# GHG NATIONAL INVENTORY REPORT
## South Africa

2000 - 2012

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

**IMPRINT**

**Published by**

Department of Environmental Affairs (DEA)

**General responsibility**

Jongikhaya Witi

**Individual chapters:**

- **Executive summary** - Luanne Stevens, Jongikhaya Witi
- **Chapter 1: *Introduction*** - Luanne Stevens, Jongikhaya Witi
- **Chapter 2: *Trends in GHG Emissions*** - Luanne Stevens, Jongikhaya Witi
- **Chapter 3: *Energy Sector*** - Lungile Manzini
- **Chapter 4: *Industrial Processes and Product Use*** - Jongikhaya Witi
- **Chapter 5: *Agriculture, Forestry and Land Use*** - Luanne Stevens, Lindeque Du Toit
- **Chapter 6: *Waste*** - Jongikhaya Witi

**Report compiled by**

Luanne Stevens

**Report edited by**

Phindile Mangwana
Dumisani Nxumalo

**External report reviewers:**

- ***IBIS Environmental Social Governance Consulting South Africa Pty Ltd (IBIS) Generalists*** - Paul Ben Israel and Simon Clarke
- ***Energy Sector*** - Anthony Dane
- ***Industrial Processes and Product Use (IPPU) Sector*** - Simon Clarke
- ***Agriculture Forestry and other Land Uses (AFOLU) Sector*** - Tony Knowles
- ***Waste Sector*** - Fred Goede

**Layout by**

Twaai Design



**Contact information**

Department of Environmental Affairs
Environment House
473 Steve Biko Street
Arcadia
Pretoria 0001
South Africa

Tel: +27 12 399 9148
Email: pmangwana@environment.gov.za



Published in South Africa - August 2017

This report was kindly funded through the GIZ implemented Climate Support Programme, which is part of the international Climate initiative (IKI). The Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) supports the IKI on the basis of a decision adopted by the German Bundestag.

# GHG NATIONAL INVENTORY REPORT

## South Africa

## 2000 - 2012

January 2017

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

# PREFACE

This report has been compiled for the Department of Environmental Affairs (DEA) in response to South Africa's obligation to report its 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 Good Practice Guidance.

This report is published by the DEA, South Africa. An electronic version will be available on the website of the Department of Environmental Affairs (http://www.saaqis.org.za/) once the review process is completed. Information from this report may be reproduced, provided the source is acknowledged.

# ACKNOWLEDGEMENTS

Many people and institutes were involved in the compilation of this National Inventory Report for 2012. The main information on the energy and industrial processes and product use (IPPU) sectors was provided by the Department of Energy (DoE), the Department of Mineral Resources (DMR), Business Unity South Africa (BUSA) members, the Chamber of Mines, Eskom, Sasol, and PetroSA. The agriculture, forestry and other land use (AFOLU) sector was prepared by North West University (NWU) and Gondwana Environmental Solutions, with the major data suppliers being Tshwane University of Technology (TUT), the Department of Environmental Affairs, the Department of Agriculture, Forestry and Fisheries (DAFF), GeoTerraImage (GTI), the Food and Agriculture Organization (FAO), Forestry SA and the Agricultural Research Council (ARC). The waste sector was compiled by the DEA with the main data providers being Statistics South Africa (StatsSA), the Department of Environmental Affairs, the World Resources Institute (WRI) and the Council for Scientific and Industrial Research (CSIR).

We greatly appreciate all the contributions from organizations and individuals who were involved in the process of completing this NIR. Special thanks to the Department for International Development (DFID) for providing funding for the land change mapping and updating of the agriculture, forestry and land-use sector, as well as funds for the compilation of this national inventory report (NIR). We would also like to thank all reviewers of the various sector sections as well as the reviewers of the completed NIR.

# AUTHORS AND CONTRIBUTORS

GENERAL RESPONSIBILITY:

***Jongikhaya Witi***

INDIVIDUAL CHAPTERS:

| | |
|---|---|
| Executive summary: | ***Luanne Stevens, Jongikhaya Witi*** |
| Chapter 1: | Introduction - ***Luanne Stevens, Jongikhaya Witi*** |
| Chapter 2: | Trends in GHG Emissions - ***Luanne Stevens, Jongikhaya Witi*** |
| Chapter 3: | Energy Sector - ***Lungile Manzini*** |
| Chapter 4: | Industrial Processes and Product Use - ***Jongikhaya Witi*** |
| Chapter 5: | Agriculture, Forestry and Land Use - ***Luanne Stevens, Lindeque Du Toit*** |
| Chapter 6: | Waste - ***Jongikhaya Witi*** |

REPORT COMPILATION:

***Luanne Stevens***

REPORT EDITOR:

***Phindile Mangwana and Dumisani Nxumalo***

EXTERNAL REPORT REVIEWERS:

IBIS Environmental Social Governance Consulting South Africa Pty Ltd (IBIS) Generalists – ***Paul Ben Israel and Simon Clarke***; Energy Sector – ***Anthony Dane***, Industrial Processes and Product Use (IPPU) Sector – ***Simon Clarke***; Agriculture Forestry and other Land Uses (AFOLU) Sector – ***Tony Knowles***; and Waste Sector – ***Fred Goede***.

# CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# LIST OF ABBREVIATIONS

| | |
|---|---|
| AFOLU | Agriculture, Forestry and Other Land Use |
| AGB | Above-ground biomass |
| Bbl/d | Barrels per day |
| BCEF | Biomass conversion and expansion factor |
| BEF | Biomass expansion factor |
| BNF | Biological nitrogen fixing |
| BOD | Biological oxygen demand |
| C | Carbon |
| $C_2F_6$ | Carbon hexafluoroethane |
| $CF_4$ | Carbon tetrafluoromethane |
| CFC | Chlorofluorocarbons |
| $CH_4$ | Methane |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| $CO_2eq$ | Carbon dioxide equivalent |
| CRF | Common reporting format |
| DAFF | Department of Agriculture Affairs, Forestry and Fisheries |
| DEA | Department of Environmental Affairs |
| DEAT | Department of Environmental Affairs and Tourism |
| DFID | Department for International Development |
| DM | Dry matter |
| DMD | Dry matter digestibility |
| DMR | Department of Mineral Resources |
| DME | Department of Minerals and Energy |
| DoE | Department of Energy |
| DOM | Dead organic matter |
| DTI | Department of Trade and Industry |
| DWA | Department of Water Affairs |

| | |
|---|---|
| DWAF | Department of Water Affairs and Forestry |
| EF | Emission factor |
| F-gases | Fluorinated gases: e.g., HFC, PFC, SF6 and NF3 |
| FOD | First order decay |
| FOLU | Forestry and Other Land Use |
| FSA | Forestry South Africa |
| GDP | Gross domestic product |
| GEI | Gross energy intake |
| GFRSA | Global Forest Resource Assessment for South Africa |
| Gg | Gigagram |
| GHG | Greenhouse gas |
| GHGI | Greenhouse Gas Inventory |
| GIS | Geographical Information Systems |
| GPG | Good Practice Guidance |
| GWH | Gigawatt hour |
| GWP | Global warming potential |
| HFC | Hydrofluorocarbons |
| HWP | Harvested wood products |
| IEF | Implied emission factor |
| INC | Initial National Communication |
| IPCC | Intergovernmental Panel on Climate Change |
| IPPU | Industrial Processes and Product Use |
| ISO | International Organization for Standardization |
| LPG | Liquefied petroleum gas |
| LTO | Landing/take off |
| MCF | Methane conversion factor |
| MEF | Manure emission factor |
| MW | Megawatt |
| MWH | Megawatt hours |
| MWTP | Municipal wastewater treatment plant |

| | |
|---|---|
| NAEIS | National Atmospheric Emissions Inventory System |
| $N_2O$ | Nitrous oxide |
| NCCC | National Climate Change Committee |
| NE | Not estimated |
| NERSA | National Energy Regulator of South Africa |
| NGHGIS | National Greenhouse Gas Inventory System |
| NIR | National Inventory Report |
| NIU | National Inventory Unit |
| NMVOC | Non-methane volatile organic compound |
| NOx | Oxides of nitrogen |
| NTCSA | National Terrestrial Carbon Sinks Assessment |
| NWBIR | National Waste Baseline Information Report |
| PFC | Perfluorocarbons |
| PPM | Parts per million |
| PRP | Pastures, rangelands and paddocks |
| QA/QC | Quality assurance/quality control |
| RSA | Republic of South Africa |
| SAAQIS | South African Air Quality Information System |
| SAISA | South African Iron and Steel Institute |
| SAMI | South African Minerals Industry |
| SAPIA | South African Petroleum Industry Association |
| SAR | Second Assessment Report |
| SASQF | South African Statistical Quality Assurance Framework |
| SADC | Southern African Development Community |
| $SF_6$ | Sulphur hexafluoride |
| SNE | Single National Entity |
| TAM | Typical animal mass |
| TAR | Third Assessment Report (IPCC) |
| TJ | Terajoule |
| TM | Tier method |

| | |
|---|---|
| TMR | Total mixed ratio |
| TOW | Total organics in wastewater |
| UN | United Nations |
| UNEP | United Nations Environmental Programme |
| UNFCCC | United Nations Framework Convention on Climate Change |
| WRI | World Resources Institute |
| WWTP | Wastewater treatment plant |
| VS | Volatile solids |

# 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. Following these guidelines, in 2014 the GHG inventory for the years 2000 to 2010 were compiled.

This report documents South Africa's submission of its national greenhouse gas inventory for the year 2012. It also reports on the GHG trends for the period 2000 to 2012. 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 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.

### *Development of the National GHG Inventory System (NGHGIS)*

During the compilation of the 2010 inventory there were several challenges that affected the accuracy and completeness of the inventory, such as application of lower tier methods as a result of the unavailability of disaggregated activity data, lack of well-defined institutional arrangements, and absence of legal and formal procedures for the compilation of GHG emission inventories. 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 system will ensure: a) the sustainability of the inventory preparation in the country, b) consistency of reported emissions and c) the standard quality of results. The NGHGIS 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. Reliable GHG emission inventories are essential for the following reasons:

- To fulfil the international reporting requirements such as the National Communications and Biennial Update Reports;
- To evaluate mitigation options;
- To assess the effectiveness of policies and mitigation measures;
- To develop long term emission projections; and
- To monitor and evaluate the performance of South Africa in the reduction of GHG emissions.

South Africa is developing a National Atmospheric Emissions Inventory System (NAEIS) that will manage the mandatory reporting of GHG emissions. Due to their complex emission estimating methods, emission sectors such as agriculture, forestry and land use, and waste are to be estimated outside the NAEIS. The NAEIS, in turn, will ingest the outputs of models used in these sectors so that it can generate a national emissions profile (**Figure A**).

The successful implementation of such an information management system is highly reliant on the development

