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 1.3) are those published in the IPCC third assessment report (TAR) (IPCC, Vol. 1).

In January 2015, all countries will be mandated to use the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for compilation and reporting of national greenhouse gas inventories under the UNFCCC reporting guidelines. In addition, countries that are party to the convention shall use the GWP from the IPCC Fourth Assessment Report (FAR). Hence, the next South African inventory submission will use GWPs from (FAR).

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.

Table 1.2: 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
Energy												
Fuel combustion												
Energy industries	T1, T3	T1, CS[a]	T1, T3	DF[b]	T1, T3	DF						
Manufacturing industries and construction	T1	DF	T1	DF	T1	DF						
Transport	T1	DF	T1	DF	T1	DF						
Other sectors	T1	DF	T1	DF	T1	DF						
Non-specified	T1	DF	T1	DF	T1	DF						
Fugitive emissions from fuels												
Solid fuels	T2	CS	T2	CS								
Oil and natural gas	T3	CS										
Other emissions from energy production	T3	CS	T3	CS								
Industrial processes												
Mineral products	T1	DF										
Chemical industry	T1,T3	DF CS	T1	DF	T1	DF						
Metal industry	T2,T3	T2, PS[c]	T1	DF					T2	CS		
Non-energy products from fuels and solvents	T1	DF										
F. Product used as substitutes for ODS							T1	DF				
AFOLU												
Livestock												
Enteric fermentation			T2	CS								
Manure management			T2	CS	T2	DF						
Land												
Forest land	T1,T2	CS DF										
Cropland	T1,T2	CS DF										
Grassland	T1	DF										
Wetlands			T1	DF								
Settlements	T1	DF										
Aggregated sources and non-CO_2 emissions												
Emissions from biomass burning	T2	CS	T2	CS	T2	CS						
Liming	T1	DF										
Urea application	T1	DF										
Direct N_2O from managed soils					T1	DF						
Indirect N_2O from managed soils					T1	DF						
Indirect N_2O from manure management					T1	DF						
4.Waste												
Solid waste disposal			T1	DF								
D.Wastewater treatment and discharge			T1, T2	CS DF	T1	DF						

[a] Country specific; [b] Default factors; [c] Plant Specific emission factors

Table 1.3: 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

For the current inventory, data was gathered for 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. Discussions are under way to estimate SF6 emissions from power generation. Progress on this initiative will be reported in the next inventory submission.

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 (DMR);
- Department of Energy (DoE);
- Power utility plants;
- Chevron;
- SAPREF;
- Engen
- Energy balances and the periodically published Digests 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;
- Food and Agriculture Organization (FAO);
- Chamber of Mines provided information associated with GHG emissions from mining activities;
- Statistics South Africa;
- National Energy Regulator of South Africa (NERSA);
- Department of Government, Communications Information Systems (GCIS); and
- South African Reserve Bank.

» Industrial processes and product use:

- Business Unity South Africa;
- Chemical and Allied Industries Association (CAIA);
- Industry Associations;
- South African Mineral Industry (SAMI);
- Department of Mineral Resources (DMR);
- Department of Energy (DoE);
- South African Iron and Steel Institute (SAISI);
- Association of Cementitious Material Producers (ACMP)
- Direct communication with various industrial production plants.

» Agriculture:

- Department of Agriculture, Forestry and Fisheries (DAFF);
- Agricultural Research Council (ARC);
- Tshwane University of Technology (TUT);
- University of Pretoria (UP);
- North West University, Potchefstroom (NWU);
- Professional Livestock Associations and breed societies.

» Land use:

- DAFF;
- Forest Resource Assessment 2005;
- Forestry South Africa (FSA);
- GeoTerraImage (GTI);
- Council for Scientific and Industrial Research (CSIR),

- FAO;
- ARC.
- Aggregated and non-CO_2 sources:
- MODIS burnt area data;
- CSIR;
- NWU;
- FAO;
- DAFF;
- FSA.

» Waste:

- Statistics SA;
- World Resource Institute (WRI);
- DEA (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. FOLU) were the *energy industries* (solid fuels), *road transportation*, *manufacturing industries and construction* (solid fuels), and *energy industries* (liquid fuels) (Table 1.4) using the level assessment, while the trend assessment showed that *other sectors* (solid fuels), *energy industries* (solid fuels), *other emissions from energy production*, *iron and steel production* and *energy industries* (liquid fuels) were the top key categories (Table 1.6). When the FOLU sub-sectors are included, then *forest land remaining forest land* becomes the 5th key category in the level assessment and *land converted to grassland* becomes the most important category under the trend assessment (Table 1.5 and Table 1.7). Appendix B provides full details of all key category analyses.

A level assessment (incl. FOLU) was conducted for each year and Table 1.8 shows the changes in the top 10 key categories between 2000 and 2010. Energy industries (solid fuels) are the key category in all years. Forest land remaining forest land is the second most important category between 2000 and 2003, but then Transport fills this spot from 2004 onwards. Manufacturing industries and construction moves from 6th position in 2000 to 3rd place between 2006 and 2010.

Table 1.4: Level assessment results for 2010, excluding FOLU contributions. Only key categories are shown.

IPCC code	IPCC Category	GHG	2010 (Ex,t) (Gg CO_2 eq)	Lx,t	Cumulative Total
1.A.1	Energy Industries - Solid Fuels	CO2	5578.19	0.4306	0.4306
1.A.3.b	Road Transportation	CO2	26658.56	0.0780	0.5087
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CO2	29601.08	0.0646	0.5733
1.A.1	Energy Industries - Liquid Fuels	CO2	15385.78	0.0588	0.6321
1.A.4	Other Sectors - Solid Fuels	CO2	9704.24	0.0497	0.6818
3.A.1	Enteric Fermentation	CH4	256361.41	0.0495	0.7313
2.C.1	Iron and Steel Production	CO2	4715.48	0.0443	0.7756
1.B.3	Other emissions from Energy Production	CO2	32623.34	0.0407	0.8163
1.A.4	Other Sectors - Liquid Fuels	CO2	12766.46	0.0323	0.8486
4.A	Solid Waste Disposal	CH4	3992.53	0.0304	0.8790
3.C.4	Direct N2O Emissions from managed soils	N2O	29056.22	0.0275	0.9064
2.C.2	Ferroalloys Production	CO2	2040.00	0.0217	0.9281
3.C.5	Indirect N2O Emissions from managed soils	N2O	2217.75	0.0083	0.9363
2.A.1	Cement production	CO2	0.00	0.0077	0.9440
1.A.2	Manufacturing Industries and Con-struction - Gaseous Fuels	CO2	2520.34	0.0070	0.9511
1.A.3.a	Civil Aviation	CO2	499.06	0.0067	0.9578

Table 1.5: Level assessment results for 2010, including FOLU contributions. Only key categories are shown.

IPCC code	IPCC Category	GHG	2010 (Ex,t) (Gg CO_2 eq)	Lx,t	Cumulative Total
1.A.1	Energy Industries - Solid Fuels	CO2	234 672.13	0.3926	0.3926
1.A.3.b	Road Transportation	CO2	42 515.18	0.0711	0.4637
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CO2	35 197.37	0.0589	0.5226
1.A.1	Energy Industries - Liquid Fuels	CO2	32 052.46	0.0536	0.5763
3.B.1.a	Forest land Remaining Forest land	CO2	-27121.56	0.0454	0.6216
1.A.4	Other Sectors - Solid Fuels	CO2	27 067.04	0.0453	0.6669
3.A.1	Enteric Fermentation	CH4	26977.835	0.0451	0.7121
2.C.1	Iron and Steel Production	CO2	24146.873	0.0404	0.7525
1.B.3	Other emissions from Energy Production	CO2	22 181.07	0.0371	0.7896
1.A.4	Other Sectors - Liquid Fuels	CO2	17 589.76	0.0294	0.8190
4.A	Solid Waste Disposal	CH4	16568.6	0.0277	0.8467
3.C.4	Direct N2O Emissions from managed soils	N2O	14964.378	0.0250	0.8718
2.C.2	Ferroalloys Production	CO2	11804.993	0.0198	0.8915
3.B.3.b	Land Converted to Grassland	CO2	7012.874	0.0117	0.9032
3.D.1	Harvested Wood Products	CO2	-6204.492	0.0104	0.9136
3.B.1.b	Land Converted to Forest land	CO2	-6103.195	0.0102	0.9238
3.B.2.b	Land Converted to Cropland	CO2	5434.5258	0.0091	0.9329
3.C.5	Indirect N2O Emissions from managed soils	N2O	4502.3303	0.0075	0.9405
2.A.1	Cement production	CO2	4186.736	0.0070	0.9475
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CO2	3 837.58	0.0064	0.9539
1.A.3.a	Civil Aviation	CO2	3 657.68	0.0061	0.9600

Table 1.6: Trend assessment results for 2010 (with 2000 as the base year), excluding FOLU contributions. Only the key categories are shown.

IPCC code	IPCC Category	GHG	2000 Year Estimate Ex0 (Gg CO_2 eq)	2010 Year Estimate Ext (Gg CO_2 eq)	Trend Assessment (Txt)	% Contribution to Trend	Cumulative Total
1.A.4	Other Sectors - Solid Fuels	CO2	5 586.89	27 067.04	0.0451	0.2124	0.2124
1.A.1	Energy Industries - Solid Fuels	CO2	185 027.44	234 672.13	0.0233	0.1098	0.3223
1.B.3	Other emissions from Energy Production	CO2	26 658.56	22 181.07	0.0225	0.1059	0.4282
2.C.1	Iron and Steel Production	CO2	27 753.86	24 146.87	0.0211	0.0992	0.5274
1.A.1	Energy Industries - Liquid Fuels	CO2	33 855.83	32 052.46	0.0199	0.0938	0.6212
3.A.1	Enteric Fermentation	CH4	29 307.55	26 977.84	0.0190	0.0893	0.7105
4.A	Solid Waste Disposal	CH4	9 704.23	16 568.60	0.0107	0.0504	0.7608
3.C.4	Direct N2O Emissions from managed soils	N2O	16 118.85	14 964.38	0.0101	0.0478	0.8086
1.A.3.b	Road Transportation	CO2	32 623.34	42 515.18	0.0066	0.0313	0.8399
1.A.4	Other Sectors - Liquid Fuels	CO2	12 766.46	17 589.76	0.0047	0.0222	0.8621
2.C.2	Ferroalloys Production	CO2	8 079.14	11 804.99	0.0045	0.0211	0.8832
2.B.2	Nitric Acid Production	N2O	NS[a]	325.54	0.0035	0.0165	0.8997
3.C.5	Indirect N2O Emissions from managed soils	N2O	4 745.81	4 502.33	0.0028	0.0131	0.9128
1.A.3.a	Civil Aviation	CO2	2 040.00	3 657.68	0.0026	0.0124	0.9252
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CO2	2 217.75	3 837.58	0.0026	0.0120	0.9372
2.C.3	Aluminium production	PFCs	982.24	138.26	0.0023	0.0110	0.9482
2.F.1	Refrigeration and Air Conditioning	HFCs, PFCs	0.00	799.88	0.0018	0.0084	0.9566

[a] Not shown as the data is sensitive data and the disaggregated Chemical Industry [2B] data is not reported.

Table 1.7: Trend assessment results for 2010 (with 2000 as the base year), including FOLU contributions. Only the key categories are shown.

IPCC code	IPCC Category	GHG	2000 Year Estimate Ex0 (Gg CO_2 eq)	2010 Year Estimate Ext (Gg CO_2 eq)	Trend Assessment (Txt)	% Contribution to Trend	Cumulative Total
3.B.3.b	Land Converted to Grassland	CO2	27 382.57	7 012.87	0.0495	0.1867	0.1867
1.A.4	Other Sectors - Solid Fuels	CO2	5 586.89	27 067.04	0.0380	0.1434	0.3301
1.B.3	Other emissions from Energy Production	CO2	26 658.56	22 181.07	0.0194	0.0731	0.4032
2.C.1	Iron and Steel Production	CO2	27 753.86	24 146.87	0.0182	0.0686	0.4719
1.A.1	Energy Industries - Liquid Fuels	CO2	33 855.83	32 052.46	0.0173	0.0654	0.5372
1.A.1	Energy Industries - Solid Fuels	CO2	185 027.44	234 672.13	0.0170	0.0640	0.6013
3.A.1	Enteric Fermentation	CH4	29 307.55	26 977.84	0.0164	0.0620	0.6633
3.B.1.a	Forest land Remaining Forest land	CO2	-45 490.83	-27 121.56	0.0157	0.0594	0.7227
3.B.2.b	Land Converted to Cropland	CO2	571.63	5 434.53	0.0089	0.0335	0.7562
4.A	Solid Waste Disposal	CH4	9 704.23	16 568.60	0.0089	0.0335	0.7897
3.C.4	Direct N2O Emissions from managed soils	N2O	16 118.85	14 964.38	0.0088	0.0332	0.8229
3.B.1.b	Land Converted to Forest land	CO2	-2 549.14	-6 103.19	0.0077	0.0291	0.8520
1.A.3.b	Road Transportation	CO2	32 623.34	42 515.18	0.0051	0.0193	0.8714
1.A.4	Other Sectors - Liquid Fuels	CO2	12 766.46	17 589.76	0.0038	0.0143	0.8857
2.C.2	Ferroalloys Production	CO2	8 079.14	11 804.99	0.0037	0.0138	0.8995
3.D.1	Harvested Wood Products	CO2	-5 785.55	-6 204.49	0.0032	0.0120	0.9115
2.B.2	Nitric Acid Production	N2O	NS[a]	325.54	0.0030	0.0113	0.9227
3.C.5	Indirect N2O Emissions from managed soils	N2O	4 745.81	4 502.33	0.0024	0.0091	0.9318
1.A.3.a	Civil Aviation	CO2	2 040.00	3 657.68	0.0022	0.0083	0.9401
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CO2	2 217.75	3 837.58	0.0021	0.0080	0.9481
2.C.3	Aluminium production	PFCs	982.24	138.26	0.0020	0.0075	0.9556

[a] Not shown as the data is sensitive data and the disaggregated Chemical Industry [2B] data is not reported.

Table 1.8:Trends in the top 10 key categories (including FOLU) with the level assessment over the period 2000 – 2010.

Category position	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
1	Energy Industries - Solid Fuels	Energy Industries - Solid Fuels	Energy Industries - Solid Fuels	Energy Industries - Solid Fuels	Energy Industries - Solid Fuels	Energy Industries - Solid Fuels	Energy Industries - Solid Fuels	Energy Industries - Solid Fuels	Energy Industries - Solid Fuels	Energy Indus-tries - Solid Fuels	Energy Industries - Solid Fuels
2	Forest land Remaining Forest land	Forest land Remaining Forest land	Forest land Remaining Forest land	Forest land Remaining Forest land	Road Transportation	Road Transportation	Road Transportation	Road Transportation	Road Transportation	Road Transportation	Road Transportation
3	Energy Industries - Liquid Fuels	Energy Industries - Liquid Fuels	Road Transportation	Road Transportation	Forest land Remaining Forest land	Forest land Remaining Forest land	Manufacturing Industries and Construction - Solid Fuels	Manufacturing Industries and Construction - Solid Fuels	Manufacturing Industries and Construction - Solid Fuels	Manufacturing Industries and Construction - Solid Fuels	Manufacturing Industries and Construction - Solid Fuels
4	Road Transportation	Road Transportation	Energy Industries - Liquid Fuels	Energy Industries - Liquid Fuels	Manufacturing Industries and Construction - Solid Fuels	Manufacturing Industries and Construction - Solid Fuels	Energy Industries - Liquid Fuels	Energy Industries - Liq-uid Fuels	Energy Industries - Liquid Fuels	Forest land Remaining Forest land	Energy Industries - Liquid Fuels
5	Enteric Fermentation	Enteric Fermentation	Manufacturing Industries and Construction - Solid Fuels	Manufacturing Industries and Construction - Solid Fuels	Energy Industries - Liquid Fuels	Energy Industries - Liquid Fuels	Iron and Steel Production	Forest land Remaining For-est land	Forest land Remaining Forest land	Energy Industries - Liquid Fuels	Forest land Remaining Forest land
6	Manufacturing Industries and Construction - Solid Fuels	Manufacturing Industries and Construction - Solid Fuels	Iron and Steel Production	Iron and Steel Production	Iron and Steel Production	Iron and Steel Production	Forest land Remaining Forest land	Iron and Steel Production	Enteric Fermentation	Enteric Fermentation	Other Sectors - Solid Fuels
7	Iron and Steel Production	Iron and Steel Production	Land Converted to Grassland	Land Converted to Grassland	Land Converted to Grassland	Land Converted to Grassland	Enteric Fermentation	Enteric Fermentation	Iron and Steel Production	Other Sectors - Solid Fuels	Enteric Fermentation
8	Land Converted to Grassland	Land Converted to Grassland	Enteric Fermentation	Enteric Fermentation	Enteric Fermentation	Enteric Fermentation	Other emissions from Energy Production	Other emissions from Energy Production	Other Sectors - Solid Fuels	Iron and Steel Production	Iron and Steel Production
9	Other emis-sions from Energy Production	Other emis-sions from Energy Production	Other emissions from Energy Production	Other emissions from Energy Production	Other emissions from Energy Production	Other emissions from Energy Production	Other Sectors - Solid Fuels	Other Sectors - Solid Fuels	Other emissions from Energy Production	Other emissions from Energy Production	Other emissions from Energy Production
10	Direct N2O Emissions from managed soils	Direct N2O Emissions from managed soils	Direct N2O Emissions from managed soils	Direct N2O Emissions from managed soils	Other Sectors - Liquid Fuels	Other Sectors - Solid Fuels	Other Sectors - Liquid Fuels	Other Sectors - Liquid Fuels	Other Sectors - Liquid Fuels	Other Sectors - Liquid Fuels	Other Sectors - Liquid Fuels

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.

1.4.1 Quality control

Quality controls that were applied for this GHG inventory involved generic quality checks related to the calculations, data processing, completeness and documents which were applicable to the inventory. The QC procedures that were applied in this inventory are summarised in Table 1.9.

Table 1.9: QC activity and procedures applied in this inventory

QC Activity	Procedures
The NIR was checked for transcription errors in data input and references	Confirmation that all references cited are included in the reference list and the text Cross-check input data from each category for transcription errors
The National inventory was checked to ensure that emissions and removals are calculated accurately	The IPCC software database was applied to reproduce a set of emissions and removals
The National Inventory was checked to ensure that the parameters and units were recorded and that the conversion factors were applied appropriately	The units properly labelled The units and conversion factors were consistent throughout the calculations
The National inventory was checked for time series consistency	Temporal consistency was checked in time series input data Consistency in the methods applied for calculations Methodological and data changes which resulted from the recalculations of the 2000 inventory
The national inventory was checked for completeness	Transparency in all the categories and subcategories which were included and excluded from the inventory Transparency in the data gas from incomplete estimates
Trend check	Comparison of the trends of the time series and the transparency in the causes of significant changes or variations Checked on any usual and unexplained trends which were evident for activity data or other parameters across the time series

1.4.2 Quality assurance (QA)

The QA process was done by external reviewers who were not involved in the compilation process of the inventory for the purpose of conducting an unbiased review of the inventory and that have a different technical perspective. The external reviewers ensured that the inventory's results, assumptions and methods were reasonable. Furthermore public review process was undertaken to supplement the external review. The independent review process that was followed is demonstrated by the diagram below. Essentially, the draft GHG inventory report was published for public comment in a Government Gazette. Parallel to the publication for public comment, the independent technical review of activity data, emission factors and methodologies used was undertaken by the independent company. Comments that were submitted during the public commenting process were incorporated in the independent review process. Findings and recommendations from the independent review process were then used to refine the draft GHG Inventory report. Currently, DEA is preparing a detailed 3-year supplementary improvement plan to address recommendations from the independent review process. Some of the projects that are currently listed in the Greenhouse Gas Improvement Programme (GHGIP) are as a result of the findings of this review.

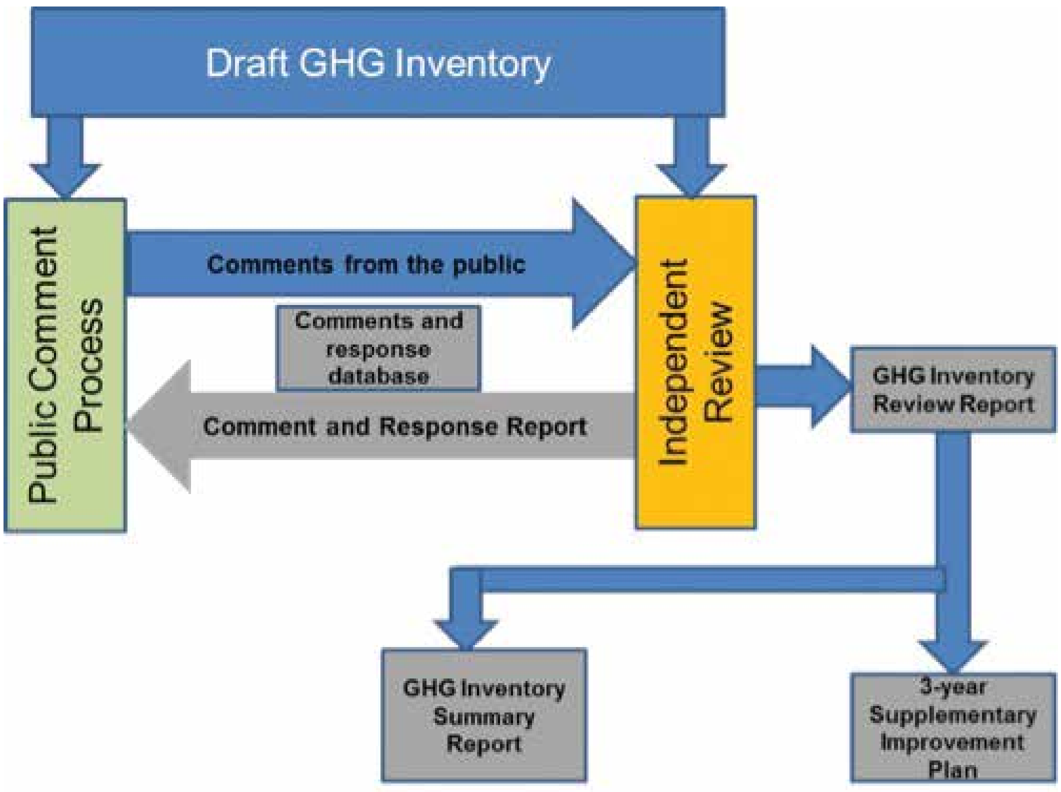

Figure 1.1: The independent review process for the 2000 – 2010 inventory.

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 Good Practice 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;
  - Other product manufacture and use;
  - Pulp and paper industry;
  - Food and beverages industry.

» AFOLU sector:
  - Enteric fermentation from buffalo and other game as population data are uncertain;
  - DOM due to insufficient data;
  - Other lands and land converted to other lands;
  - 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 A.

In 2010 the total GHG emissions (excl. FOLU) in South Africa were estimated at 544 314 Gg CO_2eq. There has been a slow increase of 21.1% since 2000 (449 498 Gg CO_2eq). The 2000 emissions were also 29.4% 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. FOLU) was 2.9% lower than the estimate originally provided in the 2000 national inventory (463 044 Gg CO_2eq, excl. FOLU). Figure 2.1 shows the trends and relative contributions of the different gases to the aggregated national GHG emissions (excl. FOLU). There was a 24.3% and 12.4% increase in CO_2 and CH_4 (in CO_2eq) respectively between 2000 and 2010, and a decline (7.0%) in N_2O emissions over this period. Fluorinated gases (F-gases) fluctuated between 680 Gg CO_2eq (2009) and 1 374 Gg CO_2eq (2007) during the 10 year period and contributed <0.3% to the total GHG budget.

The *land* and *HWP* sub-sectors show annual variation, but were estimated to be a net sink of CO_2. Including the emissions and removals from these two sub-sectors in the overall inventory produces a total GHG emission estimate of 425 219 Gg CO_2eq in 2000, which increase by 21.9% to 518 239 Gg CO_2eq in 2010 (Figure 2.2). The recalculated total GHG emission estimates including FOLU sector were 3.9% lower than the value reported in the National GHG Inventory for 2000 (DEAT, 2009).

That was due to the incorporation of more detailed Land data, correction of errors made in the 2000 calculations, addition of HWPs, as well as the inclusion of additional land categories that were not previously reported on. Including FOLU in the total emissions led to a slight decline in the CO_2 contribution from an average of 84.7% to 84.1% over the 10 years. The contribution from CH_4 and N_2O increased by 0.4% and 0.2% respectively; while the average contribution from F-gases remained the same (Figure 2.2).

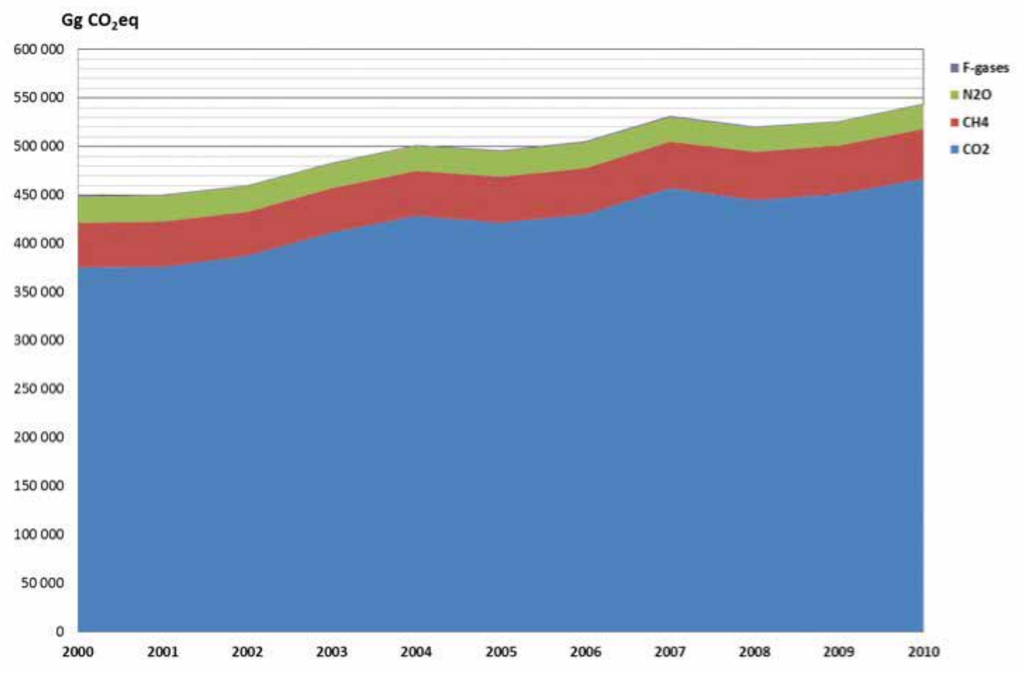

Figure 2.1: Greenhouse gases: Trend and emission levels (excl. FOLU), 2000 – 2010.

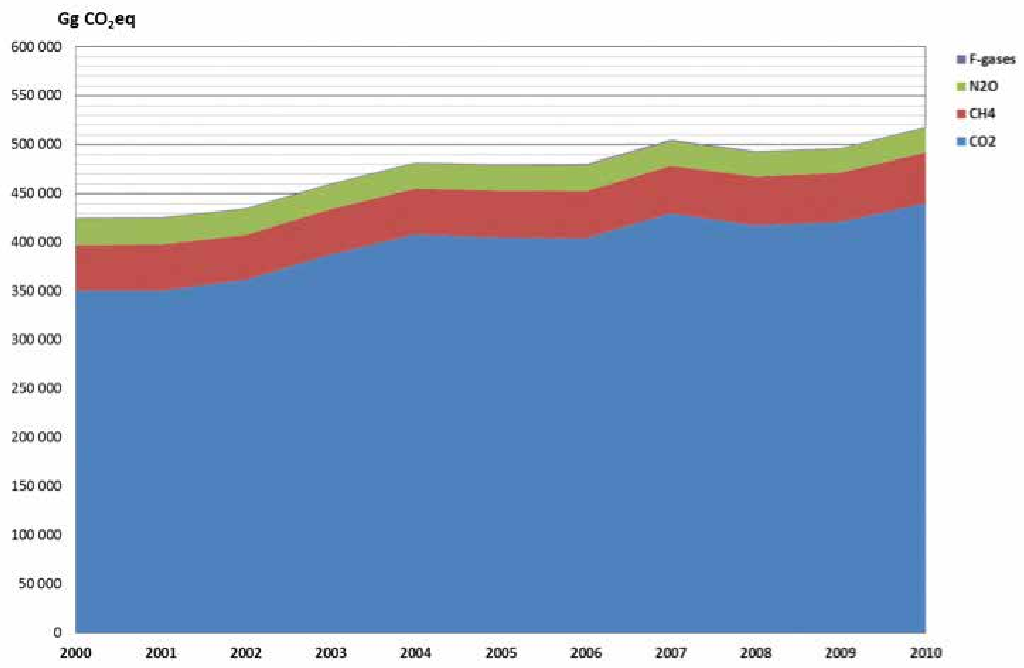

Figure 2.2: Greenhouse gases: Trend and emission levels (including FOLU sub-sectors), 2000 – 2010.

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. FOLU). The emissions increased by 24.3% between 2000 and 2010. The Energy sector was by far the largest contributor to CO_2 emissions in South Africa, contributing an average of 89.1% between 2000 and 2010, with the categories *1A1 energy industries* (57.2%), *1A3 transport* (9.5%) and *1A2 manufacturing industries and construction* (8.8%) being the major contributors to CO_2 emissions in 2010.

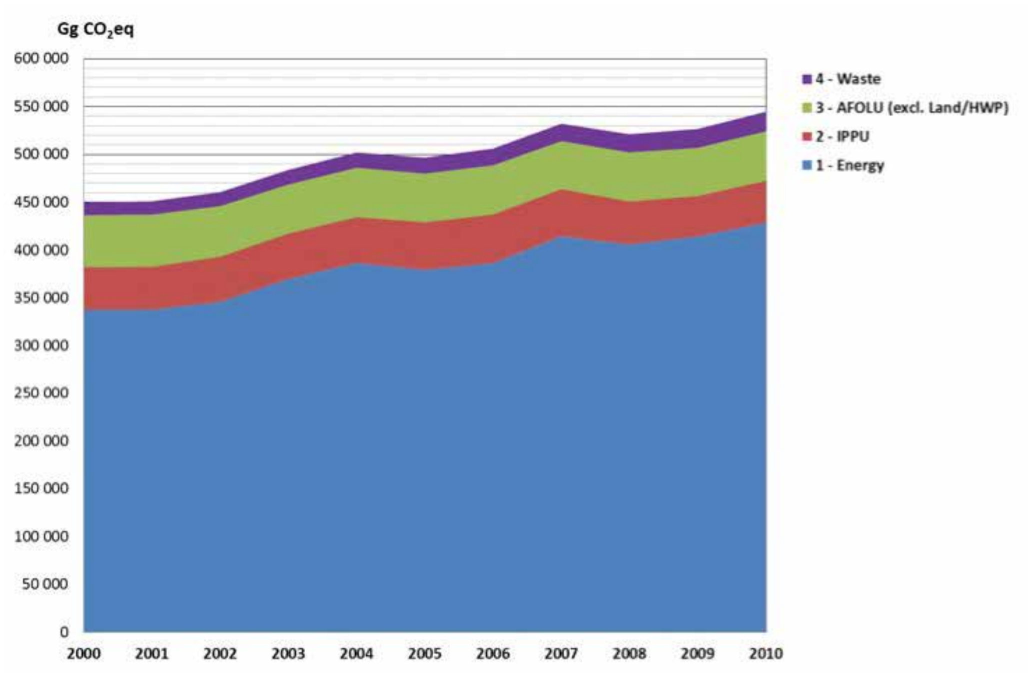

Figure 2.3: CO_2: Trend and emission levels of sectors (excl. FOLU), 2000 – 2010.

2.2.2 Methane

The sector contributions to the total CH_4 emissions (excl. FOLU) in South Africa are shown in Figure 2.4. The national CH_4 emissions increased from 45 868 Gg CO_2eq in 2000 to 51 545 Gg CO_2eq in 2010 (12.4% increase). The AFOLU Livestock category and Waste sectors were the major contributors, providing an average of 54.1% and 37.21% to the total CH_4 emissions in 2010 respectively. The contribution from Livestock has declined by 11.8%, while the contribution from the Waste sector has increased by a similar amount (11.3%) 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 7.0% 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 80.1% to the total N_2O emissions over the period 2000 to 2010, while the energy and livestock (which includes manure management) sectors contributed an average of 8.9% and 3.9% respectively.

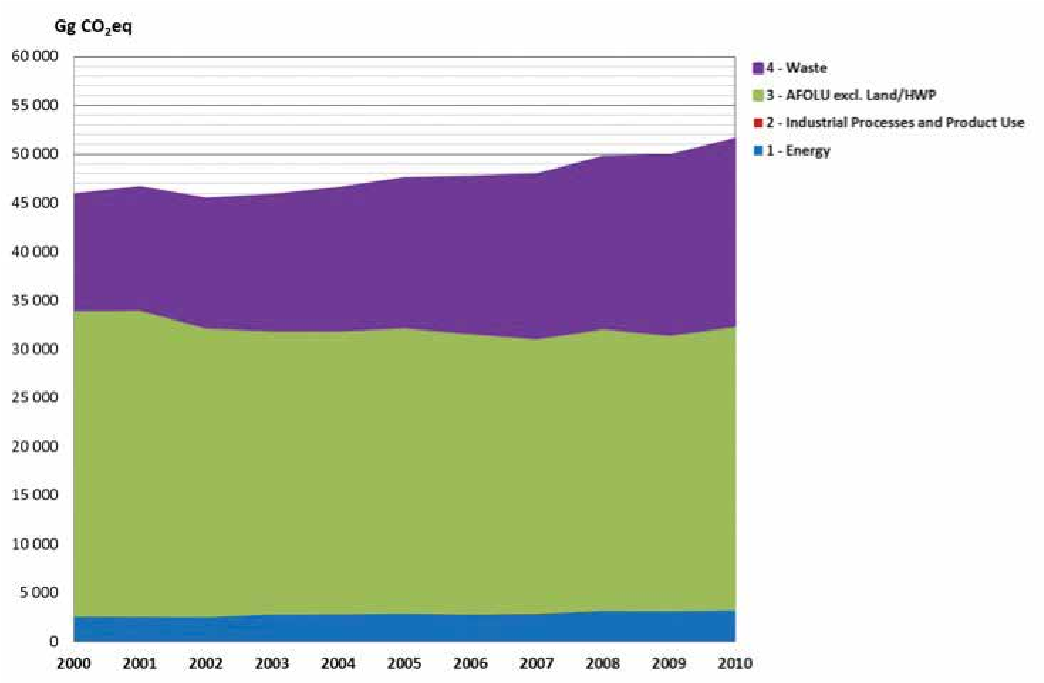

Figure 2.4: CH_4: Trend and emission levels of sectors (excl. FOLU), 2000 – 2010

2.2.4 Fluorinated gases

Estimates of hydrofluorocarbons (HFC) and perfluorocarbons (PFC) emissions were only given for the IPPU sector in South Africa. Emission estimates vary annually between 680 Gg CO_2eq and 1374 Gg CO_2eq (Figure 2.6). HFC emissions in 2005 were estimated at 126 Gg CO_2eq and this increased to 800 Gg CO_2eq in 2010. There were no data prior to 2005. The PFC emissions were estimated at 982 Gg CO_2eq in 2000 and this increased to 548 Gg CO_2eq in 2008, then declined to 108 Gg CO_2eq and 138 GgCO_2eq in 2009 and 2010 respectively.

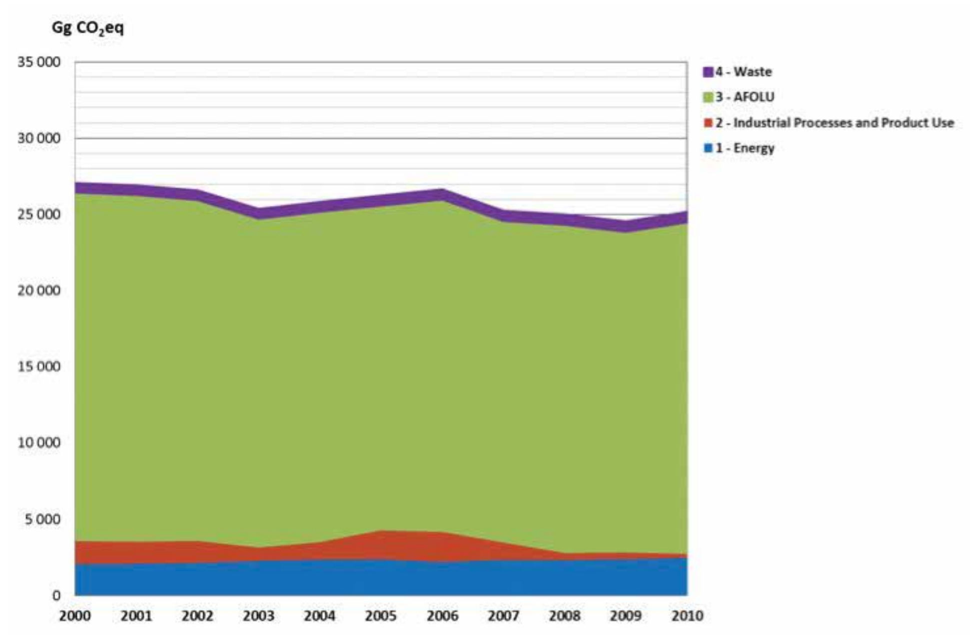

Figure 2.5: N_2O: Trend and emission levels of sectors, 2000 – 2010.

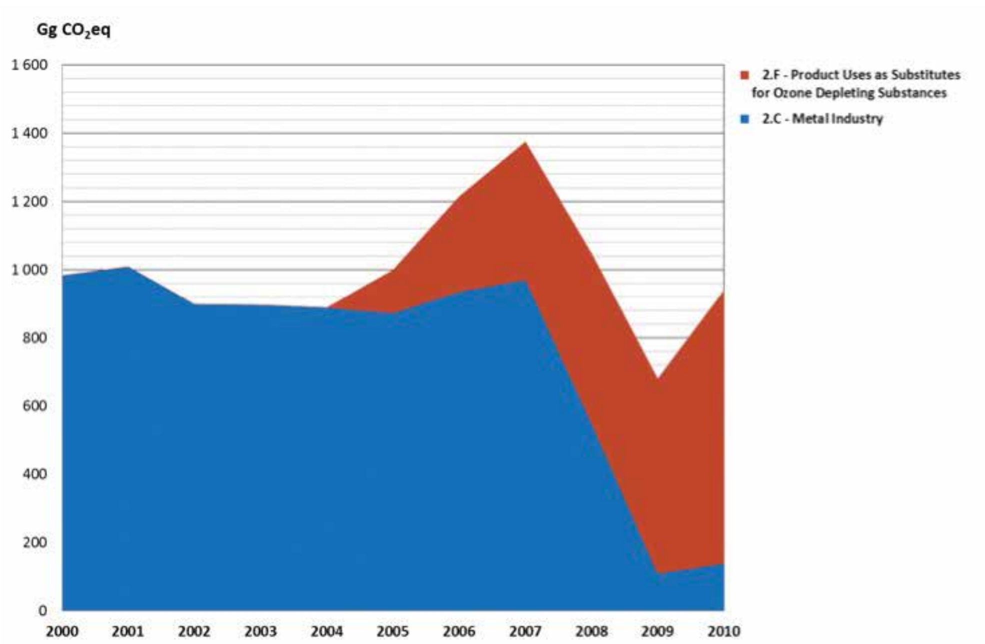

Figure 2.6: F-Gases: Trend and emission levels of sectors, 2000 – 2010.

2.3 Emission trends specified by source category

Figure 2.7 provides an overview of emission trends per IPCC sector in Gg CO_2eq (excl. FOLU). The energy sector was by far the largest contributor to the total GHG emissions, providing 75.1% in 2000 and increasing to 78.7% in 2010. The total GHG estimate of 449 498 Gg CO_2 eq (excl. FOLU) for 2000 was 29.4% higher than the 1990 estimate. The AFOLU sector (excl. FOLU) and the IPPU sector contribute 9.5% and 8.2%, respectively, to the total GHG emissions in 2010. Their contributions have decreased by 5.5% and 1.2% respectively since 2000. The percentage contribution from the waste sector has increased from 2.8% to 3.6% over the 10 year period. Trends in emissions by sub-categories in each sector are described in more detail in Chapters 3-6.

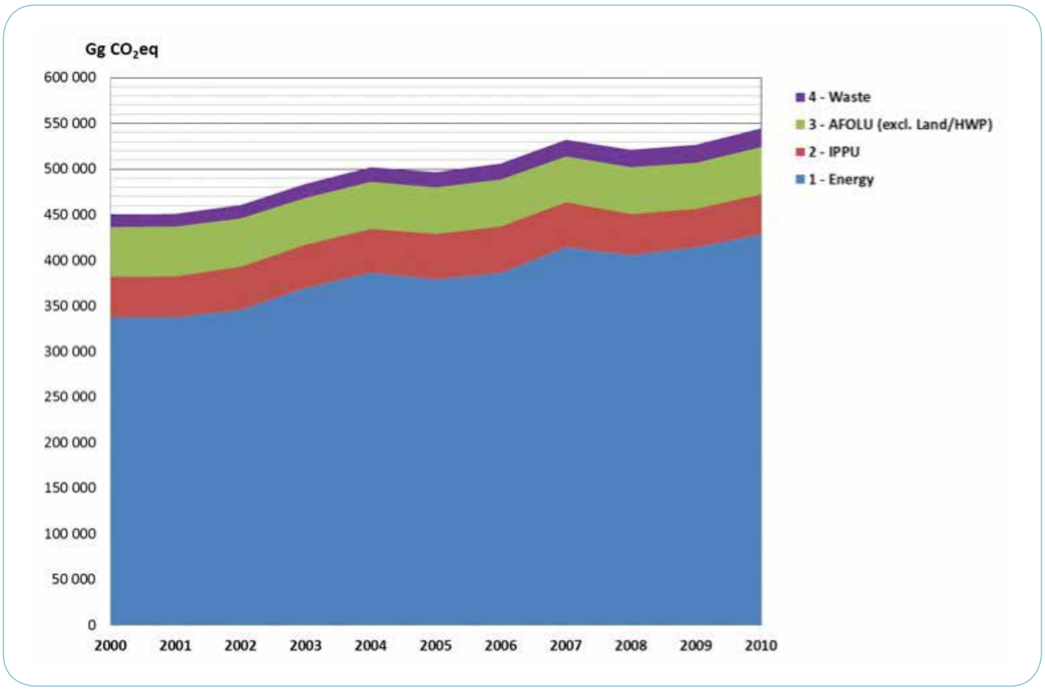

Figure 2.7: Total GHG: Trend and levels from sectors (excl. FOLU), 2000 – 2010.

2.4 Emission trends for indirect GHG

The trend in total emissions of carbon monoxide (CO) and nitrogen oxides (NO_x) is shown in Table 2.1. These emissions were only recorded for biomass burning. An average of 1 384 Gg CO and 54 Gg NO_x were estimated to be produced from biomass burning over the period 2000 to 2010. The highest values were recorded in 2007 and 2008, while the lowest was in 2000. The CO and NO_x emission estimates were not reported in the previous inventory (DEAT, 2009).

Table 2.1: Precursor GHG: Trend and emission levels in CO and NO_x (Gg of gas) from biomass burning, 2000 – 2010.

Gas	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
CO	1 340	1 346	1 341	1 362	1 362	1 373	1 380	1 456	1 466	1 395	1 399
NOx	53	53	53	54	54	54	54	55	55	55	55

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 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 waste (7.6%) as well as natural gas (2.8%) (DoE, 2010) (Figure 3.1).

3.1.2.1 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.

3.1.2.2 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.

3.1.2.3 Renewable energy

Renewable energy and waste 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.

3.1.2.4 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.

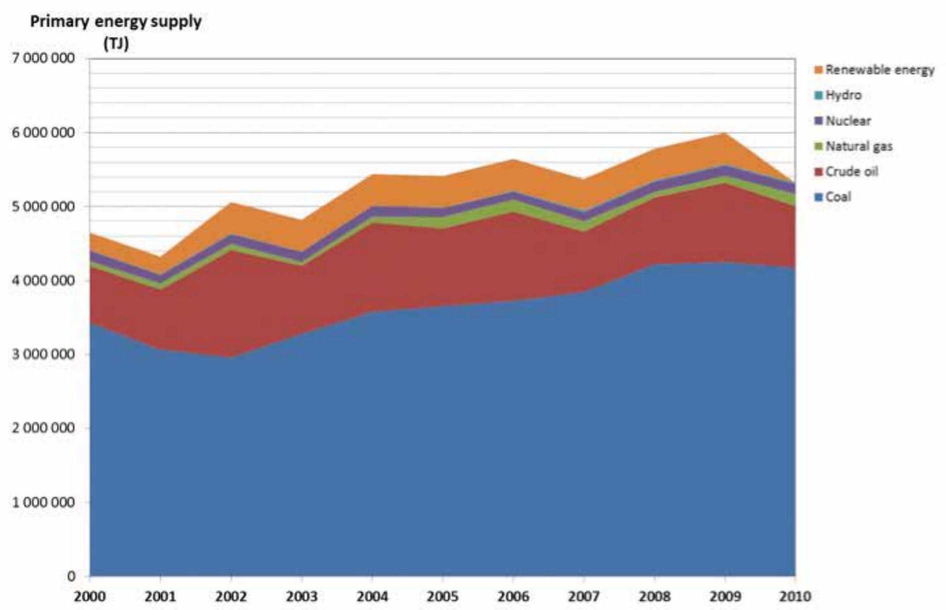

Figure 3.1: Sector 1 Energy: Trend in the primary energy consumption in South Africa, 2000 – 2010.

3.1.2.5 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.

3.1.2.6 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 from 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 (Statistics SA, 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.

3.1.3.1 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.

3.1.3.2 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.

3.1.3.3 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.

3.1.3.4 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 for the energy sector increased by 27% between 2000 and 2010, and produced a total accumulated GHG estimate of 4 204 640 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 (63.6%) (Figure 3.2), followed by 10.8% from transport and 9.8% 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 55.1% (2 316 071 Gg CO_2eq) of the total accumulated emissions. The second largest emitting subcategory was the transport sector which accounted for 453 924 Gg CO_2eq over the period 2000 - 2010. The manufacturing industry and construction and the fugitive emissions from energy production accounted for 410 205 Gg CO_2eq and 297 606 Gg CO_2eq (7.1% of the total emissions), respectively, between 2000 and 2010. The manufacture of solid fuels and other energy industries accounted for an accumulated 326 706 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 170 964 Gg CO_2eq and 157 662 Gg CO_2eq of emissions respectively.

The total GHG emissions in the energy sector increased from 337 382 GgCO_2eq in 2000 to 428 368 Gg CO_2eq in 2010 (Figure 3.3). The majority of emissions were from electricity production, which accounted for a total of 62.5% of the total GHG emissions from the energy sector in 2010. Total GHG emissions increased between 2001 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 (2.0%). Table 3.1 shows the contribution of the source categories in the energy sector to the total national GHG inventory.

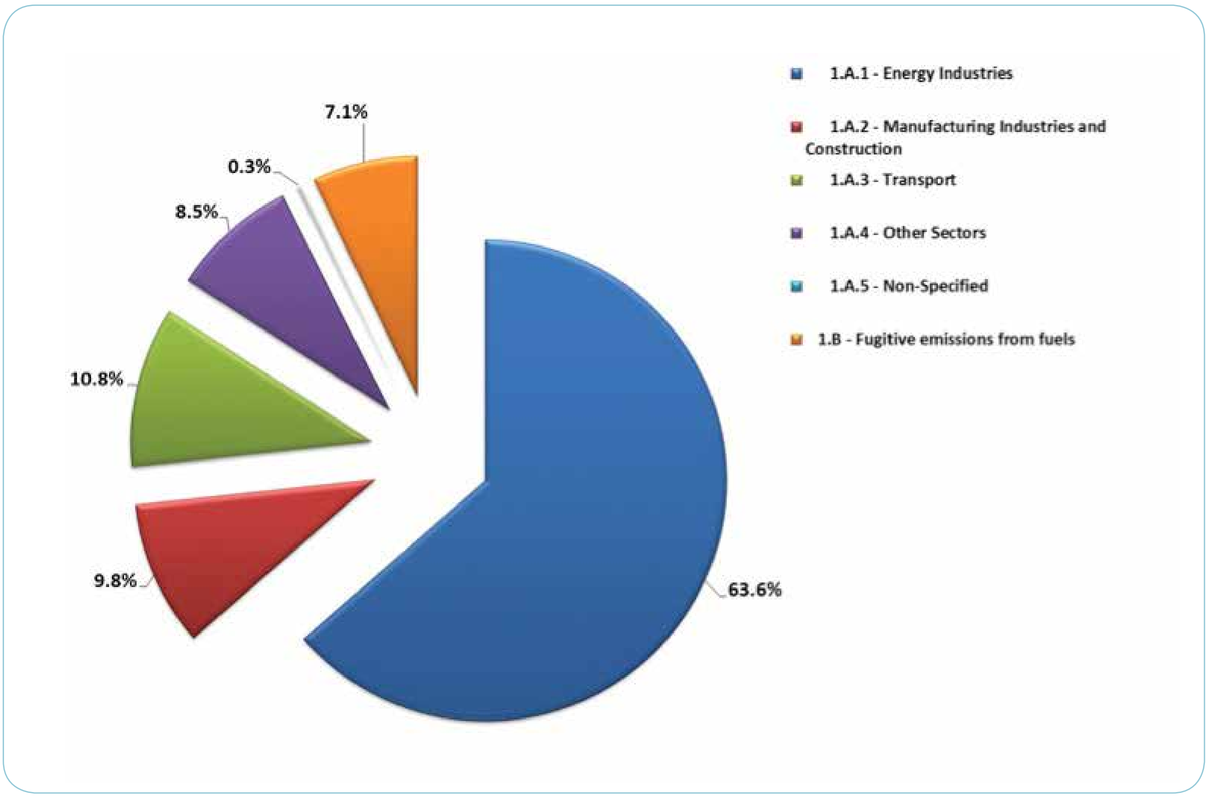

Figure 3.2: Sector 1 Energy: Average contribution of source categories to the total energy sector GHG emissions between 2000 and 2010.

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 29.32% in total GHG emissions from the energy sector, and between 2000 and 2010 there was a further 27.0% 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.

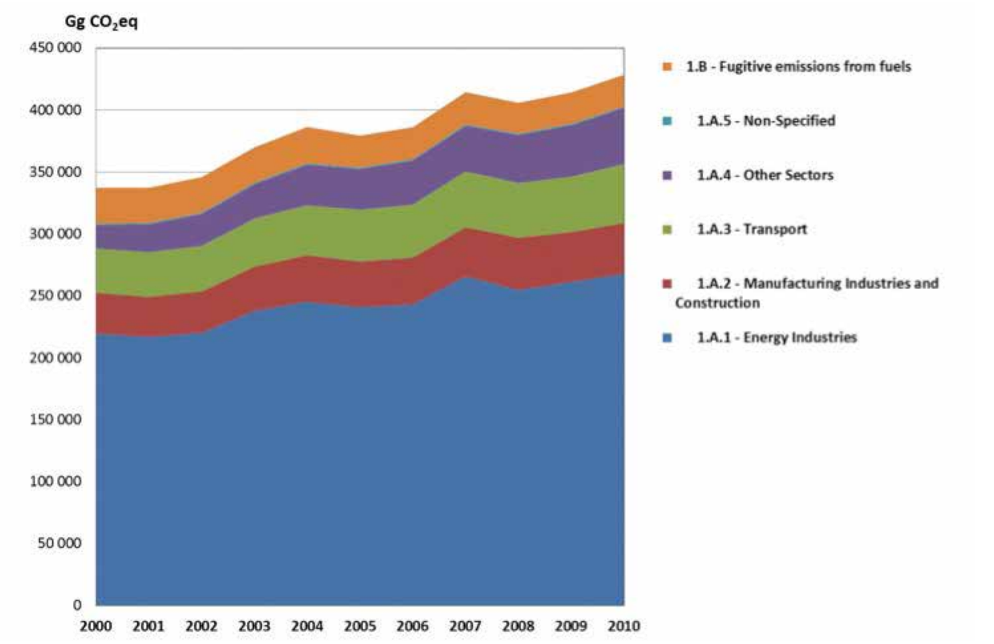

Figure 3.3: Sector 1 Energy: Trend and emission levels of source categories, 2000 – 2010.

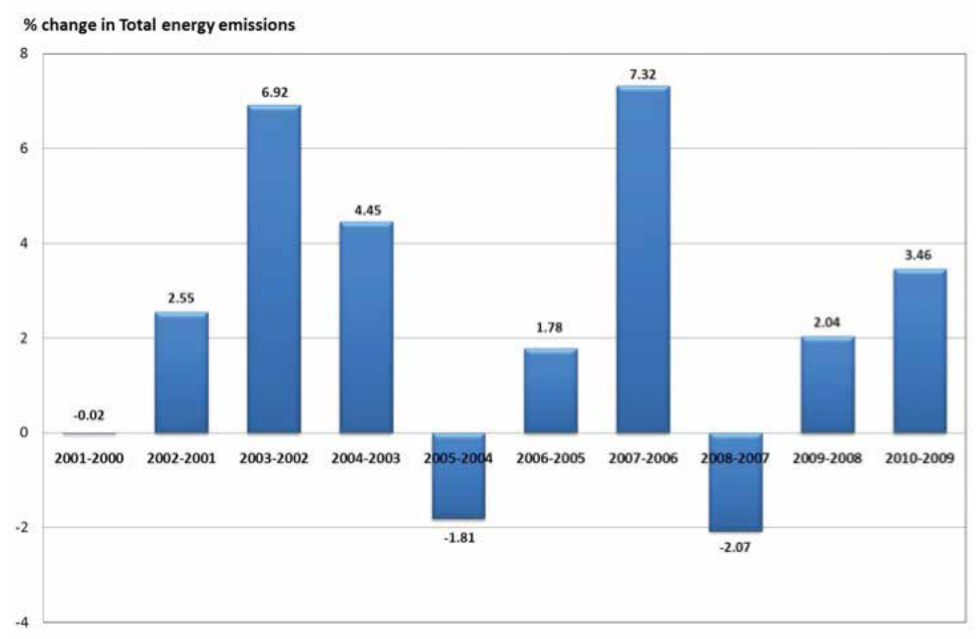

Figure 3.4: Sector 1 Energy: Annual change in total GHG emissions between 2000 and 2010.

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

Total CO_2 (Gg CO_2 eq)											
Period	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Electricity generation	185 925	180 906	187 149	203 866	211 905	209 920	212 304	233 883	223 477	229 937	236 798
Petroleum Refining	3 848	5 445	2 323	2 383	2 356	2 301	2 194	2 297	2 314	2 298	2 284
Manufacture of Solid Fuels and Other Energy Industries	29885	30491	30667	31561	30 769	28490	28420	29 741	28943	29127	28611
Manufacturing Industries and Construction	32 652	32 181	33 390	35 899	37 878	37 149	38 071	39 463	42 277	40 129	41 118
Domestic Aviation	2 047	2 079	2 204	2 626	2 837	3 147	3 118	3 374	3 413	3 469	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
Railway	615	604	589	558	582	579	535	552	522	538	497
Commercial/ Institutional	9 557	11 052	12 219	13 198	16 179	15 226	16 517	15 175	15 409	15 992	17 137
Residential	7 100	9 227	11 110	12 313	13 989	15 024	16 222	18 425	20 288	22 450	24 817
Agriculture/ forestry/ fishing/ fish farms	2 388	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 0151	1 045	1 062	1 073	1 100	1 053	1 076	1 139
Fugitive emissions from Coal Mining	2 003	1 990	1 961	2 118	2 167	2 181	2 180	2 205	2 246	2 230	2 266
Fugitive emissions from Natural Gas – Venting	325	250	196	1 065	254	266	291	325	237	237	619
Fugitive emissions - Other Emissions from energy production	26 694	26 266	26 707	25 305	26 932	23 403	23 302	23 485	22 440	22 796	22 666
Total GHG Emissions (Gg CO_2 eq)	337 382	337 300	345 892	369 834	386 309	379 315	386 082	414 350	405 770	414 039	428 368

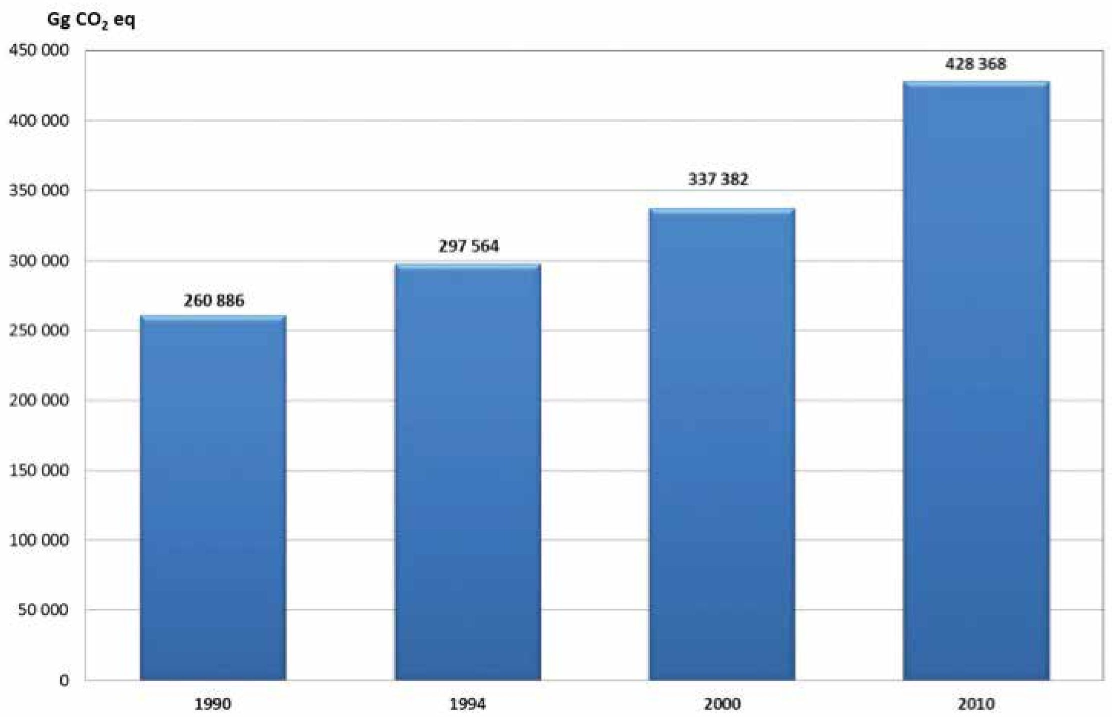

Figure 3.5: Sector 1 Energy: Trend and emission levels of total GHG's from the energy sector, 1990 – 2010

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 27.0% over the 10 years, 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 2.6% and 6.9% 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 1.8% 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 2.0% 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 3.5% 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 1.4 and Table 1.6). 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 2010 the CO_2 emissions were higher using the reference approach. Reporting has improved over the 10 year period as the difference between the two approaches has declined from 56% in 2000 to 20% in 2010. There are a number of possible reasons for the discrepancy:

- Net Calorific Values (NCV) used in the sectoral approach differs from those used in the reference approach. In power generation, NCV values in the sectoral approach vary over the 2000-2010 time series based on the information provided by industry;
- Activity data on Liquid fuels in the sectoral approach particularly for energy industries is sourced directly from the companies involved and has been reconciled with other publicly available datasets;
- Allocation of solid fuels between energy use, non-energy use as well use for synfuels production remains one of the key drives for the differences observed between the two datasets.

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 emissions from 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

3.3.3.1.1 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. 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.

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

3.3.3.1.2 Petroleum Refining [1A1b]

This source category includes combustion emissions from crude oil refining and excludes emissions from manufacturing of synthetic fuels from coal and natural gas. Combustion related emissions from manufacture of synthetic fuels from coal and natural gas are accounted for under 1A1c. 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 directly from refineries. National energy balance data from DoE is used to verify data reported by the petroleum industry.

3.3.3.1.2 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

3.3.3.2.1 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 23 347 592 TJ. The consumption of fuels has increased by 33.3% over this period (Table 3.4).

The total estimation of cumulative GHG emissions from the public electricity producer was 2 257 524 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	CO_2	CH_4	N_2O	Total GHG
Period	(TJ)	(Gg)	(Gg CO_2 eq)	(Gg CO_2 eq)	(Gg CO_2 eq)
2000	1 806 317	173 858	42	802	174 702
2001	1 823 120	175 475	42	809	176 327
2002	1 883 709	181 307	43	836	182 187
2003	2 025 821	194 985	47	899	195 931
2004	2 126 649	204 690	49	944	205 683
2005	2 142 682	206 209	49	951	207 209
2006	2 155 477	207 465	50	957	208 471
2007	2 369 988	228 111	55	1 052	229 218
2008	2 271 791	218 543	53	1 007	219 602
2009	2 335 102	224 579	54	1 034	225 667
2010	2 406 935	231 405	56	1 065	232 526

In the year 2000 the GHG emissions from the public electricity producer accounted for a total of 174 702 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 174 702 Gg CO_2eq to 229 218 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 resorted 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 public electricity producer decreased by 4.2% 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 58 547 Gg CO_2 eq. Overall, from 2000 through to 2010, the GHG emissions decreased by 61.9% (Table 3.5). The total GHG emissions from the auto-electricity producers in South Africa fluctuated significantly from year to year, showing a decrease in 2001, 2004, 2005 and 2008 with an increase in the other years.

In 2003 the emissions increased by 59.9%, and this may have been due to the economic growth in that period which increased the demand for electricity. During 2008 there was a global economic crisis and this could have been the main cause of the 16.9% decline in GHG emissions during this year.

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

	Consumption	CO_2	CH_4	N_2O	Total GHG
	(TJ)	(Gg)	(Gg CO_2 eq)	(Gg CO_2 eq)	**(Gg CO_2 eq)**
2000	116 046	11 169	2.67	52	11 224
2001	47 346	4 557	1.09	21	4 579
2002	51 311	4 939	1.18	23	4 963
2003	82 036	7 896	1.89	36	7 934
2004	64 333	6 192	1.48	29	6 222
2005	28 029	2 698	0.64	12	2 711
2006	39 627	3 814	0.91	18	3 833
2007	48233	4 642	1.11	21	4 665
2008	40 066	3 856	0.92	18	3 875
2009	44 149	4 294	1.02	20	4 270
2010	44 171	4 251	1.02	20	4 272

3.3.3.2.2 Petroleum Refining [1A1b]

The total cumulative consumption of fuels for Petroleum refining was estimated at 475 081 TJ, with refinery gas contributing 76.6% in 2010. The total GHG emissions from Petroleum refining was estimated at 3 848 Gg CO_2eq in 2000 and 2 284 Gg CO_2 eq in 2010 (Table 3.6). There was an increase of 41.5% in 2001, but this then decreased by 57.3% in 2002 after which emissions fluctuated until 2010. In 2000 refinery gas contributed 50.7% to the total GHG emissions in this category and this has increased to 85.4% in 2010. Emissions from residual fuel oil decreased from contributing 41.5% in 2000 to only 3.4% 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	CO_2	CH_4	N_2O	Total GHG
Period	(TJ)	Gg	(Gg CO_2 eq)	(Gg CO_2 eq)	(Gg CO_2 eq)
2000	57 477	3 841	2.41	5.20	3 848
2001	78 089	5 432	3.83	8.86	5 445
2002	37 992	2 320	1.07	1.74	2 323
2003	38 641	2 380	1.11	1.86	2 383
2004	38 336	2 353	1.09	1.80	2 356
2005	37 629	2 298	1.04	1.68	2 301
2006	36 550	2 192	0.97	1.48	2 194
2007	37 568	2 294	1.04	1.66	2 297
2008	37 753	2 312	1.05	1.7	2 314
2009	37 594	2 296	1.04	1.67	2 298
2010	37 457	2 281	1.03	1.64	2 284

3.3.3.2.3 Manufacture of Solid Fuels and Other Energy Industries [1A1c]

The total GHG emissions from the Manufacture of solid fuels and other energy industries was 29 885 Gg CO_2 eq in 2000, and that declined by 4.3% over the next 10 years to 28 611 Gg CO_2 eq in 2010 as shown in Table 3.7. Emissions remained fairly constant over the period 2000 to 2010, with annual changes varying between -7.4% to 4.6%. The CO_2 emissions contributed 99.6% 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	CH_4	N_2O	Total GHG
Period	**(Gg)**	**(Gg CO_2 eq)**	**(Gg CO_2 eq)**	**(Gg CO_2 eq)**
2000	29 768	11.6	105	29 885
2001	30 373	11.8	107	30 492
2002	30 550	11.7	106	30 668
2003	31 436	12.4	112	31 561
2004	30650	11.8	107	30 769
2005	28 377	11.1	102	28 490
2006	28 309	10.9	100	28 420
2007	29 623	11.6	106	29 741
2008	28 827	11.3	104	28 943
2009	29 011	11.4	105	29 127
2010	28 495	10.9	105	28 610

3.3.3.3 Methodological issues

3.3.3.3.1 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.

3.3.3.3.2 Petroleum Refining [1A1b]

GHG emissions from petroleum refining were estimated based on a Tier 1 approach and IPCC default emission factors.

3.3.3.3.3 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.

3.3.3.4 Data sources

3.3.3.4.1 Main activity Electricity and Heat Production [1A1a]

Data on fuel consumption for public electricity generation was obtained directly from the national power utility for the period 2000 to 2010. Activity data for the auto electricity producers for the period of 2000 to 2006 was sourced from the DoE Energy Digest and for the period of 2007 to 2010 the data was extrapolated using the. South African

Minerals Industry (SAMI) annual publications on total coal consumption. To convert fuel quantities into energy units for the public electricity generation the net calorific values estimated by the national utility annually were applied. A country-specific average Net Calorific Value of 0.0192 TJ/ tonne was used to convert fuel quantities into energy units and this was sourced from Eskom annual report for 2010 (Eskom, 2010) for auto electricity producers.

A Tier 2 approach with country specific 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, a Tier 1 with default 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.

Table 3.8: Sector 1 Energy: Emission factors for GHG emissions (Source: 2006 IPCC Guidelines, Vol 2 and Zhou et al., 2009).

Type of Fuel	Emission factor (kg TJ^{-1})		
	CO_2	CH_4	N_20
Sub-Bituminous Coal	96 250	1	1.5
Other Kerosene	71 500	3	0.6
Gas/ Diesel Oil	74 100	3	0.6

3.3.3.4.2 Petroleum Refining [1A1b]

The activity data for petroleum refining was sourced directly from petroleum refineries. The IPCC methods for filling data gaps were used to complete activity data time series. IPCC 2006 default EF's (IPCC, 2006) were used (Table 3.9).

3.3.3.4.3 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. GHG emissions from charcoal production were not estimated in this category due to a lack of data on fuel use in charcoal production plants, therefore it was assumed that the consumption was included under *manufacturing and industries* (1A2).

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)		
	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

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

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). An independent reviewer was appointed to assess the quality of the inventory, determine the conformity of the procedures which were followed for the compilation of this inventory and to identify areas of improvements.

3.3.3.7 Source-specific recalculations

In the previous 2000 GHG inventory, the activity data was sourced mainly from publicly available publications, such the national energy balances and SAPIA. For this inventory report improvements were made through the collection of data directly from the national utility and the petroleum refineries. As for the collection of more accurate activity data the year 2000 for all sources within the Energy Industries sector had to be recalculated. 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

3.3.3.8.1 Main activity Electricity and Heat Production [1A1a]

The electricity generation sector is a key category, and its estimate has a significant influence on the country's total inventory of GHGs. Therefore increasing the accuracy of GHG calculation by applying country-specific emission factors for this sector will improve the estimation of national GHG inventory. Another improvement for this category will be to formalise the data collection process to ensure continuous collection of data and time series consistency. Further 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.

3.3.3.8.2 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 such as net caloric and carbon content values and also develop country specific emission factors that can be used for the calculation of GHG emissions in this category.

3.3.3.8.3 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 *manufacturing industries and construction* subsector 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.) categories. The largest category 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 410 205 Gg CO_2 eq. The emissions were estimated at 32 653 Gg CO_2eq in 2000 and this increased by 25.9% to 41 117 Gg CO_2eq in 2010 (Figure 3.6). Solid fuels contributed 86.0% to the total in 2010, while liquid and gaseous fuels contributed 4.6% and 9.3% respectively. There has been a 2.5% increase in the contribution from gaseous fuels, 1% increase from liquid fuels and a 3.5% decline in the contribution from solid fuels over the 10 year period.

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.

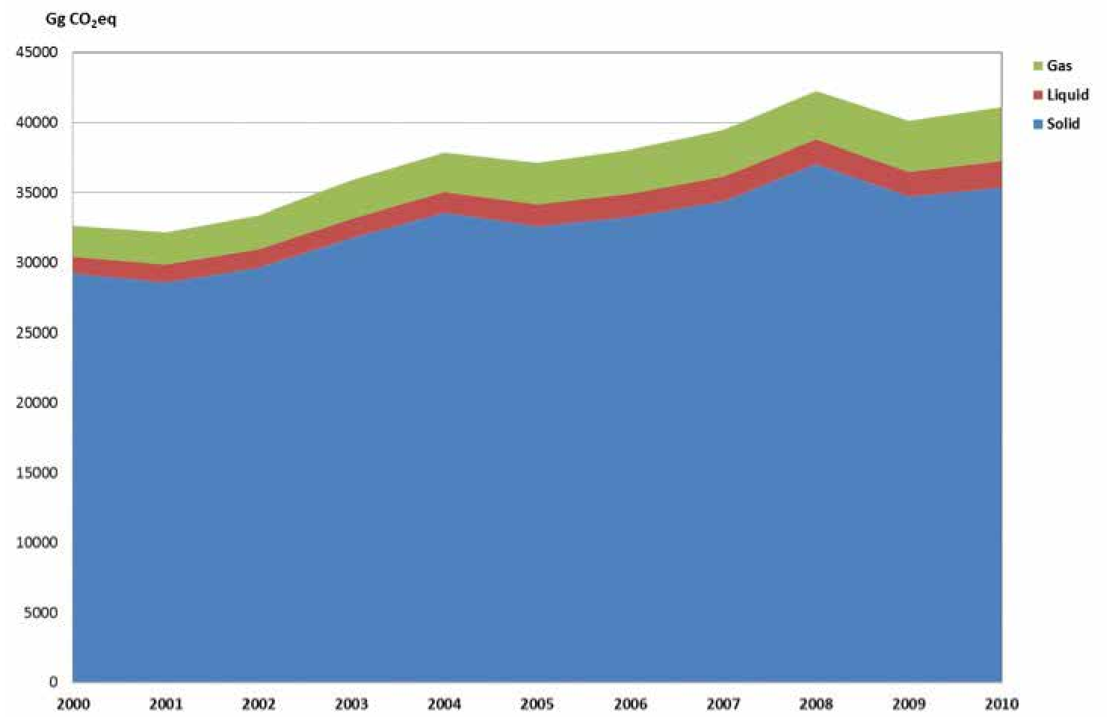

Figure 3.6: Sector 1 Energy: Trend in sources of total GHG emissions from fuel used in manufacturing industries and construction category (1A2), 2000 - 2010.

3.3.4.3 Methodological issues

GHG emissions included in this subsector 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.

3.3.4.4 Data sources

Data in the *manufacturing and construction* sector were sourced from the Energy digest from the DoE for solid fuels for the period 2000-2007, for the remaining period of 2007-2010 for solid fuels the SAMI report was used to extrapolate the fuel consumption. The activity data on liquid fuels for this category was sourced from SAPIA. Data from industries were also acquired and used to compare the figures in the energy digest and SAMI. 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 was used to convert fuel quantities into energy units (DoE, 2009a). To avoid double counting of fuel activity data fuel consumption associated with petroleum refining (1A1b) was subtracted from fuel consumption activity data sourced for 1A2.

3.3.4.4.1 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.

Table 3.10: Sector 1 Energy: Fuel consumption (TJ) in the manufacturing industries and construction category, 2000 – 2010.

Period	Other Kerosene (TJ)	Gas/Diesel Oil (TJ)	Residual Fuel Oil (TJ)	LPG (TJ)	Bitumen (TJ)	Sub-Bituminous Coal (TJ)	Natural Gas (TJ)	Total **(TJ)**
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	353 466
2002	606	10 410	187	113	6 161	306 401	43 048	366 926
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	421 620
2007	567	14 870	164	122	7 707	355 304	58 908	437 642
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	446 891
2010	469	16 129	219	111	8 044	365 687	68 406	459 065

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)		
	CO_2	CH_4	N_2O
Sub-Bituminous Coal	96 250	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

3.3.4.5 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.

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. An independent reviewer was appointed to assess the quality of the inventory, determine the conformity of the procedures which were followed for the compilation of this inventory and to identify areas of improvements.

3.3.4.7 Source-specific recalculations

In the previous 2000 GHG inventory, the activity data for this category was sourced from the Energy Balances which are published by the Department of Energy. For this inventory a combination of the Energy digest and SAMI were used as a source of activity data for solid fuels, and the SAPIA was used for the source of activity data from liquid fuels. The combination of a variety of publicly available information has improved the accuracy of the activity data for this category.

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 the activity data.

3.3.5 Transport [IA3]

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 Main activity electricity producer category and not under the transport category. 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

3.3.5.1.1 Civil Aviation [IA3a]

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) [IA3ai]

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*.

3.3.5.1.2 Road transport [IA3b]

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 (91.2% 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).

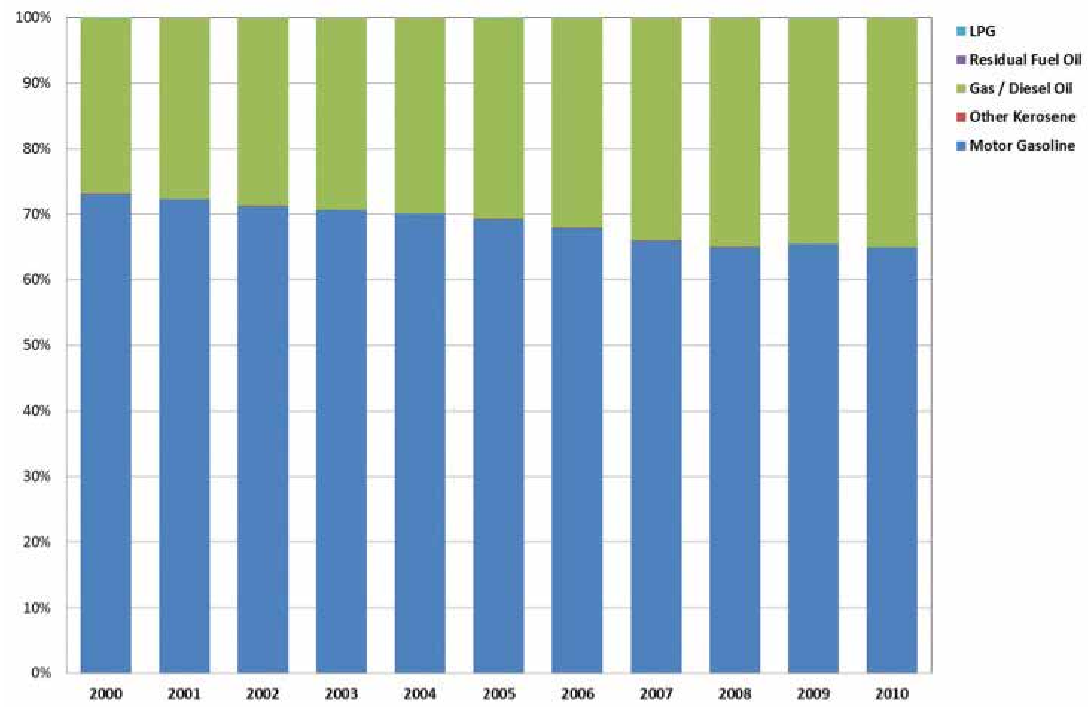

Figure 3.7: Sector 1 Energy: Percentage contribution of the various fuel types to fuel consumption in the road transport category (1A3b), 2000 – 2010.

3.3.5.1.3 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 generates emissions. South Africa's railway sector uses electricity as its main source of energy, with diesel being the only other energy source (DME, 2002).

3.3.5.1.4 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) [1A3di]

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 453 924 Gg CO_2 eq. GHG emissions from transport activities have increased by 32.2% from 36 016 Gg CO_2 eq in the year 2000 to 47 607 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 (2.1% in 2010) (Figure 3.9).

Road transport contributed 91.2% towards the total transport GHG emissions in 2010 (43 440 Gg CO_2 eq), while 7.7% was from domestic civil aviation and 1.07% 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 2.7% 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%.

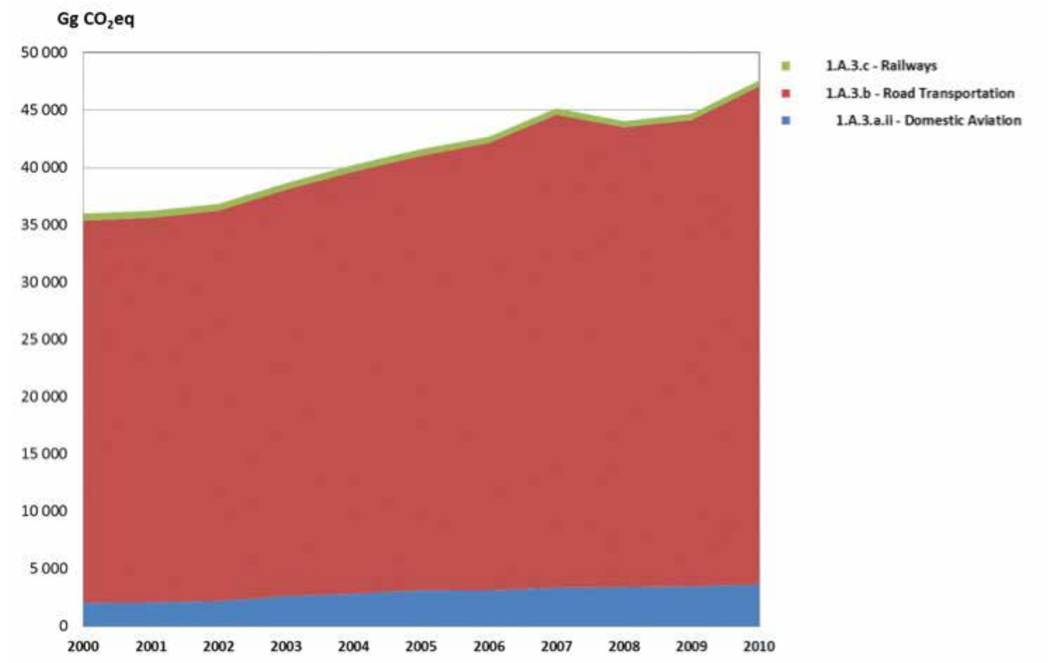

Figure 3.8: Sector 1 Energy: Trend in total GHG emissions from the transport sector, 2000 – 2010.

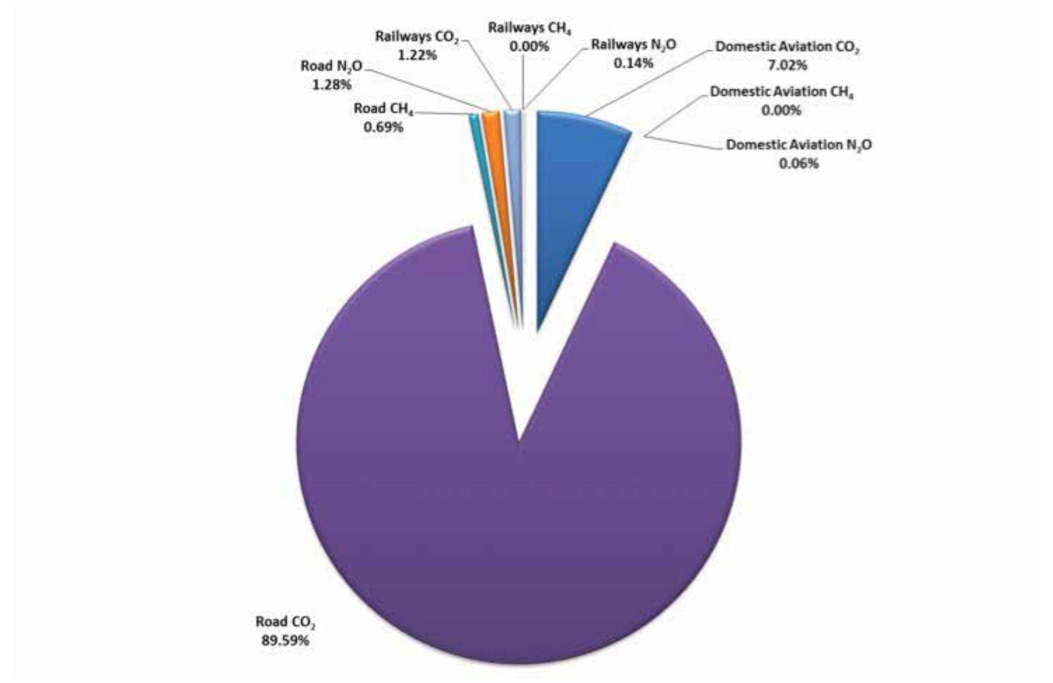

Figure 3.9: Sector 1 Energy: Percentage contribution of CO_2, CH_4 and N_2O from the transport sector, 2000 – 2010.

3.3.5.2.1 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 (Statistics 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 36 016 Gg CO_2eq in the year 2000 to 45 180 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. This could explain the decline in emissions in 2008. 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 (4.9%). 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 2.5%, 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) [1A3ai]

It was estimated that for the period 2000 to 2010 the total cumulative GHG emissions from international aviation activities were 28 163 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 1.9% increase in 2007.

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

	CO_2	CH_4	N_2O	Total GHG
Period	(Gg)	**(Gg CO_2 eq)**	**(Gg CO_2 eq)**	**(Gg CO_2 eq)**
2000	2 972	2.87	7.38	2 983
2001	2 708	2.61	6.73	2 718
2002	2 687	2.59	6.67	2 696
2003	2 584	2.49	6.42	2 593
2004	2 316	2.24	5.75	2 324
2005	2 267	2.19	5.63	2 275
2006	2 510	2.42	6.23	2 518
2007	2 557	2.47	6.35	2 566
2008	2 478	2.39	6.16	2 487
2009	2 423	2.34	6.02	2 431
2010	2 564	2.47	6.37	2 573

3.3.5.3 Methodological issues

Net Calorific Values which were applied in the transport sector to convert fuel quantities into energy units were sourced from DoE (Table 3.13).

Table 3.13: Net Calorific Values for the transport Sector (Source: DoE 2009a)

Type of Fuel	Net Caloric Value (TJ/L)
Motor Gasoline	0.0000342
Gas/ Diesel Oil	0.0000381
Residual Fuel Oil	0.0000416
Aviation Gasoline	0.0000343
Bitumen	0.0000402
LPG	0.0000267

3.3.5.3.1 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 calculation of aviation emissions as operational data was not available. The Tier 1 approach makes use of consumption of fuel and fuel emission factors.

3.3.5.3.2 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 African 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.

3.3.5.3.3 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.

3.3.5.4 Data sources

3.3.5.4.1 Civil Aviation [1A3a]

Activity data on fuel consumption was sourced from the South African Petroleum Industry Association's (SAPIA) annual reports (Table 3.14).

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.

International Aviation (International Bunkers) [1A3ai]

The energy balance by the DoE was the main source of data for the amount of fuel consumed (Table 3.15). That did not indicate whether aviation fuel consumption figures included military aviation activities (which might have been excluded for security reasons).

Table 3.14: 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
Period	(TJ)	(TJ)	(TJ)	(TJ)	(TJ)	(TJ)	(TJ)	(TJ)
2000	835	27 714	337 766	316	123 904	113	54	7 442
2001	880	28 113	335 947	289	128 540	114	0	7 307
2002	843	29 888	335 784	274	135 336	109	0	7 123
2003	764	35 854	346 571	283	143 895	108	0	6 749
2004	760	38 803	356 889	294	152 129	116	0	7 043
2005	802	43 070	362 751	280	160 774	100	54	7 009
2006	745	42 727	366 455	272	172 523	97	0	6 467
2007	758	46 286	375 519	257	193 306	96	0	6 672
2008	752	46 840	359 632	196	193 405	96	0	6 317
2009	746	47 613	367 559	201	193 405	121	0	6 504
2010	790	50 383	388 942	201	209 678	128	0	6 006

3.3.5.4.2 Road transport [1A3b]

SAPIA annual reports were the main sources of activity data for the transport sector (Table 3.14). 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 3.15: Sector 1 Energy: Fuel consumption (TJ) in the international aviation category, 2000 – 2010.

Period	Jet Kerosene (TJ)
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

3.3.5.4.3 Railways [1A3c]

The national railway operator Transnet provided activity data on diesel fuel consumption for the national railway fleet. The SAPIA report on the impact of liquid fuels on air pollution was used to disaggregate actual diesel consumption for railway transport sector (Table 3.14). An assumption was made that the split of diesel consumption for railway activities was constant for the whole time series (2000-2010) 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.

3.3.5.4.4 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* subsector. 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.

3.3.5.4.5 Emission Factors

IPCC 2006 default emission factors were used in the estimation of GHG emissions from the transport sector (Table 3.16). The GHG emission factors are applicable to all activities within this sector since similar fuels are combusted.

Table 3.16: Sector 1 Energy: Emission factors used for the transport sector emission calculations (Source: 2006 IPCC Guidelines).

Type of Fuel	Emission factor		
	CO_2 (kg/TJ)	CH_4 (kg/TJ)	N_20 (kg/TJ)
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

3.3.5.5.1 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).

3.3.5.5.2 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) 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.

3.3.5.5.3 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.

3.3.5.5.4 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

In the previous 2000 GHG inventory, the activity data for this category was sourced from the Energy Balances which are published by the Department of Energy. For this inventory the energy balances published by the DoE were used as a source of activity data. The SAPIA report on the Impact of liquid fuels on air pollution was used to disaggregate fuel consumption into the various users. This 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

3.3.5.8.1 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).

3.3.5.8.2 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.

3.3.5.8.3 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.

3.3.5.8.4 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

3.3.6.1.1 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 most to the fuel consumption in this sector (75.5% in 2010) followed by solid fuels (24.3% in 2010).

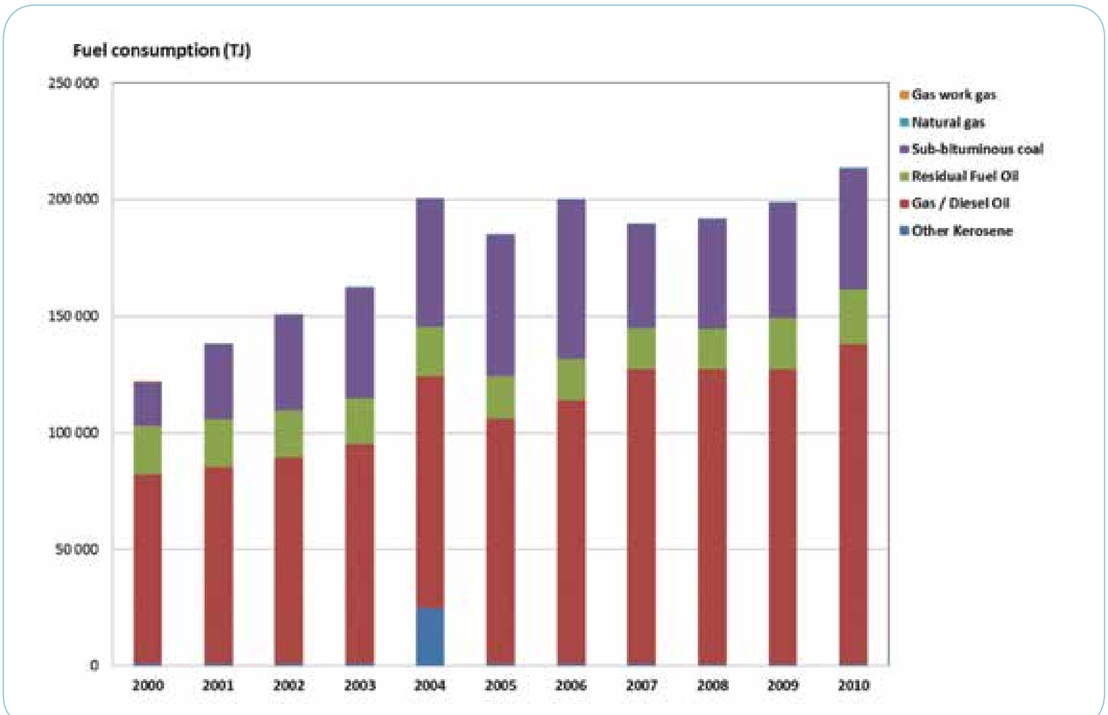

Figure 3.10: Sector 1 Energy: Fuel consumption in the commercial/institutional category, 2000 – 2010.

3.3.6.1.2 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 was no data reported for other primary solid biomass (Figure 3.11) therefore the biomass fuel source declined to 35.0% in 2010.

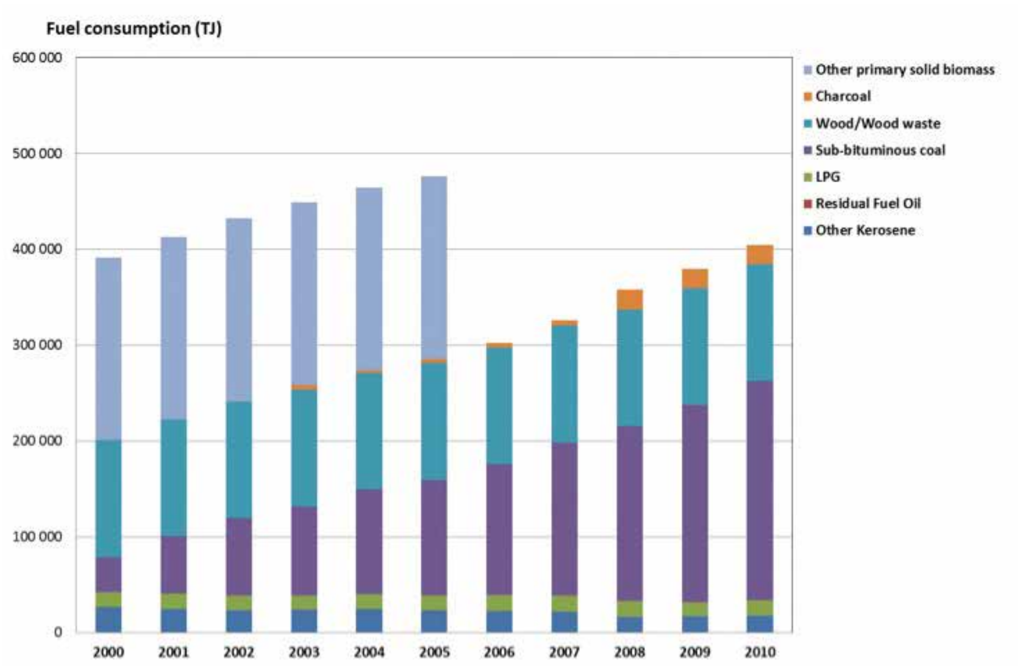

Figure 3.11: Sector 1 Energy: Trend in fuel consumption in the residential category, 2000 – 2010.

3.3.6.1.3 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 (DoE, 2009) sub-bituminous coal was only used in 2000.

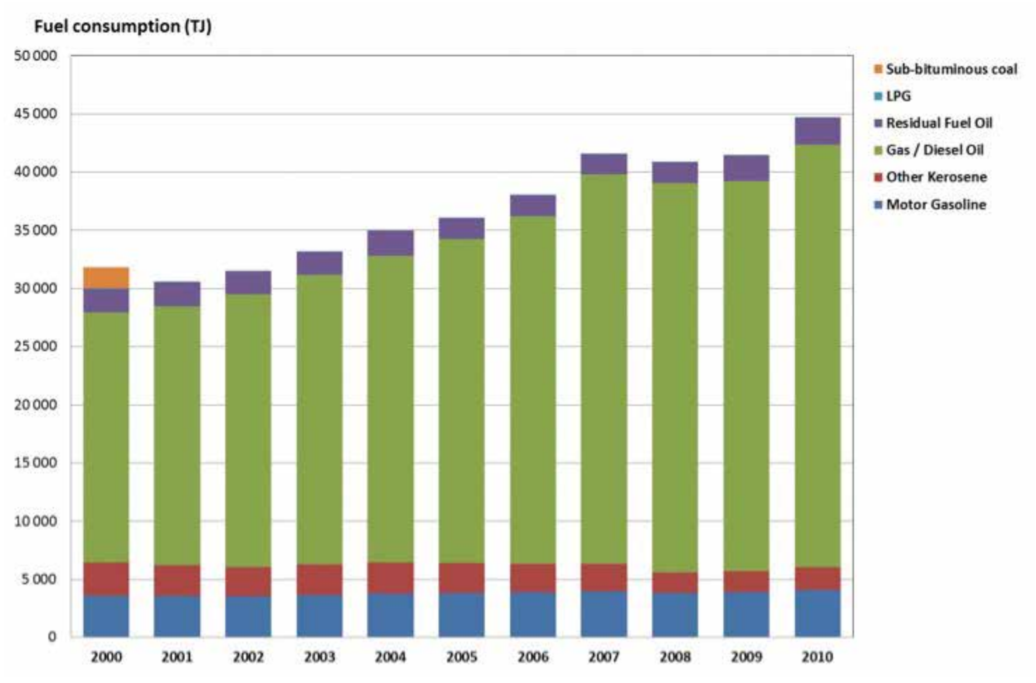

Figure 3.12: Sector 1 Energy: Trend in fuel consumption in the agriculture/forestry/fishing category, 2000 – 2010.

3.3.6.2 Overview of shares and trends in emissions

3.3.6.2.1 Commercial/ Institutional [1A4a]

The estimation of total cumulative GHG emissions in the commercial/institution category for the period 2000 to 2010 was 157 662 Gg CO_2 eq. Emissions increased by 79.3% over the 10 year period from 9 557 Gg CO_2 eq in 2000 to 17 137 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 15.6% 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. The increase in 2004 (22.6%) 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 decreases by 8.1%, and this was mainly because of the electricity crisis in that year, which decreased the consumption of coal for heating purposes. As the country recovered from the recession the GHG emissions increased by 3.8% in 2009.

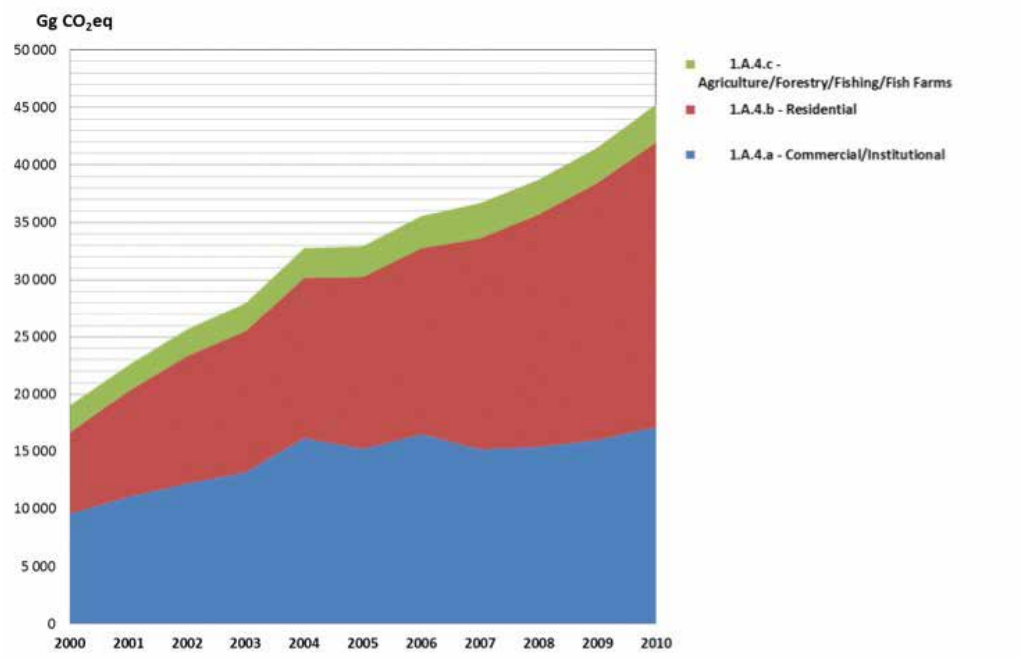

Figure 3.13: Sector 1 Energy: Trend in total GHG emissions from other sectors, 2000 – 2010.

3.3.6.2.2 Residential [1A4b]

The estimation of total GHG emissions in the residential category for the period 2000 to 2010 was 170 963 Gg CO_2eq. Emissions in the residential sector have increased more than 3 fold from 7 100 Gg CO_2eq in 2000 to 24 817 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 250% 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.

3.3.6.2.3 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 2 388 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 1.3%. That was mainly because of the global economic crisis that affected South Africa in 2008/09.

3.3.6.3 Methodological issues

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 3.17).

3.3.6.4 Data sources

3.3.6.4.1 Commercial/ Institutional [1A4a]

Data on fuel consumption in the commercial/institutional buildings was sourced from the DoE energy digest reports, DMR South African Mineral Report (solid fuels and natural gas) and SAPIA (liquid fuels). The DoE energy reports were used to source solid fuels for the period 2000 to 2006, for remaining period (20007-2010) the SAMI report was used to extrapolate the consumption of solid fuels for this category. A Net Calorific Value of 0.0243 TJ/tonne was used to convert fuel quantities into energy units (DoE, 2009a).

3.3.6.4.2 Residential [1A4b]

Data on fuel consumption in the residential sector was obtained from DoE energy digest reports, DMR South African Mineral Industry, Food and agriculture organization and SAPIA. The DoE energy reports were used to source solid fuels for the period 2000 to 2006, for remaining period (20007-2010) the SAMI report was used to extrapolate the consumption of solid fuels for this category. A Net Calorific Value of 0.0243 TJ/tonne was used to convert fuel quantities into energy units (DoE, 2009a).

3.3.6.4.3 Agriculture/ Forestry/ Fishing/ Fish Farms [1A4c]

Data on fuel consumption in the agriculture, forestry, fishing and fish farms was obtained from the Energy digest 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.

3.3.6.4.4 Emission factors

IPCC 2006 Guideline default emission factors were used to determine emissions from all other sectors (Table 3.17).

Table 3.17: Sector 1 Energy: Emission factors used for all other sectors (Source: 2006 IPCC Guidelines).

Type of Fuel	Emission factor (kg/TJ)		
	CO_2	CH_4	N_2O
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	96 250	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

An independent reviewer was appointed to assess the quality of the inventory, determine the conformity of the procedures which were followed for the compilation of this inventory and to identify areas of improvements.

3.3.6.7 Source-specific recalculations

In the previous 2000 GHG inventory, the activity data for this category was sourced from the Energy Balances which are published by the Department of Energy. For this inventory a combination of sources of activity data were used, this includes the energy digest from DoE, SAMI report from DMR, SAPIA and the Food and Agriculture Organization. The inclusion of various sources of data has improved the accuracy of the GHG inventory which led to a recalculation of emissions for these categories. The results for the published 2000 GHG inventory had to be recalculated as a result of availability of more robust activity data.

3.3.6.8 Source-specific planned improvements and recommendations

3.3.6.8.1 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.

3.3.6.8.2 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.

3.3.6.8.3 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.

3.3 7.1.1 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 3.18). There was a slight decline of 0.71% between 2000 and 2002 and a 4.2% decline in 2008.

Table 3.18: Sector 1 Energy: Trend in consumption and GHG emissions from the non-Specified sector, 2000 – 2010.

	Consumption	CO_2	CH_4	N_2O	Total GHG
Period	(TJ)	Gg	(Gg CO_2 eq)	(Gg CO_2 eq)	(Gg CO_2 eq)
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 Methodological issues

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.

3.3.7.4 Data sources

Data on fuel consumption in the non- specified category was sourced from the energy digest reports (solid fuels and natural gas), SAMI report to extrapolate activity data for solid fuels for the period 2007-2010 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 (DoE, 2009a).

3.3.7.4.1 Emission factors

IPCC default emission factors from the 2006 IPCC guidelines were used in the estimation of GHG emissions from non-specified sector (Table 3.19).

Table 3.19: Sector 1 Energy: Emission factors for calculating emissions from the Non-Specified sector (Source: 2006 IPCC Guidelines).

Type of Fuel	Emission factor (kg/TJ)		
	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

An independent reviewer was appointed to assess the quality of the inventory, determine the conformity of the procedures which were followed for the compilation of this inventory and to identify areas of improvements.

3.3.7.7 Source-specific recalculations

In the previous GHG 2000 GHG inventory, the non-specified category was excluded from the estimations. For this inventory the energy digest and SAPIA was used to source data for this category to ensure completeness by including all categories as recommended by the IPCC guidelines. 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

3.4.1.1.1 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

3.4.1.2.1 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 2 003 Gg CO_2eq in 2000 to 2 266 Gg CO_2eq in 2010 (Table 3.20). 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 3.20: Sector 1 Energy: Fugitive emissions from coal mining for the period 2000 to 2010.

	CO_2	CH_4	Total GHG
Period	Gg	(Gg CO_2 eq)	(Gg CO_2 eq)
2000	24	1 979	2 003
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 Methodological issues

3.4.1.3.1 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.

3.4.1.4 Data sources

3.4.1.4.1 1B1a Coal Mining and Handling [1B1a]

Data on coal production (Table 3. 21) was obtained from the South Africa's Mineral Industry (SAMI), a report compiled by the Department of Mineral Resources (SAMI, 2009) and Coaltech.

3.4.1.4.2 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 3.22).

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: 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

Table 3.22: 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

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

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. An independent reviewer was appointed to assess the quality of the inventory, determine the conformity of the procedures which were followed for the compilation of this inventory and to identify areas of improvements.

3.4.1.7 Source-specific recalculations

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

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 4 065 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 3.23).

Table 3.23: Sector 1 Energy: Total GHG emissions from venting and flaring for the period 2000 – 2010.

Period	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Gg CO_2eq	325	250	196	1 065	254	266	291	325	237	237	619

3.4.2.3 Methodological issues

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.

3.4.2.4 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 from the Energy Digest reports (DoE, 2009a).

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

An independent reviewer was appointed to assess the quality of the inventory, determine the conformity of the procedures which were followed for the compilation of this inventory and to identify areas of improvements.

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 269 995 Gg CO_2eq for the period 2000 to 2010. Emissions fluctuated up and down throughout the 10 year period (Table 3.24).

Table 3.24: Sector 1 Energy: Total GHG emissions from the category other emissions from energy production (1B3), 2000 – 2010.

Period	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Gg CO_2eq	26 694	26 266	26 707	25 305	26 932	23 403	23 302	23 485	22 440	22796	22 666

3.4.3.3 Methodological issues

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* have been estimated using real continuous monitoring results and material balances.

3.4.3.4 Data sources

Data on other emissions from energy production were obtained from both Sasol and PetroSA.

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 ad-hoc manner wherein the department reviews the material balance and measurement data supplied by facilities. An independent reviewer was appointed to assess the quality of the inventory, determine the conformity of the procedures which were followed for the compilation of this inventory and to identify areas of improvements.

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 can. 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. FOLU), whereas in 1994 and 2000 it contributed 8.0% and 6.5%, respectively. When analysing the recalculated IPPU sector emissions for the year 2000, there has been an increase of 4.6% when compared to 1990. Between 2000 and 2010 there was a 1.2% decrease in overall emissions from the IPPU sector, although there were increases during this period.

The GHG emissions in the IPPU sector fluctuated during the ten year reporting period (Figure 4.1). IPPU sector emissions increased annually by an average of 2.3% between 2000 and 2006 due to robust economic growth during this time. This led to an increased demand in products. Between 2006 and 2009 there was a decline of 17.9% (from 51 538 Gg CO_2eq to 42 833 Gg CO_2eq) in the IPPU emissions. 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. In 2010 emissions increased again by 3.5%. The economy was beginning 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.

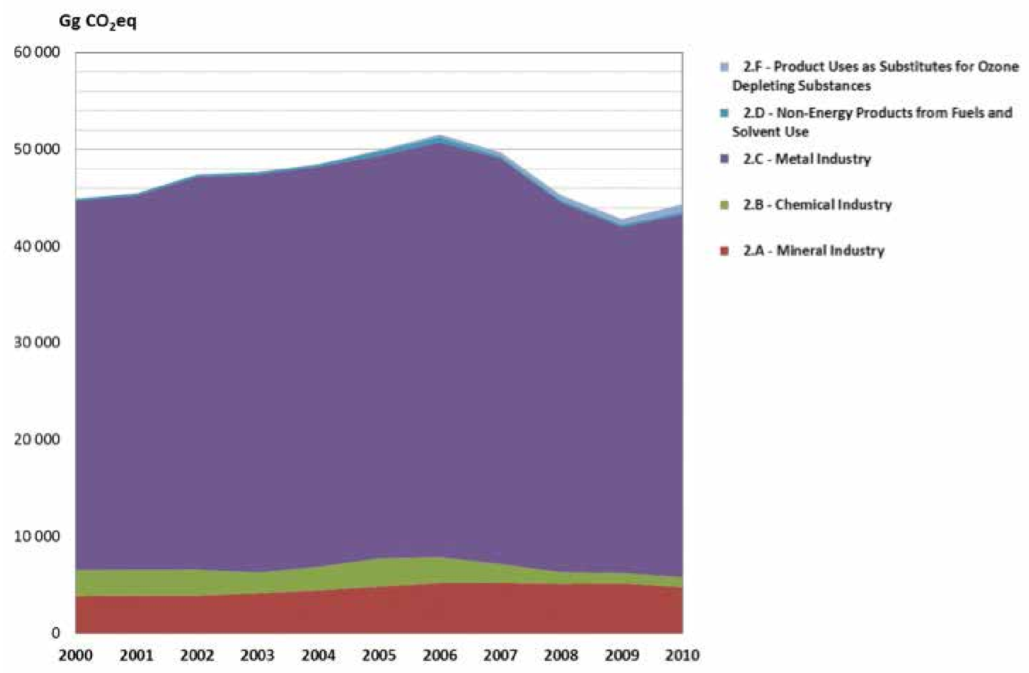

Figure 4.1: Sector 2 IPPU: Trend and emission levels of source categories, 2000 –2010.

The most significant source of emissions in the IPPU sector was the *metal industries*, which contributed between 83.2% and 86.3% over the period 2000 to 2010. The biggest contributor in 2010 to the *metal industry* emissions was the iron and steel industry (64.4%). CO_2 emissions constitute between 93.5% and 97.1% of the total IPPU emissions between 2000 and 2010, while HFCs and PFCs contribute an average of 0.5% and 1.6% respectively (Figure 4.2).

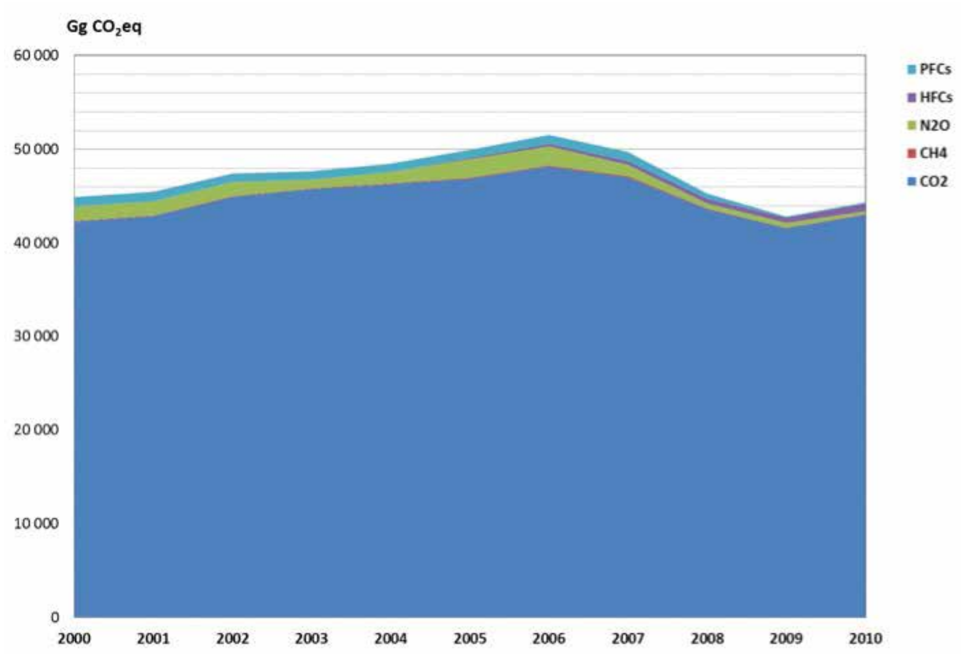

Figure 4.2: Sector 2 IPPU: Trends and emission levels of the various greenhouse gases, 2000 – 2010.

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 were *ferroalloys production* and *cement production* (see Table 1.3 and Table 1.5). These are key categories throughout the 10 year period. In the trend assessment (2000 – 2010) *iron and steel production* was one of the top five categories. *Cement production* was not shown to be a key category in the trend assessment; however this assessment showed thee additional key categories in the IPPU sector, namely *ferroalloy production, nitric acid production* and *aluminium 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 Glyoxylic 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	Not Estimated (NE): Emissions and/or removals occur but have not been estimated or reported.
	2E2 TFT flat panel display	
	2E3 Photovoltaics	
	2E4 Heat transfer fluid	
2G Other Product Manufacture and Use	2G1 Electrical equipment 2G2 SF6 and PFCs from other product uses 2G3 N2O from product uses	Not Estimated (NE): Emissions and/or removals occur but have not been estimated or reported.
2H Other	2H1 Pulp and Paper Industry	Not Estimated (NE): Emissions and/or removals occur but have not been estimated or reported.
	2H2 Food and Beverages industry	

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 emissions are reported for three sub-categories: 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 (DMR, 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 $CaMg(CO_3)_2$ 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 50 547 Gg CO_2eq. Emissions increased by 35% between 2000 and 2006 to 5 193 Gg CO_2 eq, after which emissions slowly declined (by 8.1%) until 2010 (Figure 4.3). Over the 10 year period the emissions from the Mineral Industries increased by 24.6%. The most significant GHG emission sources in 2010 were cement production (contributing 87.4% of total GHG emissions), followed by lime production (10.5%). GHG emissions from glass production accounted for only 2.2% 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 4 187 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 2.4% decrease in emissions and an 8.0% 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 (DMR, 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 (Association of Cement and Concrete Institute, 2008). In 2009 GHG emissions from cement production increased by 1.7% as a result of the preparation of the 2010 World Cup which increased a demand in infrastructure.

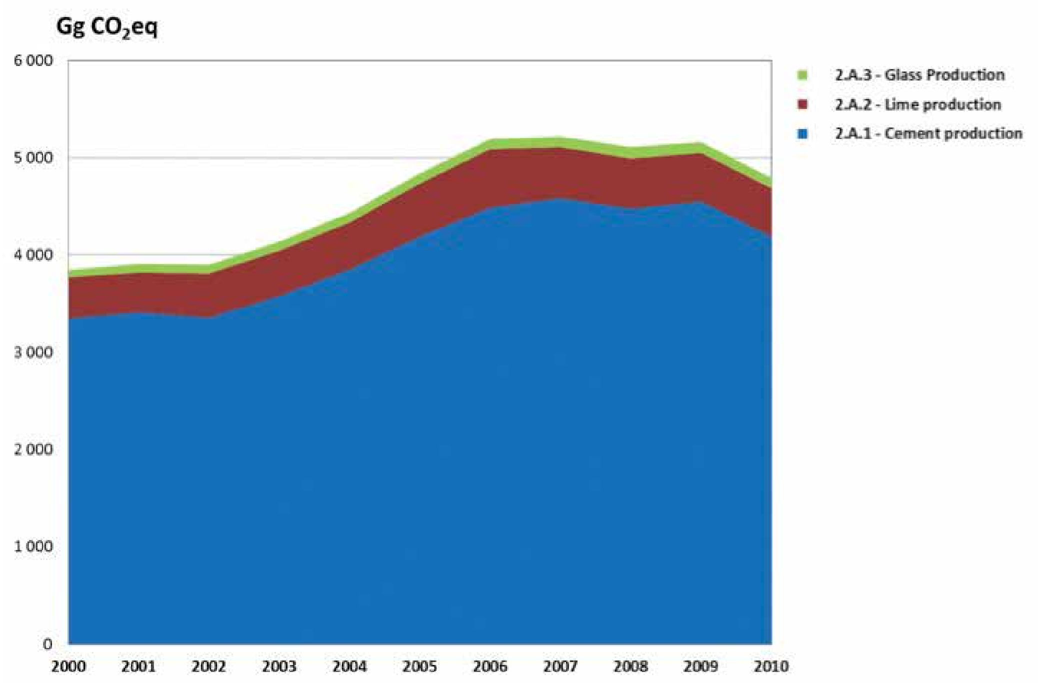

Figure 4.3: Sector 2 IPPU: Trend and emission levels in the Mineral Industries, 2000 – 2010.

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 5 470 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 3.4%. Overall the GHG emissions from this category have increased by 17.8% 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 Methodological issues

4.2.3.1 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 country specific emission factors. A Tier 1 approach was used to estimate emissions.

4.2.3.2 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.

4.2.3.3 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.

4.2.4 Data sources

4.2.4.1 Cement production [2A1]

Data on cement production in South Africa was obtained from the cement production industry (Table 4.2). According to the Association of Cementitious Material Producers (2008), 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 crisis, 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	Hydrated lime	Total Glass Produced	Recycled Glass
Period	Tonnes	Tonnes	Tonnes	Tonnes	Tonnes
2000	6 436 640	532 100	46 270	561 754	189 958
2001	6 551 695	522 910	45 470	624 156	202 228
2002	6 451 258	572 369	49 771	667 110	225 379
2003	6 879 106	586 969	51 041	702 008	245 360
2004	7 404 575	608 056	52 874	726 644	247 184
2005	8 054 255	685 860	59 640	775 839	264 023
2006	8 627 144	755 302	65 678	808 328	299 475
2007	8 812 852	660 772	57 458	858 382	333 443
2008	8 603 568	648 462	56 388	978 488	391 618
2009	8 749 099	626 465	54 475	993 784	444 947
2010	8 051 414	626 777	54 502	1 009 043	489 621

4.2.4.1.1 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. 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.

Period	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Country specific clinker fraction	0.76	0.75	0.73	0.73	0.73	0.72	0.73	0.71	0.7	0.71	0.69

4.2.4.2 Lime production [2A2]

The DMR publishes data on limestone and dolomite production in South Africa on the South Africa's Mineral Industry publication (DMR, 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' (6.0%) in the breakdown of limestone demand goes to lime production.

4.2.4.2.1 Emission factors

For the calculation of GHG emissions from 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]

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

4.2.4.3.1 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

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. An independent reviewer was appointed to assess the quality of the inventory, determine the conformity of the procedures which were followed for the compilation of this inventory and to identify areas of improvements.

4.2.7 Source-specific recalculations

4.2.7.1 Cement production [2A1]

Recalculations have been performed for year 2000 emission estimates. In the previous inventory national statistics were used as source of activity data. For this inventory activity data from cement and glass production was sourced directly from the industry. 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. As a result the recalculated emissions for the year 2000 improved the accuracy of the estimates.

4.2.7.2 Lime production [2A2]

Emissions for the year 2000 were recalculated using the SAMI report which provides a breakdown on lime production, furthermore the DMR Report (R85/2010) provided a breakdown between quicklime and hydrated lime.

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, titanium dioxide production and carbon black. 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, pg.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, pg. 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 sub-sector contains confidential information, so following the IPCC Guidelines for reporting of confidential information no disaggregate source-category level emission data are reported; only the emissions at the sector scale are discussed. Emission estimates are, however, based on bottom-up activity data and methodologies.

The Chemical Industries contributed a total of 23 299 Gg CO_2eq over the period 2000 to 2010. Emissions from this category fluctuated considerably over the 10 year period, with a maximum of 2 889 Gg CO_2eq in 2005 and a minimum of 1 011 Gg CO_2eq in 2010 (Figure 4.4). Overall there was a 62.6% decline in GHG emissions from this category over the 10 years.

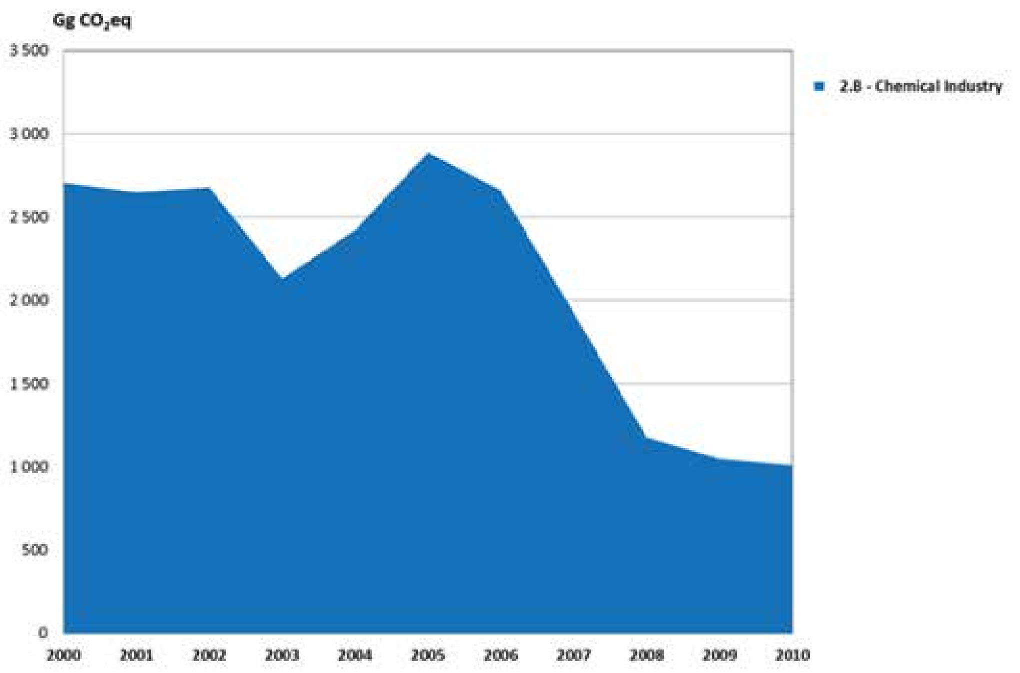

Figure 4.4: Sector 2 IPPU: Trend and emission levels in the chemical industries between 2000 and 2010.

4.3.3 Methodological issues

4.3.3.1 Ammonia production [2B1]

GHG emission estimates from Ammonia production were obtained through the Tier 3 approach, 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.

4.3.3.2 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.

4.3.3.3 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.

4.3.3.4 Titanium Dioxide production [2B6]

The Tier 1 approach was used for calculating GHG emissions from titanium dioxide production, using 2006 IPCC default emission factors.

4.3.3.5 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.

4.3.4 Data sources

4.3.4.1 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.

4.3.4.2 Nitric Acid production [2B2]

The amount of nitric acid emission released was sourced from the nitric acid production plants. 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.

4.3.4.2.1 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.

4.3.4.3 Carbide production [2B5]

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

4.3.4.3.1 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.

4.3.4.4 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.

4.3.4.5 Carbon black [2B8f]

Carbon black activity data was sourced directly from industry.

4.3.4.5.1 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.

4.3.5 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 was performed for the Chemical Industry. However, activity data and material balance data was verified with industry sectors.

4.3.7 Source-specific recalculations

Recalculations have been performed for year 2000 emission estimates. In the previous inventory a research report on Nitric Acid production (Lauriente, 2007) was used as the source of activity data. For this inventory activity data from the chemical industry was sourced directly from the industry, furthermore the data sourced from the industry was based on higher tier methods which are more accurate. As a result the recalculated emissions for the year 2000 improved the accuracy of the estimates.

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 which were applied by the industry be made transparent. 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 438 005 Gg CO_2eq between 2000 and 2010. The major contributor over this period was *iron and steel production* (69.6%), followed by *ferroalloy production* (24.8%) and *aluminium production* (5.1%) (Figure 4.4). In 2000 almost half of the total GHG emissions (in Gg CO_2eq) from *aluminium production* were due to PFC emissions, but this declined to 9.4% in 2010.

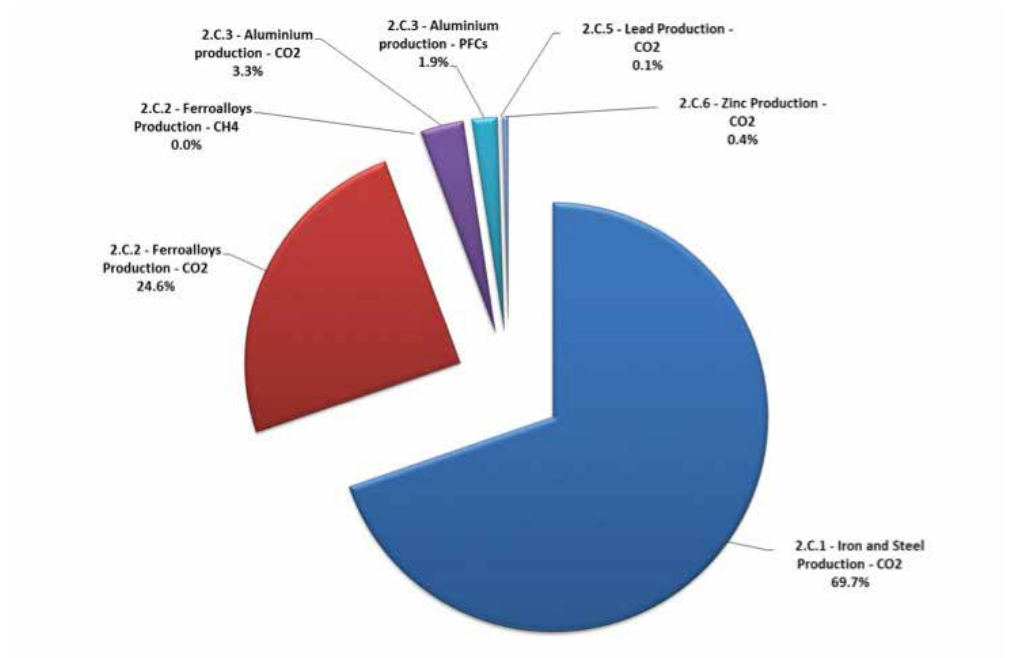

Figure 4.4: Sector 2 IPPU: Percentage contribution from the various industries and gases to the total accumulated GHG emissions from the metal industries between 2000 and 2010.

Total emissions in the *metal industry* increased between 2000 and 2006, with a sharp decline (16.5%) between 2006 and 2009 (Figure 4.5). This decrease was evident in the three major contributing industries, with emissions from Iron and Steel production showing a decline of 24.0% between 2006 and 2009, while the Aluminium Production emissions declined by 42.0% between 2007 and 2009. Ferroalloy Industry emissions increased every year, except in 2008 when they declined by 0.6%. 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 4.7% from 35 818 Gg CO_2eq in 2009 to 37 513 Gg CO_2eq in 2010. Although emissions from Zinc Production were relatively small, their emissions decreased by 60.8% between 2009 and 2010.

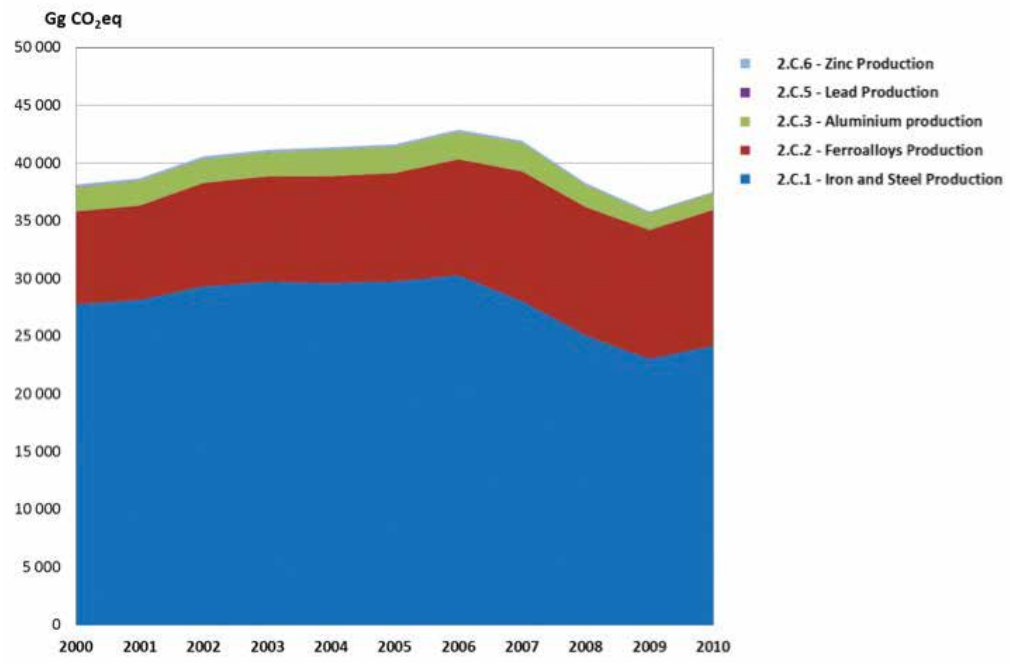

Figure 4.5: Sector 2 IPPU: Trend and emission levels in the metal industry, 2000 – 2010.

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 (DMR, 2005). During 2004/05 zinc production decreased by 6.3% due to the closure of Metorex's Maranda operation in July 2004 (DMR, 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) (DMR, 2009).

Over the 10 year period emissions from iron and steel, aluminium, lead and zinc production declined (13.0%, 29.7%, 32.8%, and 68.1% respectively), while emissions increased by 46.1% from the ferroalloy industry.

4.4.3 Methodology

4.4.3.1 Iron and steel production [2C1]

A combination of Tier 1 and Tier 2 approach (country-specific emission factors) was applied to calculate the GHG emissions from iron and steel for the different process types. Default IPCC emission factors were used for the calculation of GHG emissions from Basic Oxygen Furnace, Electric Arc Furnace and Pig Iron Production and country specific emission factors were used for the estimation of GHG emissions from Direct Reduced Iron Production. The separation between energy and process emissions emanating from the use of coke was not done due to lack of disaggregated information on coke consumption. Hence, energy related emission from iron and steel production have been accounted for through the application of default IPCC emission factors.

4.4.3.2 Ferroalloys production [2C2]

The Tier 1 approach was used to calculate the GHG emissions from ferroalloys production.

4.4.3.3 Aluminium production [2C3]

The Tier 1 approach was used to calculate the GHG emissions from aluminium production. For aluminium production, it was assumed that the activity data is mainly for primary aluminium only, without any re-smelting.

4.4.3.4 Lead production [2C5]

Emissions from Lead production were estimated using a Tier 1 approach. In the calculation of lead production, it was assumed that that lead production was 80% Imperial Smelting Furnace and 20% direct smelting.

4.4.3.5 Zinc production [2C6]

Emissions from Zinc Production were calculated with the Tier 1 approach.

4.4.4 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, 2001).

4.4.4.1 Iron and steel production [2C1]

The South African Iron and Steel Institute provided data for iron and steel production (Table 4.5).

Table 4.5: Sector 2 IPPU: Activity data for the various metal industries, 2000 – 2010.

	Consumption (tons)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Iron and Steel Production	Basic Oxygen Furnace production	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	4 549 828	4 716 954	4 888 870	5 353 456	5 508 488	5 089 818	5 413 204	5 473 908	4 581 523	4 359 556	4 235 993
	Pig Iron Production (not converted into steel)	4 674 511	4 849 655	5 051 936	4 474 699	4 224 487	4 441 904	4 435 551	3 642 520	3 746 786	3 184 566	3 695 327
	Direct Reduced Iron (DRI) Production	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
	Other (Corex etc.)	705 872	706 225	706 578	706 931	733 761	735 378	739 818	705 428	460 746	429 916	584 452
Ferroalloy Production	Chromium Alloys	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)	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)	310 400	259 176	315 802	313 152	373 928	275 324	277 703	327 794	259 014	117 683	260 700
	Silicon Alloys (Assume 65% Si)	108 500	107 600	141 700	135 300	140 600	127 000	148 900	139 600	134 500	110 400	128 760
	Silicon Metal	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	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	113 000	110 000	113 000	113 000	112 000	108 000	101 000	97 000	91 000	92 000	36 100

4.4.4.1.1 Emission factors

A combination of country specific emission factors and IPCC default emission factors were applied for the calculation of GHG emissions from iron and steel. Country-specific emission factors were sourced from one of the Iron and Steel Companies in South Africa (Table 4.6) and these were based on actual process analysis at the respective plants. The country-specific emission factor for Electric Arc Furnace is slightly higher than the IPCC default value; this emission factor was not used for the estimation of GHG emissions from EAF because it still needs to be investigated further. The country specific emission factor for Direct Reduced Iron Production is more than twice the default factor (Table 4.7) and it was used for the estimation of GHG emissions from this process. 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.

Table 4.6: 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 Technology	CO_2 Emission factor (tones CO_2 per tonne iron and steel)	
	Country-specific	IPCC 2006 default
Basic Oxygen Furnace		1.46
Electric Arc Furnace	1.1	0.08
Pig Iron Production (not converted into steel)	-	1.35
Direct Reduced Iron (DRI) Production	1.525	0.7
Sinter Production	0.34	0.2

4.4.4.2 Ferroalloy, Aluminium, Lead and Zinc Production

The source of activity data for these categories was sourced from South Africa's Mineral Industry (Table 4.5). IPCC default emission factors were used (Table 4.7 and Table 4.8). The emission factor of 0.52 tonnes CO_2 per tonne lead and 1.72 tonnes CO_2 per tonne zinc were sourced from the IPCC 2006 Guidelines.

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.

Table 4.7: 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 4.8: 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

4.4.6 Source-specific QA/QC and verification

An independent reviewer was appointed to assess the quality of the inventory, determine the conformity of the procedures which were followed for the compilation of this inventory and to identify areas of improvements.

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 between 2000 and 2004, and between 221 Gg CO_2eq and 234 Gg CO_2eq between 2007 and 2010, with a peak in emission occurring in 2006 (Figure 4.6). Emissions from Lubricant Use contributed over 98% to the total emissions from this category.

4.5.3 Methodological issues

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.

4.5.4 Data sources

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

4.5.4.1 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.

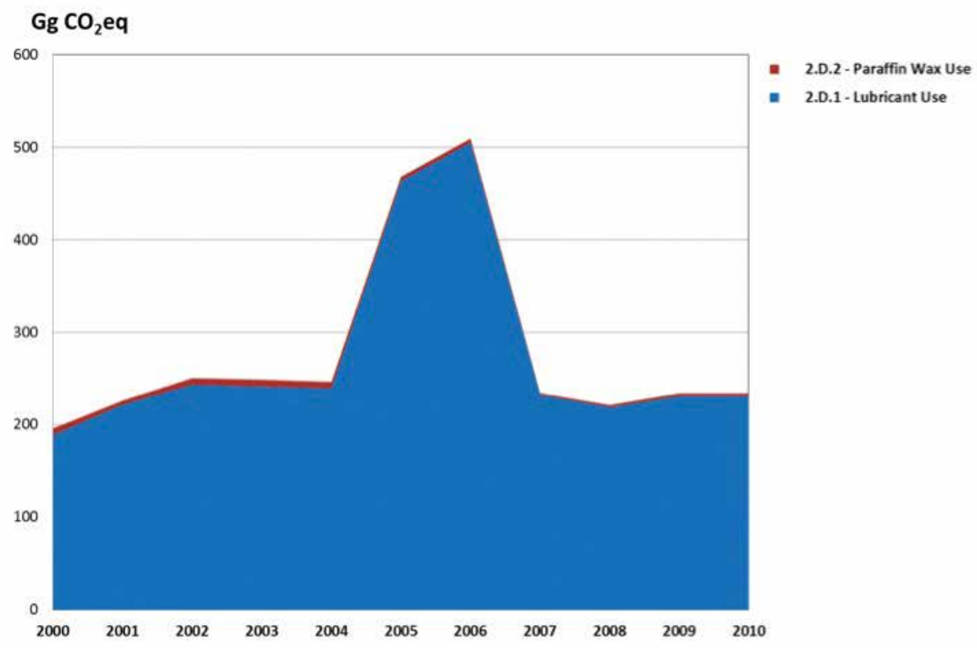

Figure 4.6: Sector 2 IPPU: Trends and emission levels from the non-energy products from fuels and solvent use category, 2000 – 2010.

Table 4.9: Sector 2 IPPU: Total fuel consumption in the Non-energy use of Fuels and Solvent Use category, 2000 – 2010.

Period	Fuel consumption	
	Lubricants (TJ)	Paraffin Wax (TJ)
2000	12 851	507
2001	15 092	314
2002	16 561	506
2003	16 430	521
2004	16 295	490
2005	31 549	350
2006	34 391	324
2007	15 819	141
2008	14 891	182
2009	15 707	231
2010	15 715	231

4.5.5 Uncertainty and time-series consistency

The default Oxidised During Use (ODU) 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 (IPCC, 2006). 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

An independent reviewer was appointed to assess the quality of the inventory, determine the conformity of the procedures which were followed for the compilation of this inventory and to identify areas of improvements.

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 from 126 Gg CO_2eq in 2005 to 780 Gg CO_2eq in 2010 (Figure 4.7). There was no available data for the years prior to 2005. HFC-134a is the biggest contributor (average contribution of 79.1%) and HFC-143a contributing an average of 12.0%.

4.6.2 Methodological issues

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 de faults from the 2006 IPCC guidelines.

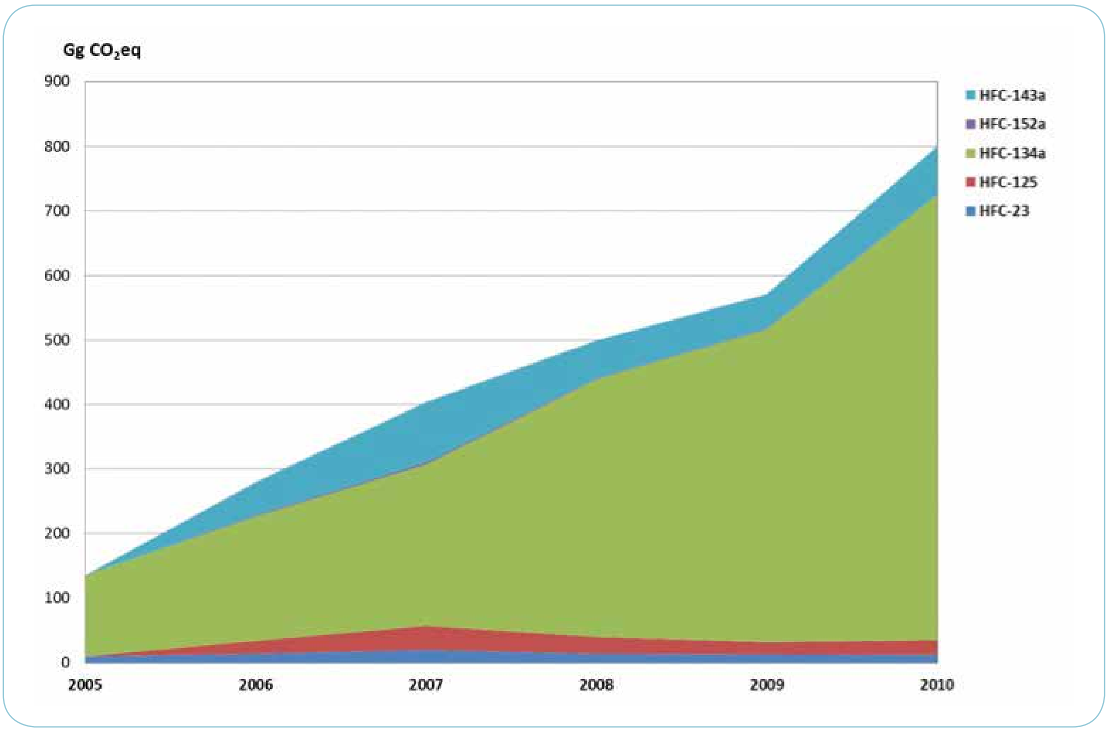

Figure 4.7: Sector 2 IPPU: Trends and emission levels of HFC's, 2005 – 2010.

4.6.3 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.

4.6.4 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 GHG emissions and removals from Agriculture as well as Land Use and Forestry. 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.

The Land Use component includes land remaining in the same land use as well as land converted to another land use. This section includes a basic Tier 1 approach to the mineral soil carbon pool, while organic soils are not reported on as the area of organic soils in SA was estimated to be insignificant. Dead organic matter is not included in this section due to insufficient data.

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. 2013d). 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, mainly due to the effects of land use change, but overall there appeared to be a decreasing trend. The main cause of this decline was the decreasing emissions from the *livestock* and *aggregated and non-CO_2 emission* sub-sectors. The 2000 estimate in this inventory was 52.3% higher (30 497 Gg CO_2eq) than the previous inventory estimate of 20 022 Gg CO2eq (DEAT, 2009) and the change was attributed to (a) improved methodologies in the *livestock* category, (b) the use of different land cover change maps, (c) inclusion of converted lands, and (d) the inclusion of HWP. The land sub-sector data was also updated to include 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	3.D – Other (HWP)
2000	30 497	*31 119*	*-18 493*	*23 775*	*-5 786*
2001	29 854	*31 169*	*-18 519*	*23 712*	*-6 389*
2002	28 054	*29 402*	*-17 751*	*23 863*	*-7 338*
2003	28 514	*28 796*	*-13 601*	*22 819*	*-9 373*
2004	31 984	*28 802*	*-10 260*	*22 991*	*-9 419*
2005	34 971	*29 087*	*-8 119*	*22 184*	*-8 037*
2006	25 982	*28 637*	*-17 865*	*22 904*	*-7 538*
2007	23 500	*27 950*	*-18 591*	*22 431*	*-8 128*
2008	24 183	*28 650*	*-19 518*	*22 997*	*-5 025*
2009	20 760	*28 146*	*-24 585*	*22 390*	*-5 025*
2010	25 714	*28 986*	*-19 871*	*22 803*	*-6 205*

Total GHG emissions from livestock declined by 6.9%, from 31 119 Gg CO_2eq in 2000 to 28 986 Gg CO_2eq in 2010. The decline was attributed mainly to the decreasing cattle, sheep and goat populations. Between 1990 and 2000 there was a 23% decline, although the recalculations and updated methodology accounts for 19% of this, as the previous inventory estimated emissions in 2000 to be 38 716 Gg CO_2eq (DEAT, 2009). The Land component is estimated to be a sink, varying between 8 119 Gg CO_2eq and 24 585 Gg CO_2eq (Table 5.1), and the variation is caused by changes in carbon stocks in Forest lands and land use changes in the Croplands in particular.

Emissions from *aggregated and non-CO_2 emission sources* fluctuated annually between a low of 22 184 Gg CO_2eq (2005) and a high of 23 863 Gg CO_2eq (2002). The fluctuation is driven mainly by changes in biomass burning and liming and urea application. 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).

Harvested wood products (HWP) was included for the first time and these are estimated to be a fairly large sink for CO_2, varying between 5 025 Gg CO_2eq and 9 419 Gg CO_2eq over the 10 year period. No clear trend is evident.

In all years CH_4 emissions contribute the most to the total AFOLU emissions (Figure 5.1), but this contribution declines from 40.5% in 2000 to 38.5% in 2010. *Enteric fermentation* contributed 93% of the CH_4. The contribution from N_2O fluctuated annually but was in the range of 26.6% to 31.6% with 68% of this coming from *Direct N_2O emissions from managed soils*.

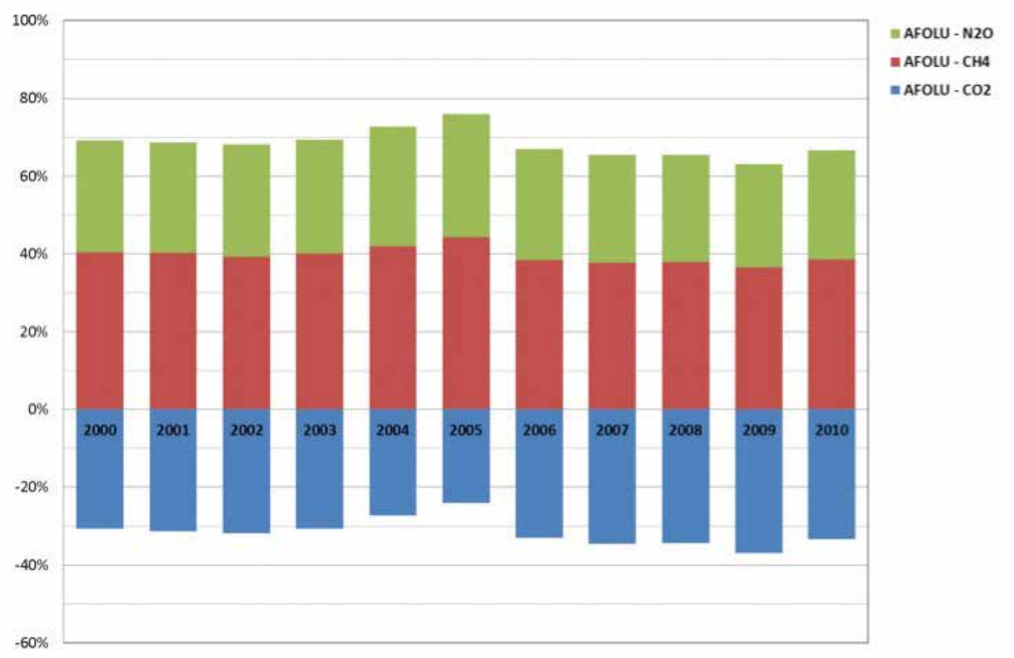

Figure 5.1: Sector 3 AFOLU: Percentage contribution of the various GHG to the total AFOLU inventory, 2000 – 2010.

5.2.2 Key sources

A level and trend key category analysis including the AFOLU sector was carried out on the 2010 data (Appendix B). These showed that with the level assessment the main key categories in this sector are *forest land remaining forest land*, *enteric fermentation* and, to a lesser extent, *direct N_2O from managed soils*. On the other hand, the trend assessment indicated that *land converted to Grassland* is the most important key category. Further down the list are *enteric fermentation*, *forest land remaining forest land* and *land converted to Cropland*. It should be noted that the key category assessment is incomplete due to the incomplete reporting of all sources.

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 by Du Toit et al., 2013a, 2013b, 2013c). Due to these updated activity data and emission factors the livestock emission in 2000 were recalculated.

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

- New land use change maps were developed for 2001 to 2005 and 2005 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;
- Grasslands, Croplands, Wetlands and Settlements were included;
- All converted land categories were included;
- Basic soil carbon estimates were included; and
- Harvested wood products were included.

The *land* estimates for 2000 were recalculated based on these changes. Even though this sub-section has had significant advances since the previous inventory, it still requires further improvements, which will be discussed below in each of the relevant sections.

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 320 745 Gg CO_2eq between 2000 and 2010. Overall livestock emissions have declined by 6.9% over the same period from 31 119 Gg CO_2eq in 2000 to 28 986 Gg CO_2eq in 2010 (Figure 5.2). There was a decline of 7.4% between 2001 and 2004, with an increase of 1.0%, 2.5% and 3.0% 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 93% of the GHG emissions from livestock, while the rest was from manure management. Emissions from manure management showed a 10% increase in emissions between 2000 (1 811 Gg CO_2eq) and 2010 (2 008 Gg CO_2eq). This increase is mainly due to the increase in the poultry population with all of the manure from this livestock category being managed. If poultry manure is excluded then there is a slight decline in manure emissions from all other livestock, with little annual variation.

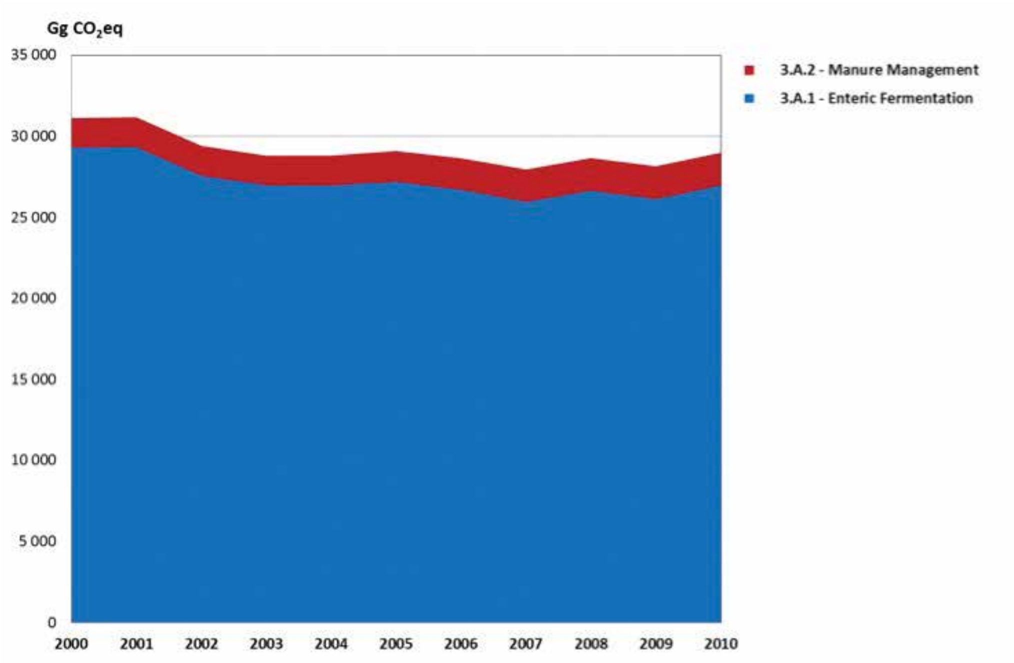

Figure 5.2: Sector 3 AFOLU: Trends in GHG emissions from the livestock category, 2000 – 2010.

5.3.2 Overview of trends in activity data

The total annual livestock population increased by 22.1% 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 8.1%) in the remaining livestock population over the 10 year period (Figure 5.3). Commercial beef cattle population has declined from 7.3 million in 2000 to 6.88 million in 2010, and the communal beef cattle have also declined from 5 million in 2000 to 4.73 million in 2010. The dairy cattle population declined between 2000 and 2004, but then increased again between 2005 and 2010. Sheep and goat populations declined by 8.9% and 12.9% respectively, and swines by 3.2% over the 10 year period. The annual average poultry population increased by 39.8% from 85 million in 2000 to 120 million in 2010 (Figure 5.3).

Generally the commercial population numbers were higher than the communal numbers, except for goats where the communal goat population was approximately twice that of the commercial population.

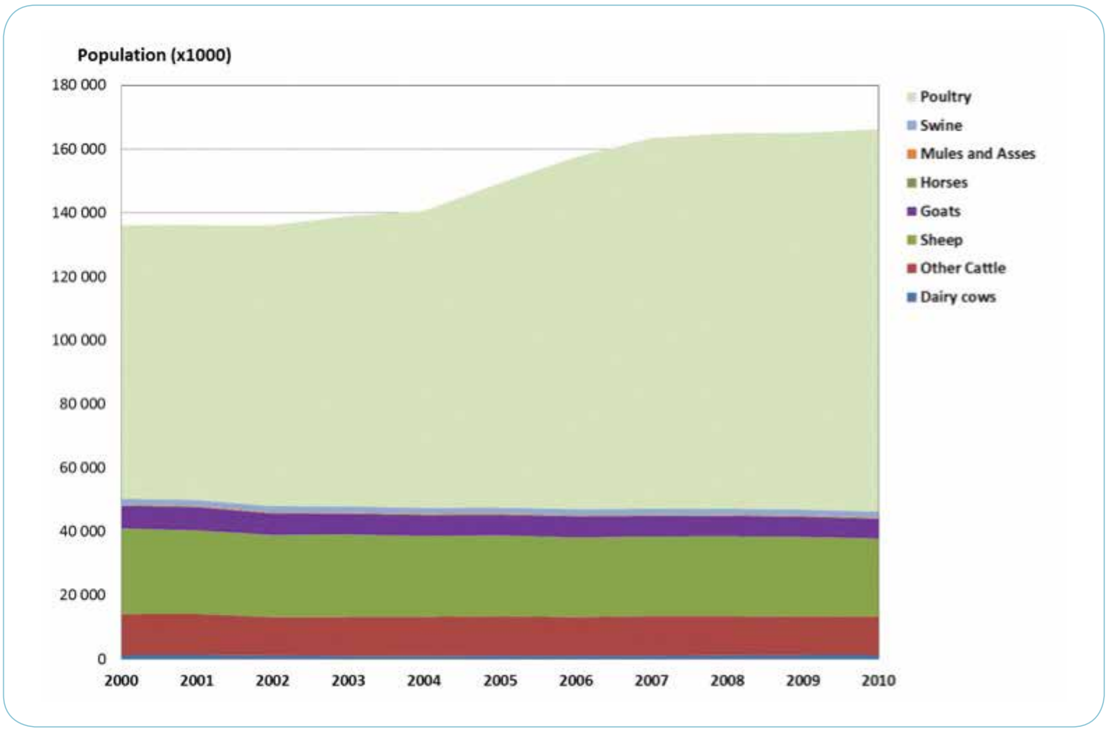

Figure 5.3: Sector 3 AFOLU - Livestock: Trends in livestock population numbers, 2000 – 2010.

5.3.3 Enteric fermentation [3A1]

5.3.3.1 Source-category description

Methane is the main greenhouse gas produced from agricultural livestock production. 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, and goats), pseudo-ruminants (horses, donkeys) and monogastric animals (pigs) (DAFF, 2010).

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. Using several assumptions, Du Toit et al. (2013c) estimated that the game industry could contribute an additional 131.9 Gg CH_4 yr^{-1} (estimate for 2010) to the enteric fermentation emissions from South Africa. Therefore, as more data becomes available, the inclusion of game should be considered in future inventories. Enteric fermentation emissions from poultry are not estimated as the amount produced is considered negligible (IPCC, 2006). No default emission factors are provided in the IPCC Guidelines as it states that there is insufficient data for the calculation. This exclusion of poultry from enteric fermentation emissions is in line with the IPCC 2006 Guidelines, however there are some reports of CH_4 emissions from poultry (Wang and Huang, 2005; Burns, 2012). These emissions are small, but in light of South Africa's growing poultry population it should be investigated further in future inventories.

5.3.3.2 Overview of shares and trends in emissions

Enteric fermentation emissions from livestock declined by 7.9% between 2000 (29 307 Gg CO_2eq) and 2010 (26 978 Gg CO_2eq) (Figure 5.4), mainly due to a decline in population numbers. There was a slight increase in emissions in 2005 (0.8%), 2008 (2.6%) and 2010 (3.2%). These increases are 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 (81.9% in 2010), with 12% from dairy cattle, 14.1% from sheep and 3.2% from goats (Figure 5.6).

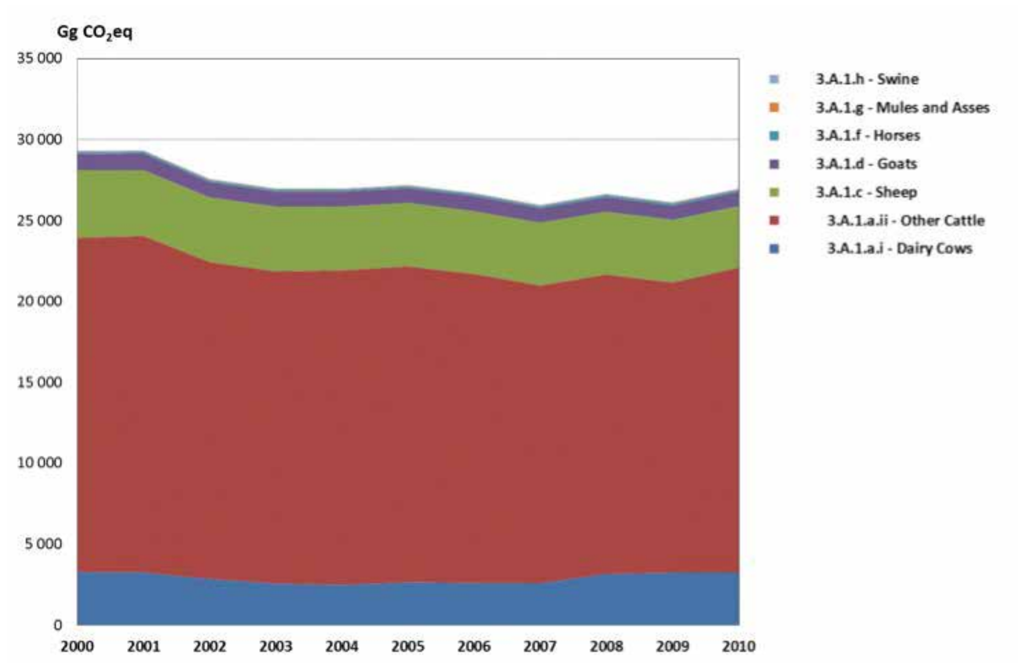

Figure 5.4: Sector 3 AFOLU - Livestock: Trend and emission levels of enteric fermentation emissions in the livestock categories, 2000 – 2010.

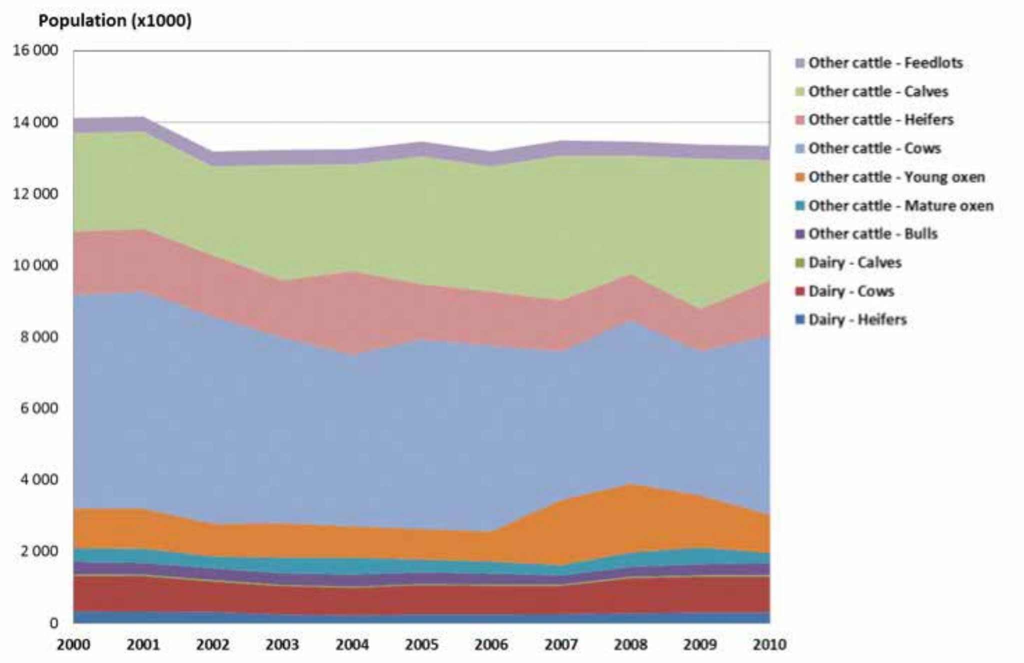

Figure 5.5: Sector 3 AFOLU - Livestock: Trend in cattle herd composition, 2000 – 2010.

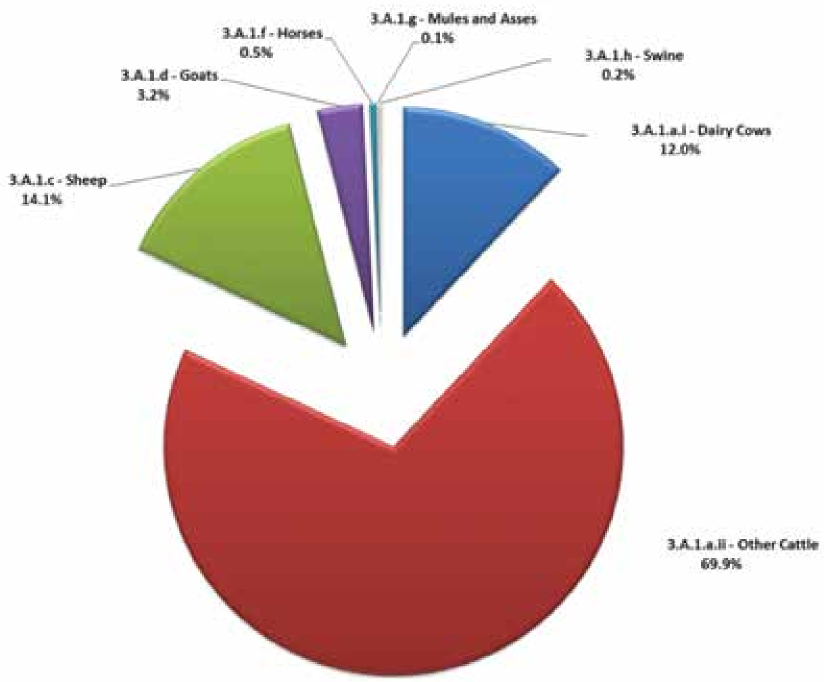

Figure 5.6: Sector 3 AFOLU – Livestock: Contribution of the livestock categories to the enteric fermentation emissions in 2010.

5.3.3.3 Methodological issues

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. (2013a, 2013b), and are summarized below. Emissions from enteric fermentation are calculated from activity data on animal numbers and the appropriate emission factor:

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

5.3.3.3.1 Dairy cattle [3A1Ai]

Emission factors for the various sub-categories of dairy cattle were taken from Du Toit et al. (2013a). These EF's were calculated using a Tier 2 approach following the equation:

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

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. An average daily milk production (14.5 kg/day) was sourced from LACTO data (2010).

Further details of how the various factors were calculated are provided in Du Toit et al. (2013a).

5.3.3.3.2 Other cattle [3A1Aii]

The emission factors for commercial and communal cattle were taken from Du Toit et al. (2013a). 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:

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

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. (2013a).

Feedlot beef cattle

Feedlot enteric methane emission factors were taken from du Toit et al. (2013a) who based their calculations on intake of specific diet components using an equation developed by Moe and Tyrrell (1979):

$$EF = (3.406 + 0.510SR + 1.736H + 2.648C) \times 365 \quad (Eq.5.4)$$

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:

$$EF = (Y / F) \times 365 \quad (Eq.5.5)$$

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).

5.3.3.3.3 Sheep [3A1c]

Sheep CH_4 emission factors were taken from Du Toit et al. (2013b) which are based on the equations of Howden et al. (1994):

$$EF = (I \times 0.0188 + 0.00158) \times 365 \quad (Eq.5.6)$$

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.

5.3.3.3.4 Goats [3A1d]

The CH_4 emission factors for the various goat sub-categories were taken from Du Toit et al. (2013b). 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.

5.3.3.3.5 Swine [3A2h]

CH_4 emission factors for the pig sub-categories were taken from Du Toit et al. (2013c) which were based on the methodology described in the Australian National Inventory (ANIR, 2009):

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

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).

5.3.3.3.6 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.

5.3.3.4 Data sources

5.3.3.4.1 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. The sub-categories for sheep, goats and swine were obtained by combining some of the more detailed sub-categories given in Du Toit et al. (2013a, 2013b, 2013c) (see Appendix D) as some of the populations were small and EF's didn't vary significantly. The inclusion of all the detailed sub-categories should be considered in future inventories.

The commercial cattle (dairy and other), sheep, goat and swine population data were obtained from the Abstracts of Agricultural Statistics 2012. The 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, and goats the average annual herd composition given in Du Toit et al. (2013a, 2013b) was applied to these numbers. The average annual herd composition for swine was assumed to be 1.9% boars, 32.2% sows, 33% piglets, 4.9% porkers and 28% baconers (Du Toit et al., 2013c). Du Toit et al. (2013a, 2013b, 2013c) obtained data from the individual livestock industries. It was assumed that the population split remained constant between 2000 and 2010.

The total communal population numbers for cattle, sheep, goats and swine was obtained by using the ratio of commercial to communal population from the quarterly census numbers which have been recorded by DAFF from 1996 onwards (*available from DAFF; http://www.daff.gov.za/docs/statsinfo - LivstkNoComNov09.xls accessed on 12 Aug 2010*). The ratios were 0.6868 for cattle, 0.1396 for sheep, 1.9752 for goats and 0.1306 for swine. The communal livestock numbers were given as a total so to determine the number in each livestock sub-category the same herd composition 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
		TMR[a]-based	Pasture-based						
Sub-category	Commercial	Lactating cow	Lactating cow	Bulls	Non-wool ewe	Buck	Boars		
		Lactating Heifer	Lactating Heifer	Cows	Non-wool ram	Doe	Sows		
		Dry cow	Dry cow	Heifers	Non-wool lamb	Kids	Piglets		
		Pregnant heifers	Pregnant heifers	Ox	Wool ewe	Angora	Baconers		
		Heifers >1 yr	Heifers >1 yr	Young ox	Wool ram	Milk goat	Porkers		
		Heifers 6-12 mths	Heifers 6-12 mths	Calves	Wool lamb				
		Heifers 2-6months	Heifers 2-6months	Feedlot					
		Calves < 2 months	Calves < 2 months						
	Communal			Bulls	Non-wool ewe	Buck	Boars		
				Cows	Non-wool ram	Doe	Sows		
				Heifers	Non-wool lamb	Kids	Piglets		
				Ox	Wool ewe		Baconers		
				Young ox	Wool ram		Porkers		
				Calves	Wool lamb				

[a]Total mixed ration

Annual feedlot cattle numbers were only available for the years 2008 – 2010 (Feedlot Association of SA), so an average of 420 000 (SA Feedlot Association, 2013; Ford, Dave, 2013. Pers. Comm.) was used for each year between 2000 and 2007. 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 (Ford, Dave, 2013).

Data on horse and donkey populations in South Africa are very scarce and the data that is available varies greatly. Census data obtained from 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 however based on 1995 data. FAO data (http://faostat.fao.org/site/573/default.aspx#ancor; accessed on 14 April 2014) gives a constant value of 270 000 for horses and 164 000 mules/asses in South Africa between 2000 and 2005. After which the numbers increase slightly. The population data varies quite widely, and it was decided to use the more consistent FAO data set for horses, mules and asses. All livestock population numbers are provided in Appendix D.

5.3.3.4.2 Live weight data

The live weight (or Typical Animal Mass (TAM)) data of the various livestock categories and sub-categories was taken from Du Toit et al. (2013a, 2013b, 2013c) (Table 5.3). For sheep, goats and swine where some of the sub-categories were combined a weighted average TAM (based on population numbers) was calculated for the livestock sub-categories used in this inventory.

5.3.3.4.3 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. (2013a, 2013b, 2013c) (Table 5.3) who developed country specific methodologies based on the methods developed by Australia and described in detail in their National Inventory Reports (ANIR, 2009).

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 EF takes into account the climate, feed digestibility and energy intake of the various livestock. In some cases there were more detailed sub-categories, so in these cases a weighted average EF was calculated for the livestock sub-categories used in this inventory. Du Toit et al. (2013a, 2013b, 2013c) 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 mules and asses.

Table 5.3: Sector 3 AFOLU – Livestock: Livestock weights, methane EF's and IPCC 2006 default EF's.

Livestock category	Livestock sub-category	TAM (kg)	$EF_{enteric}$ (kg/head/year)	IPCC default EF (kg/head/year)	
				Africa	Oceania
Dairy – TMR	Lactating cows	590	132.00	40	81
	Lactating heifers	503	127.00		
	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	127.00	40	81
	Lactating heifers	438	116.00		
	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	92.06		
	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	60	9.07	5	8
	Non-wool ram	78	11.47		
	Non-wool lamb	29	4.39		
	Wool ewe	55	8.27		
	Wool ram	92	13.83		
	Wool lamb	28	4.31		

Sheep – communal	Non-wool ewe	48	6.46	5	8
	Non-wool ram	62	8.13		
	Non-wool lamb	23	3.30		
	Wool ewe	44	5.95	5	8
	Wool ram	70	9.80		
	Wool lamb	22	3.24		
Goats – commercial	Buck	106	16.25	5	5
	Doe	74	11.30		
	Kid	32	4.82		
	Angora	24	3.91		
	Milk goat	39	6.49		
Goats – communal	Buck	68	9.54	5	5
	Doe	51	6.93		
	Kid	21	3.05		
Swine – commercial	Boars	253	2.06	1.0	1.5
	Sows	306	2.29		
	Piglets	9	0.43		
	Baconers	90	0.99		
	Porkers	70	0.51		
Swine – communal	Boars	212	1.65	1.0	1.5
	Sows	245	1.84		
	Piglets	7	0.34		
	Baconers	70	0.79		
	Porkers	56	0.41		
Horses		595	18	18	18
Mules and asses		250	10	10	10

Comparison of Methane EF with IPCC defaults

A comparison of the calculated methane emission factors (EF) for cattle, sheep, goats and swine and the IPCC default factors is provided in Table 5.4. The EF'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 (Table 5.4). 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)	322 – 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

5.3.3.5 Uncertainty and time-series consistency

Uncertainty for enteric fermentation was estimated to be in the order of 5%, however a more complete uncertainty analysis needs to be conducted in the next inventory following the IPCC 2006 Chapter 3 and the *IPCC Good Practice Guidance*. 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 FAO data and numbers from the individual livestock organizations for the year 2010. These numbers were found to vary slightly, however the variation for all livestock 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. Poultry population data appeared to be lower than other values and it may be worth using the annual census data in future inventories. Swine population data in this inventory and in FAO data are much higher than the figures reported by Du Toit et al. (2013c) so the reason for the discrepancy should be investigated in future.

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.

An independent reviewer was appointed to assess the quality of the inventory, determine the conformity of the procedures which were followed for the compilation of this inventory and to identify areas of improvements.
No source-specific QA/QC procedure has been defined or followed for this source category and this needs to be addressed in future inventories.

5.3.3.7 Source-specific recalculations

Disaggregated livestock population numbers, along with updated methane emission factors and live weights for each sub-category were incorporated into this inventory. Therefore the recalculations for the year 2000 were completed using the same methodology but updated activity data.

5.3.3.8 Source-specific planned improvements and recommendations

In this inventory the communal livestock numbers are estimated using a constant ratio over the 10 year period. There are plans to incorporate the annual variation in this ratio to provide annual variation in communal livestock population numbers. Also, the effects of incorporating the more detailed sub-categories for sheep, goats and swine need to be investigated further in the next inventory. Discrepancies in population numbers between national and individual livestock association data should also be checked. There are no other planned improvements, however it is recommended that if sufficient data is available annual emission factors, incorporating changes in feed quality and milk production, should be considered instead of assuming a constant emission factor across all years. Also, as mentioned in section 5.3.3.1, the incorporation of game should also be considered in future inventories. It is also recommended that a more thorough uncertainty analysis be completed, following the IPCC 2006 Uncertainty Guidelines and *Good Practice Guidelines*.

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.
As mentioned in Section 5.3.3.1, the inclusion of wildlife should be considered in future inventories. 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 2 008 Gg CO_2eq in 2010, which was an increase from the 1 811 Gg CO_2eq produced in 2000 (Figure 5.7). Methane emissions accounted for an average of 46.5% of the manure emissions over the 10 year period, and these emissions showed a peak in 2001 (1 826 Gg CO_2eq) and in 2010 (2 008 Gg CO_2eq) (Figure 5.8). The largest contributor to the CH_4 emissions were swine (an average of 69.5%), followed by dairy cattle (average of 22.5%). The contribution of CH_4 from dairy cattle manure management increased by 0.1% over the 10 year period, while the contribution from swine manure declined by 1.8%. N_2O emissions from manure management increased from 913 Gg CO_2eq to 1 116 Gg CO_2eq between 2000 and 2010, mainly due to the increased manure from poultry. Poultry contributed an average of 64.3% to the N_2O emissions and manure from cattle feedlots contributed 29.4% (Figure 5.9). Swine manure N_2O emissions declined by 3.2% between 2000 and 2010. The total emissions from poultry manure increased by 40.0% over the 10 years, and their contribution increased from 32.2% to 40.7%.

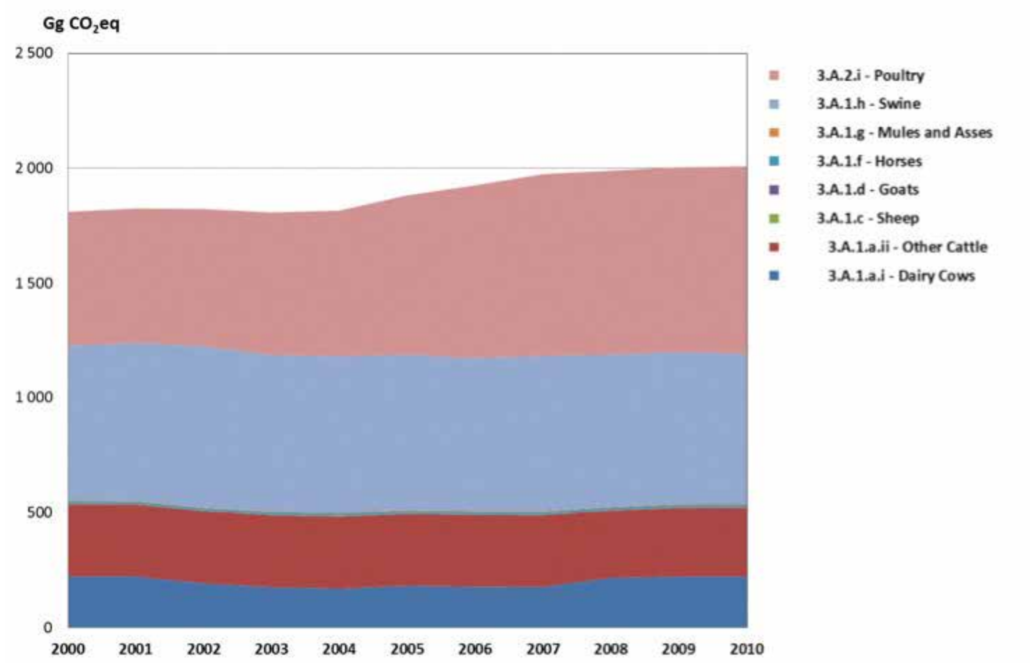

Figure 5.7: Sector 3 AFOLU – Livestock: Total manure management trend and emission levels from source categories, 2000 – 2010.

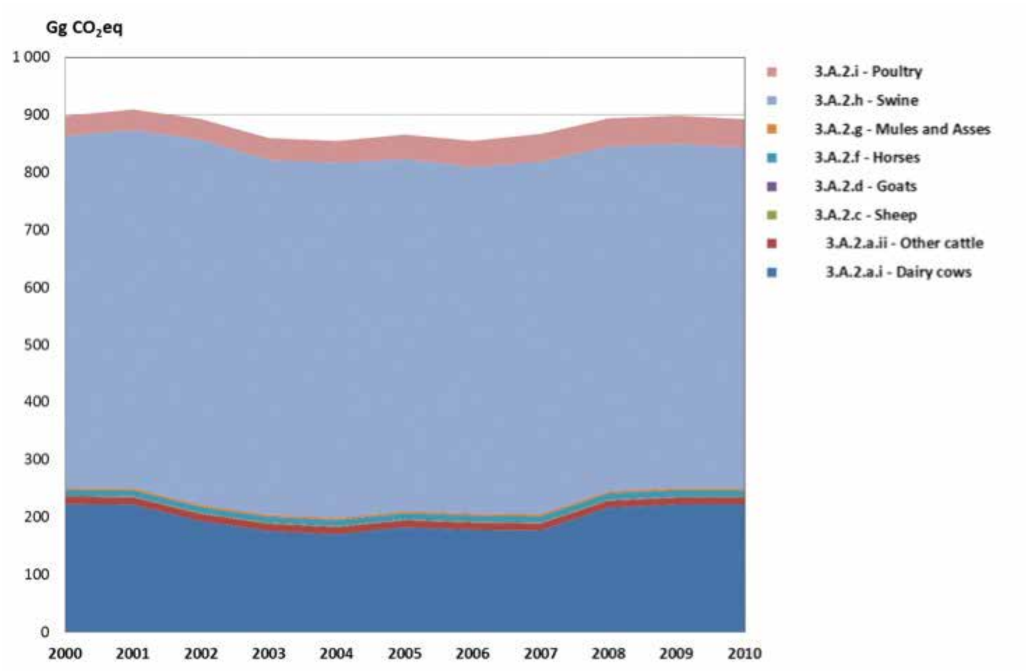

Figure 5.8: Sector 3 AFOLU – Livestock: Manure Management CH_4 trend and emission levels from source categories, 2000 – 2010.

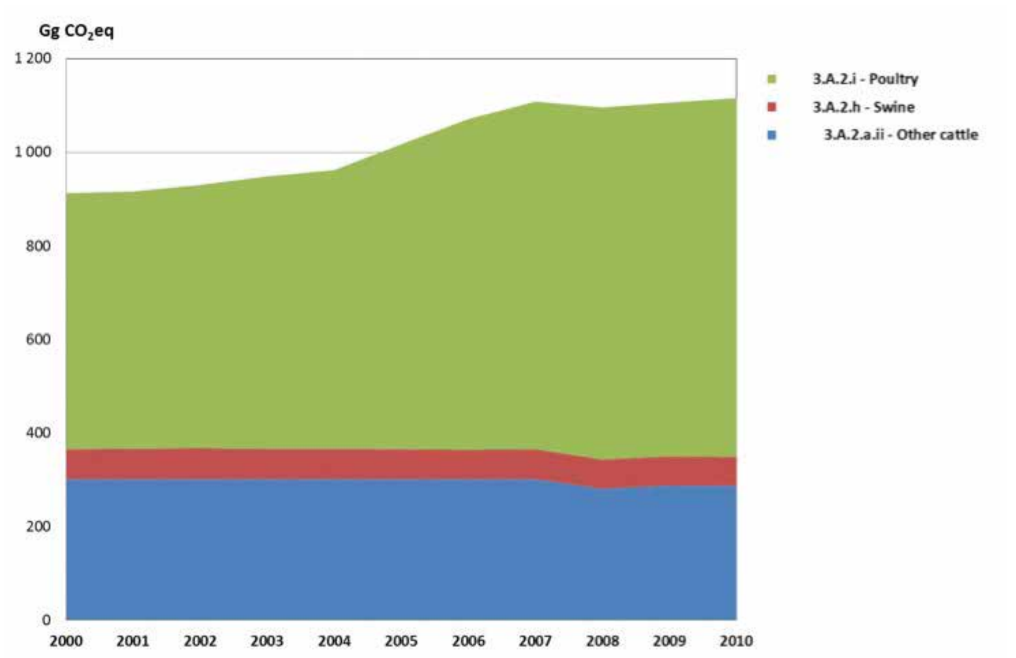

Figure 5.9: Sector 3 AFOLU – Livestock: Manure Management N_2O trend an emission levels from source categories, 2000 – 2010.

5.3.4.3 Methodological issues

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. 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).

5.3.4.3.1 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. (2013a). A tier 2 approach was used and the emissions (kg head^{-1} year^{-1}) were determined using the equation:

$$EF = (VS \times B_o \times MCF \times p) \times 365$$
(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:

$$VS = I \times (1 - DMD) \times (1 - A)$$
(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. (2013a and 2013b) who followed the methods used in the Australian inventory (ANIR, 2009):

$$EF = (I \times (1 - DMD) \times MEF) \times 365$$
(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. (2013c) and calculated following the equations provided in ANIR (2009):

$$EF = (VS \times B_o \times MCF \times p) \times 365$$
(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 calculated the volatile solid production from South African pigs by using the following equation provided in the IPCC 2006 Guidelines:

$$VS = [GE \times (1 - (DE\%/100)) + (UE \times GE)] \times [(1 - ASH)/18.45]$$
(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 calculated according to Equation 5.8, using an integrated MCF of 1.5% (IPCC, 2006; Du Toit et al., 2013c). 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).

5.3.4.3.2 N_2O emissions from animal manure

Du Toit et al. (2013a) 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 calculations 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.

5.3.4.4 Data sources

Population data sources for all livestock except poultry are described in section 5.3.3.3 and the Typical Animal Mass (TAM) are provided in Table 5.3. Poultry were also included in the manure management emission calculations. The total number of layers and slaughtered broilers was obtained from the SA Poultry Association (Prinsloo, Magda, 2014, Pers. Comm.).

The layer population numbers were used as they were provided but for broilers the annual average population (AAP) was calculated as a broiler is not alive for 365 days a year. The AAP was determined using the following equation (IPCC, 2006):

AAP = *Days_alive* * (NAPA/365)
(Eq.5.13)

NAPA is the number of animals produced annually, which was taken to be the number of broilers slaughtered. The life cycle of broilers is 38 days, therefore the *Days_alive* value was taken to be 38 days. Communal broilers were calculated as 4.2% of the commercial population (Prinsloo, Magda, 2014, Pers. Comm.). The TAM for poultry was 1.8kg for commercial broilers, 2 kg for commercial layers and 0.9 kg for communal broilers (DAFF, 2010; IPCC, 2006). Population data is provided in Appendix D.

5.3.4.4.1 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., 2013a). 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 (Du Toit et al., 2013a, 2014b, DAFF, 2010). All swine manure is managed either as lagoon, liquid/slurry, drylot and daily spread (Du Toit et al., 2013c; Table 5.5). All cattle feedlot manure and poultry manure is managed as drylot (Du Toit et al., 2013a; DAFF, 2010).

Table 5.5: Sector 3 AFOLU – Livestock: Manure management system usage (%) for different livestock categories, 2000 – 2010 (Source: DAFF, 2010; Du Toit et al., 2013a and 2013b).

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

5.3.4.4.2 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. (2013a, 2013b). Emission factors for cattle, sheep, goats, swine and poultry (Table 5.6) were taken from Du Toit et al. (2013a, 2013b, 2013c) and the methods are described in section 5.3.3.4. In the case of sheep, goats and swine there were additional livestock subcategories in Du Toit et al. (2013a, 2013b, 2013c) (see Appendix D) and in these cases a weighted average emission factor was calculated. IPCC 2006 Africa default values were used for horses and donkeys.

Table 5.6: Sector 3 AFOLU – Livestock: CH_4 manure EF's for the various livestock compared to the IPCC 2006 default factors and the Australian EF's (Source: Du Toit et al., 2013a, b, c; IPCC 2006 Guidelines; ANIR, 2009).

Livestock category	Livestock sub-category	EF_{manure}	IPCC default EF (kg/head/year)		Autralian EF
		(kg/h/year)	Africa	Oceania	(kg/head/year
	Lactating cows	14.800			
	Lactating heifers	14.700			
	Dry cows	1.470			
	Pregnant heifers	1.240			
Dairy - TMR	Heifers > 1 year	1.190	1	29	8.8
	Heifers 6 – 12 months	0.750			
	Heifers 2 – 6 months	0.370			
	Calves	0.210			
	Lactating cows	4.980			
	Lactating heifers	4.800			
	Dry cows	1.110			
Dairy - pasture	Pregnant heifers	0.880	1	29	8.8
	Heifers > 1 year	0.780			
	Heifers 6 – 12 months	0.580			
	Heifers 2 – 6 months	0.400			
	Calves	0.320			
	Bulls	0.022			
	Cows	0.018			
	Heifers	0.016			0.04
Other cattle - commercial	Ox	0.018	1	2	
	Young ox	0.012			
	Calves	0.012			
	Feedlot	0.870			2.91
	Bulls	0.017			
	Cows	0.015			
Other cattle - communal	Heifers	0.013	1	2	0.04
	Ox	0.015			
	Young ox	0.010			
	Calves	0.010			

Livestock category	Livestock sub-category	EF_{manure} (kg/h/year)	IPCC default EF (kg/head/year) Africa	IPCC default EF (kg/head/year) Oceania	Autralian EF (kg/head/year
Sheep - commercial	Non-wool ewe	0.003	0.15	0.28	0.002
	Non-wool ram	0.003			
	Non-wool lamb	0.001			
	Wool ewe	0.002			
	Wool ram	0.004			
	Wool lamb	0.001			
Sheep - communal	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	0.003			
	Wool lamb	0.001			
Goats - commercial	Buck	0.018	0.17	0.2	
	Doe	0.012			
	Kid	0.005			
	Angora	0.004			
	Milk goat	0.005			
Goats - communal	Buck	0.011	0.17	0.2	
	Doe	0.008			
	Kid	0.004			
Swine - commercial	Boars	17.470	1	13 - 24	23
	Sows	24.190			
	Piglets	3.740			
	Baconers	20.960			
	Porkers	17.960			
Swine - communal	Boars	0.390	1	13 - 24	23
	Sows	0.540			
	Pre-wean piglets	0.080			
	Baconers	0.460			
	Porkers	0.400			
Horses		1.640	1.64	2.34	
Mules and asses		0.900	0.9	1.1	
Poultry	Layers	0.000		0.03	0.04
	Broilers	0.000		0.02	

Comparison of manure EF's and IPCC defaults

A comparison of the calculated manure emission factors with IPCC default values is given in Table 5.6. For dairy cattle the EF for lactating cows and heifers was much higher than the Africa default, while the rest of the dairy cattle were only slightly higher. If an average dairy cattle EF was calculated from this data the EF would be close to the Australian EF. For other cattle the EF are lower than the Africa default values, but are in a similar range to the Australian EF. All cattle EF are lower than the Oceania IPCC 2006 default values. Swine EF were much higher than the Africa default values and are in a similar range to those of Oceania and Australia (Table 5.6). Poultry manure EF for N_2O was lower than all default values.

5.3.4.4.3 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).

5.3.4.5 Uncertainty and time-series consistency

5.3.4.5.1 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.

5.3.4.5.2 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.

An independent reviewer was appointed to assess the quality of the inventory, determine the conformity of the procedures which were followed for the compilation of this inventory and to identify areas of improvements.

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 stratify the livestock population by climate, 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. (2013a) 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

The Land component of the AFOLU sector includes CO_2 emissions and sinks of the carbon pools above-ground and below-ground biomass, and soils from the categories Forest land (3.B.1), Croplands (3.B.2), Grasslands (3.B.3), Wetlands (3.B.4), Settlements (3.B.5) and the relevant land-use change categories. In the category other Land (3.B.6), no anthropogenic emissions and sinks occur, since the relevant land areas are not used.

This inventory includes a dead wood component in the Forest land category; however the dead wood and organic matter carbon pool are not included in the other categories due to a lack of data. 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 also included following the methodology in the previous inventory (DEAT, 2009). 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% (DEA, 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 (Forestry South Africa, 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 Croplands, Grasslands and Settlements are estimated to increase by 16.7%, 1.2% and 1.6% respectively. Forest lands are estimated to decrease by 4.1% and Wetlands by 3.2%.

5.4.2.2 Trends in CO_2

The Land sector was estimated to be a net sink of CO_2, but this sink fluctuated over the 10 year period (Figure 5.10). The biomass carbon pool contributes the most to the Land sector (Figure 5. 11), however very limited soil carbon data, and only a Tier 1 approach, was incorporated into this inventory so this may change as the inventory is improved in future.

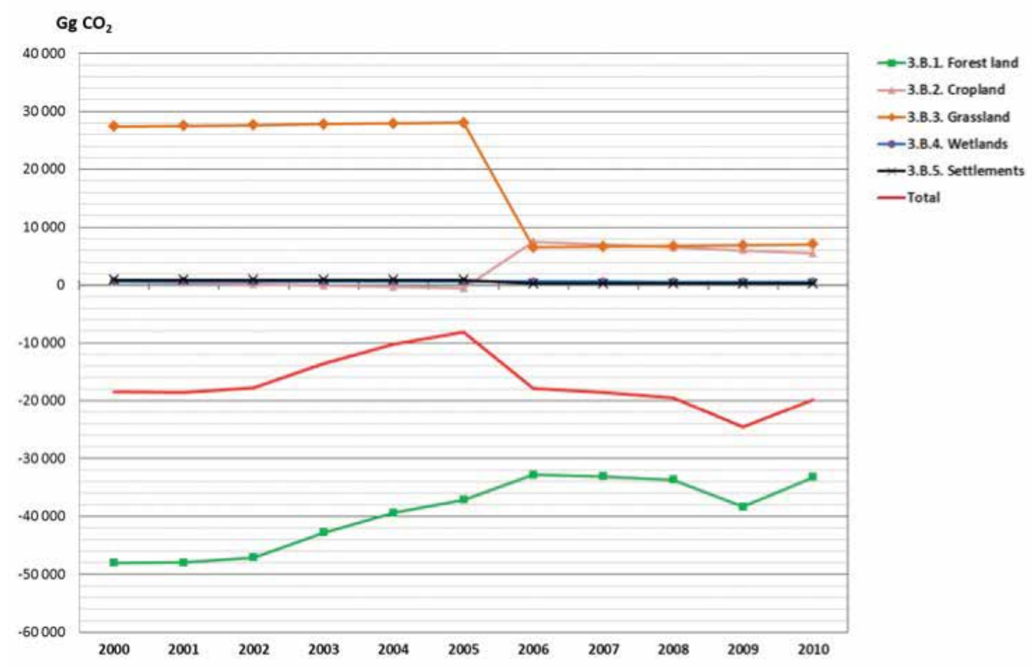

Figure 5.10: Sector 3 AFOLU – Land: Trend in emissions and sinks (in Gg CO_2) in the Land sub-sector between 2000 and 2010, differentiated by sub-category.

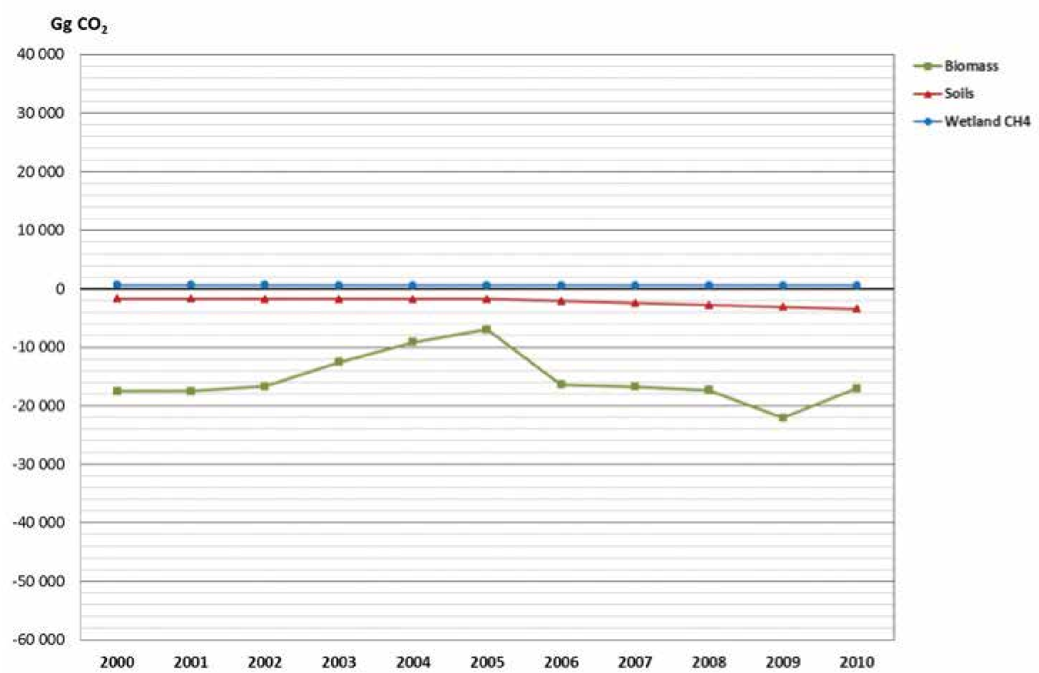

Figure 5. 11: Sector 3 AFOLU – Land: Trend in emissions and sinks (in Gg CO_2) in the Land sub-sector between 2000 and 2010, differentiated by source category.

Forest land (3B1) comprised emissions and removals from the above and below ground, and soil carbon pools for the *forest land remaining forest land* and *land converted to forest land* subcategories. Forest lands include 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 be a net sink for CO_2 in all years between 2000 and 2010, varying between 32 784 Gg CO_2 and 48 040 Gg CO_2 over the 10 year period. *Forest land remaining forest land* accounted for an average of 88.9% of the Forest land CO_2, while the *land converted to forest land* contributed 5.3% in 2000 and this increased to 18.4% in 2010.

Croplands (3B2) comprised emissions and removals from the biomass and soil carbon pools in the *croplands remaining croplands* and the *land converted to croplands* sub-categories. Croplands include annual crops, perennial crops (sugarcane, viticulture, orchards), and subsistence or semi-commercial croplands. Croplands varied between a weak sink (513 Gg CO_2) and a source (7 529 Gg CO_2) of CO_2. Land conversions to croplands during 2005 to 2010 were responsible for the increased CO_2 source during this period. *Croplands remaining croplands* are generally assumed to be in balance and therefore have no emissions or removals; however there was a small emission due to conversions between annual and perennial crops.

Grasslands (3B3) comprised emissions and removals from the biomass and soil carbon pools for *grasslands remaining grasslands* and *land converted to grasslands*. The Grassland category includes grasslands and the Fynbos vegetation. As with croplands, *grassland remaining grasslands* was assumed to have no net emissions or removals. Land converted to grasslands was estimated to produce a large sink of CO_2. The sink averaged 27 713 Gg CO_2 between 2000 and 2005, but this then declined to an average of 6 768 Gg CO_2 between 2006 and 2010.

Wetlands (3B4) were estimated not to have any emissions or removals of CO_2, but CH_4 emissions were estimated. Wetlands were therefore estimated to be a weak source of emissions which declined from 665 Gg CO_2eq in 2000 to 581 Gg CO_2eq in 2010. Wetlands included wetlands and waterbodies.

Settlements (3B5) comprised of *settlements remaining settlements* and *land converted to settlements*. This category includes settlements and mines. *Settlements remaining settlements* do not have any CO_2 emissions or uptakes, but land conversions to settlements produced a weak sink (average of 609 Gg CO_2 over the 10 years). Other lands (3B6) were assumed to have zero CO_2 change.

5.4.3 General methodology

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) as well as all the land conversion categories. Due to the diverse nature of South Africa's vegetation, the 6 land classes had several subdivisions (Table 5.7) and these divisions are further explained in section 5.4.5. 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 5.4.4.

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 due to biomass losses were estimated from equations 2.11 to 2.14 and 2.27 of the IPCC 2006 Guidelines. For the *land converted to another land* category the Tier 1 approach was used. Changes in biomass carbon stocks were estimated from IPCC 2006 equations 2.15 and 2.16. Changes in mineral soil carbon stocks for both *land remaining land* and *land converted to a new land use* were estimated from the formulation B of equation 2.25 (IPCC, 2006 Guidelines, vol. 4, pg. 2.34).

Table 5.7: 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
Settlements	Settlements
	Mines
Wetlands	Wetlands
	Waterbodies
Other Lands	Nama karoo Succulent karoo Bare ground
	Other

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. The soil carbon data can be improved and data for the DOM component are required.

5.4.4 Method for obtaining land-use matrix

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 Meraka Institute at CSIR in 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) (Appendix E). This also includes a summary list of the source image data used to generate the geographic masks.

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.

5.4.4.1 Data sources

Details of the source imagery used to develop the land cover maps for South Africa are given in the GeoTerraImage (2013) report, but a summary is given in Table 5.8.

Table 5.8: Sector 3 AFOLU – Land: Source of imagery for the land cover maps used in this inventory.

Province	Coverage	2000	2004	2005		2006		2007	2008	2009	2010
		Land-sat	Land-sat	Land-sat	SPOT	Land-sat	SPOT	SPOT	SPOT	SPOT	SPOT
Eastern Cape	Full	√									
	Partial									√	√
Free State	Full	√								√	
	Partial										√
Gauteng	Full	√								√	
	Partial										√
KwaZulu Natal	Full	√							√		
	Partial			√						√	√
Limpopo	Full	√								√	
	Partial			√				√			√
Mpumalanga	Full	√									
	Partial		√	√						√	√
North West	Full	√					√				
	Partial										√
Northern Cape	Full	√									
	Partial								√		√
Western Cape	Full	√									
	Partial				√	√				√	√

5.4.4.2 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).

5.4.4.3 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 allowed for an approach 3 methodology (IPCC, 2006) to represent areas of land cover and change, and to develop the Land cover change matrix. Due to the low resolution of the land use change maps there is a high degree of uncertainty associated with the area of the converted lands, but it was the best available data at the time of compiling this inventory. The estimations can be refined in the future as better data becomes available.

5.4.4.4 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.

5.4.4.5 Comparison with land cover data for 2000 inventory

For the purpose of this inventory a comparison was made between the national land cover data which was used in the previous inventory, and the 2000 data used in this inventory (Figure 5.12). In the 2000 inventory the national land cover classes were redefined to biome classes using the biome boundaries of Mucina and Rutherford (2006) (DEAT, 2009). It is difficult to make direct comparisons as in most cases different land classifications were used. The following results were found:

- Plantation area was overestimated. Plantation area was compared with data from FSA (Forestry South Africa, 2012) 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 that of the previous inventory 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 data from the previous inventory 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 2000 inventory. 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 previous inventory 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 2000 inventory, 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 previous inventory (72 466 577ha).
- Other lands appear to be overestimated (15 008 199 ha) when compared to the 2000 inventory 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 before being incorporated.

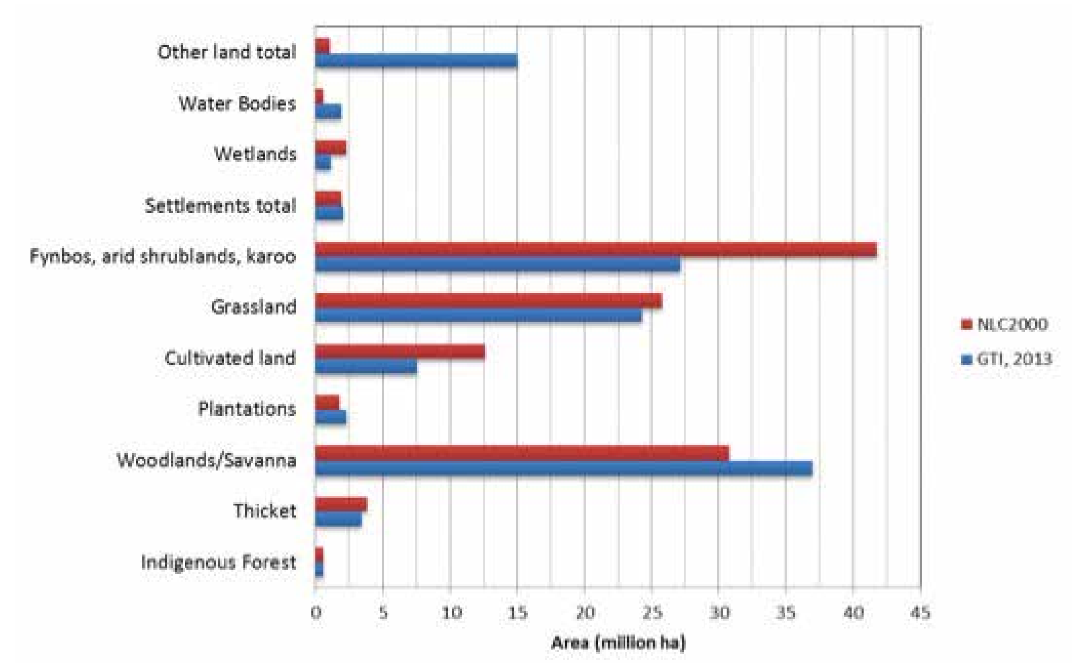

Figure 5.12: Sector 3 AFOLU – Land: Comparison of land areas obtained from the 2000 inventory and the maps used in this inventory. Direct comparison is difficult due to the use of different categories and definitions.

5.4.4.6 Area corrections

Plantation area was compared with data from Forestry South Africa (2012) and was found to be overestimated due to the reason given above (section 5.4.4.4). Plantations were high on the hierarchical overlay sequence (GeoTerraImage, 2013) and were 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 data in the 2000 inventory (DEAT, 2009) the plantation area overestimation is less than this (about 25%). This area overestimation would lead to an overestimation in the carbon gains of forest lands, while the removals would be based on the FSA data. This would lead to an overestimate of the carbon sink and for this reason an area correction was made. The area of plantations was taken to be that provided by FSA. 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 Woodland/savanna and Grassland categories. This correction does not have a large impact on the outputs as plantations cover a very small area of South Africa's land surface.

5.4.4.7 Derivation of land use in 1990 and 2000

The IPCC has a default transition period of 20 years which means that once a land area is converted to another land type it has to remain in the converted land category for the 20 year transition period. Therefore information on land use change for 20 years prior to the inventory year are required. South Africa does not have historical land use change maps that are consistent with the maps used in this inventory. The land change between 2001 and 2005 was used to extrapolate land change in 2000 and back to 1990 by using a linear interpolation approach. It was not reasonable to extrapolate further back than this using this approach, so no change was assumed before 1990. This means that the 2000 inventory numbers only include 10 years of historical data, whereas the 2010 includes the full 20 years. If more historical land use data becomes available or if higher resolution land-use change maps are developed this extrapolation can be improved and the full 20 years incorporated for all years.

5.4.4.8 Derivation of annual land-use changes

The observation period was divided into change periods of differing lengths (1990-2001, 2001-2005, 2005-2010). No useful annual change data were available within the observation period so the annual changes in these periods were calculated on a proportional basis, via linear interpolation.

5.4.4.9 Land use changes

The resulting land use change matrices, including transitions beginning in 1990, for 2000 and 2010 are shown in Table 5.9 and Table 5.10. These land changes may be overestimated due to the lower resolution of the land cover maps but these will be corrected as the maps are improved.

Table 5.9: AFOLU – Land: Land-use matrix for 2000 with highlighted numbers on the diagonal showing the area (ha) remaining in the same category and the other cells show the relevant land-use changes from 1999 to 2000 (including the transitions since 1990).

Initial/ Final	Forest land	Croplands	Grasslands	Settle-ments	Wetlands	Other lands	∑ reductions	∑ additions – ∑ reductions
Forest land	41 563 539	836 834	1 280 188	42 861	12 697	729 466	2 902 046	-1 817 839
Croplands	422 191	4 809 701	1 028 391	4 288	16 518	29 966	1 501 353	1 078 338
Grasslands	67 343	1 623 203	28 166 156	30 685	11 940	411 346	2 144 517	526 364
Settlements	18 713	349	33 272	1 879 667	3 848	537	56 718	33 851
Wetlands	56 031	26 730	38 402	2 377	2 902 786	36 615	160 155	-112 163
Other lands	519 929	92 576	290 628	10 357	2 989	35 059 645	916 480	291 449
∑ additions	1 084 207	2 579 692	2 670 881	90 569	47 992	1 207 929		
∑ land use category	42 647 746	7 389 393	30 837 037	1 970 236	2 950 778	36 267 574		
Total area	122 062 764							

Table 5.10: AFOLU – Land: Land-use matrix for 2010 with highlighted numbers on the diagonal showing the area (ha) remaining in the same category and the other cells show the relevant land-use changes from 2009 to 2010 (including the transitions since 1990).

Initial/ Final	Forest land	Croplands	Grasslands	Settle-ments	Wetlands	Other lands	∑ reductions	∑ additions – ∑ reductions
Forest land	38 164 000	1 722 875	2 589 268	85 379	46 967	1 985 977	6 430 467	-3 676 364
Croplands	876 538	3 360 419	2 083 506	8 275	33 250	64 483	3 066 052	2 197 362
Grasslands	136 790	3 298 847	25 420 780	62 036	42 169	1 186 018	4 725 859	1 052 727
Settlements	37 447	440	66 715	1 820 939	7 738	1 095	113 435	67 703
Wetlands	134 879	51 077	96 059	4 712	2 711 590	80 979	367 706	-224 326
Other lands	1 568 450	190 175	943 038	20 736	13 255	33 145 862	2 735 653	582 899
∑ additions	2 754 103	5 263 414	5 778 587	181 138	143 380	3 318 552		
∑ land use category	40 918 103	8 623 833	31 199 367	2 002 077	2 854 970	36 464 414		
Total area	122 062 764							

5.4.4.10 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.

5.4.4.11 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 (1996 and 2000) (DEAT, 2009). 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; Appendix E).

5.4.4.12 Planned improvements

The Department of Environmental Affairs (DEA) has recently started a GHG Inventory Improvement Programme and under this programme there is currently a project which is updating the Land-use change maps to improve the resolution. During this project higher resolution maps for 1990 and 2010 are being developed. This will significantly improve the accuracy of the land-use change area estimates, which will in turn improve the emission estimates for the Land category. In a separate project under the GHG Inventory Improvement Programme improvements are being made so as to incorporate the full 20 year transition period for all years between 2000 and 2010.

5.4.5 Land use definitions and classifications

5.4.5.1 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 (DEAT, 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;

» 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.

5.4.5.2 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.

5.4.5.3 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 fynbos as it has a woody component but they do not meet the above mentioned requirements of a forest land. The fynbos 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.

5.4.5.4 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.

5.4.5.5 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.

5.4.5.6 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. Also grouped in this category are the Nama-karoo and Succulent karoo biomes as there is also a lack of data of these biomes and they are considered unmanaged. The Nama-karoo is dominated by steppe type vegetation, comprising a mixture of shrubs, dwarf shrubs, and annual and perennial grasses (Palmer and Ainslie, 2002), while the Succulent karoo is comprised mainly of shrubs (0.5-1.5m) and dwarf shrubs (<0.5m) with succulent leaves and stems (Palmer and Ainslie, 2002). If more data becomes available these biomes will be included in the inventory. In future the possible inclusion of these biomes into the Grassland category, along with the fynbos, should be considered.

5.4.5.7 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, except other lands. Inclusion of the other land category may be considered in the future.

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.

» 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 was classified under Grasslands. Nama karoo and Succulent karoo placed under other lands.
- Land classified as mines and quarries was incorporated into the Settlements category, as opposed to other lands as in the previous inventory.

- Land conversion data:
    - Sinks and removals from all land converted to another land type were included in this inventory. Only land converted to plantations was included in the previous inventory.

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

Specific recalculations completed for each land class are discussed in detail under the specific sections below.

5.4.7 Forest land [3B1]

5.4.7.1 Source-category description

Reporting in this category covers emissions and removals from above-ground and below-ground biomass, dead wood and mineral soils. 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. Harvested wood 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 (DEAT, 2009).

This category reports emissions and removals from the category *forest land remaining forest land* (forest that remains forest during the period covered by the report) and the *land converted to forest land* (new forest established, via afforestation or natural succession, on areas previously used for other land-use classes) category. Calculations are carried out on the basis of a 20-year transition period in that once a land area is converted it remains in the converted land category for 20 years. In this inventory transition data was only available from 1990 (see section 5.4.4.7) therefore all calculations include transitions since 1990.

In 2010 the total sink from forests amounted to 33 225 Gg CO_2, which was down from the 48 040 Gg CO_2 in 2000 (Figure 5.13). Of the 2010 sink a total of 17 007 Gg CO_2 occurred via removals of biomass and dead wood, while 3 444 Gg CO_2 resulted from removals in mineral soils. The biomass carbon dominated the forest land carbon sink (97.5%) (Figure 5.14). In 2000 the sink was 48 040 Gg CO_2 with the soils contributing 1 681 Gg CO_2.

Forest land remaining forest land contributed approximately 80% towards the total sink over the 10 year period, with land conversions accounting for an average of 4 175 Gg CO_2 per year.

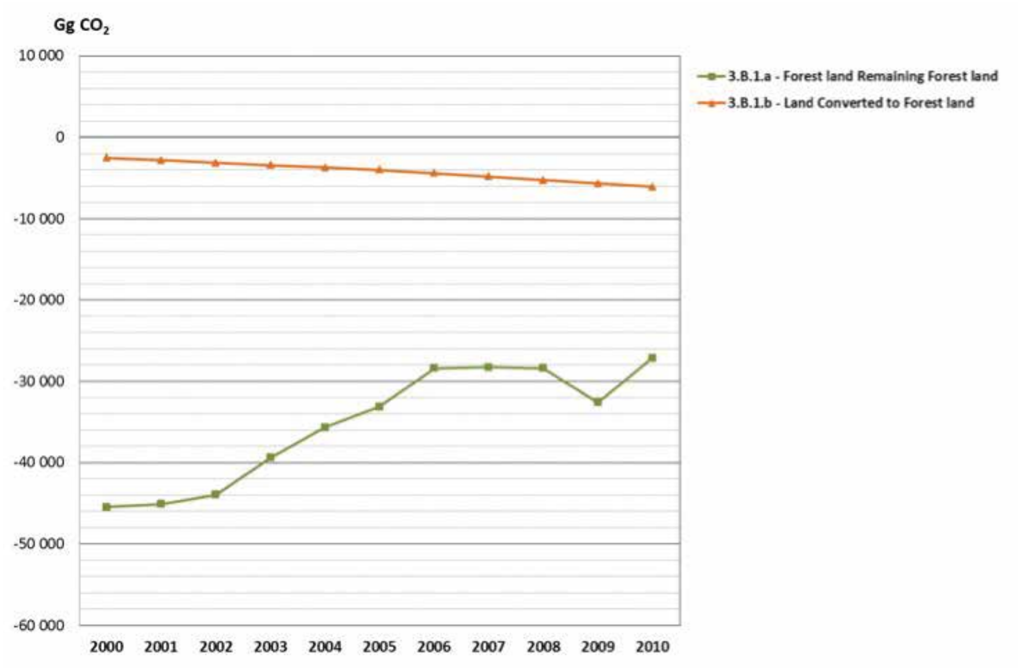

Figure 5.13: AFOLU – Land: Trend in emissions and sinks (in Gg CO_2) in the forest land between 2000 and 2010, differentiated by sub-category.

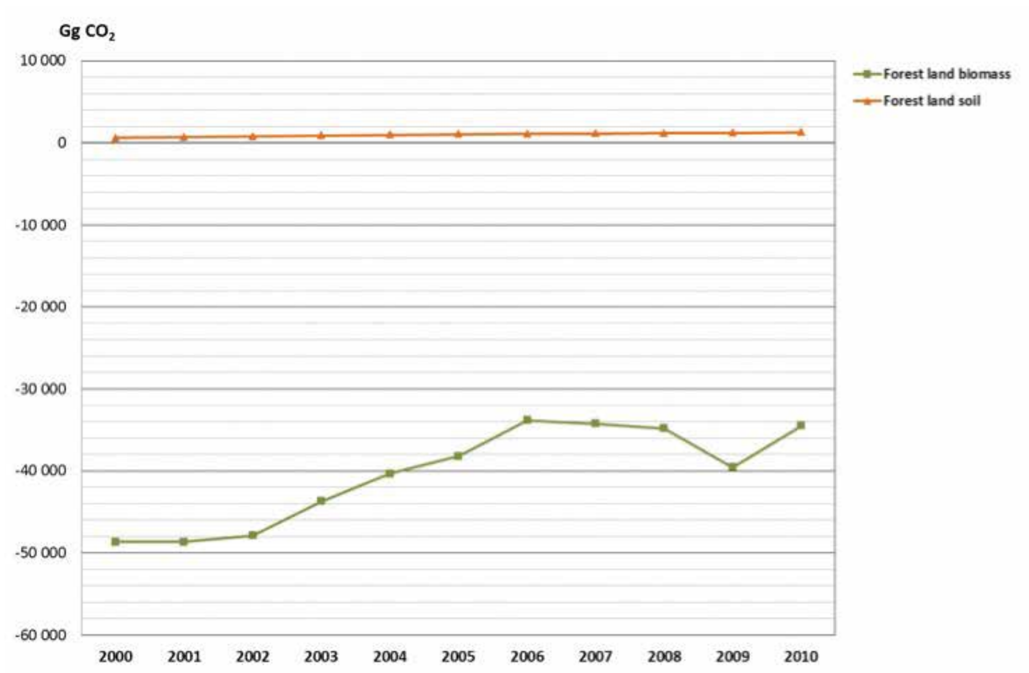

Figure 5.14: AFOLU – Land: Trend in emissions and sinks (in Gg CO_2) in the forest land between 2000 and 2010, differentiated by source category.

5.4.7.2 Methodological issues

5.4.7.2.1 Biomass

Forest land remaining forest land

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 (Forestry South Africa, 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 savanna/woodland and Grassland categories. The composition of the plantation in terms of the 5 species was determined by using the average composition between 2000 and 2005 and 2005 and 2010.

Removals and emissions of CO_2 from changes in above- and below-ground 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) which were adapted to include a dead wood component following the methods of the previous inventory (DEA, 2009):

$$\Delta CG = \sum(A_i * G_{TOTALi} * CF_i)$$
(Eq.5. 14)

Where:

$G_{TOTALi} = \sum[G_{Wi} * (1+R+DW)]$
(Eq.5. 15)

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 harvested wood;

Loss of carbon from fuelwood removals; and

Loss of carbon from disturbance.

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

$L_{wood\text{-}removals} = [H * BCEF_R * (1+R) * CF$
(Eq.5. 16)

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):

$L_{fuelwood} = [FG_{trees} * BCEF_R * (1+R) + FG_{part} * D] * CF$
(Eq.5. 17)

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:

$L_{disturbances} = A_{disturbance} * B_W * (1+R) * CF * fd$
(Eq.5. 18)

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):

$$L_{fire} = A * M_B * C_f * G_{ef} * 10^{-3} * (12/44)$$
(*Eq.5. 19*)

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):

$$\Delta C = \Delta CG - L_{wood\text{-}removals} - L_{fuelwood} - L_{disturbances}$$
(Eq.5. 20)

Land converted to forest land

The area of *land converted to forest land* includes all land converted since 1990. The land converted to plantations could not be split into the various plantation types due to a lack of data so the values for Eucalyptus were used as this is the dominant species. Annual increase in biomass carbon stocks were calculated in the same way as for *forest land remaining forest land*. If a land area is converted to a plantation then it is unlikely wood would be harvested in the year following the conversion, therefore it was assumed that no wood was harvested or removed for fuel wood from the converted land. All annual harvested wood and fuel wood losses were therefore allocated to the *forest land remaining forest land* category. There was insufficient data to determine how much of the annual disturbance in a plantation occurred on the converted land. For the purpose of this inventory it was assumed that no disturbance occurred on converted land, but this assumption will need to be corrected in future inventories. Losses due to fire disturbance were calculated for land converted to Woodlands/savannas using equation 2.27 in the IPCC 2006 Guidelines. A detailed description of the methodology for calculating losses due to fire is given in section 5.5.2. As with *forest land remaining forest land* indigenous forests and thickets were assumed not to burn.

5.4.7.2.2 Mineral soils

Land converted to forest land

Annual change in carbon stocks in mineral soils were calculated by applying a Tier 1 method with equation 2.25 of the IPCC 2006 Guidelines (IPCC, 2006, vol 4, pg. 2.30). The activity data was collected with Approach 3, therefore formulation B of this equation was appropriate:

$$\Delta C_{Mineral} = (\sum[\{(SOC_{REF}*F_{LU}*F_{MG}*F_I)_0 - (SOC_{REF}*F_{LU}*F_{MG}*F_I)_{(0-T)}\}*A])/D$$
(*Eq.5. 21*)

Where:
SOC_{REF} = the reference carbon stock (t C ha^{-1});
F_{LU} = stock change factor for land-use system for a particular land-use (dimensionless);
F_{MG} = stock change factor for management regime (dimensionless);
F_I = stock change factor for input of organic matter (dimensionless);
Time $_0$ = last year of inventory time period;
Time $_{(0-T)}$ = beginning of the inventory time period;
A = land area (ha);
D = time dependence of stock change factor (default = 20 years).

5.4.7.3 Data sources

The land areas for *forest land remaining forest land* and *land converted to forest land* were obtained from the land use maps discussed in section 5.4.5, while the plantation data was obtained from FSA data (Forestry South Africa, 2012).

5.4.7.3.1 Biomass

Biomass gains

Annual biomass growth data for plantations was calculated from FSA 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 annual biomass growth values range between 3.95 and 9.53 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, 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 (DEAT, 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 (DEAT, 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 so this was corrected.

Losses due to wood harvesting

Loss of carbon due to wood harvesting was only calculated for plantations using the FSA data (Forestry South Africa, 2012) (Table 5.11). 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 Forestry South Africa (2012) provided annual data on wood removed for firewood/charcoal (Table 5.12).

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 woodland/savannas a BECF value of 2.9 t biomass removed (m^3 of removals)$^{-1}$ was calculated from the GFRASA (2005). . This is much 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 was therefore decided that the IPCC default value would be used until better data becomes available.

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. This data was used to determine the weighted average fraction of biomass lost in the disturbance (by assuming a slight damage had an fd = 0.3 and serious damage with total loss had a fd = 1) for harwood (fd = 0.636) and softwood (fd = 0.489) species. 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 plantation 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 (DEAT, 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.

Table 5.11: Sector 3 AFOLU – Land: Annual wood harvest data (m3/yr) from plantations between 2000 and 2010 (source: FSA, 2012).

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Softwood –sawlogs	4 234 000	4 168 545	4 177 707	4 979 429	5 196 035	5 423 737	5 692 158	5 243 114	5 004 230	4 239 987	3 845 011
Softwood-pulp	3 574 970	3 058 964	3 126 909	3 402 798	2 765 001	3 751 951	3 636 937	3 759 857	3 837 417	3 421 600	3 343 702
Eucalyptus sp.	7 462 139	8 162 556	8 028 142	9 626 900	11 041 417	11 422 565	11 985 132	10 059 191	10 209 075	9 962 654	9 105 586
Acacia sp.	1 205 401	953 701	992 205	960 728	993 457	1 084 651	1 176 582	954 447	796 124	928 456	900 317
Other sp.	37 312	22 739	65 379	20 422	50 253	28 841	45 311	8 235	20 442	22 537	38 682
Total	16 513 822	16 366 506	16 390 342	18 990 277	20 046 163	21 711 745	22 536 120	20 024 844	19 867 288	18 575 234	17 233 297

Table 5.12: Sector 3 AFOLU – Land: Annual removal of fuelwood (m3/yr) from plantations between 2000 and 2010 (source: FSA, 2012).

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Softwood –sawlogs	18 855	21 523	22 356	20 148	24 333	39 772	42 661	26 537	28 396	38 669	21 051
Softwood-pulp	0	0	0	0	0	0	0	0	0	0	0
Eucalyptus sp.	61 014	116 982	90 233	90 260	140 200	88 274	117 941	144 927	119 793	148 717	132 183
Acacia sp.	80 944	94 991	113 718	101 730	99 400	134 037	130 150	132 358	122 114	123 065	127 498
Other sp.	5 664	6 873	2 661	3 094	1 094	2 510	320	1 835	0	1 894	0
Total	166 477	240 368	228 968	215 231	265 026	264 593	291 073	305 657	270 303	312 345	280 732

5.4.7.3.2 Mineral soils

The climate in South Africa is classified as warm temperate and dry (Moeletsi et al., 2013). The land categories have not yet been stratified by soil type (this is planned for the next inventory) so for the purpose of this inventory the reference carbon stock (SOC_{REF}) for the dominant soil is used. Moeletsi et al. (2013) indicated that the dominant soil type in SA is soil with high activity clay, therefore the IPCC default SOC_{REF} of 38 t C ha^{-1} (IPCC 2006, vol 4, pg. 2.31, Table 2.3) was applied. For Forest lands, Grasslands, Settlements and Other lands the soil C stocks are assumed equal to the reference value (i.e. F_{LU}, F_{MG} and F_I = 1). IPCC default stock change factors were determined for each crop type by using data reported in Moeletsi et al. (2013) (Table 5.13). The area converted is the total area converted since 1990.

Table 5.13: Sector 3 AFOLU – Land: Relative stock change factors (± error) for different management activities on croplands.

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

[a] long term cultivated; [b] perennial/tree crop; [c] frequent tillage; [d] no till; [e] medium inputs; [f] low inputs.

5.4.7.4 Uncertainties and time-series consistency

5.4.7.4.1 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 (DEAT, 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 and woodland/savannas default factors were used and these have an uncertainty range of 0.6 – 3.0 t dm ha^{-1} yr^{-1} and 0.8 – 1.5 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 fuel wood harvest numbers from FAO were not provided but this is expected to be high.

For default soil organic C stocks for mineral soils there is a nominal error estimate of ±90% (IPCC 2006 Guidelines, pg 2.31). The error on the stock change factors is indicated in Table 5.13.

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.

5.4.7.5 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.

5.4.7.6 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, previous inventories and to default values where ever possible. No other source-specific QA/QC procedures were carried out on this category. An independent reviewer provided comment on the forest land category and the inventory was improved accordingly.

5.4.7.6 Source-specific recalculations

Recalculations were made for 2000. In this inventory Woodland/savanna 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. The previous inventory did include a portion of *land converted to forest land* as conversions to plantations were included. In this inventory all *land converted to forest land* were reported, and an estimation (Tier 1) of the soil carbon (mineral soils) pool was provided.

5.4.7.7 Category-specific planned improvements and recommendations

There are plans to improve the soil carbon data by incorporating more detail from the soil maps (Moeletsi et al., 2013) and the Carbon Sinks Assessment (DEA, 2014), as well as by improving extrapolation of land use change data to incorporate a full 20 year transition period for all years. In addition, improvements to the estimates of carbon losses from Land converted to forest land are planned. In future it may be useful 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 future. Information on litter carbon stocks is provided in the Carbon Sinks Assessment (DEA, 2014), so an attempt should be made to incorporate these values.

5.4.8 Cropland [3B2]

5.4.8.1 Source category description

Reporting in the *cropland* category covers emissions and removals of CO_2 from mineral soils, and from above- and below-ground biomass. Croplands include annual commercial crops, annual semi-commercial or subsistence crops, orchards, viticulture and sugar cane. This category reports emissions and removals from the category *cropland remaining cropland* (cropland that remains cropland during the period covered by the report) and the *land converted to* *cropland* category. Calculations are carried out on the basis of a 20-year transition period in that once a land area is converted it remains in the converted land category for 20 years. In this inventory transition data was only available from 1990 (see section 5.4.4.7) therefore all calculations include transitions since 1990.

Cropland remaining cropland was estimated to be a weak source of CO_2 (between 39.3 Gg CO_2 and 53 Gg CO_2) over the 10 year period (Figure 5.15) and this was due to fire disturbance in perennial croplands and small changes in soil carbon due to conversions between annual and perennial crops. *Land converted to cropland* was a source of CO_2 between 2000 and 2002, and this then changed to a sink between 2003 and 2005 due to an increase in the soil carbon between 2000 and 2005 (Figure 5.16). More land conversions occurred in 2005 which created a CO_2 source of 7 476 Gg in 2006. This declined to 5 435 Gg CO_2 by 2010. Between 2000 and 2005 the soil carbon sink is equal to the biomass source brought about by land conversions; whereas between 2006 and 2010 the biomass CO_2 source is twice that of the soil sink (Figure 5.16).

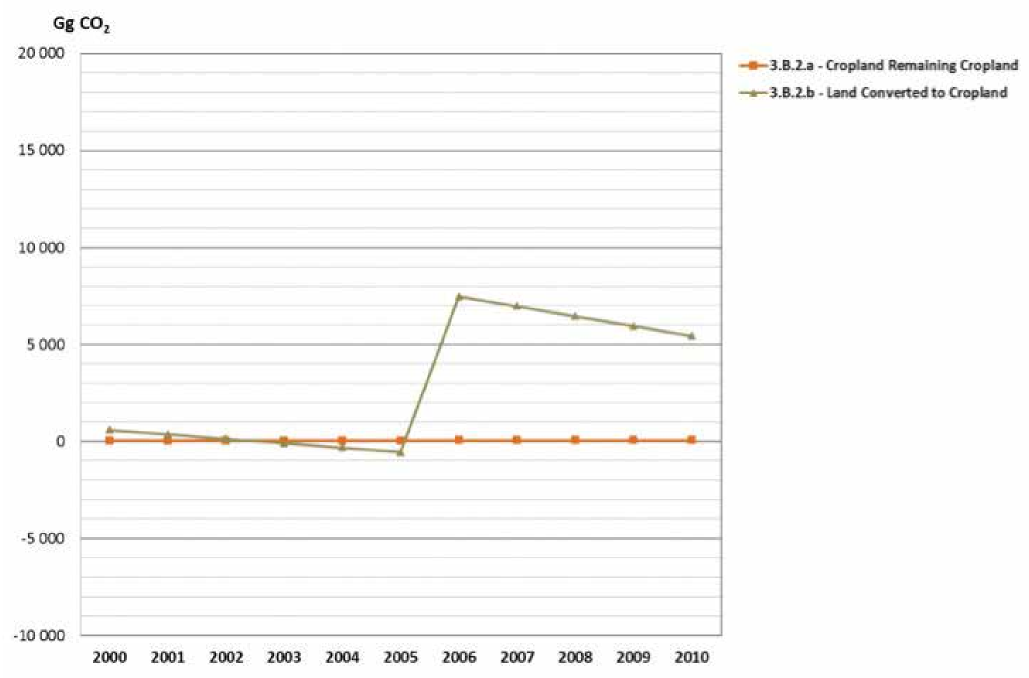

Figure 5.15: Sector 3 AFOLU – Land: Trend in emissions and sinks (in Gg CO_2) in Croplands between 2000 and 2010, differentiated by sub-category.

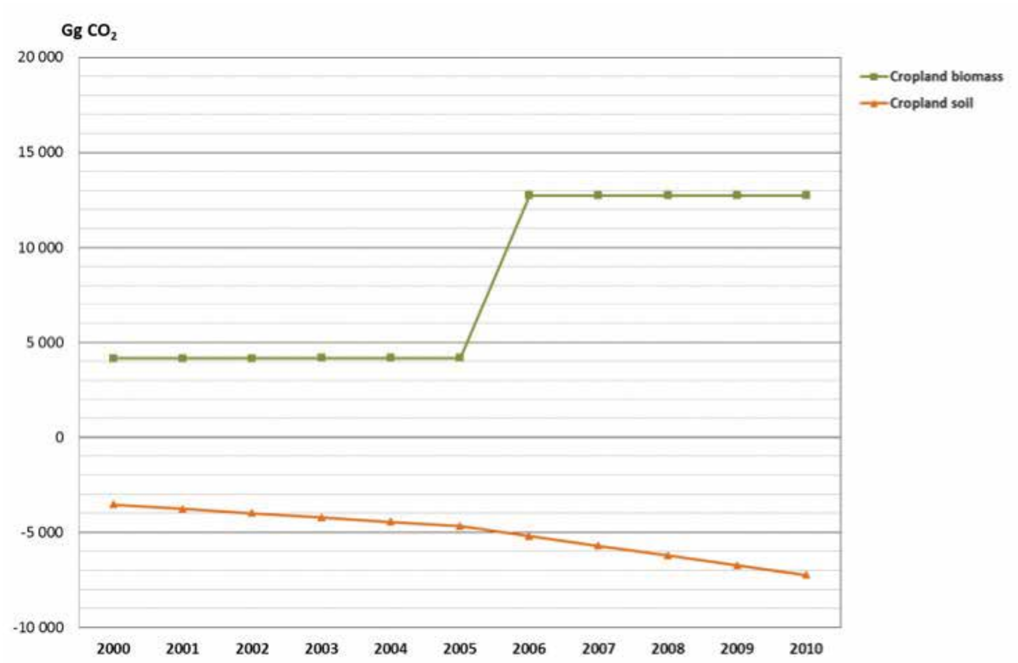

Figure 5.16: Sector 3 AFOLU – Land: Trend in emissions and sinks (in Gg CO_2) in Croplands between 2000 and 2010, differentiated by source category.

5.4.8.2. Methodological issues

5.4.8.2.1 Biomass

Cropland remaining cropland

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 annual 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. CO_2 emissions from the burning of perennial crops were included by using equation 2.27 from IPCC 2006 Guidelines (see section 5.5.2).

Land converted to croplands

For this a Tier 1 combined with a Tier 2 approach was applied. The annual increase in carbon stocks in biomass due to land conversions were estimated using the following IPCC 2006 equation:

$$\Delta C_B = \Delta C_G + ((B_{AFTER} - B_{BEFORE}) * \Delta A_{TO\_OTHER}) * CF - \Delta C_L$$
(Eq.5. 22)

Where:

ΔC_B = annual change in carbon stocks in biomass (t C yr^{-1});
ΔC_G = annual biomass carbon growth (t C ha^{-1} yr^{-1});
B_{AFTER} = biomass stocks on the land type immediately after conversion (t dm ha^{-1});
B_{BEFORE} = biomass stocks before the conversion (t dm ha^{-1});
ΔA_{TO_OTHER} = annual area of land converted to cropland (ha);
CF = carbon fraction of dry matter (t C/t dm^{-1});
ΔC_L = annual loss of biomass carbon (t C ha^{-1} yr^{-1}).

5.4.8.2.2 Mineral soils

Cropland remaining cropland and Land converted to cropland

Soil carbon sources and sinks were calculated as described in section 5.4.7.2.2. The land areas for the various categories were obtained from the land-use change maps (GeoTerraImage, 2013) and described in section 5.4.4. For *croplands remaining croplands* this includes conversions between croplands, and for *land converted to croplands* the land area includes all converted land since 1990.

5.4.8.3 Data sources

5.4.8.3.1 Biomass

The areas of the various *cropland remaining cropland* and *land converted to croplands* were obtained from the updated land use maps developed by GeoTerraImage (2013) and are discussed in detail in section 5.4.5. IPCC default values for carbon stocks after 1 year of growth in crops planted after conversion (ΔC_G) (5 t C ha^{-1} for annual croplands; 2.1 t C ha^{-1} for perennial crops) were used. It is assumed that land is cleared before it is converted to a crop, there the biomass stock immediately after conversion is assumed to be zero. Biomass carbon stocks in the various land classes are provided in Table 5.14, with Wetlands and Settlements having a value of zero. The carbon fraction was the default of 0.5 t C/t dm^{-1}. Loss of carbon due to fire disturbance was determined as described in section 5.5.2. The area of each land class that was disturbed by fires was determined from MODIS burnt area (discussed in detail in section 5.5.2.4). The M_B factor for crops was taken from DAFF (2010), while the C_f factors were taken from the previous inventory (DEAT, 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.

5.4.8.3.2 Mineral soils

Data is as described in section 5.4.7.3.2.

Table 5.14: Sector 3 AFOLU – Land: Above ground biomass for the various land classes.

Land class	Biomass carbon stock ($t\ dm\ ha^{-1}$)	Data source
Plantations Eucalyptus sp. Softwood sawlogs Softwood pulp Acacia Other sp.	 60 75 74 43 28	Values for plantation species were calculated from FSA data and Dovey and Smith (2005) dry matter ratios.
Natural forest	81	IPCC GPG, 2003
Thicket	60	Mills et al. (2005): Mills and Cowling (2006); Lechmere-Oertel (2003) and data supplied by Mike Powell.
Woodland/savanna	65	GFRASA (2005); Shackelton and Scholes (2011).
Grasslands	6.1	IPCC 2006 default for warm, dry temperate systems
Fynbos	30	Mills et al. (2012); Cowling et al. (1997).

5.4.8.4 Uncertainties and time-series consistency

5.4.8.4.1 Uncertainties

The main uncertainties were associated with the area estimates of the croplands and this is discussed in section 5.4.5. Uncertainty on the biomass carbon stocks for forest land categories was not determined, but default biomass carbon stocks have an error of ±75%. IPCC default values for carbon stocks after 1 year of growth in crops planted after conversion also have an error of ±75% (IPCC, 2006, pg. 5.28).

For default soil organic C stocks for mineral soils there is a nominal error estimate of ±90% (IPCC 2006 Guidelines, pg 2.31). The error on the stock change factors is indicated in Table 5.13. The uncertainty on the burnt area, M_B and C_f factors is discussed in section 5.5.2.5.

5.4.8.4.2 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.

5.4.8.5 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). Land use change and activity data was compared to the literature and other data sources where possible; otherwise no other source-specific QA/QC procedures were carried out on this sub-category.

5.4.8.6 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. This inventory calculated updated estimates for the year 2000.

5.4.8.7 Category-specific planned improvements and recommendations

Under the GHG Improvement Programme initiated by DEA, there is a project which will be collecting improved cropland data (land management, inputs, carbon stocks) for a more disaggregated list of crops and this data will need to be considered when developing the next inventory. There is an additional project which aims to improve the soil carbon data and stratify the crops by climate and soil, so more detailed information can be incorporated into the next inventory. It is also recommended that more data on carbon gains and losses from perennial crops be collected.

5.4.9 Grassland [3B3]

5.4.9.1 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 was also included under grasslands. This section deals with emissions and removals of CO_2 in the biomass and mineral soil carbon pools, but there was insufficient data to include the DOM pool. 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.

Grasslands remaining grasslands are assumed to be in balance so there are no emissions from this sub-category. *Land converted to grasslands* was estimated to be a source of CO_2 because of land use conversions (Figure 5.17). Between 2000 and 2005 the source averaged 27 713 Gg CO_2 per year, whereas it declined to an average of 6 768 Gg CO_2 between 2006 and 2010. In 2000 the biomass carbon dominated (95.5%), but this declined to 64.1% by 2010 (Figure 5. 18). The soils contributed an average of 33.5% (2 272 Gg CO_2) to the total carbon for grasslands between 2006 and 2010.

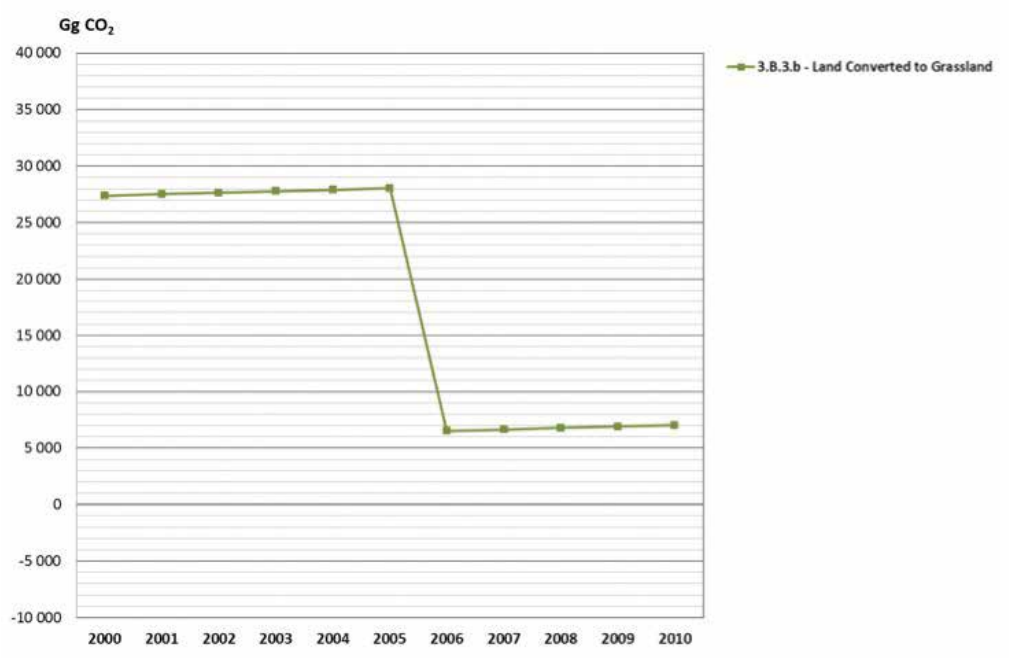

Figure 5.17: Sector 3 AFOLU – Land: Trend in emissions and sinks (in Gg CO_2) in grassland between 2000 and 2010, differentiated by sub-category.

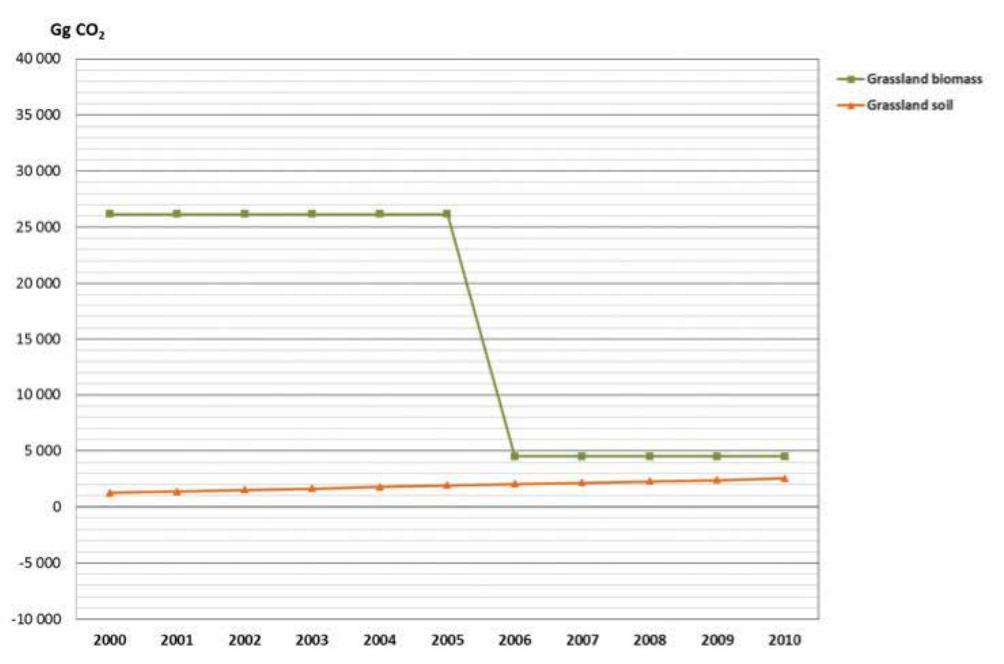

Figure 5. 18: Sector 3 AFOLU – Land: Trend in emissions and sinks (in Gg CO_2) in grassland between 2000 and 2010, differentiated by source category.

5.4.9.2 Methodological issues

5.4.9.2.1 Biomass

Grassland remaining grassland

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.

Land converted to grassland

Annual change in biomass carbon stocks on *land converted to grasslands* was estimated using equation 5.22 above.

5.4.9.2.2 Mineral soils

Grasslands remaining grasslands and Land converted to grasslands

Soil carbon sources and sinks were calculated as described in section 5.4.7.2.2. The land areas for the various categories were obtained from the land-use change maps (GeoTerraImage, 2013). For *grasslands remaining grasslands* this includes conversions between grasslands and fynbos, and for Land converted to grasslands the land area includes all converted land since 1990.

5.4.9.3 Data sources

5.4.9.3.1 Biomass

The areas of *grassland remaining grassland* and annual area of *land converted to grassland* were obtained from the updated land use maps developed by GeoTerraImage (2013) and are discussed in detail in section 5.4.5. It was assumed that the conversion between grassland and indigenous forest, thicket and woodland/savanna was something which occurred over time and was not an abrupt change. It was therefore assumed that 80% of the grassland carbon stock is present on the land after it was converted (i.e. B_{AFTER} = 5 t dm ha^{-1}) from indigenous forest, thicket or Woodland/savanna. For plantation conversions it was assumed that land was cleared, so B_{AFTER} = 0. This also applied to Croplands, Settlements and Wetlands.

Biomass carbon stocks before the conversion for Forest lands are given in Table 5.14, while for annual and perennial croplands the IPCC 2006 default values of 10 t dm ha^{-1} (IPCC 2006 Guidelines, p. 6.27) and 63 t dm ha^{-1} (IPCC 2006 Guidelines, Table 5.1, p. 5.9) respectively, for a warm temperate climate were used.

For sugarcane an average value of 50 t dm ha^{-1} was applied (Donaldson, 2009; Van Heerden et al., 2010; Donaldson et al., 2008), which is in between the annual and perennial default values. A carbon fraction of 0.47 was applied. Following the Tier 1 approach, it was assumed that grasslands achieved their steady-state biomass during the first year following conversion so no stock changes were associated with Phase 2 (i.e. no change due to growth or losses).

5.4.9.3.2 Mineral soils

Data is as described in section 5.4.7.3.2.

5.4.9.4 Uncertainty and time-series consistency

5.4.9.4.1 Uncertainties

The main uncertainties were associated with the area estimates of the grassland categories (discussed in section 5.4.5.3). Uncertainty on the biomass carbon stocks for forest land categories was not determined, but default biomass carbon stocks for the various land categories have an error of ±75%. IPCC default values for carbon stocks after 1 year of growth in crops planted after conversion also have an error of ±75% (IPCC, 2006, pg. 5.28)

For default soil organic C stocks for mineral soils there is a nominal error estimate of ±90% (IPCC 2006 Guidelines, pg 2.31). The error on the stock change factors is indicated in Table 5.13. The uncertainty on the burnt area, M_B and C_f factors is discussed in section 5.5.2.5.

5.4.9.4.2 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.

5.4.9.5 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). Land use change and activity data was compared to the literature and other data sources where possible; otherwise no other source-specific QA/QC procedures were carried out on this sub-category.

5.4.9.6 Source-specific recalculations

No recalculations were necessary as no estimates were provided in the previous inventory.

5.4.9.7 Category-specific planned improvements and recommendations

No specific improvements are planned for this category; however there is a project under the GHG Improvement Programme that is investigating the incorporation of degraded grasslands. This data should be used to improve the estimates of future inventories. DOM data should also be collected so that this category can be included in future.

5.4.10 Wetlands [3B4]

5.4.10.1 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. CO_2 emissions from *wetlands remaining wetlands* and *land converted to wetlands* are not reported, however an estimate is provided for CH_4 from flooded lands. In 2000 wetlands produced 665 Gg CO_2eq and this declined by 12.6% to 581 Gg CO_2eq in 2010 (Figure 5.19). This decline is related to the reduced area of flooded lands due to land conversions.

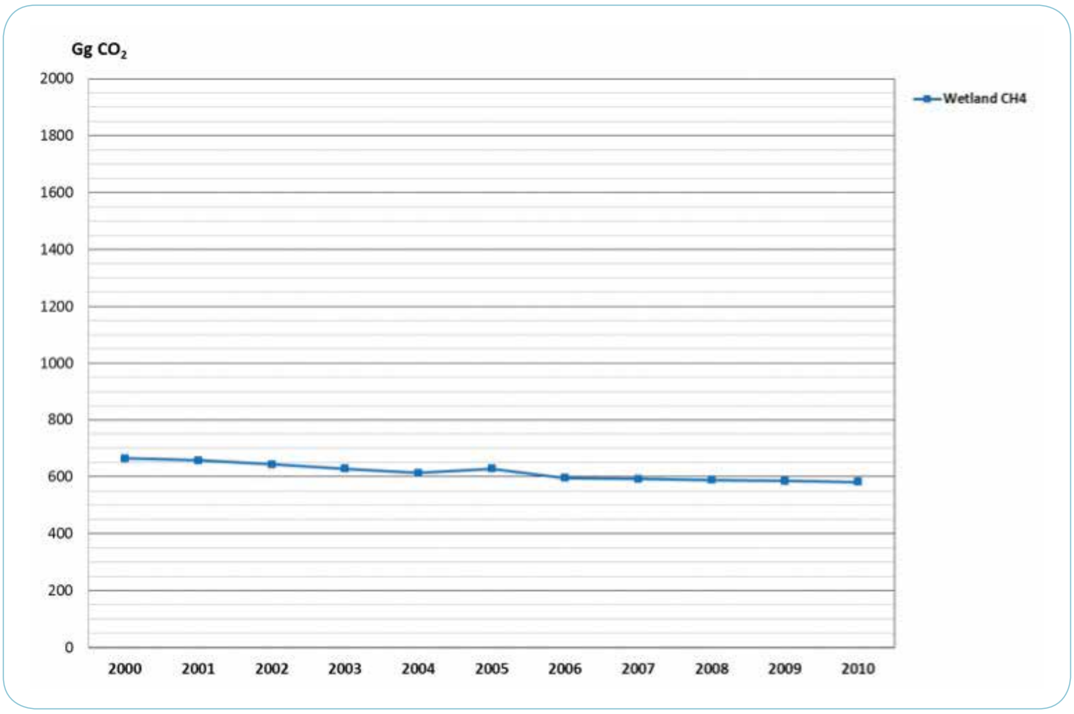

Figure 5.19: Sector 3 AFOLU – Land: Trend in CH_4 emissions (in Gg CO_2eq) in wetlands between 2000 and 2010.

5.4.10.2 Methodological issues

CH_4 emissions from wetlands were calculated as in the previous inventory following the equation:

CH_4 $emissions_{WWFlood} = P * E(CH_4)_{diff} * A * 10^{-6}$
(Eq.5. 23)

Where:

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

5.4.10.3 Data sources

As in the previous inventory it was assumed that the area of flooded land is the same as the area of waterbodies. This provides an overestimate as water bodies include rivers, lakes and lagoons and Otter and Scholes (2000) showed that emissions only occur from shallow water. This can be adjusted in future inventories when more data becomes available. The area of waterbodies was taken from the GeoTerraImage (2013) land use maps. For South Africa the ice-free period is taken as 365 days. The emission factor ($E(CH_4)_{diff}$) was selected to be a median average for the warm temperate dry climate values provided in Table 3.A2 (IPCC 2006, vol 3). This emission factor is the lowest of all climates and therefore provides a conservative estimate.

5.4.10.4 Uncertainty and time-series consistency

5.4.10.4.1 Uncertainties

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

5.4.10.4.2 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.

5.4.10.5 Source-specific recalculations

The 2000 emissions were recalculated using the updated wetland area.

5.4.10.6 Source-specific planned improvements and recommendations

It is planned that the next inventory will included an adjusted area for flooded lands (so that it represents flooded lands only and not all waterbodies), as well as provide a CO_2 emission estimate for land converted to flooded land.

5.4.11 Settlements [3B5]

5.4.11.1 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 was just under 50 million (Statistics South Africa, 2010), with the urban population increasing from 52% to 62% over the past two decades (DEA, 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.

This category assumes there are no emissions from *settlements remaining settlements*, but includes emissions and sinks from biomass and soil carbon pools for *land converted to settlements*. This category was found to be a source of CO_2, due to land conversions. Emissions increased from 889 Gg CO_2 in 2000 to 891 Gg CO_2 in 2004 (Figure 5.20). This then decreased to 271 Gg CO_2 in 2006 which then slowly increased again to 273 Gg CO_2 in 2010. Soils contributed between 0.6% and 3.4% between 2000 and 2010 (Figure 5.21).

5.4.11.2 Methodological issues

5.4.11.2.1 Biomass

Land converted to settlements

Annual change in biomass carbon stocks on land converted to settlements was estimated using equation 5.22 above.

5.4.11.2.2 Mineral soils

Land converted to settlements

Soil carbon sources and sinks were calculated as described in section 5.4.7.2.2.

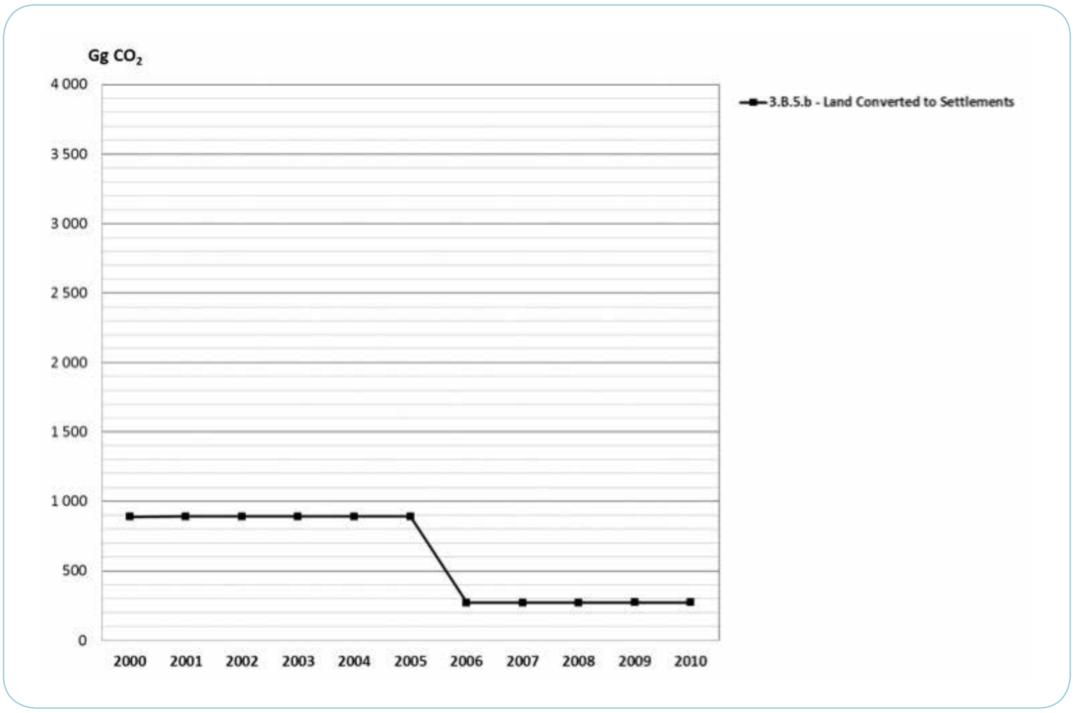

Figure 5.20: Sector 3 AFOLU – Land: Trend in emissions and sinks (in Gg CO_2) in settlements between 2000 and 2010, differentiated by sub-category.

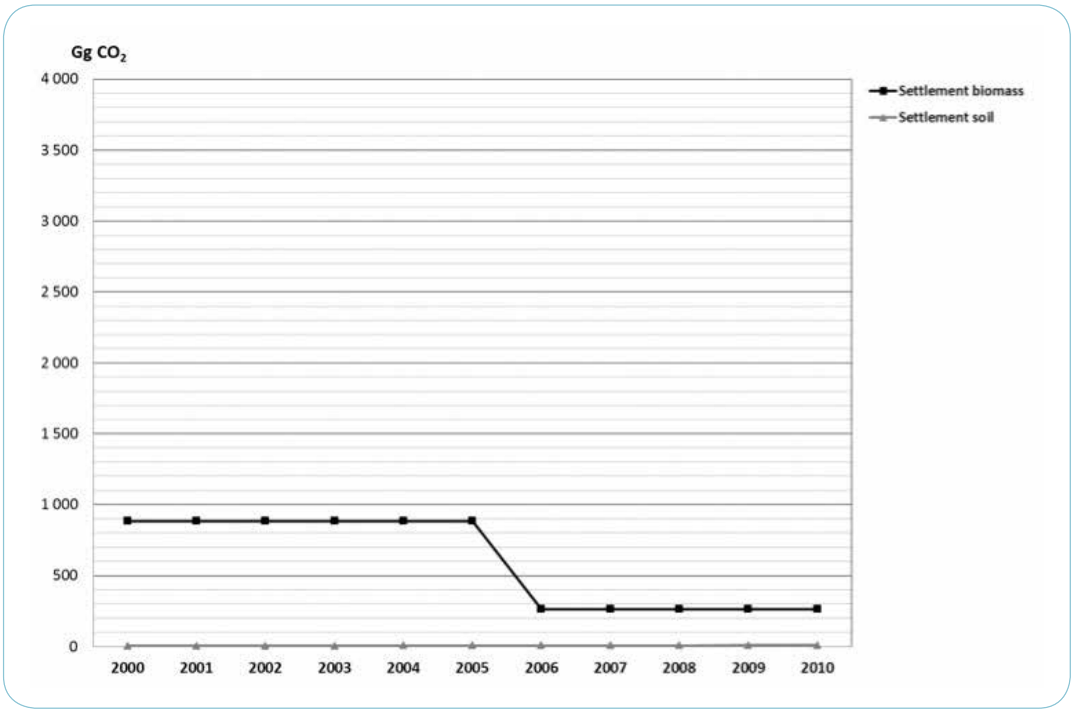

Figure 5.21: Sector 3 AFOLU – Land: Trend in emissions and sinks (in Gg CO_2) in settlements between 2000 and 2010, differentiated by source category.

5.4.11.3 Data sources

5.4.11.3.1 Biomass

The area of Land converted to settlements was obtained from the updated land use maps developed by GeoTerraImage (2013) and are discussed in detail in section 5.4.5. Biomass carbon stocks before conversion for forest land are given in Table 5.14, and for Croplands the data is provided in section 5.4.9.3.1. Tier 1 method assumes that all biomass is cleared when preparing a site for settlements, thus the default for biomass immediately after conversion is zero. It is also assumed that there is no additional growth or loss of carbon on the land after it becomes a settlement.

5.4.11.3.2 Mineral soils

The land areas for the various categories was obtained from the land-use change maps (GeoTerraImage, 2013) and described in section 5.4.4. For *land converted to settlements* the land area includes all converted land since 1990. All other data is described in section 5.4.7.3.2.

5.4.11.4 Uncertainties and time-series consistency

5.4.11.4.1 Uncertainties

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

5.4.11.4.2 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.

5.4.11.5 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). Land use change and activity data was compared to the literature and other data sources where possible; otherwise no other source-specific QA/QC procedures were carried out on this sub-category.

5.4.11.6 Source-specific recalculations

No recalculations were necessary as no data was provided for this category in the previous inventory.

5.4.11.7 Category-specific planned improvements and recommendations

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 Source category description

Other land includes bare soil, rock, and all other land areas that do not fall into the other land classes (including Nama karoo and Succulent karoo biomes). Since, by definition, the areas in this category consist of areas that are not managed, the sizes of such areas are included solely for the purpose of completing the area matrix. The Tier 1 method assumes no change in carbon stocks in this category, so growth and loss are in balance and no emissions are reported. Generally carbon stock changes on *land converted to other lands* is not reported as it is assumed that once a land use has taken place it cannot be converted back to an "unused" state. The IPCC guidelines do, however, indicate that emissions and removals from other lands should be estimated following conversion (by following Eq. 5.22 given above) as these changes could be a result of deforestation and degradation.

The land use change matrix in this inventory indicates that there is conversion to other lands. Due to the inclusion of Nama karoo and succulent karoo in *other lands*, it means that B_{AFTER} in Eq. 5.22 is not necessarily zero. Using zero may lead to an overestimate of carbon losses. In this inventory the carbon losses and gains for *land converted to other lands* have not yet been estimated due to an incomplete data set. Data is currently being collected for Nama and succulent karoo so that estimates for *land converted to other land* can be included in the next inventory.

5.4.12.2 Uncertainties and time-series consistency

5.4.12.2.1 Uncertainties

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

5.4.12.2.2Time-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 QA/QC and verification

The land area in the land cover maps were compared to other data sets (section 5.4.5.4). No source-specific QA/QC procedures were carried out on this sub-category.

5.4.12.4 Source-specific recalculations

No recalculations were necessary.

5.4.12.5 Category-specific planned improvements and recommendations

There are plans to obtain more data for lands being converted to other lands, and new, higher resolution land use change maps are being developed. Therefore, it is planned that carbon losses and gains for land converted to other land will be included in the next inventory.

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 251 460 Gg CO_2 eq over the 10 year period. This fluctuated between a low of 22 040 Gg CO_2eq in 2005 and a high of 23 594 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. Direct N_2O emissions from managed soil were the biggest contributor to this category, producing between 65.6% (2010) and 68.1% (2000) of the total annual aggregated and non-CO_2 emissions. This was followed by indirect N_2O emissions from managed soils (19.6% - 20.1%) and biomass burning (7.9% - 9.2%) (Figure 5.22).

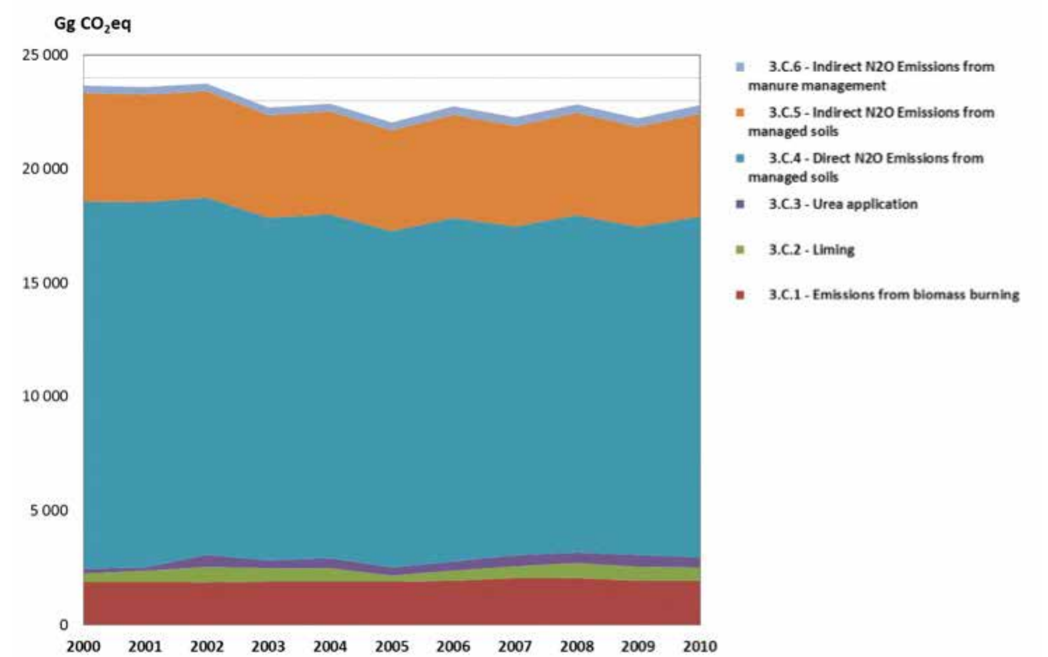

Figure 5.22: Sector 3 AFOLU – Aggregated and non-CO_2 sources: Trend and emission levels, 2000 – 2010.

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 (DEAT, 2009) fire plays an important role in South African biomes where grassland, savanna and fynbos fires maintain ecological health. 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 (DEAT, 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 savanna 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 annual 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 these categories.

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 1 867 Gg CO_2 eq (2002) and 2 054 Gg CO_2eq (2008) to the overall emissions in the AFOLU sector. Of this about 63% was CH_4 and 37% N_2O. Grasslands contributed the most to biomass burning emissions (50.8% - 54.2%), followed by Forest lands (28.9% - 34.1%) and then Croplands contributing around 14.6% (Figure 5.23). In the previous inventory (DEAT, 2009) Grasslands contributed about 68% and Forest lands 28%, compared to the 53.2% and 31.0%, 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. This 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.

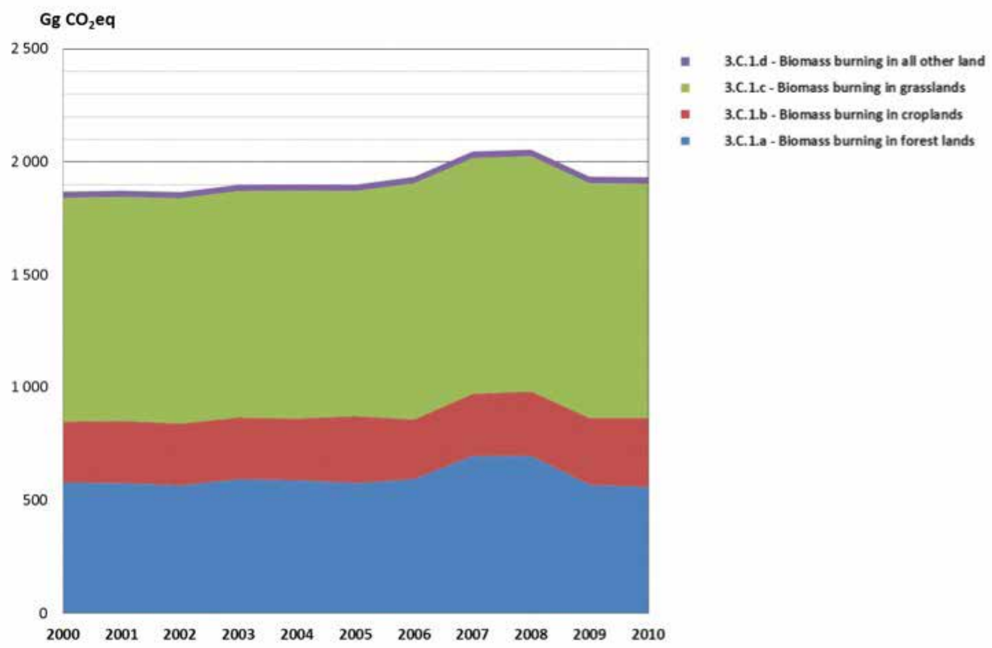

Figure 5.23: Sector 3 AFOLU – Biomass burning: Contribution of the various land categories to the biomass burning emissions, 2000 – 2010.

5.5.2.3 Methodological issues

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):

$$L_{fire} = A * M_B * Cf * G_{ef} * 10^{-3}$$
(Eq.5. 24)

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)

5.5.2.4 Data sources

5.5.2.4.1 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 (Forestry South Africa, 2012) 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 (DEAT, 2009) this was corrected for. Similarly for the categories settlements and waterbodies. All the burnt area from these categories were subtracted from these categories and added equally to the Grassland and Woodland/savanna category. The Other land burnt area was split between the Grassland, Woodland/savanna and Fynbos categories. The resultant burnt area for each land class is shown in Table 5.15. Since the land cover maps were not for individual years the percentage area burnt for each category was averaged over the period 2000 to 2004 and 2005 to 2010, and then these averages were applied to each year in the respective time periods.

Table 5.15: Sector 3 AFOLU – Biomass burning: Burnt area (ha) and the average % area burnt, 2000 – 2004.

	2000	2001	2002	2003	2004	Average % area burnt
Indigenous forest	0	0	0	0	0	0
Thicket	0	0	0	0	0	0
Woodland / Savanna	1 406 673	1 987 400	1 719 003	809 809	1 110 920	4.03
Plantations	20 221	17 266	16 727	28 983	28 326	1.66
Annual crops	380 100	389 300	447 700	319 000	309 600	6.25
Orchard	1 300	2 200	2 000	1 400	1 100	0.98
Viticulture	2 100	900	900	1 200	200	0.44
Annual semi-commercial / subsistence crops	63 600	110 300	75 600	58 500	60 700	12.14
Sugarcane	1 500	2 500	3 100	3 900	2 500	1.19
Settlements	0	0	0	0	0	0
Wetlands	67 300	80 500	90 600	58 300	66 900	6.94
Grasslands	2 463 473	2 630 200	2 833 503	2 373 709	1 904 020	10.04
Water bodies	0	0	0	0	0	0
Fynbos	54 333	38 733	88 367	67 200	52 033	1.05
Nama Karoo	8 200	5 000	7 900	14 700	8 400	0.08
Succulent Karoo	0	100	0	100	0	0
Other lands	0	0	0	0	0	0

	2005	2006	2007	2008	2009	2010	Average % area burnt
Indigenous forest	0	0	0	0	0	0	0.00
Thicket	0	0	0	0	0	0	0.00
Woodland / Savanna	1 909 878	1 573 503	1 036 068	1 681 044	1 140 698	1 987 144	4.08
Plantations	22 445	28 895	70 697	70 812	19 805	15 812	3.25
Annual crops	475 500	486 800	279 500	323 700	324 700	395 200	5.49
Orchard	2 000	2 000	2 900	3 900	1 800	3 700	1.58
Viticulture	900	1 700	700	200	1 400	600	0.39
Annual semi-commercial / subsistence crops	116 000	98 100	139 400	104 400	113 800	155 800	14.22
Sugarcane	5 500	2 900	3 800	6 100	4 300	7 800	1.62
Settlements	0	0	0	0	0	0	0.00
Wetlands	102 500	100 200	63 200	79 100	80 200	89 300	7.24
Grasslands	2 983 478	2 694 303	2 700 568	2 262 844	2 469 298	2 682 344	10.07
Water bodies	0	0	0	0	0	0	0
Fynbos	69 200	48 200	58 067	70 700	128 100	82 900	1.32
Nama Karoo	8 400	2 400	9 100	16 500	6 100	15 300	0.11
Succulent Karoo	0	0	0	600	0	1 300	0.01
Other lands	0	0	0	0	0	0	0

5.5.2.4.2 Mass of fuel available for combustion

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

5.5.2.4.3 Combustion factor

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

5.5.2.4.4 Emission factors

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

5.5.2.5 Uncertainty and time-series consistency

5.5.2.5.1 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 (DEAT, 2009) still applies to this data set.

5.5.2.5.2 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 (DEAT, 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. 16: Sector 3 AFOLU – Biomass burning: Comparison of burnt area percentage (mean with SD in brackets) with previous inventory, 2000 – 2007.

Vegetation class	Burnt area (%)	
	DEAT (2009)	This inventory
Arid shrubland	0.02 (0.01)	0.04 (0.05)
Plantations	1.71 (0.42)	2.22 (1.41)
Fynbos	0.93 (0.26)	1.01 (0.26)
Grassland	8.79 (1.12)	10.17 (1.29)
Savanna	3.8 (1.07)	3.92 (1.16)
Wetlands	3.57 (0.62)	7.01 (1.51)

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.

An independent reviewer was appointed to assess the quality of the inventory, determine the conformity of the procedures which were followed for the compilation of this inventory and to identify areas of improvements.

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 specific planned improvements for this category; however there are plans to develop higher resolution land use maps. These could be overlaid with the appropriate burnt area data to improve estimates for those years. Higher resolution land use maps will reduce the need for corrections.

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 5.24). The variation was directly linked to the limestone and dolomite consumption (Figure 5.25). The CO_2 emissions from Urea application showed a similar annual variability (Figure 5.24). 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 Methodological issues

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).

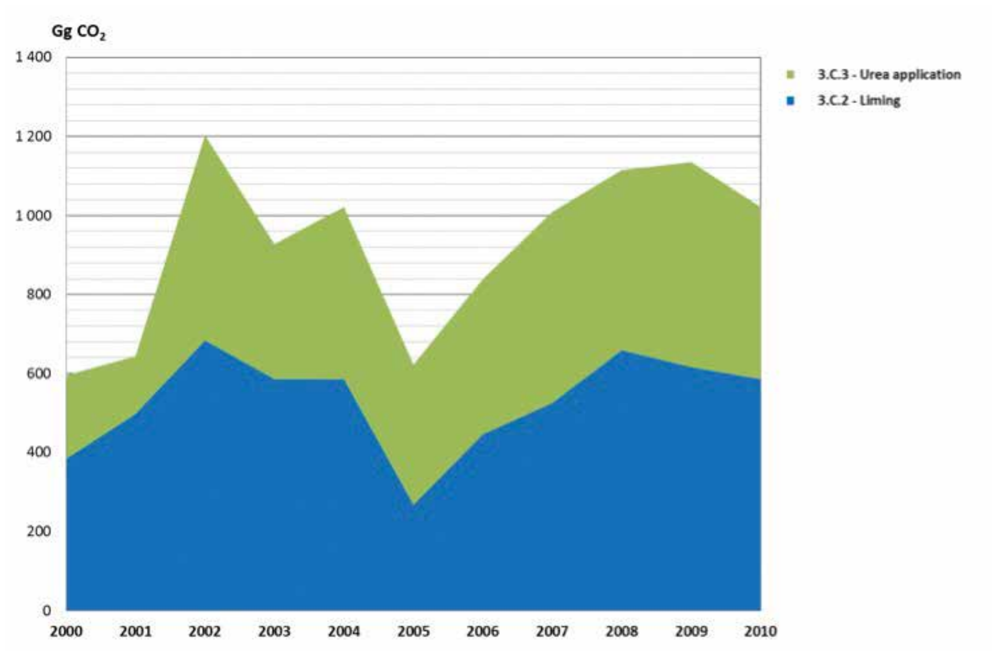

Figure 5.24: Sector 3 AFOLU – Aggregated sources: Trends and emission levels from liming and urea application, 2000 – 2010.

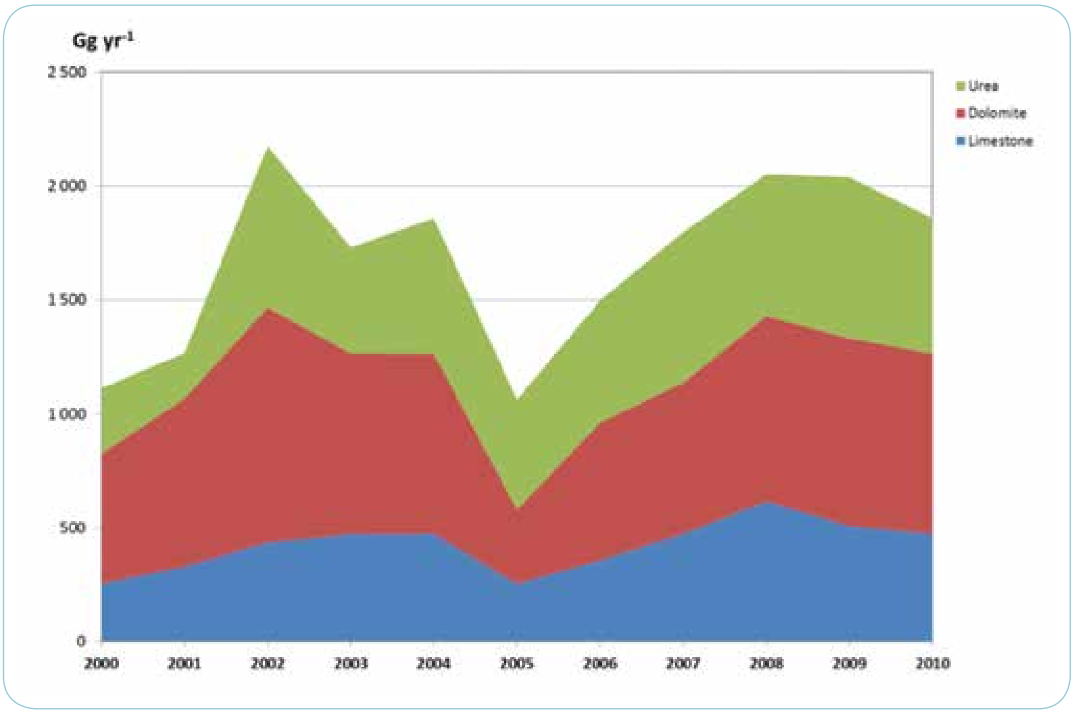

Figure 5.25: Sector 3 AFOLU – Aggregated sources: Annual amount of lime and urea applied to soils, 2000 – 2010.

5.5.3.4 Data sources

The amount of limestone and dolomite applied was obtained from the Fertilizer Society of South Africa (http://www.fssa.org.za/Statistics.html) (Table 5.17). Data for 2010 was not available so an amount was estimated by linear extrapolation of data from previous years. 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). This is probably an overestimate, so alternative data sources should be sought in future inventories.

Table 5.17: Limestone, dolomite and urea use between 2000 – 2010 (source: Fertilizer Society of SA; FAOSTAT).

Year	Amount used (t yr⁻¹)		
	Limestone	**Dolomite**	**Urea**
2000	254 116	571 136	288 400
2001	329 996	738 361	200 000
2002	436 743	1 031 172	707 333
2003	473 006	792 736	465 847
2004	474 215	790 673	594 404
2005	253 606	326 898	483 833
2006	357 970	605 148	536 022
2007	474 753	662 893	660 756
2008	616 844	812 959	621 732
2009	508 526	823 382	707 304
2010	487 816	667 564	745 577

5.5.3.4.1 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

5.5.3.5.1 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).

5.5.3.5.2 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 166 359 Gg CO_2eq between 2000 and 2010. Emissions fluctuated annually with 2000 having the highest and 2009 the lowest emissions of 14 387 Gg CO_2eq (Figure 5.26). The variation was due mainly to the fluctuation in manure synthetic fertilizer inputs, while emissions from compost, 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 urine and dung deposited in pasture, range and paddocks which contributed between 80.3% and 83.2% over the 10 year period.

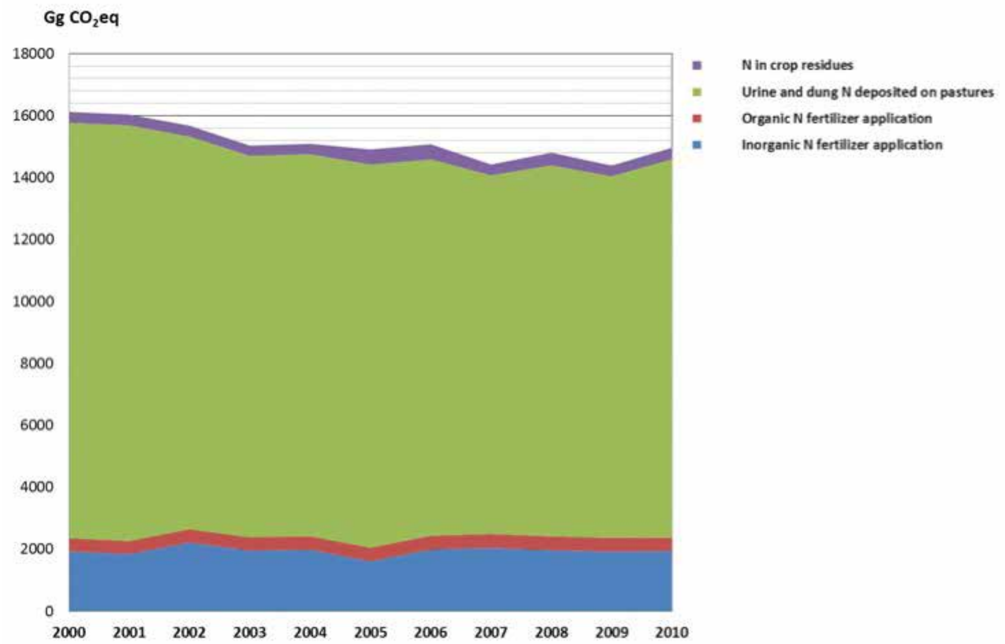

Figure 5.26: Sector 3 AFOLU – Direct N_2O: Trend and emission levels of direct N_2O from managed soils, 2000 – 2010.

5.5.4.3 Methodological issues

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:

$$N_2O_{Direct}\text{-}N = N_2O\text{-}N_{N\ inputs} + N_2O\text{-}N_{PRP}$$
(Eq.5. 25)

Where:

$$N_2O\text{-}N_{N\ inputs} = [(F_{SN} + F_{ON} + F_{CR}) * EF_1]$$
(Eq.5. 26)

$$N_2O\text{-}N_{PRP} = [(F_{PRP,CPP} * EF_{3PRP,CPP}) + (F_{PRP,SO} * EF_{3PRP,SO})]$$
(Eq.5. 27)

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.

5.5.4.3.1 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.

5.5.4.3.2 *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 Data sources

5.5.4.4.1 *Synthetic fertilizer inputs (F_{SN})*

National consumption data for N fertilizer was obtained from the Fertilizer Society of South Africa (http://www.fssa.org.za).

5.5.4.4.2 *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) and Otter (2011)).

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) and outputs are given in Otter (2011).

5.5.4.4.3 *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).

5.5.4.4.4 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.

5.5.4.4.5 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).

5.5.4.5 Uncertainty and time-series consistency

5.5.4.5.1 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.

5.5.4.5.2 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.

5.5.4.6 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. An independent reviewer was appointed to assess the quality of the inventory, determine the conformity of the procedures which were followed for the compilation of this inventory and to identify areas of improvements.

5.5.4.7 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.

5.5.4.8 Source-specific planned improvements and recommendations

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. It is therefore very important for South Africa to determine country specific EFs for these emissions instead of using the IPCC default values. Furthermore, 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 the emission estimates in this category.

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 49 851 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 7.3% and losses due to leaching and runoff declining by 6.3% (Figure 5.27). Indirect N_2O losses due to leaching and runoff accounted for 56.3% of the indirect emissions.

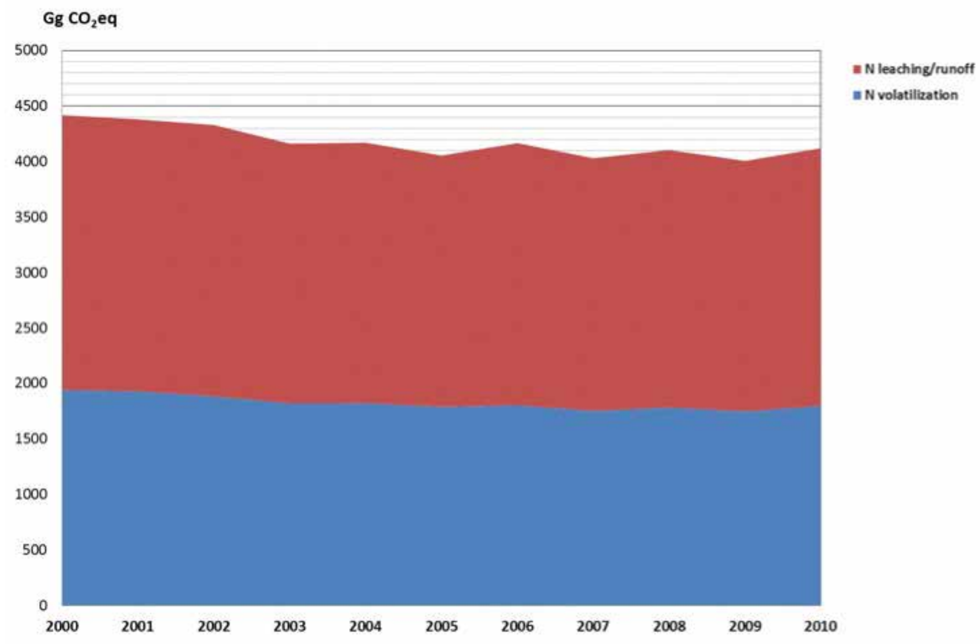

Figure 5.27: Sector 3 AFOLU – Indirect N_2O: Trend and emission level estimates of indirect N_2O losses from managed soils, 2000 – 2010.

5.5.5.3 Methodological issues

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).

5.5.5.4 Data sources

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).

5.5.5.5 Uncertainty and time-series consistency

5.5.5.5.1 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).

5.5.5.5.2 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 (DEAT, 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 3 910 Gg CO_2eq between 2000 and 2010. The annual variation was low and there was an increasing trend from 328 Gg CO_2eq in 2000 to 382 Gg CO_2eq in 2010 (Table 5.18).

Table 5.18: 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	328	331	335	336	339	354	367	379	379	381	382

5.5.6.3 Methodological issues

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 5.19).

5.5.6.4.1 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 5.19: 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

5.5.6.5.1 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 5.18) and uncertainty on manure management system usage. The uncertainty range on EF_4 is 0.002 – 0.05 (IPCC 2006 guidelines, Table 11.3).

5.5.6.5.2 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. An independent reviewer was appointed to assess the quality of the inventory, determine the conformity of the procedures which were followed for the compilation of this inventory and to identify areas of improvements.

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 and recommendations

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.

5.5.7 Harvested wood products

5.5.7.1 Source category description

Much of the wood that is harvested from Forest land, Cropland and other land types remains in products for differing lengths of time. This section of the report estimates the contribution of these harvested wood products (HWP) to annual CO_2 emissions or removals. HWP include all wood material that leaves harvest sites.

5.5.7.2 Overview of shares and trends in emissions

HWPs were estimated to be a sink of CO_2 which fluctuated annually between 2000 and 2010. The total accumulated sink over the 10 years was estimated at 81 018 Gg CO_2. The sink increased by 62.8% between 2000 and 2004 to 9 419 Gg CO_2. There was an overall decrease of 46.7% between 2004 and 2009 (although there was an increase in 2007) to 5 024 Gg CO_2 (Table 5.20). In 2010 the sink increased slightly to 6 205 Gg CO_2.

Table 5.20: Sector 3 AFOLU – HWP: Trend in the HWP CO_2 sink (Gg) between 2000 and 2010.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
HWP	5 786	6 389	7 338	9 373	9 419	8 037	7 538	8 128	7 782	5 025	6 205

5.5.7.3 Methodological issues

The IPCC Harvested Wood Product Model, with the Simple Decay Approach, was used to estimate the contribution from HWP.

5.5.7.4 Data sources

All the data on production, imports and exports of roundwood, sawnwood, wood-based panels, paper and paperboard, wood pulp and recycled paper, industrial roundwood, chips and particles, wood charcoal and wood residues were obtained from the FAOSTAT database (http://faostat.fao.org/). Most data was available since 1960, but there were some gaps. The export of wood chips was only available from 1985; imports of wood charcoal and imports and exports of wood residues were only available from 1990. For the purpose of this inventory the initial values in these categories was assumed to be zero.

5.5.7.5 Uncertainty and time-series consistency

Uncertainties for activity data and parameters associated with HWP variables are provided in the IPCC Guidelines (IPCC 2006, vol 4, pg. 12.22).

5.5.7.6 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.

5.5.7.7 Source-specific recalculations

No recalculations were necessary as HWP was not included in the previous inventory.

5.5.7.8 Source-specific planned improvements and recommendations

It is planned, under a project in the GHG Inventory Improvement Programme, that the data extrapolation methods for filling gaps in activity data will be investigated. The project aims to extrapolate the existing data back to 1960 for all data sets, thereby improving the HWP sink estimate.

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 (DEAT, 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.

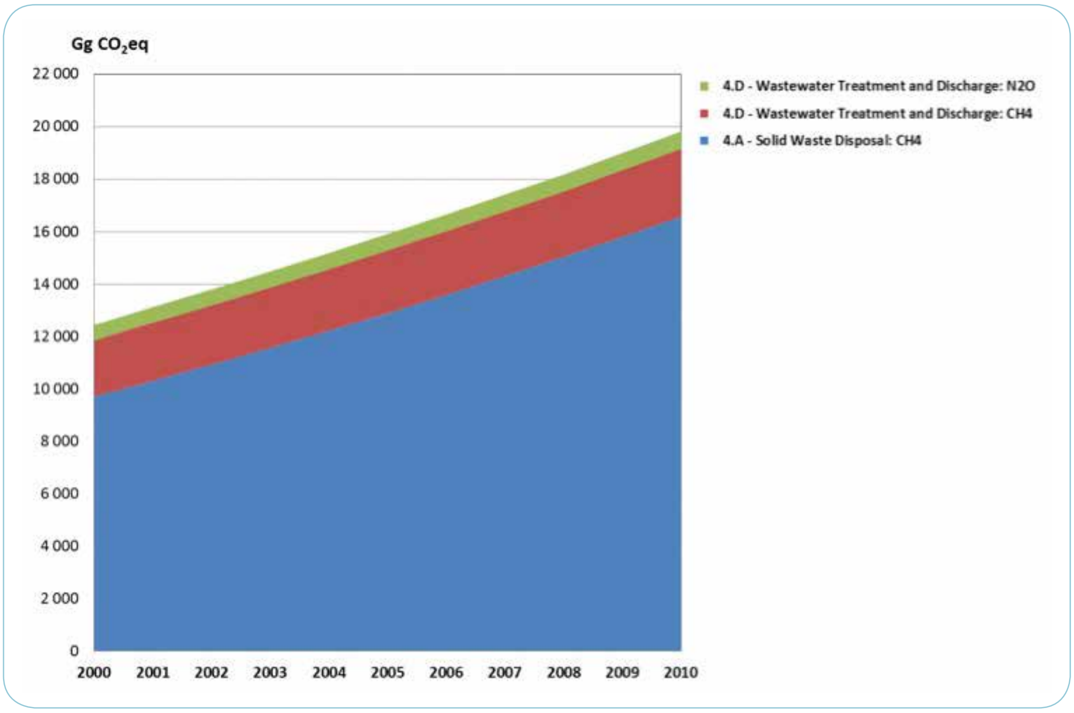

Figure 6.1: Sector 4 Waste: Trends and emission levels of source categories, 2000 – 2010.

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 (DEAT 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 Methodological issues and data sources

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 (DEAT, 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 Statistics SA datasets and DEA's waste baseline study.

An independent reviewer was appointed to assess the quality of the inventory, determine the conformity of the procedures which were followed for the compilation of this inventory and to identify areas of improvements.

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 and recommendations

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 Methodological issues and data sources

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 (DEAT, 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 (DEAT, 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, 2012), 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: DEAT, 2009).

Type of treatment or discharge	Maximum CH_4 producing capacity (BOD)	CH_4 correction factor for each treatment system	Emission factor
	(kg CH_4/kg BOD)	(MCF)	(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: DEAT, 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 and recommendations

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.

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8. APPENDIX A: SUMMARY TABLES

INVENTORY YEAR: 2000	Emissions/removals (Gg CO_2eq)					
Categories	Net CO_2	CH_4	N_2O	HFCs	PFCs	Total
Total including FOLU	350 647.17	46 532.31	27 057.67	0.00	982.24	425 219.38
Total excluding FOLU	375 590.19	45 867.60	27 057.67	0.00	982.24	449 497.69
1 - Energy	332 715.48	2 580.37	2 085.79			337 381.63
1.A - Fuel Combustion Activities	305 708.25	566.56	2 085.79			308 360.60
1.A.1 - Energy Industries	218 636.14	58.27	964.09			219 658.51
1.A.2 - Manufacturing Industries and Construction	32 505.42	8.93	138.17			32 652.52
1.A.3 - Transport	35 214.80	270.27	531.12			36 016.18
1.A.4 - Other Sectors	18 366.30	228.11	449.88			19 044.30
1.A.5 - Non-Specified	985.58	0.98	2.53			989.09
1.B - Fugitive emissions from fuels	27 007.23	2 013.80				29 021.03
1.B.1 - Solid Fuels	23.67	1 978.88				2 002.55
1.B.2 - Oil and Natural Gas	325.00					325.00
1.B.3 - Other emissions from Energy Production	26 658.56	34.92				26 693.48
2 - Industrial Processes and Product Use	42 279.16	75.50	1 570.25		982.24	44 907.14
2.A - Mineral Industry	3 847.80					3 847.80
2.A.1 - Cement production	3 347.05					3 347.05
2.A.2 - Lime production	426.37					426.37
2.A.3 - Glass Production	74.38					74.38
2.B - Chemical Industry	1 063.45	71.88	1 570.25			2 705.58
2.C - Metal Industry	37 171.99	3.62			982.24	38 157.84
2.C.1 - Iron and Steel Production	27 753.86					27 753.86
2.C.2 - Ferroalloys Production	8 079.14	3.62				8 082.76
2.C.3 - Aluminium production	1 105.47				982.24	2 087.71
2.C.4 - Magnesium production						
2.C.5 - Lead Production	39.16					39.16
2.C.6 - Zinc Production	194.36					194.36
2.D - Non-Energy Products from Fuels and Solvent Use	195.92					195.92
2.D.1 - Lubricant Use	188.48					188.48
2.D.2 - Paraffin Wax Use	7.44					7.44
2.F - Product Uses as Substitutes for ODS				0		
3 - Agriculture, Forestry, and Other Land Use	-24 347.47	32 032.87	22 811.28			30 496.68
3.A - Livestock		30 205.89	912.73			31 118.62
3.A.1 - Enteric Fermentation		29 307.55				29 307.55

INVENTORY YEAR: 2000	Emissions/removals (Gg CO_2eq)					
Categories	Net CO_2	CH_4	N_2O	HFCs	PFCs	Total
3.A.2 - Manure Management		898.34	912.73			1 811.07
3.B - Land	-19 157.47	664.71				-18 492.76
3.B.1 - Forest land	-48 039.97					-48 039.97
3.B.2 - Cropland	610.97					610.97
3.B.3 - Grassland	27 382.57					27 382.57
3.B.4 - Wetlands		664.71				664.71
3.B.5 - Settlements	888.97					888.97
3.C - Aggregate sources and non-CO2 emissions sources on land	595.55	1 162.27	21 898.55			23 656.37
3.C.1 - Emissions from biomass burning		1 162.27	705.97			1 868.25
3.C.2 - Liming	384.05					384.05
3.C.3 - Urea application	211.49					211.49
3.C.4 - Direct N2O Emissions from managed soils			16 118.85			16 118.85
3.C.5 - Indirect N2O Emissions from managed soils			4 745.81			4 745.81
3.C.6 - Indirect N2O Emissions from manure management			327.91			327.91
3.D - Other	-5 785.55					-5 785.55
3.D.1 - Harvested Wood Products	-5 785.55					-5 785.55
4 - Waste		11 843.57	590.35			12 433.93
4.A - Solid Waste Disposal		9 704.23				9 704.23
4.D - Wastewater Treatment and Discharge		2 139.35	590.35			2 729.70
Memo Items (5)						
International Bunkers	2 972.40	2.87	7.38			2 982.65
1.A.3.a.i - International Aviation (International Bunkers)	2 972.40	2.87	7.38			2 982.65
1.A.3.d.i - International water-borne navigation (International bunkers)						
1.A.5.c - Multilateral Operations						

INVENTORY YEAR: 2001	Emissions/removals (Gg CO_2eq)					
Categories	Net CO_2	CH_4	N_2O	HFCs	PFCs	Total
Total including FOLU	350 586.71	47 250.09	26 903.43		1 008.22	425 748.45
Total excluding FOLU	376 152.70	46 592.61	26 903.43		1 008.22	450 656.96
1 - Energy	332 632.93	2 568.34	2 098.93			337 300.20
1.A - Fuel Combustion Activities	306 128.57	566.95	2 098.93			308 794.45
1.A.1 - Energy Industries	215 837.97	58.68	946.29			216 842.94
1.A.2 - Manufacturing Industries and Construction	32 036.37	8.88	135.46			32 180.71
1.A.3 - Transport	35 448.67	269.24	533.67			36 251.59
1.A.4 - Other Sectors	21 825.31	229.17	481.00			22 535.48
1.A.5 - Non-Specified	980.25	0.98	2.51			983.74
1.B - Fugitive emissions from fuels	26 504.35	2 001.39				28 505.74
1.B.1 - Solid Fuels	23.35	1 966.46				1 989.81
1.B.2 - Oil and Natural Gas	250.00					250.00
1.B.3 - Other emissions from Energy Production	26 231.00	34.93				26 265.93
2 - Industrial Processes and Product Use	42 875.96	75.72	1 512.39		1 008.22	44 464.06
2.A - Mineral Industry	3 910.28					3 910.28
2.A.1 - Cement production	3 406.88					3 406.88
2.A.2 - Lime production	419.01					419.01
2.A.3 - Glass Production	84.39					84.39
2.B - Chemical Industry	1 065.31	72.16	1 512.39			2 649.85
2.C - Metal Industry	37 674.40	3.56			1 008.22	37 677.96
2.C.1 - Iron and Steel Production	28 145.77					28 145.77
2.C.2 - Ferroalloys Production	8 195.95	3.56				8 199.51
2.C.3 - Aluminium production	1 116.55				1 008.22	1 116.55
2.C.4 - Magnesium production						
2.C.5 - Lead Production	26.94					26.94
2.C.6 - Zinc Production	189.20					189.20
2.D - Non-Energy Products from Fuels and Solvent Use	225.97					225.97
2.D.1 - Lubricant Use	221.36					221.36
2.D.2 - Paraffin Wax Use	4.61					4.61
2.F - Product Uses as Substitutes for ODS						
3 - Agriculture, Forestry, and Other Land Use	-24 922.18	32 075.91	22 700.21			29 853.94
3.A - Livestock		30 252.59	916.16			31 168.74
3.A.1 - Enteric Fermentation		29 343.15				29 343.15
3.A.2 - Manure Management		909.44	916.16			1 825.59

INVENTORY YEAR: 2001	Emissions/removals (Gg CO_2eq)					
Categories	Net CO_2	CH_4	N_2O	HFCs	PFCs	Total
3.B - Land	-19 176.78	657.48				-18 519.29
3.B.1 - Forest land	-47 967.15					-47 967.15
3.B.2 - Cropland	386.11					386.11
3.B.3 - Grassland	27 514.88					27 514.88
3.B.4 - Wetlands		657.48				657.48
3.B.5 - Settlements	889.38					889.38
3.C - Aggregate sources and non-CO2 emissions sources on land	643.82	1 165.84	21 784.05			23 593.71
3.C.1 - Emissions from biomass burning		1 165.84	706.95			1 872.79
3.C.2 - Liming	497.15					497.15
3.C.3 - Urea application	146.67					146.67
3.C.4 - Direct N2O Emissions from managed soils			16 034.83			16 034.83
3.C.5 - Indirect N2O Emissions from managed soils			4 711.56			4 711.56
3.C.6 - Indirect N2O Emissions from manure management			330.72			330.72
3.D - Other	-6 389.22					-6 389.22
3.D.1 - Harvested Wood Products	-6 389.22					-6 389.22
4 - Waste		12 530.12	591.90			13 122.02
4.A - Solid Waste Disposal		10 303.43				10 303.43
4.D - Wastewater Treatment and Discharge		2 226.69	591.90			2 818.60
Memo Items (5)						
International Bunkers	2 708.42	2.61	6.73			2 717.76
1.A.3.a.i - International Aviation (International Bunkers)	2 708.42	2.61	6.73			2 717.76
1.A.3.d.i - International water-borne navigation (International bunkers)						
1.A.5.c - Multilateral Operations						

INVENTORY YEAR: 2002	Emissions/removals (Gg CO_2eq)					
Categories	Net CO_2	CH_4	N_2O	HFCs	PFCs	Total
Total including FOLU	361 601.19	46 075.13	26 576.30		898.28	435 150.89
Total excluding FOLU	387 333.07	45 432.35	26 576.30		898.28	460 240.00
1 - Energy	341 194.18	2 540.51	2 157.47			345 892.16
1.A - Fuel Combustion Activities	314 303.70	567.32	2 157.47			317 028.48
1.A.1 - Energy Industries	219 115.77	57.24	966.51			220 139.52
1.A.2 - Manufacturing Industries and Construction	33 239.84	9.24	140.40			33 389.48
1.A.3 - Transport	36 050.18	269.83	540.11			36 860.12
1.A.4 - Other Sectors	24 918.15	230.04	507.93			25 656.11
1.A.5 - Non-Specified	979.76	0.98	2.51			983.25
1.B - Fugitive emissions from fuels	26 890.48	1 973.20				28 863.67
1.B.1 - Solid Fuels	23.02	1 938.08				1 961.10
1.B.2 - Oil and Natural Gas	196.00					196.00
1.B.3 - Other emissions from Energy Production	26 671.46	35.12				26 706.58
2 - Industrial Processes and Product Use	44 936.49	72.97	1 508.05		898.28	46 517.50
2.A - Mineral Industry	3 901.62					3 901.62
2.A.1 - Cement production	3 354.65					3 354.65
2.A.2 - Lime production	458.64					458.64
2.A.3 - Glass Production	88.33					88.33
2.B - Chemical Industry	1 102.00	68.53	1 508.05			2 678.59
2.C - Metal Industry	39 682.55	4.43			898.28	39 686.98
2.C.1 - Iron and Steel Production	29 321.26					29 321.26
2.C.2 - Ferroalloys Production	8 970.27	4.43				8 974.70
2.C.3 - Aluminium production	1 170.97				898.28	1 170.97
2.C.4 - Magnesium production						
2.C.5 - Lead Production	25.69					25.69
2.C.6 - Zinc Production	194.36					194.36
2.D - Non-Energy Products from Fuels and Solvent Use	250.32					250.32
2.D.1 - Lubricant Use	242.89					242.89
2.D.2 - Paraffin Wax Use	7.42					7.42
2.F - Product Uses as Substitutes for ODS						
3 - Agriculture, Forestry, and Other Land Use	-24 529.48	30 272.93	22 310.55			28 054.01
3.A - Livestock		28 472.01	930.25			29 402.27
3.A.1 - Enteric Fermentation		27 578.99				27 578.99
3.A.2 - Manure Management		893.02	930.25			1 823.28

INVENTORY YEAR: 2002	Emissions/removals (Gg CO_2eq)					
Categories	Net CO_2	CH_4	N_2O	HFCs	PFCs	Total
3.B - Land	-18 393.89	642.77				-17 751.12
3.B.1 - Forest land	-47 092.70					-47 092.70
3.B.2 - Cropland	161.82					161.82
3.B.3 - Grassland	27 647.20					27 647.20
3.B.4 - Wetlands		642.77				642.77
3.B.5 - Settlements	889.79					889.79
3.C - Aggregate sources and non-CO2 emissions sources on land	1 202.40	1 158.15	21 380.30			23 740.85
3.C.1 - Emissions from biomass burning		1 158.15	708.34			1 866.49
3.C.2 - Liming	683.69					683.69
3.C.3 - Urea application	518.71					518.71
3.C.4 - Direct N2O Emissions from managed soils			15 673.49			15 673.49
3.C.5 - Indirect N2O Emissions from managed soils			4 663.78			4 663.78
3.C.6 - Indirect N2O Emissions from manure management			334.69			334.69
3.D - Other	-7 337.99					-7 337.99
3.D.1 - Harvested Wood Products	-7 337.99					-7 337.99
4 - Waste		13 188.71	600.22			13 788.94
4.A - Solid Waste Disposal		10 918.91				10 918.91
4.D - Wastewater Treatment and Discharge		2 269.81	600.22			2 870.03
Memo Items (5)						
International Bunkers	2 686.97	2.59	6.67			2 696.24
1.A.3.a.i - International Aviation (International Bunkers)	2 686.97	2.59	6.67			2 696.24
1.A.3.d.i - International water-borne navigation (International bunkers)						
1.A.5.c - Multilateral Operations						

INVENTORY YEAR: 2003	Emissions/removals (Gg CO_2eq)					
Categories	Net CO_2	CH_4	N_2O	HFCs	PFCs	Total
Total including FOLU	387 802.09	46 431.85	25 360.23	0.00	896.23	460 490.41
Total excluding FOLU	411 403.77	45 803.79	25 360.23	0.00	896.23	483 464.03
1 - Energy	364 719.09	2 822.60	2 292.51			369 834.20
1.A - Fuel Combustion Activities	338 467.27	586.61	2 292.51			341 346.39
1.A.1 - Energy Industries	236 697.43	62.02	1 049.75			237 809.20
1.A.2 - Manufacturing Industries and Construction	35 738.40	9.93	150.49			35 898.82
1.A.3 - Transport	37 825.84	279.15	558.09			38 663.08
1.A.4 - Other Sectors	27 194.38	234.49	531.59			27 960.47
1.A.5 - Non-Specified	1 011.23	1.01	2.59			1 014.82
1.B - Fugitive emissions from fuels	26 251.82	2 235.99				28 487.81
1.B.1 - Solid Fuels	24.85	2 092.96				2 117.81
1.B.2 - Oil and Natural Gas	1 065.00					1 065.00
1.B.3 - Other emissions from Energy Production	25 161.97	143.03				25 304.99
2 - Industrial Processes and Product Use	45 757.06	75.65	936.31		896.23	46 769.02
2.A - Mineral Industry	4 138.74					4 138.74
2.A.1 - Cement production	3 577.14					3 577.14
2.A.2 - Lime production	470.34					470.34
2.A.3 - Glass Production	91.26					91.26
2.B - Chemical Industry	1 123.51	71.20	936.31			2 131.02
2.C - Metal Industry	40 246.20	4.45			896.23	40 250.65
2.C.1 - Iron and Steel Production	29 692.63					29 692.63
2.C.2 - Ferroalloys Production	9 156.40	4.45				9 160.85
2.C.3 - Aluminium production	1 182.06				896.23	1 182.06
2.C.4 - Magnesium production						
2.C.5 - Lead Production	20.75					20.75
2.C.6 - Zinc Production	194.36					194.36
2.D - Non-Energy Products from Fuels and Solvent Use	248.61					248.61
2.D.1 - Lubricant Use	240.97					240.97
2.D.2 - Paraffin Wax Use	7.64					7.64
2.F - Product Uses as Substitutes for ODS						
3 - Agriculture, Forestry, and Other Land Use	-22 674.07	29 665.50	21 522.87			28 514.30
3.A - Livestock		27 848.14	948.51			28 796.65
3.A.1 - Enteric Fermentation		26 988.41				26 988.41

INVENTORY YEAR: 2003	Emissions/removals (Gg CO_2eq)					
Categories	Net CO_2	CH_4	N_2O	HFCs	PFCs	Total
3.A.2 - Manure Management		859.73	948.51			1 808.23
3.B - Land	-14 229.02	628.06				-13 600.96
3.B.1 - Forest land	-42 836.26					-42 836.26
3.B.2 - Cropland	-62.48					-62.48
3.B.3 - Grassland	27 779.51					27 779.51
3.B.4 - Wetlands		628.06				628.06
3.B.5 - Settlements	890.20					890.20
3.C - Aggregate sources and non-CO2 emissions sources on land	927.61	1 189.30	20 574.36			22 691.28
3.C.1 - Emissions from biomass burning		1 189.30	709.50			1 898.80
3.C.2 - Liming	585.99					585.99
3.C.3 - Urea application	341.62					341.62
3.C.4 - Direct N2O Emissions from managed soils			15 031.65			15 031.65
3.C.5 - Indirect N2O Emissions from managed soils			4 497.38			4 497.38
3.C.6 - Indirect N2O Emissions from manure management			335.83			335.83
3.D - Other	-9 372.66					-9 372.66
3.D.1 - Harvested Wood Products	-9 372.66					-9 372.66
4 - Waste		13 868.10	608.55			14 476.65
4.A - Solid Waste Disposal		11 553.94				11 553.94
4.D - Wastewater Treatment and Discharge		2 314.17	608.55			2 922.71
Memo Items (5)						
International Bunkers	2 584.15	2.49	6.42			2 593.07
1.A.3.a.i - International Aviation (International Bunkers)	2 584.15	2.49	6.42			2 593.07
1.A.3.d.i - International water-borne navigation (International bunkers)						
1.A.5.c - Multilateral Operations						

INVENTORY YEAR: 2004	Emissions/removals (Gg CO_2eq)					
Categories	Net CO_2	CH_4	N_2O	HFCs	PFCs	Total
Total including FOLU	408 121.64	47 118.67	25 815.28		888.40	481 943.98
Total excluding FOLU	428 414.09	46 505.32	25 815.28		888.40	501 623.08
1 - Energy	381 095.79	2 833.50	2 379.94			386 309.22
1.A - Fuel Combustion Activities	353 977.71	598.42	2 379.94			356 956.08
1.A.1 - Energy Industries	243 885.49	63.31	1 081.75			245 030.55
1.A.2 - Manufacturing Industries and Construction	37 708.14	10.46	159.08			37 877.67
1.A.3 - Transport	39 384.78	287.96	580.39			40 253.12
1.A.4 - Other Sectors	31 957.93	235.67	556.06			32 749.65
1.A.5 - Non-Specified	1 041.37	1.04	2.67			1 045.08
1.B - Fugitive emissions from fuels	27 118.07	2 235.07				29 353.15
1.B.1 - Solid Fuels	25.43	2 141.35				2 166.78
1.B.2 - Oil and Natural Gas	254.00					254.00
1.B.3 - Other emissions from Energy Production	26 838.64	93.73				26 932.37
2 - Industrial Processes and Product Use	46 296.86	79.51	1 207.03		888.40	47 583.40
2.A - Mineral Industry	4 433.53					4 433.53
2.A.1 - Cement production	3 850.38					3 850.38
2.A.2 - Lime production	487.24					487.24
2.A.3 - Glass Production	95.92					95.92
2.B - Chemical Industry	1 140.19	74.88	1 207.03			2 422.10
2.C - Metal Industry	40 476.96	4.63			888.40	40 481.59
2.C.1 - Iron and Steel Production	29 594.64					29 594.64
2.C.2 - Ferroalloys Production	9 282.69	4.63				9 287.32
2.C.3 - Aluminium production	1 387.49				888.40	1 387.49
2.C.4 - Magnesium production						
2.C.5 - Lead Production	19.50					19.50
2.C.6 - Zinc Production	192.64					192.64
2.D - Non-Energy Products from Fuels and Solvent Use	246.18					246.18
2.D.1 - Lubricant Use	238.99					238.99
2.D.2 - Paraffin Wax Use	7.19					7.19
2.F - Product Uses as Substitutes for ODS						
3 - Agriculture, Forestry, and Other Land Use	-19 271.01	29 643.27	21 611.44			31 983.70
3.A - Livestock		27 840.84	961.90			28 802.74
3.A.1 - Enteric Fermentation		26 986.08				26 986.08

INVENTORY YEAR: 2004	Emissions/removals (Gg CO_2eq)					
Categories	Net CO_2	CH_4	N_2O	HFCs	PFCs	Total
3.A.2 - Manure Management		854.75	961.90			1 816.65
3.B - Land	-10 873.35	613.35				-10 260.00
3.B.1 - Forest land	-39 389.01					-39 389.01
3.B.2 - Cropland	-286.78					-286.78
3.B.3 - Grassland	27 911.83					27 911.83
3.B.4 - Wetlands		613.35				613.35
3.B.5 - Settlements	890.61					890.61
3.C - Aggregate sources and non-CO2 emissions sources on land	1 021.44	1 189.09	20 649.54			22 860.06
3.C.1 - Emissions from biomass burning		1 189.09	711.24			1 900.33
3.C.2 - Liming	585.54					585.54
3.C.3 - Urea application	435.90					435.90
3.C.4 - Direct N2O Emissions from managed soils			15 090.19			15 090.19
3.C.5 - Indirect N2O Emissions from managed soils			4 508.93			4 508.93
3.C.6 - Indirect N2O Emissions from manure management			339.17			339.17
3.D - Other	-9 419.10					-9 419.10
3.D.1 - Harvested Wood Products	-9 419.10					-9 419.10
4 - Waste		14 562.39	616.87			15 179.26
4.A - Solid Waste Disposal		12 208.24				12 208.24
4.D - Wastewater Treatment and Discharge		2 354.15	616.87			2 971.02
Memo Items (5)						
International Bunkers	2 316.24	2.24	5.75			2 324.23
1.A.3.a.i - International Aviation (International Bunkers)	2 316.24	2.24	5.75			2 324.23
1.A.3.d.i - International water-borne navigation (International bunkers)						
1.A.5.c - Multilateral Operations						

INVENTORY YEAR: 2005	Emissions/removals (Gg CO_2eq)					
Categories	Net CO_2	CH_4	N_2O	HFCs	PFCs	Total
Total including FOLU	404 741.51	48 164.57	26 235.27	126.29	871.87	480 139.51
Total excluding FOLU	421 525.72	47 535.99	26 235.27	126.29	871.87	496 295.14
1 - Energy	374 031.23	2 893.32	2 390.49			379 315.05
1.A - Fuel Combustion Activities	350 471.51	602.78	2 390.49			353 464.78
1.A.1 - Energy Industries	239 582.35	62.09	1 066.77			240 711.22
1.A.2 - Manufacturing Industries and Construction	36 983.25	10.37	154.86			37 148.48
1.A.3 - Transport	40 738.29	293.55	596.39			41 628.23
1.A.4 - Other Sectors	32 109.14	235.71	569.75			32 914.60
1.A.5 - Non-Specified	1 058.49	1.05	2.71			1 062.25
1.B - Fugitive emissions from fuels	23 559.72	2 290.54				25 850.26
1.B.1 - Solid Fuels	25.60	2 155.57				2 181.17
1.B.2 - Oil and Natural Gas	266.00					266.00
1.B.3 - Other emissions from Energy Production	23 268.12	134.97				23 403.09
2 - Industrial Processes and Product Use	46 872.26	103.56	1 971.93	126.29	871.87	49 945.91
2.A - Mineral Industry	4 840.21					4 840.21
2.A.1 - Cement production	4 188.21					4 188.21
2.A.2 - Lime production	549.58					549.58
2.A.3 - Glass Production	102.41					102.41
2.B - Chemical Industry	818.00	99.16	1 971.93			2 889.09
2.C - Metal Industry	40 746.20	4.40			871.87	41 622.47
2.C.1 - Iron and Steel Production	29 751.97					29 751.97
2.C.2 - Ferroalloys Production	9 384.03	4.40				9 388.43
2.C.3 - Aluminium production	1 402.50				871.87	2 274.37
2.C.4 - Magnesium production						
2.C.5 - Lead Production	21.94					21.94
2.C.6 - Zinc Production	185.76					185.76
2.D - Non-Energy Products from Fuels and Solvent Use	467.85					467.85
2.D.1 - Lubricant Use	462.72					462.72
2.D.2 - Paraffin Wax Use	5.13					5.13
2.F - Product Uses as Substitutes for ODS				126.29		126.29
3 - Agriculture, Forestry, and Other Land Use	-16 161.99	29 885.60	21 247.65			34 971.26
3.A - Livestock		28 069.98	1 016.89			29 086.87
3.A.1 - Enteric Fermentation		27 204.24				27 204.24
3.A.2 - Manure Management		865.74	1 016.89			1 882.63

INVENTORY YEAR: 2005	Emissions/removals (Gg CO_2eq)					
Categories	Net CO_2	CH_4	N_2O	HFCs	PFCs	Total
3.B - Land	-8 747.27	628.58				-8 118.70
3.B.1 - Forest land	-37 169.11					-37 169.11
3.B.2 - Cropland	-513.33					-513.33
3.B.3 - Grassland	28 044.14					28 044.14
3.B.4 - Wetlands		628.58				628.58
3.B.5 - Settlements	891.03					891.03
3.C - Aggregate sources and non-CO2 emissions sources on land	622.22	1 187.04	20 230.76			22 040.02
3.C.1 - Emissions from biomass burning		1 187.04	711.97			1 899.01
3.C.2 - Liming	267.41					267.41
3.C.3 - Urea application	354.81					354.81
3.C.4 - Direct N2O Emissions from managed soils			14 755.29			14 755.29
3.C.5 - Indirect N2O Emissions from managed soils			4 409.19			4 409.19
3.C.6 - Indirect N2O Emissions from manure management			354.30			354.30
3.D - Other	-8 036.93					-8 036.93
3.D.1 - Harvested Wood Products	-8 036.93					-8 036.93
4 - Waste		15 282.09	625.21			15 907.30
4.A - Solid Waste Disposal		12 883.77				12 883.77
4.D - Wastewater Treatment and Discharge		2 398.32	625.21			3 023.52
Memo Items (5)						
International Bunkers	2 266.84	2.19	5.63			2 274.65
1.A.3.a.i - International Aviation (International Bunkers)	2 266.84	2.19	5.63			2 274.65
1.A.3.d.i - International water-borne navigation (International bunkers)						
1.A.5.c - Multilateral Operations						

INVENTORY YEAR: 2006	Emissions/removals (Gg CO_2eq)					
Categories	Net CO_2	CH_4	N_2O	HFCs	PFCs	Total
Total including FOLU	404 114.97	48 278.40	26 643.25	279.51	934.55	480 250.68
Total excluding FOLU	430 113.68	47 683.26	26 643.25	279.51	934.55	505 654.26
1 - Energy	381 102.75	2 766.14	2 212.84			386 081.73
1.A - Fuel Combustion Activities	357 619.41	477.05	2 212.84			360 309.30
1.A.1 - Energy Industries	241 779.53	62.34	1 076.04			242 917.91
1.A.2 - Manufacturing Industries and Construction	37 902.78	10.68	158.26			38 071.71
1.A.3 - Transport	41 792.69	297.26	608.80			42 698.74
1.A.4 - Other Sectors	35 075.12	105.71	367.00			35 547.83
1.A.5 - Non-Specified	1 069.30	1.06	2.74			1 073.10
1.B - Fugitive emissions from fuels	23 483.34	2 289.09				25 772.43
1.B.1 - Solid Fuels	25.58	2 154.20				2 179.78
1.B.2 - Oil and Natural Gas	291.00					291.00
1.B.3 - Other emissions from Energy Production	23 166.76	134.89				23 301.65
2 - Industrial Processes and Product Use	48 171.89	113.30	2 038.21	279.51	934.55	51 537.46
2.A - Mineral Industry	5 193.19					5 193.19
2.A.1 - Cement production	4 486.12					4 486.12
2.A.2 - Lime production	605.23					605.23
2.A.3 - Glass Production	101.85					101.85
2.B - Chemical Industry	513.21	108.40	2 038.21			2 659.82
2.C - Metal Industry	41 956.33	4.90			934.55	42 895.78
2.C.1 - Iron and Steel Production	30 266.53					30 266.53
2.C.2 - Ferroalloys Production	10 063.83	4.90				10 068.72
2.C.3 - Aluminium production	1 427.14				934.55	2 361.69
2.C.4 - Magnesium production						
2.C.5 - Lead Production	25.12					25.12
2.C.6 - Zinc Production	173.72					173.72
2.D - Non-Energy Products from Fuels and Solvent Use	509.15					509.15
2.D.1 - Lubricant Use	504.40					504.40
2.D.2 - Paraffin Wax Use	4.75					4.75
2.F - Product Uses as Substitutes for ODS				279.51		279.51
3 - Agriculture, Forestry, and Other Land Use	-25 159.67	29 381.38	21 760.44			25 982.15
3.A - Livestock		27 566.48	1 070.96			28 637.44
3.A.1 - Enteric Fermentation		26 711.64				26 711.64

INVENTORY YEAR: 2006	Emissions/removals (Gg CO_2eq)					
Categories	Net CO_2	CH_4	N_2O	HFCs	PFCs	Total
3.A.2 - Manure Management		854.84	1 070.96			1 925.80
3.B - Land	-18 460.36	595.14				-17 865.22
3.B.1 - Forest land	-32 783.71					-32 783.71
3.B.2 - Cropland	7 529.20					7 529.20
3.B.3 - Grassland	6 523.47					6 523.47
3.B.4 - Wetlands		595.14				595.14
3.B.5 - Settlements	270.69					270.69
3.C - Aggregate sources and non-CO2 emissions sources on land	839.04	1 219.76	20 689.48			22 748.28
3.C.1 - Emissions from biomass burning		1 219.76	714.28			1 934.04
3.C.2 - Liming	445.96					445.96
3.C.3 - Urea application	393.08					393.08
3.C.4 - Direct N2O Emissions from managed soils			15 074.88			15 074.88
3.C.5 - Indirect N2O Emissions from managed soils			4 533.18			4 533.18
3.C.6 - Indirect N2O Emissions from manure management			367.14			367.14
3.D - Other	-7 538.36					-7 538.36
3.D.1 - Harvested Wood Products	-7 538.36					-7 538.36
4 - Waste		16 017.58	631.76			16 649.34
4.A - Solid Waste Disposal		13 581.62				13 581.62
4.D - Wastewater Treatment and Discharge		2 435.96	631.76			3 067.73
Memo Items (5)						
International Bunkers	2 509.65	2.42	6.23			2 518.31
1.A.3.a.i - International Aviation (International Bunkers)	2 509.65	2.42	6.23			2 518.31
1.A.3.d.i - International water-borne navigation (International bunkers)						
1.A.5.c - Multilateral Operations						

INVENTORY YEAR: 2007	Emissions/removals (Gg CO_2eq)					
Categories	Net CO_2	CH_4	N_2O	HFCs	PFCs	Total
Total including FOLU	429 872.80	48 496.28	25 232.20	404.00	970.11	504 975.39
Total excluding FOLU	457 182.74	47 904.64	25 232.20	404.00	970.11	531 693.69
1 - Energy	409 179.71	2 808.37	2 361.51			414 349.59
1.A - Fuel Combustion Activities	385 479.23	494.03	2 361.51			388 334.76
1.A.1 - Energy Industries	264 670.86	68.28	1 181.53			265 920.68
1.A.2 - Manufacturing Industries and Construction	39 287.73	11.14	163.64			39 462.51
1.A.3 - Transport	44 230.25	306.27	643.74			45 180.26
1.A.4 - Other Sectors	36 194.68	107.25	369.78			36 671.71
1.A.5 - Non-Specified	1 095.70	1.09	2.81			1 099.60
1.B - Fugitive emissions from fuels	23 700.48	2 314.35				26 014.83
1.B.1 - Solid Fuels	25.88	2 179.14				2 205.01
1.B.2 - Oil and Natural Gas	325.00					325.00
1.B.3 - Other emissions from Energy Production	23 349.60	135.21				23 484.81
2 - Industrial Processes and Product Use	46 993.61	152.84	1 195.78	404.00	970.11	49 716.34
2.A - Mineral Industry	5 217.23					5 217.23
2.A.1 - Cement production	4 582.68					4 582.68
2.A.2 - Lime production	529.48					529.48
2.A.3 - Glass Production	105.07					105.07
2.B - Chemical Industry	581.39	148.25	1 195.78			1 925.41
2.C - Metal Industry	40 960.91	4.60			970.11	41 935.62
2.C.1 - Iron and Steel Production	28 038.77					28 038.77
2.C.2 - Ferroalloys Production	11 245.95	4.60				11 250.55
2.C.3 - Aluminium production	1 487.57				970.11	2 457.68
2.C.4 - Magnesium production						
2.C.5 - Lead Production	21.79					21.79
2.C.6 - Zinc Production	166.84					166.84
2.D - Non-Energy Products from Fuels and Solvent Use	234.08					234.08
2.D.1 - Lubricant Use	232.01					232.01
2.D.2 - Paraffin Wax Use	2.07					2.07
2.F - Product Uses as Substitutes for ODS				404.00		404.00
3 - Agriculture, Forestry, and Other Land Use	-26 300.52	28 763.74	21 037.11			23 500.34
3.A - Livestock		26 841.80	1 107.95			27 949.75
3.A.1 - Enteric Fermentation		25 974.90				25 974.90
3.A.2 - Manure Management		866.90	1 107.95			1 974.85

INVENTORY YEAR: 2007	Emissions/removals (Gg CO_2eq)					
Categories	Net CO_2	CH_4	N_2O	HFCs	PFCs	Total
3.B - Land	-19 182.29	591.64				-18 590.66
3.B.1 - Forest land	-33 118.03					-33 118.03
3.B.2 - Cropland	7 018.76					7 018.76
3.B.3 - Grassland	6 645.82					6 645.82
3.B.4 - Wetlands		591.64				591.64
3.B.5 - Settlements	271.17					271.17
3.C - Aggregate sources and non-CO2 emissions sources on land	1 009.42	1 330.30	19 929.16			22 268.89
3.C.1 - Emissions from biomass burning		1 330.30	715.59			2 045.90
3.C.2 - Liming	524.87					524.87
3.C.3 - Urea application	484.55					484.55
3.C.4 - Direct N2O Emissions from managed soils			14 425.27			14 425.27
3.C.5 - Indirect N2O Emissions from managed soils			4 409.32			4 409.32
3.C.6 - Indirect N2O Emissions from manure management			378.98			378.98
3.D - Other	-8 127.65					-8 127.65
3.D.1 - Harvested Wood Products	-8 127.65					-8 127.65
4 - Waste		16 771.32	637.80			17 409.12
4.A - Solid Waste Disposal		14 298.50				14 298.50
4.D - Wastewater Treatment and Discharge		2 472.82	637.80			3 110.62
Memo Items (5)						
International Bunkers	2 556.84	2.47	6.35			2 565.66
1.A.3.a.i - International Aviation (International Bunkers)	2 556.84	2.47	6.35			2 565.66
1.A.3.d.i - International water-borne navigation (International bunkers)						
1.A.5.c - Multilateral Operations						

INVENTORY YEAR: 2008	Emissions/removals (Gg CO_2eq)					
Categories	Net CO_2	CH_4	N_2O	HFCs	PFCs	Total
Total including FOLU	417 088.86	50 279.80	24 990.83	499.44	548.12	493 407.05
Total excluding FOLU	444 976.77	49 691.66	24 990.83	499.44	548.12	520 706.82
1 - Energy	400 233.41	3 192.09	2 343.98			405 769.48
1.A - Fuel Combustion Activities	378 012.64	490.48	2 343.98			380 847.10
1.A.1 - Energy Industries	253 537.80	65.81	1 130.54			254 734.15
1.A.2 - Manufacturing Industries and Construction	42 089.47	11.82	175.97			42 277.26
1.A.3 - Transport	43 145.12	294.22	625.89			44 065.23
1.A.4 - Other Sectors	38 190.91	117.59	408.89			38 717.39
1.A.5 - Non-Specified	1 049.34	1.04	2.69			1 053.07
1.B - Fugitive emissions from fuels	22 220.77	2 701.61				24 922.38
1.B.1 - Solid Fuels	26.35	2 219.14				2 245.50
1.B.2 - Oil and Natural Gas	237.00					237.00
1.B.3 - Other emissions from Energy Production	21 957.42	482.47				22 439.89
2 - Industrial Processes and Product Use	43 628.50	78.38	529.63	499.44	548.12	45 284.06
2.A - Mineral Industry	5 110.89					5 110.89
2.A.1 - Cement production	4 473.86					4 473.86
2.A.2 - Lime production	519.62					519.62
2.A.3 - Glass Production	117.42					117.42
2.B - Chemical Industry	574.34	73.85	529.63			1 177.83
2.C - Metal Industry	37 722.20	4.52			548.12	38 274.84
2.C.1 - Iron and Steel Production	25 026.07	0.00				25 026.07
2.C.2 - Ferroalloys Production	11 175.34	4.52				11 179.87
2.C.3 - Aluminium production	1 340.13				548.12	1 888.25
2.C.4 - Magnesium production						
2.C.5 - Lead Production	24.13					24.13
2.C.6 - Zinc Production	156.52					156.52
2.D - Non-Energy Products from Fuels and Solvent Use	221.07					221.07
2.D.1 - Lubricant Use	218.40					218.40
2.D.2 - Paraffin Wax Use	2.67					2.67
2.F - Product Uses as Substitutes for ODS				499.44		499.44
3 - Agriculture, Forestry, and Other Land Use	-26 773.05	29 480.04	21 476.64			24 183.63
3.A - Livestock		27 554.70	1 095.65			28 650.36
3.A.1 - Enteric Fermentation		26 660.81				26 660.81

INVENTORY YEAR: 2008	Emissions/removals (Gg CO_2eq)					
Categories	Net CO_2	CH_4	N_2O	HFCs	PFCs	Total
3.A.2 - Manure Management		893.89	1 095.65			1 989.55
3.B - Land	-20 105.98	588.14				-19 517.84
3.B.1 - Forest land	-33 654.11					-33 654.11
3.B.2 - Cropland	6 508.32					6 508.32
3.B.3 - Grassland	6 768.17					6 768.17
3.B.4 - Wetlands		588.14				588.14
3.B.5 - Settlements	271.65					271.65
3.C - Aggregate sources and non-CO2 emissions sources on land	1 114.86	1 337.20	20 380.98			22 833.04
3.C.1 - Emissions from biomass burning		1 337.20	716.84			2 054.04
3.C.2 - Liming	658.92					658.92
3.C.3 - Urea application	455.94					455.94
3.C.4 - Direct N2O Emissions from managed soils			14 803.14			14 803.14
3.C.5 - Indirect N2O Emissions from managed soils			4 482.45			4 482.45
3.C.6 - Indirect N2O Emissions from manure management			378.55			378.55
3.D - Other	-7 781.93					-7 781.93
3.D.1 - Harvested Wood Products	-7 781.93					-7 781.93
4 - Waste		17 529.29	640.58			18 169.87
4.A - Solid Waste Disposal		15 036.96				15 036.96
4.D - Wastewater Treatment and Discharge		2 492.33	640.58			3 132.91
Memo Items (5)						
International Bunkers	2 477.98	2.39	6.16			2 486.52
1.A.3.a.i - International Aviation (International Bunkers)	2 477.98	2.39	6.16			2 486.52
1.A.3.d.i - International water-borne navigation (International bunkers)						
1.A.5.c - Multilateral Operations						

INVENTORY YEAR: 2009	Emissions/removals (Gg CO_2eq)					
Categories	Net CO_2	CH_4	N_2O	HFCs	PFCs	Total
Total including FOLU	420 981.08	50 423.07	24 780.13	571.31	108.25	496 863.84
Total excluding FOLU	451 175.76	49 838.44	24 780.13	571.31	108.25	526 473.89
1 - Energy	408 456.09	3 186.50	2 395.92			414 038.51
1.A - Fuel Combustion Activities	385 880.67	498.57	2 395.92			388 775.17
1.A.1 - Energy Industries	260 134.58	67.55	1 160.61			261 362.74
1.A.2 - Manufacturing Industries and Construction	39 951.83	11.34	165.43			40 128.60
1.A.3 - Transport	43 765.46	300.31	635.12			44 700.89
1.A.4 - Other Sectors	40 956.32	118.31	432.01			41 506.63
1.A.5 - Non-Specified	1 072.49	1.07	2.75			1 076.30
1.B - Fugitive emissions from fuels	22 575.42	2 687.93				25 263.35
1.B.1 - Solid Fuels	26.18	2 204.26				2 230.44
1.B.2 - Oil and Natural Gas	237.00					237.00
1.B.3 - Other emissions from Energy Production	22 312.24	483.67				22 795.91
2 - Industrial Processes and Product Use	41 584.75	56.58	512.02	571.31	108.25	42 832.91
2.A - Mineral Industry	5 161.23					5 161.23
2.A.1 - Cement production	4 549.53					4 549.53
2.A.2 - Lime production	501.99					501.99
2.A.3 - Glass Production	109.71					109.71
2.B - Chemical Industry	483.76	52.97	512.02			1 048.75
2.C - Metal Industry	35 706.00	3.60			108.25	35 817.85
2.C.1 - Iron and Steel Production	23 015.82					23 015.82
2.C.2 - Ferroalloys Production	11 189.41	3.60				11 193.01
2.C.3 - Aluminium production	1 317.00				108.25	1 425.25
2.C.4 - Magnesium production						
2.C.5 - Lead Production	25.53					25.53
2.C.6 - Zinc Production	158.24					158.24
2.D - Non-Energy Products from Fuels and Solvent Use	233.76					233.76
2.D.1 - Lubricant Use	230.37					230.37
2.D.2 - Paraffin Wax Use	3.39					3.39
2.F - Product Uses as Substitutes for ODS				571.31		571.31
3 - Agriculture, Forestry, and Other Land Use	-29 059.76	28 841.01	21 221.80			21 003.05
3.A - Livestock		27 039.62	1 105.87			28 145.49
3.A.1 - Enteric Fermentation		26 140.91				26 140.91

INVENTORY YEAR: 2009	Emissions/removals (Gg CO_2eq)					
Categories	Net CO_2	CH_4	N_2O	HFCs	PFCs	Total
3.A.2 - Manure Management		898.71	1 105.87			2 004.58
3.B - Land	-25 170.06	584.64				-24 585.43
3.B.1 - Forest land	-38 330.59					-38 330.59
3.B.2 - Cropland	5 997.88					5 997.88
3.B.3 - Grassland	6 890.52					6 890.52
3.B.4 - Wetlands		584.64				584.64
3.B.5 - Settlements	272.12					272.12
3.C - Aggregate sources and non-CO2 emissions sources on land	1 134.92	1 216.76	20 115.92			22 467.60
3.C.1 - Emissions from biomass burning		1 216.76	717.79			1 934.55
3.C.2 - Liming	616.23					616.23
3.C.3 - Urea application	518.69					518.69
3.C.4 - Direct N2O Emissions from managed soils			14 570.80			14 570.80
3.C.5 - Indirect N2O Emissions from managed soils			4 446.64			4 446.64
3.C.6 - Indirect N2O Emissions from manure management			380.69			380.69
3.D - Other	-5 024.62					-5 024.62
3.D.1 - Harvested Wood Products	-5 024.62					-5 024.62
4 - Waste		18 338.99	650.39			18 989.37
4.A - Solid Waste Disposal		15 795.57				15 795.57
4.D - Wastewater Treatment and Discharge		2 543.42	650.39			3 193.80
Memo Items (5)						
International Bunkers	2 422.71	2.34	6.02			2 431.06
1.A.3.a.i - International Aviation (International Bunkers)	2 422.71	2.34	6.02			2 431.06
1.A.3.d.i - International water-borne navigation (International bunkers)						
1.A.5.c - Multilateral Operations						

INVENTORY YEAR: 2010	Emissions/removals (Gg CO_2eq)					
Categories	Net CO_2	CH_4	N_2O	HFCs	PFCs	Total
Total including FOLU	440 018.14	52 125.94	25 156.83	799.88	138.26	518 239.04
Total excluding FOLU	466 674.46	51 544.80	25 156.83	799.88	138.26	544 314.23
1 - Energy	422 633.08	3 244.30	2 490.99			428 368.38
1.A - Fuel Combustion Activities	399 806.42	519.94	2 490.99			402 817.35
1.A.1 - Energy Industries	266 432.88	68.94	1 191.15			267 692.96
1.A.2 - Manufacturing Industries and Construction	40 936.94	11.70	168.81			41 117.45
1.A.3 - Transport	46 617.91	318.14	670.45			47 606.50
1.A.4 - Other Sectors	44 683.84	120.03	457.68			45 261.55
1.A.5 - Non-Specified	1 134.86	1.13	2.91			1 138.90
1.B - Fugitive emissions from fuels	22 826.67	2 724.37				25 551.03
1.B.1 - Solid Fuels	26.59	2 239.46				2 266.05
1.B.2 - Oil and Natural Gas	619.00					619.00
1.B.3 - Other emissions from Energy Production	22 181.07	484.91				22 665.98
2 - Industrial Processes and Product Use	43 019.94	67.09	325.54	799.88	138.26	44 350.71
2.A - Mineral Industry	4 792.91					4 792.91
2.A.1 - Cement production	4 186.74					4 186.74
2.A.2 - Lime production	502.24					502.24
2.A.3 - Glass Production	103.93					103.93
2.B - Chemical Industry	622.89	62.88	325.54			1 011.31
2.C - Metal Industry	37 370.27	4.21			138.26	37 512.74
2.C.1 - Iron and Steel Production	24 146.87					24 146.87
2.C.2 - Ferroalloys Production	11 804.99	4.21				11 809.20
2.C.3 - Aluminium production	1 330.00				138.26	1 468.26
2.C.4 - Magnesium production						
2.C.5 - Lead Production	26.31					26.31
2.C.6 - Zinc Production	62.09					62.09
2.D - Non-Energy Products from Fuels and Solvent Use	233.87					233.87
2.D.1 - Lubricant Use	230.49					230.49
2.D.2 - Paraffin Wax Use	3.39					3.39
2.F - Product Uses as Substitutes for ODS				799.88		799.88
3 - Agriculture, Forestry, and Other Land Use	-25 634.89	29 664.87	21 683.63			25 713.61
3.A - Livestock		27 870.36	1 115.64			28 985.99
3.A.1 - Enteric Fermentation		26 977.84				26 977.84

INVENTORY YEAR: 2010	Emissions/removals (Gg CO_2eq)					
Categories	Net CO_2	CH_4	N_2O	HFCs	PFCs	Total
3.A.2 - Manure Management		892.52	1 115.64			2 008.16
3.B - Land	-20 451.84	581.13				-19 870.70
3.B.1 - Forest land	-33 224.75					-33 224.75
3.B.2 - Cropland	5 487.44					5 487.44
3.B.3 - Grassland	7 012.87					7 012.87
3.B.4 - Wetlands		581.13				581.13
3.B.5 - Settlements	272.60					272.60
3.C - Aggregate sources and non-CO2 emissions sources on land	1 021.44	1 213.38	20 567.99			22 802.81
3.C.1 - Emissions from biomass burning		1 213.38	718.98			1 932.36
3.C.2 - Liming	585.54					585.54
3.C.3 - Urea application	435.90					435.90
3.C.4 - Direct N2O Emissions from managed soils			14 964.38			14 964.38
3.C.5 - Indirect N2O Emissions from managed soils			4 502.33			4 502.33
3.C.6 - Indirect N2O Emissions from manure management			382.31			382.31
3.D - Other	-6 204.49					-6 204.49
3.D.1 - Harvested Wood Products	-6 204.49					-6 204.49
4 - Waste		19 149.66	656.67			19 806.33
4.A - Solid Waste Disposal		16 568.60				16 568.60
4.D - Wastewater Treatment and Discharge		2 581.06	656.67			3 237.73
Memo Items (5)						
International Bunkers	2 563.63	2.47	6.37			2 572.47
1.A.3.a.i - International Aviation (International Bunkers)	2 563.63	2.47	6.37			2 572.47
1.A.3.d.i - International water-borne navigation (International bunkers)						
1.A.5.c - Multilateral Operations						

9. APPENDIX B: KEY CATEGORY ANALYSIS

9.1 Level assessment: 2000 (including FOLU)

IPCC Category code	IPCC Category	GHG	2000 (Gg CO_2 Eq)	Level Assessment	Cumulative Total
1.A.1	Energy Industries - Solid Fuels	CO2	185 027.44	0.3471	0.3471
3.B.1.a	Forest land Remaining Forest land	CO2	-45 490.83	0.0853	0.4324
1.A.1	Energy Industries - Liquid Fuels	CO2	33 855.83	0.0635	0.4959
1.A.3.b	Road Transportation	CO2	32 623.34	0.0612	0.5571
3.A.1	Enteric Fermentation	CH4	29 307.55	0.0550	0.6120
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CO2	29 101.57	0.0546	0.6666
2.C.1	Iron and Steel Production	CO2	27 753.86	0.0521	0.7187
3.B.3.b	Land Converted to Grassland	CO2	27 382.57	0.0514	0.7701
1.B.3	Other emissions from Energy Production	CO2	26 658.56	0.0500	0.8201
3.C.4	Direct N2O Emissions from managed soils	N2O	16 118.85	0.0302	0.8503
1.A.4	Other Sectors - Liquid Fuels	CO2	12 766.46	0.0239	0.8742
4.A	Solid Waste Disposal	CH4	9 704.23	0.0182	0.8924
2.C.2	Ferroalloys Production	CO2	8 079.14	0.0152	0.9076
3.D.1	Harvested Wood Products	CO2	-5 785.55	0.0109	0.9184
1.A.4	Other Sectors - Solid Fuels	CO2	5 586.89	0.0105	0.9289
3.C.5	Indirect N2O Emissions from managed soils	N2O	4 745.81	0.0089	0.9378
2.A.1	Cement production	CO2	3 347.05	0.0063	0.9441
3.B.1.b	Land Converted to Forest land	CO2	-2 549.14	0.0048	0.9489
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CO2	2 217.75	0.0042	0.9530
4.D	Wastewater Treatment and Discharge	CH4	2 139.35	0.0040	0.9571
1.A.3.a	Civil Aviation	CO2	2 040.00	0.0038	0.9609
1.B.1	Solid Fuels	CH4	1 978.88	0.0037	0.9646
2.B.2	Nitric Acid Production	N2O	C[a]	0.0029	0.9675
3.C.1	Emissions from biomass burning	CH4	1 215.71	0.0023	0.9698
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	CO2	1 186.10	0.0022	0.9720
2.C.3	Aluminium production	CO2	1 105.47	0.0021	0.9741
1.A.5	Non-Specified - Liquid Fuels	CO2	985.58	0.0018	0.9760
2.C.3	Aluminium production	PFCs	982.24	0.0018	0.9778
3.A.2	Manure Management	N2O	912.73	0.0017	0.9795
3.A.2	Manure Management	CH4	898.34	0.0017	0.9812
3.B.5.b	Land Converted to Settlements	CO2	888.97	0.0017	0.9829
1.A.1	Energy Industries - Solid Fuels	N2O	853.53	0.0016	0.9845

IPCC Category code	IPCC Category	GHG	2000 (Gg CO_2 Eq)	Level Assessment	Cumulative Total
3.C.1	Emissions from biomass burning	N2O	721.77	0.0014	0.9858
3.B.4.a.ii	Flooded land remaining flooded land	CH4	664.71	0.0012	0.9871
4.D	Wastewater Treatment and Discharge	N2O	590.35	0.0011	0.9882
3.B.2.b	Land Converted to Cropland	CO2	571.63	0.0011	0.9893
1.A.3.c	Railways	CO2	551.45	0.0010	0.9903
2.B.1	Ammonia Production	CO2	C[a]	0.0009	0.9912
1.A.3.b	Road Transportation	N2O	463.05	0.0009	0.9921
2.B.6	Titanium Dioxide Production	CO2	C[a]	0.0008	0.9929
2.A.2	Lime production	CO2	426.37	0.0008	0.9937
3.C.2	Liming	CO2	384.05	0.0007	0.9944
3.C.6	Indirect N2O Emissions from manure management	N2O	327.91	0.0006	0.9950
1.B.2.a	Oil	CO2	325.00	0.0006	0.9956
1.A.3.a	Civil Aviation	CH4	270.27	0.0005	0.9961
1.A.3.b	Road Transportation	CH4	267.59	0.0005	0.9966
3.C.3	Urea application	CO2	211.49	0.0004	0.9970
2.D	Non-Energy Products from Fuels and Solvent Use	CO2	195.92	0.0004	0.9974
2.C.6	Zinc Production	CO2	194.36	0.0004	0.9978
1.A.4	Other Sectors - Biomass	N2O	167.72	0.0003	0.9981
2.B.8	Petrochemical and Carbon Black Production	CO2	C[a]	0.0003	0.9983
1.A.2	Manufacturing Industries and Construction - Solid Fuels	N2O	134.25	0.0003	0.9986
1.A.1	Energy Industries - Liquid Fuels	N2O	110.63	0.0002	0.9988
1.A.4	Other Sectors - Biomass	CH4	97.74	0.0002	0.9990
2.A.3	Glass Production	CO2	74.38	0.0001	0.9991
2.B.1	Ammonia Production	CH4	C[a]	0.0001	0.9993
1.A.3.c	Railways	N2O	63.00	0.0001	0.9994
1.A.4	Other Sectors - Solid Fuels	N2O	51.46	0.0001	0.9995
1.A.1	Energy Industries - Solid Fuels	CH4	44.21	0.0001	0.9996
3.B.2.a	Cropland Remaining Cropland	CO2	39.34	0.0001	0.9996
2.C.5	Lead Production	CO2	39.16	0.0001	0.9997
1.B.3	Other emissions from Energy Production	CH4	34.92	0.0001	0.9998
1.A.4	Other Sectors - Liquid Fuels	N2O	28.78	0.0001	0.9998
1.B.1	Solid Fuels	CO2	23.67	0.0000	0.9999
1.A.1	Energy Industries - Liquid Fuels	CH4	14.14	0.0000	0.9999
1.A.4	Other Sectors - Gaseous Fuels	CO2	12.96	0.0000	0.9999
1.A.4	Other Sectors - Liquid Fuels	CH4	11.35	0.0000	0.9999
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CH4	6.95	0.0000	1.0000
1.A.3.a	Civil Aviation	N2O	5.07	0.0000	1.0000

IPCC Category code	IPCC Category	GHG	2000 (Gg CO_2 Eq)	Level Assessment	Cumulative Total
2.C.2	Ferroalloys Production	CH4	3.62	0.0000	1.0000
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	N2O	2.75	0.0000	1.0000
1.A.5	Non-Specified - Liquid Fuels	N2O	2.53	0.0000	1.0000
2.B.5	Carbide Production	CO2	C[a]	0.0000	1.0000
1.A.4	Other Sectors - Solid Fuels	CH4	1.34	0.0000	1.0000
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	N2O	1.17	0.0000	1.0000
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	CH4	1.07	0.0000	1.0000
1.A.5	Non-Specified - Liquid Fuels	CH4	0.98	0.0000	1.0000
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CH4	0.91	0.0000	1.0000
1.A.3.c	Railways	CH4	0.71	0.0000	1.0000
2.B.8	Petrochemical and Carbon Black Production	CH4	C[a]	0.0000	1.0000

[a] *Confidential - disaggregated Chemical Industry [2B] data is not shown.*

9.2 Level assessment: 2000 (excluding FOLU)

IPCC Category code	IPCC Category	GHG	2000 (Gg CO_2 Eq)	Level Assessment	Cumulative Total
1.A.1	Energy Industries - Solid Fuels	CO2	185 027.44	0.4114	0.4114
1.A.1	Energy Industries - Liquid Fuels	CO2	33 855.83	0.0753	0.4867
1.A.3.b	Road Transportation	CO2	32 623.34	0.0725	0.5592
3.A.1	Enteric Fermentation	CH4	29 307.55	0.0652	0.6244
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CO2	29 101.57	0.0647	0.6891
2.C.1	Iron and Steel Production	CO2	27 753.86	0.0617	0.7508
1.B.3	Other emissions from Energy Production	CO2	26 658.56	0.0593	0.8100
3.C.4	Direct N2O Emissions from managed soils	N2O	16 118.85	0.0358	0.8459
1.A.4	Other Sectors - Liquid Fuels	CO2	12 766.46	0.0284	0.8743
4.A	Solid Waste Disposal	CH4	9 704.23	0.0216	0.8958
2.C.2	Ferroalloys Production	CO2	8 079.14	0.0180	0.9138
1.A.4	Other Sectors - Solid Fuels	CO2	5 586.89	0.0124	0.9262
3.C.5	Indirect N2O Emissions from managed soils	N2O	4 745.81	0.0106	0.9368
2.A.1	Cement production	CO2	3 347.05	0.0074	0.9442
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CO2	2 217.75	0.0049	0.9492
4.D	Wastewater Treatment and Discharge	CH4	2 139.35	0.0048	0.9539
1.A.3.a	Civil Aviation	CO2	2 040.00	0.0045	0.9584
1.B.1	Solid Fuels	CH4	1 978.88	0.0044	0.9628
2.B.2	Nitric Acid Production	N2O	C[a]	0.0035	0.9663
3.C.1	Emissions from biomass burning	CH4	1 215.71	0.0027	0.9690
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	CO2	1 186.10	0.0026	0.9717
2.C.3	Aluminium production	CO2	1 105.47	0.0025	0.9741
1.A.5	Non-Specified - Liquid Fuels	CO2	985.58	0.0022	0.9763
2.C.3	Aluminium production	PFCs	982.24	0.0022	0.9785
3.A.2	Manure Management	N2O	912.73	0.0020	0.9805
3.A.2	Manure Management	CH4	898.34	0.0020	0.9825
1.A.1	Energy Industries - Solid Fuels	N2O	853.53	0.0019	0.9844
3.C.1	Emissions from biomass burning	N2O	721.77	0.0016	0.9860
4.D	Wastewater Treatment and Discharge	N2O	590.35	0.0013	0.9874
1.A.3.c	Railways	CO2	551.45	0.0012	0.9886
2.B.1	Ammonia Production	CO2	C[a]	0.0011	0.9897
1.A.3.b	Road Transportation	N2O	463.05	0.0010	0.9907
2.B.6	Titanium Dioxide Production	CO2	C[a]	0.0010	0.9917
2.A.2	Lime production	CO2	426.37	0.0009	0.9926

IPCC Category code	IPCC Category	GHG	2000 ($Gg\ CO_2\ Eq$)	Level Assessment	Cumulative Total
3.C.2	Liming	CO2	384.05	0.0009	0.9935
3.C.6	Indirect N2O Emissions from manure management	N2O	327.91	0.0007	0.9942
1.B.2.a	Oil	CO2	325.00	0.0007	0.9949
1.A.3.a	Civil Aviation	CH4	270.27	0.0006	0.9955
1.A.3.b	Road Transportation	CH4	267.59	0.0006	0.9961
3.C.3	Urea application	CO2	211.49	0.0005	0.9966
2.D	Non-Energy Products from Fuels and Solvent Use	CO2	195.92	0.0004	0.9970
2.C.6	Zinc Production	CO2	194.36	0.0004	0.9974
1.A.4	Other Sectors - Biomass	N2O	167.72	0.0004	0.9978
2.B.8	Petrochemical and Carbon Black Production	CO2	C[a]	0.0003	0.9981
1.A.2	Manufacturing Industries and Construction - Solid Fuels	N2O	134.25	0.0003	0.9984
1.A.1	Energy Industries - Liquid Fuels	N2O	110.63	0.0002	0.9987
1.A.4	Other Sectors - Biomass	CH4	97.74	0.0002	0.9989
2.A.3	Glass Production	CO2	74.38	0.0002	0.9991
2.B.1	Ammonia Production	CH4	C[a]	0.0002	0.9992
1.A.3.c	Railways	N2O	63.00	0.0001	0.9994
1.A.4	Other Sectors - Solid Fuels	N2O	51.46	0.0001	0.9995
1.A.1	Energy Industries - Solid Fuels	CH4	44.21	0.0001	0.9996
2.C.5	Lead Production	CO2	39.16	0.0001	0.9997
1.B.3	Other emissions from Energy Production	CH4	34.92	0.0001	0.9997
1.A.4	Other Sectors - Liquid Fuels	N2O	28.78	0.0001	0.9998
1.B.1	Solid Fuels	CO2	23.67	0.0001	0.9998
1.A.1	Energy Industries - Liquid Fuels	CH4	14.14	0.0000	0.9999
1.A.4	Other Sectors - Gaseous Fuels	CO2	12.96	0.0000	0.9999
1.A.4	Other Sectors - Liquid Fuels	CH4	11.35	0.0000	0.9999
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CH4	6.95	0.0000	1.0000
1.A.3.a	Civil Aviation	N2O	5.07	0.0000	1.0000
2.C.2	Ferroalloys Production	CH4	3.62	0.0000	1.0000
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	N2O	2.75	0.0000	1.0000
1.A.5	Non-Specified - Liquid Fuels	N2O	2.53	0.0000	1.0000
2.B.5	Carbide Production	CO2	C[a]	0.0000	1.0000
1.A.4	Other Sectors - Solid Fuels	CH4	1.34	0.0000	1.0000
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	N2O	1.17	0.0000	1.0000
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	CH4	1.07	0.0000	1.0000
1.A.5	Non-Specified - Liquid Fuels	CH4	0.98	0.0000	1.0000
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CH4	0.91	0.0000	1.0000
1.A.3.c	Railways	CH4	0.71	0.0000	1.0000
2.B.8	Petrochemical and Carbon Black Production	CH4	C[a]	0.0000	1.0000

[a] Confidential - disaggregated Chemical Industry [2B] data is not shown.

9.3 Level assessment: 2010 (including FOLU)

IPCC Category code	IPCC Category	GHG	2000 (Gg CO_2 Eq)	Level Assessment	Cumulative Total
1.A.1	Energy Industries - Solid Fuels	CO2	234 672.13	0.3926	0.3926
1.A.3.b	Road Transportation	CO2	42 515.18	0.0711	0.4637
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CO2	35 197.37	0.0589	0.5226
1.A.1	Energy Industries - Liquid Fuels	CO2	32 052.46	0.0536	0.5763
3.B.1.a	Forest land Remaining Forest land	CO2	-27 121.56	0.0454	0.6216
1.A.4	Other Sectors - Solid Fuels	CO2	27 067.04	0.0453	0.6669
3.A.1	Enteric Fermentation	CH4	26 977.84	0.0451	0.7121
2.C.1	Iron and Steel Production	CO2	24 146.87	0.0404	0.7525
1.B.3	Other emissions from Energy Production	CO2	22 181.07	0.0371	0.7896
1.A.4	Other Sectors - Liquid Fuels	CO2	17 589.76	0.0294	0.8190
4.A	Solid Waste Disposal	CH4	16 568.60	0.0277	0.8467
3.C.4	Direct N2O Emissions from managed soils	N2O	14 964.38	0.0250	0.8718
2.C.2	Ferroalloys Production	CO2	11 804.99	0.0198	0.8915
3.B.3.b	Land Converted to Grassland	CO2	7 012.87	0.0117	0.9032
3.D.1	Harvested Wood Products	CO2	-6 204.49	0.0104	0.9136
3.B.1.b	Land Converted to Forest land	CO2	-6 103.19	0.0102	0.9238
3.B.2.b	Land Converted to Cropland	CO2	5 434.53	0.0091	0.9329
3.C.5	Indirect N2O Emissions from managed soils	N2O	4 502.33	0.0075	0.9405
2.A.1	Cement production	CO2	4 186.74	0.0070	0.9475
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CO2	3 837.58	0.0064	0.9539
1.A.3.a	Civil Aviation	CO2	3 657.68	0.0061	0.9600
4.D	Wastewater Treatment and Discharge	CH4	2 581.06	0.0043	0.9643
1.B.1	Solid Fuels	CH4	2 239.46	0.0037	0.9681
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	CO2	1 901.99	0.0032	0.9712
2.C.3	Aluminium production	CO2	1 330.00	0.0022	0.9735
3.C.1	Emissions from biomass burning	CH4	1 215.71	0.0020	0.9755
1.A.5	Non-Specified - Liquid Fuels	CO2	1 134.86	0.0019	0.9774
3.A.2	Manure Management	N2O	1 115.64	0.0019	0.9793
1.A.1	Energy Industries - Solid Fuels	N2O	1 082.54	0.0018	0.9811
3.A.2	Manure Management	CH4	892.52	0.0015	0.9826
2.F.1	Refrigeration and Air Conditioning	HFCs, PFCs	799.88	0.0013	0.9839
3.C.1	Emissions from biomass burning	N2O	721.77	0.0012	0.9851
4.D	Wastewater Treatment and Discharge	N2O	656.67	0.0011	0.9862
1.B.2.a	Oil	CO2	619.00	0.0010	0.9873

IPCC Category code	IPCC Category	GHG	2000 (Gg CO_2 Eq)	Level Assessment	Cumulative Total
1.A.3.b	Road Transportation	N2O	610.52	0.0010	0.9883
3.C.2	Liming	CO2	585.54	0.0010	0.9893
3.B.4.a.ii	Flooded land remaining flooded land	CH4	581.13	0.0010	0.9902
2.A.2	Lime production	CO2	502.24	0.0008	0.9911
1.B.3	Other emissions from Energy Production	CH4	484.91	0.0008	0.9919
1.A.3.c	Railways	CO2	445.04	0.0007	0.9926
3.C.3	Urea application	CO2	435.90	0.0007	0.9934
3.C.6	Indirect N2O Emissions from manure management	N2O	382.31	0.0006	0.9940
2.B.2	Nitric Acid Production	N2O	C[a]	0.0005	0.9945
2.B.1	Ammonia Production	CO2	C[a]	0.0005	0.9951
1.A.3.a	Civil Aviation	CH4	318.14	0.0005	0.9956
1.A.3.b	Road Transportation	CH4	314.04	0.0005	0.9961
3.B.5.b	Land Converted to Settlements	CO2	272.60	0.0005	0.9966
1.A.4	Other Sectors - Solid Fuels	N2O	249.72	0.0004	0.9970
2.D	Non-Energy Products from Fuels and Solvent Use	CO2	233.87	0.0004	0.9974
1.A.4	Other Sectors – Biomass	N2O	167.72	0.0003	0.9977
1.A.2	Manufacturing Industries and Construction - Solid Fuels	N2O	162.37	0.0003	0.9980
2.B.6	Titanium Dioxide Production	CO2	C[a]	0.0003	0.9982
2.C.3	Aluminium production	PFCs	138.26	0.0002	0.9985
2.B.8	Petrochemical and Carbon Black Production	CO2	C[a]	0.0002	0.9987
1.A.1	Energy Industries - Liquid Fuels	N2O	108.76	0.0002	0.9989
2.A.3	Glass Production	CO2	103.93	0.0002	0.9990
1.A.4	Other Sectors – Biomass	CH4	97.74	0.0002	0.9992
2.B.1	Ammonia Production	CH4	C[a]	0.0001	0.9993
2.C.6	Zinc Production	CO2	62.09	0.0001	0.9994
1.A.1	Energy Industries - Solid Fuels	CH4	56.08	0.0001	0.9995
3.B.2.a	Cropland Remaining Cropland	CO2	52.91	0.0001	0.9996
1.A.3.c	Railways	N2O	50.84	0.0001	0.9997
1.A.4	Other Sectors - Liquid Fuels	N2O	40.22	0.0001	0.9997
1.A.4	Other Sectors - Gaseous Fuels	CO2	27.04	0.0000	0.9998
1.B.1	Solid Fuels	CO2	26.59	0.0000	0.9998
2.C.5	Lead Production	CO2	26.31	0.0000	0.9999
1.A.4	Other Sectors - Liquid Fuels	CH4	15.81	0.0000	0.9999
1.A.1	Energy Industries - Liquid Fuels	CH4	12.97	0.0000	0.9999
1.A.3.a	Civil Aviation	N2O	9.09	0.0000	0.9999
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CH4	8.41	0.0000	0.9999
1.A.4	Other Sectors - Solid Fuels	CH4	6.47	0.0000	1.0000
2.B.5	Carbide Production	CO2	C[a]	0.0000	1.0000

IPCC Category code	IPCC Category	GHG	2000 (Gg CO_2 Eq)	Level Assessment	Cumulative Total
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	N2O	4.42	0.0000	1.0000
2.C.2	Ferroalloys Production	CH4	4.21	0.0000	1.0000
1.A.5	Non-Specified - Liquid Fuels	N2O	2.91	0.0000	1.0000
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	N2O	2.02	0.0000	1.0000
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	CH4	1.72	0.0000	1.0000
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CH4	1.57	0.0000	1.0000
1.A.5	Non-Specified - Liquid Fuels	CH4	1.13	0.0000	1.0000
1.A.3.c	Railways	CH4	0.57	0.0000	1.0000

[a] *Confidential - disaggregated Chemical Industry [2B] data is not shown.*

9.4 Level assessment: 2010 (excluding FOLU)

IPCC Category code	IPCC Category	GHG	2000 (Gg CO_2 Eq)	Level Assessment	Cumulative Total
1.A.1	Energy Industries - Solid Fuels	CO2	234 672.13	0.4306	0.4306
1.A.3.b	Road Transportation	CO2	42 515.18	0.0780	0.5087
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CO2	35 197.37	0.0646	0.5733
1.A.1	Energy Industries - Liquid Fuels	CO2	32 052.46	0.0588	0.6321
1.A.4	Other Sectors - Solid Fuels	CO2	27 067.04	0.0497	0.6818
3.A.1	Enteric Fermentation	CH4	26 977.84	0.0495	0.7313
2.C.1	Iron and Steel Production	CO2	24 146.87	0.0443	0.7756
1.B.3	Other emissions from Energy Production	CO2	22 181.07	0.0407	0.8163
1.A.4	Other Sectors - Liquid Fuels	CO2	17 589.76	0.0323	0.8486
4.A	Solid Waste Disposal	CH4	16 568.60	0.0304	0.8790
3.C.4	Direct N2O Emissions from managed soils	N2O	14 964.38	0.0275	0.9064
2.C.2	Ferroalloys Production	CO2	11 804.99	0.0217	0.9281
3.C.5	Indirect N2O Emissions from managed soils	N2O	4 502.33	0.0083	0.9363
2.A.1	Cement production	CO2	4 186.74	0.0077	0.9440
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CO2	3 837.58	0.0070	0.9511
1.A.3.a	Civil Aviation	CO2	3 657.68	0.0067	0.9578
4.D	Wastewater Treatment and Discharge	CH4	2 581.06	0.0047	0.9625
1.B.1	Solid Fuels	CH4	2 239.46	0.0041	0.9666
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	CO2	1 901.99	0.0035	0.9701
2.C.3	Aluminium production	CO2	1 330.00	0.0024	0.9726
3.C.1	Emissions from biomass burning	CH4	1 215.71	0.0022	0.9748
1.A.5	Non-Specified - Liquid Fuels	CO2	1 134.86	0.0021	0.9769
3.A.2	Manure Management	N2O	1 115.64	0.0020	0.9789
1.A.1	Energy Industries - Solid Fuels	N2O	1 082.54	0.0020	0.9809
3.A.2	Manure Management	CH4	892.52	0.0016	0.9825
2.F.1	Refrigeration and Air Conditioning	HFCs, PFCs	799.88	0.0015	0.9840
3.C.1	Emissions from biomass burning	N2O	721.77	0.0013	0.9853
4.D	Wastewater Treatment and Discharge	N2O	656.67	0.0012	0.9865
1.B.2.a	Oil	CO2	619.00	0.0011	0.9877
1.A.3.b	Road Transportation	N2O	610.52	0.0011	0.9888
3.C.2	Liming	CO2	585.54	0.0011	0.9899
2.A.2	Lime production	CO2	502.24	0.0009	0.9908
1.B.3	Other emissions from Energy Production	CH4	484.91	0.0009	0.9917
1.A.3.c	Railways	CO2	445.04	0.0008	0.9925

IPCC Category code	IPCC Category	GHG	2000 (Gg CO_2 Eq)	Level Assessment	Cumulative Total
3.C.3	Urea application	CO2	435.90	0.0008	0.9933
3.C.6	Indirect N2O Emissions from manure management	N2O	382.31	0.0007	0.9940
2.B.2	Nitric Acid Production	N2O	C[a]	0.0006	0.9946
2.B.1	Ammonia Production	CO2	C[a]	0.0006	0.9952
1.A.3.a	Civil Aviation	CH4	318.14	0.0006	0.9958
1.A.3.b	Road Transportation	CH4	314.04	0.0006	0.9964
1.A.4	Other Sectors - Solid Fuels	N2O	249.72	0.0005	0.9968
2.D	Non-Energy Products from Fuels and Solvent Use	CO2	233.87	0.0004	0.9972
1.A.4	Other Sectors – Biomass	N2O	167.72	0.0003	0.9976
1.A.2	Manufacturing Industries and Construction - Solid Fuels	N2O	162.37	0.0003	0.9979
2.B.6	Titanium Dioxide Production	CO2	C[a]	0.0003	0.9981
2.C.3	Aluminium production	PFCs	138.26	0.0003	0.9984
2.B.8	Petrochemical and Carbon Black Production	CO2	C[a]	0.0002	0.9986
1.A.1	Energy Industries - Liquid Fuels	N2O	108.76	0.0002	0.9988
2.A.3	Glass Production	CO2	103.93	0.0002	0.9990
1.A.4	Other Sectors – Biomass	CH4	97.74	0.0002	0.9992
2.B.1	Ammonia Production	CH4	C[a]	0.0001	0.9993
2.C.6	Zinc Production	CO2	62.09	0.0001	0.9994
1.A.1	Energy Industries - Solid Fuels	CH4	56.08	0.0001	0.9995
1.A.3.c	Railways	N2O	50.84	0.0001	0.9996
1.A.4	Other Sectors - Liquid Fuels	N2O	40.22	0.0001	0.9997
1.A.4	Other Sectors - Gaseous Fuels	CO2	27.04	0.0000	0.9998
1.B.1	Solid Fuels	CO2	26.59	0.0000	0.9998
2.C.5	Lead Production	CO2	26.31	0.0000	0.9999
1.A.4	Other Sectors - Liquid Fuels	CH4	15.81	0.0000	0.9999
1.A.1	Energy Industries - Liquid Fuels	CH4	12.97	0.0000	0.9999
1.A.3.a	Civil Aviation	N2O	9.09	0.0000	0.9999
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CH4	8.41	0.0000	0.9999
1.A.4	Other Sectors - Solid Fuels	CH4	6.47	0.0000	1.0000
2.B.5	Carbide Production	CO2	C[a]	0.0000	1.0000
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	N2O	4.42	0.0000	1.0000
2.C.2	Ferroalloys Production	CH4	4.21	0.0000	1.0000
1.A.5	Non-Specified - Liquid Fuels	N2O	2.91	0.0000	1.0000
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	N2O	2.02	0.0000	1.0000
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	CH4	1.72	0.0000	1.0000
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CH4	1.57	0.0000	1.0000

IPCC Category code	IPCC Category	GHG	2000 (Gg CO_2 Eq)	Level Assessment	Cumulative Total
1.A.5	Non-Specified - Liquid Fuels	CH4	1.13	0.0000	1.0000
1.A.3.c	Railways	CH4	0.57	0.0000	1.0000
2.B.8	Petrochemical and Carbon Black Production	CH4	C[a]	0.0000	1.0000

[a] *Confidential - disaggregated Chemical Industry [2B] data is not shown.*

9.5 Trend assessment: 2000 – 2010 (including FOLU)

IPCC Category code	IPCC Category	GHG	2000	2010	Trend As-sess-ment	Cumu-la-tive Total
			($Gg\ CO_2\ Eq$)			
3.B.3.b	Land Converted to Grassland	CO2	27 382.57	7 012.87	0.0495	0.1867
1.A.4	Other Sectors - Solid Fuels	CO2	5 586.89	27 067.04	0.0380	0.3301
1.B.3	Other emissions from Energy Production	CO2	26 658.56	22 181.07	0.0194	0.4032
2.C.1	Iron and Steel Production	CO2	27 753.86	24 146.87	0.0182	0.4719
1.A.1	Energy Industries - Liquid Fuels	CO2	33 855.83	32 052.46	0.0173	0.5372
1.A.1	Energy Industries - Solid Fuels	CO2	185 027.44	234 672.13	0.0170	0.6013
3.A.1	Enteric Fermentation	CH4	29 307.55	26 977.84	0.0164	0.6633
3.B.1.a	Forest land Remaining Forest land	CO2	-45 490.83	-27 121.56	0.0157	0.7227
3.B.2.b	Land Converted to Cropland	CO2	571.63	5 434.53	0.0089	0.7562
4.A	Solid Waste Disposal	CH4	9 704.23	16 568.60	0.0089	0.7897
3.C.4	Direct N2O Emissions from managed soils	N2O	16 118.85	14 964.38	0.0088	0.8229
3.B.1.b	Land Converted to Forest land	CO2	-2 549.14	-6 103.19	0.0077	0.8520
1.A.3.b	Road Transportation	CO2	32 623.34	42 515.18	0.0051	0.8714
1.A.4	Other Sectors - Liquid Fuels	CO2	12 766.46	17 589.76	0.0038	0.8857
2.C.2	Ferroalloys Production	CO2	8 079.14	11 804.99	0.0037	0.8995
3.D.1	Harvested Wood Products	CO2	-5 785.55	-6 204.49	0.0032	0.9115
2.B.2	Nitric Acid Production	N2O	C[a]	C[a]	0.0030	0.9227
3.C.5	Indirect N2O Emissions from managed soils	N2O	4 745.81	4 502.33	0.0024	0.9318
1.A.3.a	Civil Aviation	CO2	2 040.00	3 657.68	0.0022	0.9401
1.A.2	Manufacturing Industries & Construction -Gaseous Fuels	CO2	2 217.75	3 837.58	0.0021	0.9481
2.C.3	Aluminium production	PFCs	982.24	138.26	0.0020	0.9556
3.B.5.b	Land Converted to Settlements	CO2	888.97	272.60	0.0015	0.9614
2.F.1	Refrigeration and Air Conditioning	HFCs, PFCs	0.00	799.88	0.0015	0.9670
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	CO2	1 186.10	1 901.99	0.0009	0.9703
1.B.3	Other emissions from Energy Production	CH4	34.92	484.91	0.0008	0.9734
2.B.6	Titanium Dioxide Production	CO2	C[a]	C[a]	0.0007	0.9761
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CO2	29 101.57	35 197.37	0.0005	0.9781
2.B.1	Ammonia Production	CO2	C[a]	C[a]	0.0005	0.9800
3.C.1	Emissions from biomass burning	CH4	1 215.71	1 215.71	0.0005	0.9819
3.B.4.a.ii	Flooded land remaining flooded land	CH4	664.71	581.13	0.0004	0.9835
1.A.3.c	Railways	CO2	551.45	445.04	0.0004	0.9851

IPCC Category code	IPCC Category	GHG	2000	2010	Trend As-sess-ment	Cumu-la-tive Total
1.B.2.a	Oil	CO2	325.00	619.00	0.0004	0.9867
3.A.2	Manure Management	CH4	898.34	892.52	0.0004	0.9881
1.A.4	Other Sectors - Solid Fuels	N2O	51.46	249.72	0.0004	0.9895
3.C.3	Urea application	CO2	211.49	435.90	0.0003	0.9907
2.C.6	Zinc Production	CO2	194.36	62.09	0.0003	0.9920
1.B.1	Solid Fuels	CH4	1 978.88	2 239.46	0.0003	0.9932
3.C.1	Emissions from biomass burning	N2O	721.77	721.77	0.0003	0.9943
3.C.2	Liming	CO2	384.05	585.54	0.0002	0.9951
2.A.1	Cement production	CO2	3 347.05	4 186.74	0.0002	0.9959
1.A.5	Non-Specified - Liquid Fuels	CO2	985.58	1 134.86	0.0001	0.9964
4.D	Wastewater Treatment and Discharge	N2O	590.35	656.67	0.0001	0.9968
1.A.3.b	Road Transportation	N2O	463.05	610.52	0.0001	0.9971
1.A.1	Energy Industries - Solid Fuels	N2O	853.53	1 082.54	0.0001	0.9974
1.A.4	Other Sectors – Biomass	N2O	167.72	167.72	0.0001	0.9977
2.B.8	Petrochemical and Carbon Black Production	CO2	C[a]	C[a]	0.0001	0.9979
4.D	Wastewater Treatment and Discharge	CH4	2 139.35	2 581.06	0.0001	0.9981
1.A.1	Energy Industries - Liquid Fuels	N2O	110.63	108.76	0.0000	0.9983
1.A.3.c	Railways	N2O	63.00	50.84	0.0000	0.9985
2.B.1	Ammonia Production	CH4	C[a]	C[a]	0.0000	0.9987
1.A.4	Other Sectors – Biomass	CH4	97.74	97.74	0.0000	0.9988
2.C.5	Lead Production	CO2	39.16	26.31	0.0000	0.9990
2.C.3	Aluminium production	CO2	1 105.47	1 330.00	0.0000	0.9991
2.A.2	Lime production	CO2	426.37	502.24	0.0000	0.9992
3.C.6	Indirect N2O Emissions from manure management	N2O	327.91	382.31	0.0000	0.9994
2.A.3	Glass Production	CO2	74.38	103.93	0.0000	0.9994
1.A.3.b	Road Transportation	CH4	267.59	314.04	0.0000	0.9995
1.A.3.a	Civil Aviation	CH4	270.27	318.14	0.0000	0.9996
1.A.4	Other Sectors - Gaseous Fuels	CO2	12.96	27.04	0.0000	0.9997
1.A.4	Other Sectors - Liquid Fuels	N2O	28.78	40.22	0.0000	0.9997
2.D	Non-Energy Products from Fuels and Solvent Use	CO2	195.92	233.87	0.0000	0.9998
3.B.2.a	Cropland Remaining Cropland	CO2	39.34	52.91	0.0000	0.9998
1.A.4	Other Sectors - Solid Fuels	CH4	1.34	6.47	0.0000	0.9998
1.A.1	Energy Industries - Liquid Fuels	CH4	14.14	12.97	0.0000	0.9999
1.A.3.a	Civil Aviation	N2O	5.07	9.09	0.0000	0.9999
2.B.5	Carbide Production	CO2	C[a]	C[a]	0.0000	0.9999
3.A.2	Manure Management	N2O	912.73	1 115.64	0.0000	0.9999

IPCC Category code	IPCC Category	GHG	2000	2010	Trend As-sess-ment	Cumu-la-tive Total
1.B.1	Solid Fuels	CO2	23.67	26.59	0.0000	0.9999
1.A.1	Energy Industries - Solid Fuels	CH4	44.21	56.08	0.0000	1.0000
1.A.4	Other Sectors - Liquid Fuels	CH4	11.35	15.81	0.0000	1.0000
1.A.2	Manufacturing Industries and Construction - Solid Fuels	N2O	134.25	162.37	0.0000	1.0000
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	N2O	2.75	4.42	0.0000	1.0000
1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	N2O	1.17	2.02	0.0000	1.0000
1.A.2	Manufacturing Industries & Construction - Gaseous Fuels	CH4	0.91	1.57	0.0000	1.0000
1.A.2	Manufacturing Industries & Construction - Liquid Fuels	CH4	1.07	1.72	0.0000	1.0000
1.A.3.c	Railways	CH4	0.71	0.57	0.0000	1.0000
2.C.2	Ferroalloys Production	CH4	3.62	4.21	0.0000	1.0000
1.A.5	Non-Specified - Liquid Fuels	N2O	2.53	2.91	0.0000	1.0000
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CH4	6.95	8.41	0.0000	1.0000
1.A.5	Non-Specified - Liquid Fuels	CH4	0.98	1.13	0.0000	1.0000
2.B.8	Petrochemical and Carbon Black Production	CH4	C[a]	C[a]	0.0000	1.0000

[a] *Confidential - disaggregated Chemical Industry [2B] data is not shown.*

9.6 Trend assessment: 2000 – 2010 (excluding FOLU)

IPCC Category code	IPCC Category	GHG	2000	2010	Trend Assess-ment	Cumu-la-tive Total
			($Gg\ CO_2\ Eq$)			
1.A.4	Other Sectors - Solid Fuels	CO2	5 586.89	27 067.04	0.0451	0.2124
1.A.1	Energy Industries - Solid Fuels	CO2	185 027.44	234 672.13	0.0233	0.3223
1.B.3	Other emissions from Energy Production	CO2	26 658.56	22 181.07	0.0225	0.4282
2.C.1	Iron and Steel Production	CO2	27 753.86	24 146.87	0.0211	0.5274
1.A.1	Energy Industries - Liquid Fuels	CO2	33 855.83	32 052.46	0.0199	0.6212
3.A.1	Enteric Fermentation	CH4	29 307.55	26 977.84	0.0190	0.7105
4.A	Solid Waste Disposal	CH4	9 704.23	16 568.60	0.0107	0.7608
3.C.4	Direct N2O Emissions from managed soils	N2O	16 118.85	14 964.38	0.0101	0.8086
1.A.3.b	Road Transportation	CO2	32 623.34	42 515.18	0.0066	0.8399
1.A.4	Other Sectors - Liquid Fuels	CO2	12 766.46	17 589.76	0.0047	0.8621
2.C.2	Ferroalloys Production	CO2	8 079.14	11 804.99	0.0045	0.8832
2.B.2	Nitric Acid Production	N2O	C[a]	C[a]	0.0035	0.8997
3.C.5	Indirect N2O Emissions from managed soils	N2O	4 745.81	4 502.33	0.0028	0.9128
1.A.3.a	Civil Aviation	CO2	2 040.00	3 657.68	0.0026	0.9252
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CO2	2 217.75	3 837.58	0.0026	0.9372
2.C.3	Aluminium production	PFCs	982.24	138.26	0.0023	0.9482
2.F.1	Refrigeration and Air Conditioning	HFCs, PFCs	0.00	799.88	0.0018	0.9566
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	CO2	1 186.10	1 901.99	0.0010	0.9615
1.B.3	Other emissions from Energy Production	CH4	34.92	484.91	0.0010	0.9661
2.B.6	Titanium Dioxide Production	CO2	C[a]	C[a]	0.0008	0.9700
2.B.1	Ammonia Production	CO2	C[a]	C[a]	0.0006	0.9727
3.C.1	Emissions from biomass burning	CH4	1 215.71	1 215.71	0.0006	0.9754
1.B.2.a	Oil	CO2	325.00	619.00	0.0005	0.9778
1.A.3.c	Railways	CO2	551.45	445.04	0.0005	0.9801
3.A.2	Manure Management	CH4	898.34	892.52	0.0004	0.9822
1.A.4	Other Sectors - Solid Fuels	N2O	51.46	249.72	0.0004	0.9841
3.C.3	Urea application	CO2	211.49	435.90	0.0004	0.9860
2.C.6	Zinc Production	CO2	194.36	62.09	0.0004	0.9878
1.B.1	Solid Fuels	CH4	1 978.88	2 239.46	0.0004	0.9895

IPCC Category code	IPCC Category	GHG	2000	2010	Trend Assess-ment	Cumu-la-tive Total
3.C.1	Emissions from biomass burning	N2O	721.77	721.77	0.0003	0.9911
2.A.1	Cement production	CO2	3 347.05	4 186.74	0.0003	0.9924
3.C.2	Liming	CO2	384.05	585.54	0.0003	0.9937
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CO2	29 101.57	35 197.37	0.0001	0.9944
1.A.5	Non-Specified - Liquid Fuels	CO2	985.58	1 134.86	0.0001	0.9950
4.D	Wastewater Treatment and Discharge	N2O	590.35	656.67	0.0001	0.9956
1.A.3.b	Road Transportation	N2O	463.05	610.52	0.0001	0.9961
1.A.1	Energy Industries - Solid Fuels	N2O	853.53	1 082.54	0.0001	0.9966
1.A.4	Other Sectors – Biomass	N2O	167.72	167.72	0.0001	0.9970
2.B.8	Petrochemical and Carbon Black Production	CO2	C[a]	C[a]	0.0001	0.9973
1.A.3.c	Railways	N2O	63.00	50.84	0.0001	0.9976
1.A.1	Energy Industries - Liquid Fuels	N2O	110.63	108.76	0.0001	0.9979
2.B.1	Ammonia Production	CH4	C[a]	C[a]	0.0001	0.9981
2.C.5	Lead Production	CO2	39.16	26.31	0.0000	0.9983
1.A.4	Other Sectors – Biomass	CH4	97.74	97.74	0.0000	0.9986
3.C.6	Indirect N2O Emissions from manure manage-ment	N2O	327.91	382.31	0.0000	0.9987
2.A.2	Lime production	CO2	426.37	502.24	0.0000	0.9989
2.A.3	Glass Production	CO2	74.38	103.93	0.0000	0.9990
1.A.4	Other Sectors - Gaseous Fuels	CO2	12.96	27.04	0.0000	0.9991
4.D	Wastewater Treatment and Discharge	CH4	2 139.35	2 581.06	0.0000	0.9992
1.A.3.b	Road Transportation	CH4	267.59	314.04	0.0000	0.9993
3.A.2	Manure Management	N2O	912.73	1 115.64	0.0000	0.9995
2.C.3	Aluminium production	CO2	1 105.47	1 330.00	0.0000	0.9995
1.A.3.a	Civil Aviation	CH4	270.27	318.14	0.0000	0.9996
1.A.4	Other Sectors - Liquid Fuels	N2O	28.78	40.22	0.0000	0.9997
1.A.4	Other Sectors - Solid Fuels	CH4	1.34	6.47	0.0000	0.9998
1.A.1	Energy Industries - Liquid Fuels	CH4	14.14	12.97	0.0000	0.9998
2.D	Non-Energy Products from Fuels and Solvent Use	CO2	195.92	233.87	0.0000	0.9998
1.A.3.a	Civil Aviation	N2O	5.07	9.09	0.0000	0.9999
2.B.5	Carbide Production	CO2	C[a]	C[a]	0.0000	0.9999
1.A.1	Energy Industries - Solid Fuels	CH4	44.21	56.08	0.0000	0.9999
1.B.1	Solid Fuels	CO2	23.67	26.59	0.0000	0.9999
1.A.4	Other Sectors - Liquid Fuels	CH4	11.35	15.81	0.0000	1.0000
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	N2O	2.75	4.42	0.0000	1.0000

IPCC Category code	IPCC Category	GHG	2000	2010	Trend Assess-ment	Cumu-la-tive Total
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	N2O	1.17	2.02	0.0000	1.0000
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CH4	0.91	1.57	0.0000	1.0000
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	CH4	1.07	1.72	0.0000	1.0000
1.A.3.c	Railways	CH4	0.71	0.57	0.0000	1.0000
1.A.2	Manufacturing Industries and Construction - Solid Fuels	N2O	134.25	162.37	0.0000	1.0000
2.C.2	Ferroalloys Production	CH4	3.62	4.21	0.0000	1.0000
1.A.5	Non-Specified - Liquid Fuels	N2O	2.53	2.91	0.0000	1.0000
1.A.5	Non-Specified - Liquid Fuels	CH4	0.98	1.13	0.0000	1.0000
2.B.8	Petrochemical and Carbon Black Production	CH4	C[a]	C[a]	0.0000	1.0000
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CH4	6.95	8.41	0.0000	1.0000

[a] *Confidential - disaggregated Chemical Industry [2B] data is not shown.*

10. APPENDIX D: AGRICULTURAL ACTIVITY DATA

10.1 Livestock sub-categories for sheep, goats and swine

Livestock category	Livestock sub-category from Du Toit et al. (2013b)	Livestock sub-category in this inventory
Sheep	Non-wool breeding ewe	Non-wool ewe
	Non-wool young ewe	
	Non-wool breeding ram	Non-wool ram
	Non-wool young ram	
	Non-wool weaners	Non-wool lamb
	Non-wool lamb	
	Merino breeding ewe	Wool ewe
	Merino young ewe	
	Other wool breeding ewe	
	Other wool young ewe	
	Karakul breeding ewe	
	Karakul young ewe	
	Merino breeding ram	Wool ram
	Merino young ram	
	Other wool breeding ram	
	Other wool young ram	
	Karakul breeding ram	
	Karakul young ram	
	Merino weaner	Wool lamb
	Merino lamb	
	Other wool weaner	
	Other wool lamb	
	Karakul weaner	
	Karakul lamb	

Livestock category	Livestock sub-category from Du Toit et al. (2013b)	Livestock sub-category in this inventory
Goats	Breeding buck	Buck
	Young buck	
	Breeding doe	Doe
	Young doe	
	Weaner	Kid
	Kid	
	Breeding buck	Angora
	Young buck	
	Breeding doe	
	Young doe	
	Weaner	
	Kid	
	Breeding buck	Milk goat
	Young buck	
	Breeding doe	
	Young doe	
	Weaner	
	Kid	
Swine	Boars	Boars
	Replacement boars	
	Cull boars	
	Dry gestating sow	Sows
	Lactating sow	
	Replacement sow	
	Cull sow	
	Pre-wean piglets	Piglets
	Baconers	Baconers
	Porkers	Porkers

10.2 Livestock population data

Category	Sub-category	Population										
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Dairy (Commercial - TMR)	Lactating cow	437 637	437 637	375 749	349 226	340 385	362 487	353 646	349 226	433 217	442 058	442 058
	Dry cow	106 452	106 452	91 398	84 947	82 796	88 173	86 022	84 947	105 377	107 528	107 528
	Lactating heifer	42 092	40 985	39 877	31 015	27 692	31 015	31 015	32 123	35 446	37 662	37 662
	Pregnant heifer	56 663	55 172	53 680	41 751	37 278	41 751	41 751	43 243	47 716	50 698	50 698
	Heifer >1yr	19 427	18 916	18 405	14 315	12 781	14 315	14 315	14 826	16 360	17 382	17 382
	Heifer 6-12mths	38 854	37 832	36 809	28 630	25 562	28 630	28 630	29 652	32 720	34 764	34 764
	Heifer 2-6mths	25 903	25 221	24 540	19 086	17 041	19 086	19 086	19 768	21 813	23 176	23 176
	Calves <6mths	25 903	25 221	24 540	19 086	17 041	19 086	19 086	19 768	21 813	23 176	23 176
	Total TMR	752 932	747 436	664 998	588 056	560 577	604 544	593 552	593 552	714 461	736 445	736 445
Dairy (Commercial - Pasture)	Lactating cow	358 667	358 667	307 946	286 209	278 963	297 078	289 832	286 209	355 044	362 290	362 290
	Dry cow	87 243	87 243	74 906	69 618	67 856	72 262	70 500	69 618	86 362	88 125	88 125
	Lactating heifer	34 497	33 589	32 681	25 419	22 695	25 419	25 419	26 327	29 050	30 866	30 866
	Pregnant heifer	46 438	45 216	43 994	34 218	30 551	34 218	34 218	35 440	39 106	41 550	41 550
	Heifer >1yr	15 922	15 503	15 084	11 732	10 475	11 732	11 732	12 151	13 408	14 246	14 246
	Heifer 6-12mths	31 843	31 005	30 167	23 463	20 950	23 463	23 463	24 301	26 815	28 491	28 491
	Heifer 2-6mths	21 229	20 670	20 112	15 642	13 966	15 642	15 642	16 201	17 877	18 994	18 994
	Calves <6mths	21 229	20 670	20 112	15 642	13 966	15 642	15 642	16 201	17 877	18 994	18 994
	Total Pasture	617 068	612 564	545 002	481 944	459 423	495 456	486 448	486 448	585 539	603 555	603 555
Total Dairy		1 370 000	1 360 000	1 210 000	1 070 000	1 020 000	1 100 000	1 080 000	1 080 000	1 300 000	1 340 000	1 340 000
Other cattle (Commercial)	Feedlot	420 000	420 000	420 000	420 000	420 000	420 000	391 148	400 819	399 822	461 800	484 274
	Bulls	200 000	190 000	190 000	190 000	200 000	190 000	180 000	150 000	160 000	180 000	200 000
	Cows	3 540 000	3 600 000	3 430 000	3 080 000	2 840 000	3 140 000	3 080 000	2 460 000	2 710 000	2 390 000	2 980 000
	Heifers	1 050 000	1 040 000	1 020 000	950 000	1 390 000	920 000	900 000	850 000	770 000	700 000	910 000
	Ox	230 000	240 000	200 000	260 000	280 000	210 000	200 000	170 000	240 000	280 000	170 000
	Young ox	660 000	660 000	540 000	570 000	520 000	510 000	500 000	1 080 000	1 140 000	860 000	630 000
	Calves	1 630 000	1 610 000	1 470 000	1 910 000	1 770 000	2 110 000	2 070 000	2 400 000	1 960 000	2 490 000	1 990 000
	Total commercial	7 730 000	7 760 000	7 270 000	7 380 000	7 420 000	7 500 000	7 350 000	7 530 000	7 371 148	7 300 819	7 279 822

Category	Sub-category	Population										
		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Other cattle (Cummunal)	Bulls	137 359	130 491	130 491	130 491	137 359	130 491	123 623	103 019	109 887	123 623	137 359
	Cows	2 431 256	2 472 464	2 355 709	2 115 330	1 950 499	2 156 538	2 115 330	1 689 517	1 861 216	1 641 441	2 046 651
	Heifers	721 135	714 267	700 531	652 456	954 646	631 852	618 116	583 776	528 833	480 757	624 984
	Ox	157 963	164 831	137 359	178 567	192 303	144 227	137 359	116 755	164 831	192 303	116 755
	Young ox	453 285	453 285	370 870	391 473	357 134	350 266	343 398	741 739	782 947	590 644	432 681
	Calves	1 119 477	1 105 741	1 009 589	1 311 779	1 215 628	1 449 138	1 421 667	1 648 309	1 346 119	1 710 121	1 366 723
	Total communal	5 020 475	5 041 079	4 704 549	4 780 097	4 807 568	4 862 512	4 759 493	4 883 116	4 793 833	4 738 889	4 725 153
Total Other cattle		12 750 475	12 801 079	11 974 549	12 160 096	12 227 569	12 362 512	12 109 493	12 413 115	12 164 981	12 039 708	12 004 975

Sheep (Commercial)	Wool lamb	6 610 800	6 446 000	6 427 600	6 476 000	6 395 200	6 407 600	6 219 600	6 299 200	6 389 200	6 296 000	6 174 400
	Wool ewe	9 420 390	9 185 550	9 159 330	9 228 300	9 113 160	9 130 830	8 862 930	8 976 360	9 104 610	8 971 800	8 798 520
	Wool ram	495 810	483 450	482 070	485 700	479 640	480 570	466 470	472 440	479 190	472 200	463 080
	Non-wool lamb	2 823 600	2 753 200	2 618 000	2 601 200	2 520 400	2 486 800	2 558 400	2 470 400	2 408 800	2 470 800	2 422 800
	Non-wool ewe	4 023 630	3 923 310	3 730 650	3 706 710	3 591 570	3 543 690	3 645 720	3 520 320	3 432 540	3 520 890	3 452 490
	Non-wool ram	211 770	206 490	196 350	195 090	189 030	186 510	191 880	185 280	180 660	185 310	181 710
	Total commercial	23 586 000	22 998 000	22 614 000	22 693 000	22 289 000	22 236 000	21 945 000	21 924 000	21 995 000	21 917 000	21 493 000
Sheep (Communal)	Wool lamb	922 602	899 602	897 034	903 789	892 513	894 243	868 006	879 115	891 675	878 668	861 698
	Wool ewe	1 314 708	1 281 933	1 278 274	1 287 900	1 271 831	1 274 297	1 236 909	1 252 739	1 270 637	1 252 102	1 227 920
	Wool ram	69 195	67 470	67 278	67 784	66 938	67 068	65 100	65 934	66 876	65 900	64 627
	Non-wool lamb	394 061	384 236	365 368	363 023	351 746	347 057	357 050	344 768	336 172	344 824	338 125
	Non-wool ewe	561 537	547 536	520 649	517 308	501 239	494 557	508 796	491 295	479 045	491 375	481 829
	Non-wool ram	29 555	28 818	27 403	27 227	26 381	26 029	26 779	25 858	25 213	25 862	25 359
	Total communal	3 291 657	3 209 596	3 156 005	3 167 030	3 110 648	3 103 251	3 062 639	3 059 709	3 069 617	3 058 732	2 999 558
Total sheep		26 877 657	26 207 596	25 770 005	25 860 030	25 399 648	25 339 251	25 007 639	24 983 709	25 064 617	24 975 732	24 492 558
Goats (Commercial)	Buck	207 086	213 417	194 863	189 939	190 291	187 828	191 786	186 070	185 894	182 640	180 442
	Doe	654 760	674 778	616 114	600 544	601 657	593 872	606 383	588 311	587 755	577 468	570 517
	Kids	618 749	637 667	582 229	567 515	568 566	561 210	573 033	555 955	555 429	545 708	539 140
	Angora	856 557	882 745	806 001	785 632	787 087	776 903	793 270	769 629	768 901	755 444	746 351
	Milk goats	17 847	18 392	16 793	16 369	16 399	16 187	16 528	16 035	16 020	15 740	15 550
	Total commercial	2 355 000	2 427 000	2 216 000	2 160 000	2 164 000	2 136 000	2 181 000	2 116 000	2 114 000	2 077 000	2 052 000
Goats (Communal)	Buck	147 130	151 628	138 445	134 947	135 197	133 447	136 259	132 198	132 073	129 761	128 200
	Doe	2 795 507	2 880 974	2 630 507	2 564 032	2 568 780	2 535 542	2 588 960	2 511 801	2 509 427	2 465 506	2 435 830
	Kids	1 709 028	1 761 278	1 608 155	1 567 516	1 570 419	1 550 099	1 582 756	1 535 585	1 534 134	1 507 283	1 489 140
	Total communal	4 651 664	4 793 880	4 377 107	4 266 494	4 274 395	4 219 089	4 307 974	4 179 584	4 175 634	4 102 550	4 053 170
Total goats		7 006 664	7 220 880	6 593 107	6 426 494	6 438 395	6 355 089	6 488 974	6 295 584	6 289 634	6 179 550	6 105 170
Swine (commercial)	Boars	30 563	31 138	31 732	30 860	30 860	30 637	30 099	30 637	29 969	29 932	29 579
	Sows	529 757	539 728	550 021	534 903	534 903	531 043	521 715	531 043	519 464	518 821	512 709
	Piglets	543 340	553 567	564 124	548 619	548 619	544 660	535 093	544 660	532 784	532 124	525 856
	Porkers	81 501	83 035	84 619	82 293	82 293	81 699	80 264	81 699	79 918	79 819	78 878
	Baconers	461 839	470 532	479 505	466 326	466 326	462 961	454 829	462 961	452 866	452 305	446 977
	Total commercial	1 647 000	1 678 000	1 710 000	1 663 000	1 663 000	1 651 000	1 622 000	1 651 000	1 615 000	1 613 000	1 594 000

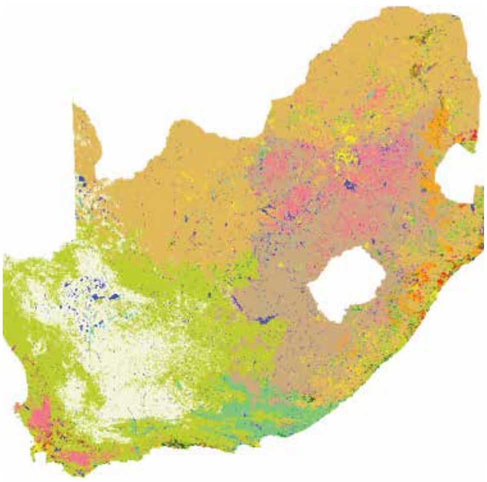
Swine (communal)	Boars	7 868	8 017	8 169	7 945	7 945	7 888	7 749	7 888	7 716	7 706	7 615
	Sows	102 290	104 216	106 203	103 284	103 284	102 539	100 738	102 539	100 303	100 179	98 999
	Piglets	52 457	53 444	54 463	52 966	52 966	52 584	51 660	52 584	51 437	51 374	50 769
	Porkers	7 868	8 017	8 169	7 945	7 945	7 888	7 749	7 888	7 716	7 706	7 615
	Baconers	44 588	45 427	46 294	45 021	45 021	44 696	43 911	44 696	43 722	43 668	43 153
	Total communal	215 072	219 120	223 299	217 161	217 161	215 594	211 807	215 594	210 893	210 632	208 151
Total swine		1 862 072	1 897 120	1 933 299	1 880 161	1 880 161	1 866 594	1 833 807	1 866 594	1 825 893	1 823 632	1 802 151
Horses	Total	270 000	270 000	270 000	270 000	270 000	270 000	280 000	290 000	298 000	300 000	300 000
Mules and asses	Asses	150 000	150 000	150 000	150 000	150 000	150 000	150 000	150 500	150 500	150 500	152 000
	Mules	14 000	14 000	14 000	14 000	14 000	14 000	14 050	14 100	14 200	14 300	14 300
Total mules/asses		164 000	164 000	164 000	164 000	164 000	164 000	164 050	164 600	164 700	164 800	166 300
Poultry (Commercial)	Annual avg broilers	65 716 784	65 716 888	67 671 233	71 163 068	72 846 641	79 846 641	86 769 951	89 769 951	90 950 137	92 129 907	93 057 627
	Layers	17 400 000	17 800 000	17 700 000	17 000 000	17 590 000	18 660 000	20 590 000	22 780 000	23 080 000	22 230 000	23 100 000
	Total commercial	83 116 784	83 516 888	85 371 233	88 163 068	90 225 595	98 506 641	106 911 425	112 549 951	114 030 137	114 359 907	116 157 627
Poultry (Communal)	Annual avg broilers	2 760 105	2 760 109	2 842 192	2 988 849	3 050 695	3 353 559	3 625 500	3 770 338	3 819 906	3 869 456	3 908 420
Total poultry		85 876 889	86 276 997	88 213 425	91 151 917	93 276 290	101 860 200	110 536 925	116 320 289	117 850 043	118 229 363	120 066047
Total livestock		136 177 756	136 197 670	136 128 386	138 982 699	140 676 063	149 317 645	157 500 889	163 413 893	164 957 871	165 052 786	166 277 200

11. APPENDIX E: METHODOLOGY FOR LAND COVER AND LAND USE CHANGE MATRIX

GEOTERRA IMAGE

Modelling of Land-Cover Change in South Africa (2001 – 2010) in Support of Green House Gas Emissions Reporting

Summary Report & Metadata.



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1. Background

The Department of Environment Affairs (DEA) requires the determination of land-cover change between the years 2000, 2005 and 2010 in support of their determination of Green House Gas Emissions reporting to the international community. The datasets described below were generated in response to this need. The data modelling approaches and final product content and format were all conceived to be in-line with DEA's urgent need for such data, which imposed significant constraints in terms of overall production time. The University of Witwatersrand (WITS) coordinated the project with GeoTerraImage Pty Ltd (GTI) on behalf of the DEA.

Due to satellite data archival limitations associated with the proposed methodology, it is not possible to access suitable historical imagery for the year 2000, simply because the data does not exist. Hence the final set of land-cover data is based on the use of satellite time series data from 2001 – 2010 instead.

2. Objective

To create three standardised land-cover datasets for the whole of South Africa, representing conditions in 2001, 2005 and 2010; and to provide quantitative estimates of land-cover change between these three assessment dates. The methodology used was practical (i.e. time, cost, available input data), scientifically defensible (i.e. transparent and rigorous), repeatable in the future (except for loss of satellite systems etc out of our control etc), and has produced usable, standardised, wall-to-wall land-cover data for the required assessment periods.

3. Deliverables

Three (3) separate land-cover data coverages have been provided, representing landscape characteristics across the full extent of South Africa in 2001, 2005 and 2010. The datasets are based on a 500 x 500 m (25 ha) raster grid framework, within which the dominant (by area) land-cover within each cell has been defined.

This is the same cell-based format and resolution as the MODIS satellite imagery used as the primary modelling dataset. All final data products have been delivered in digital (raster) format suitable for use and incorporation within GIS data modelling and analysis systems.

Table 1 lists the land-cover classes which have been modelled for each assessment year, which are in accordance with IPCC land-cover information reporting requirements:

In addition to the three digital, raster format land-cover datasets, three summary tables have been provided (in Excel spreadsheet format) that document the calculated changes in land-cover between the assessment years. These tables represent non-spatially, the changes between each cover class in both percentage and area values.

Table 1. Land-cover classes included in the national land-cover datasets for 2001, 2005 and 2010.

No	IPCC Primary Class	Sub No.	DEA GHG Sub-Classes 500m
1	Forest lands	1	Indigenous Forest
		2	Thicket (remaining untransformed biome)
		3	Woodland / Savanna (remaining untransformed biome)
		4	Plantations (incl clearfelled)
2	Crop lands	5	Annual commercial crops (non-pivot), incl other non-pivot irrigation
		6	Annual commercial crops (pivot)
		7	Permanent crops (orchard)
		8	Permanent crops (viticulture)
		9	Annual semi-commercial / subsistence crops
		10	Permanent crops (sugarcane, irrig & dry)
3	Settlements	11	Settlements
4	Wetlands	12	Wetlands
5	Grasslands	13	Grasslands (remaining untransformed biome)
6	Other lands	14	Mines
		15	Water bodies
		16	Rare ground
		17	Other
		18	Fynbos (remaining untransformed biome)
		19	Nama Karoo (remaining untransformed biome)
		20	Succulent Karoo (remaining untransformed biome)

4. Methodology: General Overview

Coarse resolution MODIS time series satellite data has been 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. Note that the MODIS time-series dataset does not form part of the final deliverables, and is supplied under a restrictive license specifically for use in only the analysis and preparation of the 2001, 2005 and 2010 SA land-cover datasets. A full description of the MODIS data is supplied in the Appendices.

The MODIS time series imagery represents summarised biomass data for each 32-day period within the period 2001 – 2010. Biomass is 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.

The 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. In some cases these datasets are available as public-access data (with permission), whilst others are proprietary products, generated, owned and sold under license by GeoTerraImage. None of these datasets form part of the final deliverables, and have only been used during the analysis and preparation of the 2001, 2005 and 2010 SA land-cover datasets. A summary list of the source image data used to generate the geographic masks is supplied in the Appendices, listed by image date and image type per province.

Using the MODIS time-series vegetation data in combination with the higher resolution cover class geographic masks, it was thus possible to model the extent of a particular cover class in each of the three assessment years, using standardised assumptions about how such a cover class is represented by the MODIS vegetation profiles.

Note however that the physical extent of each geographical mask was not used to define the *exact* boundary of that specific cover class, but rather the results of the associated (MODIS EVI) modelling process *within that geographic mask* were used to define which cells were finally representative of that cover class. This approach ensured that standardised modelling assumptions could be applied independently and repeatedly to each MODIS dataset, for each assessment year.

For example, for the "cultivated annual commercial crops" (# 5), the following modelling rules and assumptions were applied:

- All national field boundary vector data circa 2006 – 2010 (available from the Department of Agriculture, Forestry and Fisheries, DAFF) were amalgamated into a single dataset representative of the maximum extent of cultivated lands across SA in approximately the last 10 years.
- The amalgamated field vector dataset thus represented the maximum potential area of cultivated lands in each of the assessment years.
- To define the actual extent of cultivated land (w.r.t. an annual crop cover) in each assessment year, the MODIS data cell must (a) be located within the potential cultivated land mask area, and (b), exhibit a period of low / non-vegetation at some time during the (crop) growth cycle, representative of the soil preparation / planting period,
- Any MODIS cell unit not exhibiting such a pattern is not classified as an active (annual) crop cover in that assessment window.

Thus the final extent of annual commercial crops defined for each assessment period will be represented by the output from the MODIS EVI-based vegetation modelling process and *not* the original field boundary geographic mask.

Full descriptions of all the modelling rules and assumptions for each land-cover class are supplied in later sections of this report, as well as indications of the time frames for the reference datasets used as for the sources of the different geographic masks.

Note that 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. The order in which each of the land-cover classes is merged (i.e. overlaid) with the other land-cover types is defined below in Table 2.

Table 2. Hierarchical Overlay Sequence for Land-Cover Classes

Overlay Sequence	Land-Cover Class
This cover always overwrote classes below...	Settlements
This cover always overwrote classes below...	Indigenous forest
This cover always overwrote classes below...	Plantations (incl clearfelled)
This cover always overwrote classes below...	Permanent crops (sugarcane, irrig & dry)
This cover always overwrote classes below...	Permanent crops (viticulture)
This cover always overwrote classes below...	Permanent crops (orchard)
This cover always overwrote classes below...	Annual commercial crops (pivot)
This cover always overwrote classes below...	Annual semi-commercial / subsistence crops
This cover always overwrote classes below...	Annual commercial crops (non-pivot), incl other non-pivot irrigation
This cover always overwrote classes below...	Mines
This cover always overwrote classes below...	Water bodies
This cover always overwrote classes below...	Wetlands
This cover always overwrote classes below...	Bare ground
	Other (biomes)
Other (biomes)	Thicket (remaining untransformed biome)
Other (biomes)	Woodland / Savanna (remaining untransformed biome)
Other (biomes)	Grasslands (remaining untransformed biome)
Other (biomes)	Fynbos (remaining untransformed biome)
Other (biomes)	Nama Karoo (remaining untransformed biome)
Other (biomes)	Succulent Karoo (remaining untransformed biome)

4.1 Limitations of modelling approach: Area estimations

It is important to realise that the MODIS EVI modelling is based on 500 x 500 m pixels where as the geographic masks are based on 30m resolution pixels (derived independently from either Landsat or SPOT imagery). It is quite feasible that spatial misrepresentations have been 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. This may be further exacerbated by the sequence in which the individual cover classes are overlaid / merged during compilation of the final land-cover product (see Table 2). For example, plantation forestry always over-writes (i.e. dominates within a cell) all cover types listed below it in the sequence presented in Table 2, regardless of the actual area of plantation forestry in that cell.

4.2 Limitations of modelling approach: Accuracy & validation

It is important for end users to be aware that this has been 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. Full transparency in terms of the

MODIS data modelling rules and assumptions has however been provided should future users and / or analysts wish to re-calculate components of the land-cover data.

4.3 Limitations of modelling approach: Data application

Due to the modelling processes and data inputs described, it should be clearly understood and communication to all end-users that the land-cover and land-cover change products have been developed *specifically* in support of the DEA-WITS GHG / IPCC reporting requirements, and that the products should *not* be considered new national land-cover datasets for wider application without full knowledge and understanding of the manner and process with which they have been generated.

5. Modis modelling: Detailed description & logic tests

Cover-class specific upper and / or lower EVI data thresholds were determined from the MODIS data for each land-cover type using appropriate Landsat and/or high resolution thematic land-cover classifications for reference. Class specific modelling was restricted to specific geographic areas using digital masks extracted from a range of pre-existing land-cover classifications. A single reference mask was created for each cover class. The masks were created to represent the maximum geographical area of that particular cover class in all three assessment years. EVI modelling rules and assumptions were first developed on a year by year basis.

Since the geographic masks were generated from several independent reference sources, the geographical extent of each mask was not necessarily mutually exclusive, and masks could overlap. A specific sequence of priority overlaps was therefore established in order to compile the final SA land-cover datasets from each of the individual cover classes (see Table 2). For example modelled water pixels over-wrote all modelled natural vegetation pixels.

The results of the individual year modelling outputs were then tested for logical sequence across all three assessment years, and adjusted as and where deemed necessary. For example, if a cell was classified as "Water" in both 2001 and 2010, but "Plantation" in 2005, then the assumption will be that a modelling / rule error has occurred and that the logical sequence should be "Water" in all three assessment years. Only after this Quality Check has been completed was the final land-cover change assessments undertaken between the assessment years.

5.1 Modis modelling: Cover-class modelling rules

5.1.1 Indigenous forests

EVI modelling assumptions

Indigenous forests were defined as pixels which consistently exhibited EVI values representing forest during every month of a year, within the pre-defined forest geographical mask.

EVI modelling thresholds

A pixel was defined as representing forests if the EVI values exceeded a minimum threshold of 0.21 during every month of a single year. This threshold value was taken to be representative of a closed canopy tree cover. Thresholds were determined visually using comparison to equivalent seasonal and year date Landsat imagery and existing small scale land-cover classifications.

Source of geographic mask

The forest geographic mask was created by merging indigenous forest classes from previously mapped land-cover datasets and the 2006 SANBI biomes vector data (see appendix).

Land-cover class modelling assumptions

Unlike plantations, indigenous forests are never cleared and replanted therefore it was assumed that pixels must contain forestry equivalent EVI values for every month of a year for that pixel to be classified as indigenous forests. If a pixel contained EVI values less than the indigenous forest threshold for one or more months of a year then it was assumed that the area had been cleared and was no longer indigenous forest.

Final logic test

A final logic test was used to check and edit (if required) the modelled 2001, 2005 and 2010 indigenous forest datasets. It was assumed that if a pixel was defined as forest in 2010 then the same pixel also had to be forest in 2005 because indigenous forests are not replanted if cleared and therefore the forest needed to have existed prior to the assessed date. Similarly, if a pixel was defined as forest in 2005 then the same pixel also had to be forest in 2001.

It was therefore also assumed that if an EVI pixel value showed forests for 2010, but not for 2001 and 2005 then the 2010 forest is incorrect and had been removed from the class. Similarly if a pixel was defined as forest in 2005 and 2010 then that pixel had to have been forest in 2001.

5.1.2 Thicket

The thicket class boundary was extracted from the 2006 SANBI vector biome dataset, since it was outside the scope of the project and the available data to derive a MODIS EVI generated thicket boundary. Therefore the extent of thicket within the final land-cover datasets represents the biome boundary rather than the actual vegetation cover extent.

5.1.3 Woodland / Savanna

The **woodland / savanna** class boundary was extracted from the 2006 SANBI vector biome dataset, since it was outside the scope of the project and the available data to derive a MODIS EVI generated **woodland / savanna** boundary. Therefore the extent of **woodland / savanna** within the final land-cover datasets represents the biome boundary rather than the actual vegetation cover extent.

5.1.4 Plantations

EVI modelling assumptions

Plantations were defined as pixels which consistently exhibited EVI values representing forest plantations during every month of a year, within the pre-defined plantation geographical mask.

EVI modelling thresholds

A pixel was defined as representing plantations if the EVI value exceeded a minimum threshold of 0.21 during every month of a year. This threshold value was taken to be representative of closed canopy tree cover (mature stands). Thresholds were determined visually using comparison to equivalent seasonal and year date Landsat imagery and existing small scale land-cover classifications.

Source of geographic mask

The plantation geographic mask was created by merging plantation classes from previously mapped land-cover datasets (see appendix).

Land-cover class modelling assumptions

To separate temporary clear-felled stands from permanent, non-tree covered areas, a maximum period of 4 years of undetectable tree cover was allowed, before which plantation re-growth had to become evident in terms of the EVI threshold. The 4 year period was defined from the first month of detectable non-tree cover on the EVI data, for pixels which previously contained a detectable tree cover. This 4 year period was deemed sufficient to represent a 40% canopy closure for the slowest plantation growth curves. Pixel EVI values exhibiting a lack of detectable tree re-growth after 4 years were assumed to no longer be representative of the plantation class (i.e. no re-planting).

Final logic test

A final logic test was used to check and edit (if required) the modelled 2001, 2005 and 2010 plantation datasets. It was assumed that if a pixel was defined as plantation in 2001 and 2010 then the same pixel also had to be plantation in 2005. Similarly, if no plantation was defined in a pixel during 2001 and 2010, then that pixel could not contain plantations during 2005 because of tree growth rates.

5.1.5 Annual commercial crops (non pivot)

EVI modelling assumptions

Annual crops were defined as pixels which exhibited EVI values representing both bare ground and mature crops within a 12 month crop cycle, within the pre-defined annual crop geographical mask.

EVI modelling thresholds

A pixel was defined as representing annual commercial crops (non pivot) if the EVI dataset met both the bare field threshold and the mature crop threshold during a single growth year. Bare field status (i.e. bare ground prior to planting) was defined as a pixel having an EVI value below a maximum threshold of 0.148 (excluding zero as this represented "no data") during at least one month of a year. The mature crop condition was defined as a pixel with an EVI value exceeding a minimum threshold of 0.362 during at least one month of a year. Thresholds were determined visually using comparison to equivalent date Landsat imagery and the existing small scale land-cover classifications.

Source of geographic mask

The annual crop geographic mask was created by merging annual crop classes from previously mapped land-cover datasets and previously mapped field boundary datasets (see appendix).

Land-cover class modelling assumptions

Annual commercial crops (non pivot) were determined by analysing the 12 month crop cycle within the annual crop mask. For a pixel to be considered as cultivated annual crop fields the EVI data had to exhibit both the bare field minimum threshold and the mature crop maximum threshold within the annual crop geographical mask, within that crop cycle.

Final logic test

A final logic test was used to check and edit (if required) the modelled 2001, 2005 and 2010 annual crops (non pivot) dataset. It was assumed that if a pixel was defined as annual crops in 2001 and in 2010 then the same pixel was also likely to be an annual crops in 2005 due to crop rotation cycling. Similarly, if a pixel was defined as not being annual crops in 2001 and 2010 then that same pixel was unlikely to be cultivated in 2005. Note that the 2001 EVI dataset contained several areas of "no data" values during the rain months in the Western Cape, over areas of likely annual crops. In these no data value areas, if a pixel was defined as annual crops in 2005, then it was assumed that the same pixel was annual crops in 2001, in order to maintain a logical sequence.

5.1.6 Annual commercial crops (pivots)

EVI modelling assumptions

Pivots were defined as pixels which exhibited EVI values representing both bare ground and mature crops during a 12 month crop cycle, within the pre-defined pivot geographical mask.

EVI modelling thresholds

A pixel was defined as representing pivots if the EVI dataset met both the bare field threshold and the mature crop threshold requirements during a single growth year.

Bare field status (i.e. bare ground prior to planting) was defined as a pixel having an EVI value below a maximum threshold of 0.148 (excluding zero as this represented "no data") during at least one month of a year.

The mature pivot crop condition was defined as a pixel representing a maturely grown crop if the EVI value exceeded a minimum threshold of 0.362 during at least one month of a year.

Thresholds were determined visually using comparison to equivalent date Landsat imagery and the existing small scale land-cover classifications.

Source of geographic mask

The pivot geographic mask was created by merging pivot classes from previously mapped land-cover datasets and previously mapped field boundary datasets (see appendix).

Land-cover class modelling assumptions

Pivots were determined by analysing the 12 month crop cycle within the pivot mask. For a pixel to be considered as a cultivated pivot the EVI data had to exhibit both the bare field minimum threshold and the mature crop maximum threshold within the pivot mask, within that crop cycle.

Final logic test

There was no logic test because the logic is covered by the initial EVI modelling and the geographic masks were spatially explicit.

5.1.7 Permanent crops (orchards)

EVI modelling assumptions

Orchards were defined as pixels which consistently exhibited EVI values representing orchard trees during every month of a year, within the pre-defined horticulture geographical mask.

EVI modelling thresholds

A pixel was defined as representing orchards if the EVI values were between a minimum threshold of 0.35 and a maximum 0.45 during every month of a year. This threshold value was taken to be representative of a canopy cover for mature orchard trees. Deciduous orchard crops were included on the basis of achieving the EVI threshold in at least one month as explained in the modelling assumptions. Thresholds were determined visually using comparison to equivalent date Landsat imagery and the existing small scale land-cover classifications.

Source of geographic mask

The horticulture geographic mask was created by merging horticulture classes from previously mapped land-cover datasets and previously mapped field boundary datasets (see appendix).

Land-cover class modelling assumptions

Orchards were determined by analysing the 12 month crop cycle within the horticulture geographic mask. For a pixel to be considered as cultivated orchards the EVI data had to exhibit at least one month when EVI values were in the designated range.

Final logic test

A final logic test was used to check and edit (if required) the modelled 2001, 2005 and 2010 orchard dataset. It was assumed that if a pixel was defined as orchards in 2001 and 2010 then the same pixel also likely to be orchards in 2005 due to tree growth rates. Similarly, if no orchards were defined in the same pixel during 2001 and 2010, then that pixel would not likely contain orchards in 2005. It was also was assumed that horticulture only disappears if replaced by another manmade land-cover.

Therefore orchards would either remain the same in all years based on the 2001 extent or, increase in extent in subsequent years, but only reduce in area if replaced by another man-made (rather than natural) cover class. Thus the 2001 orchard extent was automatically carried through to 2005 and 2010 and similarly an expanded 2005 extent was carried through to 2010, unless replaced in any year by another man-made cover class.

5.1.8 Permanent crops (viticulture)

EVI modelling assumptions

Viticulture was defined as pixels which consistently exhibited EVI values representing vineyards during every month of a year, within the pre-defined viticulture geographical mask.

EVI modelling thresholds

A pixel had to display both EVI values representing the leaf off period and the mature, leaf on period within one growth year for it to be considered to represent a viticulture crop. The leaf off period representing bare ground was based on a EVI threshold range between 0.17 and 0.4, which must occur during at least one month of a year. The mature, leaf on crop period was defined as an EVI value range between 0.2 and 0.45, during at least one month during a year. The leaf on EVI data range was capped at 0.45 in order to exclude any surrounding areas of dense vegetation that exceeded the biomass of the viticulture crop. Thresholds were determined visually using comparison to equivalent date Landsat imagery and the existing small scale land-cover classifications.

Source of geographic mask

The viticulture geographic mask was created by merging viticulture classes from previously mapped land-cover datasets and previously mapped field boundary datasets (see appendix).

Land-cover class modelling assumptions

Viticulture was determined by analysing the 12 month vine cycle within the viticulture mask. For a pixel to be considered as cultivated viticulture land the EVI data had to exhibit at least one month of bare vine (leaf off) cover and at least one month of leaf on cover within the viticulture mask.

Final logic test

A final logic test was used to check and edit (if required) the modelled 2001, 2005 and 2010 viticulture dataset. It was assumed that if a pixel was defined as viticulture in 2001 and 2010 then the same pixel also had to be viticulture in 2005 due to vine growth rates. Similarly, if no viticulture was defined in a pixel during 2001 and 2010, then that pixel could not contain viticulture during 2005. It was also was assumed that viticulture only disappears if replaced by another manmade land cover using the same assumptions as orchards.

5.1.9 Annual semi-commercial / subsistence crops

EVI modelling assumptions

Subsistence crops were defined as pixels which exhibited EVI values representing both bare ground and mature crops characteristics within a 12 month crop cycle, within the pre-defined subsistence crop geographical mask.

EVI modelling thresholds

A pixel was defined as representing subsistence crops if the EVI dataset met both the bare field threshold and the mature crop threshold during a single growth year. Bare field status (i.e. bare ground prior to planting) was defined as a pixel having an EVI value below a maximum threshold of 0.148 (excluding zero as this represented "no data") during at least one month of a year. The mature crop condition was defined as a pixel with an EVI value exceeding a minimum threshold of 0.362 during at least one month of a year. Thresholds were determined visually using comparison to equivalent date Landsat imagery and the existing small scale land-cover classifications.

Source of geographic mask

The subsistence crop geographic mask was created by merging subsistence crop classes from previously mapped land-cover datasets and previously mapped field boundary datasets (see appendix).

Land-cover class modelling assumptions

Subsistence crops were determined by analysing the 12 month crop cycle within the subsistence crop mask.

For a pixel to be considered as cultivated annual crop fields the EVI data had to exhibit both the bare field minimum threshold and the mature crop maximum threshold within the subsistence crop geographical mask, within that crop cycle.

Final logic test

A final logic test was used to check and edit (if required) the modelled 2001, 2005 and 2010 subsistence crops dataset. It was assumed that if a pixel was defined as subsistence crops in 2001 and in 2010 then the same pixel was also likely to be subsistence crops in 2005 due to crop rotation cycling.

Similarly, if a pixel was defined as not being subsistence crops in 2001 and 2010 then that same pixel was unlikely to be cultivated in 2005.

Note that the 2001 EVI dataset contained several areas of "no data" values during the rain months in the Western Cape, over areas of likely annual crops. In these no data value areas, if a pixel was defined as annual crops in 2005, then it was assumed that the same pixel was subsistence crops in 2001, in order to maintain a logical sequence.

5.1.10 Sugarcane

EVI modelling assumptions

Sugarcane was defined as pixels which exhibited EVI values representing mature sugarcane during at least one month in an 18 month crop cycle, within the pre-defined sugarcane geographical mask.

EVI modelling thresholds

A pixel was defined as representing sugarcane if the EVI value exceeded a minimum threshold of 0.55 during at least one month in the 18 month crop cycle. This threshold value was taken to be representative of mature sugarcane. For 2001 the 18 month period was defined from the first 2001 EVI monthly dataset forward. For the 2005 dataset it was defined as from July 2004 to December 2005. For the 2010 dataset it was defined as from July 2009 to December 2010. Thresholds were determined visually using comparison to equivalent date Landsat imagery and the existing small scale land-cover classifications.

Source of geographic mask

The sugarcane geographic mask was created by merging sugarcane classes from previously mapped land-cover datasets and previously mapped field boundary datasets (see appendix).

Land-cover class modelling assumptions

Sugarcane was determined by analysing the 18 month crop cycle within the geographic sugarcane mask. The mature crop threshold had to be present within this cycle for the area to be classified as sugarcane from the EVI data.

Final logic test

A final logic test was used to check and edit (if required) the modelled 2001, 2005 and 2010 sugarcane dataset. It was assumed that sugarcane fields only disappear if replaced by another manmade land cover. Therefore if a pixel was defined as sugarcane in 2001 then that pixel was also defined as sugarcane in 2005 and 2010. Similarly, if a pixel defined as sugarcane in 2005 then it would also contain sugarcane in 2010.

5.1.11 Residential (modelling sub-component of Settlements)

EVI modelling assumptions

Residential areas were defined as pixels which consistently exhibited EVI values representing high reflectance bare ground characteristics during every month of a year, within the pre-defined urban geographical mask.

EVI modelling thresholds

A pixel was defined as representing residential areas if the EVI values were below a maximum threshold of 0.5 during every month of a year. This threshold value was taken to be representative of residential buildings and man-made, artificial surfaces and structures within the geographic mask. Thresholds were determined visually using comparison to equivalent date Landsat imagery and the existing small scale land-cover classifications.

Source of geographic mask

The residential geographic mask was extracted from land-use datasets (see appendix).

Land-cover class modelling assumptions

Residential areas were determined by analyzing the sequence and pattern of bare ground areas within the urban geographical mask for each assessment year by analysing the data across the full 10 year period. Urban areas were modelled, within the geographical residential mask, on the basis of the following assumptions:

- (a) the maximum geographical extent of the residential area in one assessment year can not exceed the maximum extent in the following assessment year,
- (b) all bare ground within the residential geographic mask is representative of residential areas irrespective of land use ,
- (c) areas exhibiting a new phase of bare ground (after being previously vegetated) are assumed to be new development residential areas,
- (d) vegetated areas occurring prior to a new phase of bare ground are representative of previously un-developed areas,
- (e) areas that are consistently vegetated from 2001 through to 2010 (within the urban geographical mask) are considered established residential areas with mature garden foliage, and
- (f) areas that are residential in 2010 were never previously industrial or commercial in previous years (although modelled industrial and commercial areas were allowed to over write residential areas on the assumption that these were new developments).

Final logic test

A final logic test was used to check and edit (if required) the modelled 2001, 2005 and 2010 residential datasets. It was assumed that a residential area could expand in size or remain static from 2001 to 2010, but it could not decrease in size. Therefore if a pixel was defined as residential in 2001, that same pixel had to be defined as residential in both 2005 and 2010. Similarly, a pixel defined as residential in 2005, had to be residential in 2010, unless reclassified as industrial or commercial.

5.1.12 Commercial and industrial (modelled sub-component of Settlement)

EVI modelling assumptions

Commercial and industrial areas were defined as pixels which consistently exhibited EVI values representing high reflectance bare ground during every month of a year, within the pre-defined commercial and industrial geographical mask.

EVI modelling thresholds

A pixel was defined as representing commercial and industrial areas if the EVI value was below a maximum threshold of 0.28 during every month of a year. This threshold value was taken to be representative of commercial and industrial buildings and man-made, artificial surfaces. Thresholds were determined visually using comparison to equivalent date Landsat imagery and the existing small scale land-cover classifications.

Source of geographic mask

The commercial and industrial geographic mask was extracted from land-use datasets (see appendix).

Land-cover class modelling assumptions

Modelling assumptions were that (a) all bare ground areas represented only commercial or industrial areas within the mask, and (b) commercial or industrial areas never reverted to residential once classified as commercial or industrial.

Final logic test

A final logic test was used to check and edit (if required) the modelled 2001, 2005 and 2010 commercial and industrial areas. It was assumed that a commercial or industrial area could expand in size or remain static from 2001 to 2010, but it could not decrease in size. Therefore if a pixel was defined as commercial or industrial in 2001 then that same pixel had to be defined as commercial or industrial in 2005 and 2010 as well. Similarly, if a pixel was defined as commercial and industrial in 2005, then it was also defined as commercial and industrial in 2010.

5.1.13 Creation of final settlement class

The final SA land-cover datasets for 2001, 2005 and 2010 do not contain separate categories for residential and commercial/industrial classes. A single "settlement" class is defined which represents the combined spatial extent of both the residential and commercial/industrial classes.

5.1.14 Wetlands

EVI modelling assumptions

For initial modelling purposes, the wetland class was split into dry, wet and vegetated wetlands. Dry wetlands were defined as pixels which consistently exhibited EVI values representing bare ground during every month of a year, within the pre-defined wetlands geographical mask. Wet wetlands were defined as pixels which exhibited EVI values representing water for a minimum of one month of a year within the pre-defined wetlands geographical mask. Vegetated wetlands were defines as pixels which did not exhibit EVI values representing bare ground or water within the pre-defined wetlands geographical mask.

EVI modelling thresholds

The EVI modelling thresholds vary depending on the nature of the wetland. A dry wetland threshold was defined as pixels with EVI values below a maximum threshold of 0.14 during every month of the year. A wet wetland threshold was defined as pixels representing water if the EVI values were below a maximum threshold of 0.18 during at least one month during a year. The vegetated wetlands threshold was defined as pixels with EVI values exceeding a threshold of 0.14, but which had not been previously classified as wet during any month of a year. Thresholds were determined visually using comparison to equivalent date Landsat imagery and the existing small scale land-cover classifications.

Source of geographic mask

The wetland geographic mask was created by merging wetland classes from previously mapped land-cover datasets (see appendix).

Land-cover class modelling assumptions

Since wetlands can become drier or wetter through out different seasons, it is assumed that if a wetland is defined by the water threshold for at least one month within a year, then that wetland is classified as wet. The dry wetland is defined by a pixel representing bare ground for every month of the year. Vegetated wetlands are defined as pixels that correspond to the vegetation threshold for at least one month in a year, but are never represented by water within the same year.

Final logic test

The vegetated and dry wetlands were collapsed into a single wetland class for use in the final SA land-cover datasets. The wet wetlands were recoded as water pixels.

5.1.15 Grasslands

The grassland class boundary was extracted from the 2006 SANBI vector biome dataset, since it was outside the scope of the project and the available data to derive a MODIS EVI generated grassland boundary. Therefore the extent of grassland within the final land-cover datasets represents the biome boundary rather than the actual vegetation cover extent.

5.1.16 Mines

EVI modelling assumptions

Mines were defined as pixels which consistently exhibited EVI values representing bare ground during every month of a year, within the pre-defined mine geographical mask.

EVI modelling thresholds

A pixel was defined as mines if the EVI values were below a maximum threshold of 0.24 during every month of a year. This threshold value was taken to be representative of bare ground characteristics that are found within a mining environment. Thresholds were determined visually using comparison to equivalent date Landsat imagery and the existing small scale land-cover classifications.

Source of geographic mask

The mine geographic mask was created by merging mine classes from previously mapped land-cover datasets and topographic vector data (see appendix). This included tailings, dumps and extraction sites.

Land-cover class modelling assumptions

The modelling process for mines did not identify flooded mine pits or surface water on tailings, although this was identified within the water modelling process and was incorporated into the final land-cover data compilations. It was assumed that mines contained bare surfaces throughout every month of the year for 2001, 2005 and 2010. Mine dumps/tailings containing a large covering of algae during the rainy season may have been misidentified.

Final logic test

A final logic test was used to check and edit (if required) the modelled 2001, 2005 and 2010 mine datasets. It was assumed that if a pixel was defined as mines in 2001 and 2010 then the same pixel also had to be mines in 2005, due to the semi-permanent nature of most mines. Similarly, if no mines were defined in a pixel during 2001 and 2010, then that pixel could not contain mines during 2005. However pixels representing mines could disappear (rehabilitation) if the disappearance was permanent within the assessment year range. This included acceptance that a mine pixel could be evident in 2001 and 2005, but not evident in 2010.

5.1.17 Water bodies

EVI modelling assumptions

Water bodies were defined as pixels which exhibited EVI values representing all types of open water (i.e. man-made and natural) within the pre-defined water geographical mask.

EVI modelling thresholds

A pixel representing water was defined as EVI values which were below a maximum threshold of 0.18 during any month of the year. This threshold value was taken to be representative of a body of water. Thresholds were determined visually using comparison to equivalent date Landsat imagery and the existing small scale land-cover classifications.

Source of geographic mask

The water geographic mask was created by merging water classes from previously mapped land-cover datasets and Chief Directorate: National Geospatial Information topographic vector data (see appendix). The dry river beds were excluded from the water geographic mask since the water threshold and bare ground thresholds overlap, which would have resulted in dry, bare river beds appearing as permanently flooded.

Land-cover class modelling assumptions

The water bodies were modelled on the basis of a candidate pixel containing at least one month in the assessment year having an EVI data value equivalent to the threshold defined for water. Therefore the modelled water output always represented the maximum geographic area of water occurrence in any of the assessment years. Note that there may be an over estimation of water pixels since the water threshold is similar to the bare ground threshold and there was no way of separating these two classes with only EVI data.

Final logic test

There was no logic test because the logic is covered by the initial EVI modelling and the geographic masks were spatially explicit.

5.1.18 Bare ground

EVI modelling assumptions

Bare ground was defined as pixels which consistently exhibited EVI values representing bare ground during every month of a year. This was modelled across the entire country without geographical masks and formed a backdrop upon which all other modelled cover classes were over laid. The final extent of bare ground in the national datasets thus represented very sparse vegetation covers and desert areas not covered by other cover classes.

EVI modelling thresholds

A pixel was defined as bare ground if EVI values were below a maximum threshold of 0.14 during every month of a year. This threshold value was taken to be representative of bare ground. Thresholds were determined visually using comparison to equivalent date Landsat imagery and the existing small scale land-cover classifications.

Land-cover class modelling assumptions

The bare ground was defined as pixels that exhibited non-vegetated / bare ground EVI characteristics for all months consistently in any assessment year. There may be an under estimation of bare ground that occur within the geographic water masks as the water and bare ground EVI thresholds are similar.

Final logic test

There was no logic test because the logic is covered by the initial EVI modelling.

5.1.19 Fynbos

The fynbos class boundary was extracted solely from the 2006 SANBI vector biome dataset, as an additional request outside the scope of the original ToR. Therefore the extent of fynbos within the final land-cover datasets represents the un-transformed extent of the potential biome boundary rather than the actual vegetation cover extent (which may or may not contain local areas of non-fynbos vegetation cover).

5.1.20 Nama-karoo

The nama-karoo class boundary was extracted solely from the 2006 SANBI vector biome dataset, as an additional request outside the scope of the original ToR. Therefore the extent of nama karoo within the final land-cover datasets represents the un-transformed extent of the potential biome boundary rather than the actual vegetation cover extent (which may or may not contain local areas of non-karoo vegetation cover).

5.1.21 Succulent karoo

The succulent karoo class boundary was extracted solely from the 2006 SANBI vector biome dataset, as an additional request outside the scope of the original ToR. Therefore the extent of succulent karoo within the final land-cover datasets represents the un-transformed extent of the potential biome boundary rather than the actual vegetation cover extent (which may or may not contain local areas of non-karoo vegetation cover).

NOTES

NOTES

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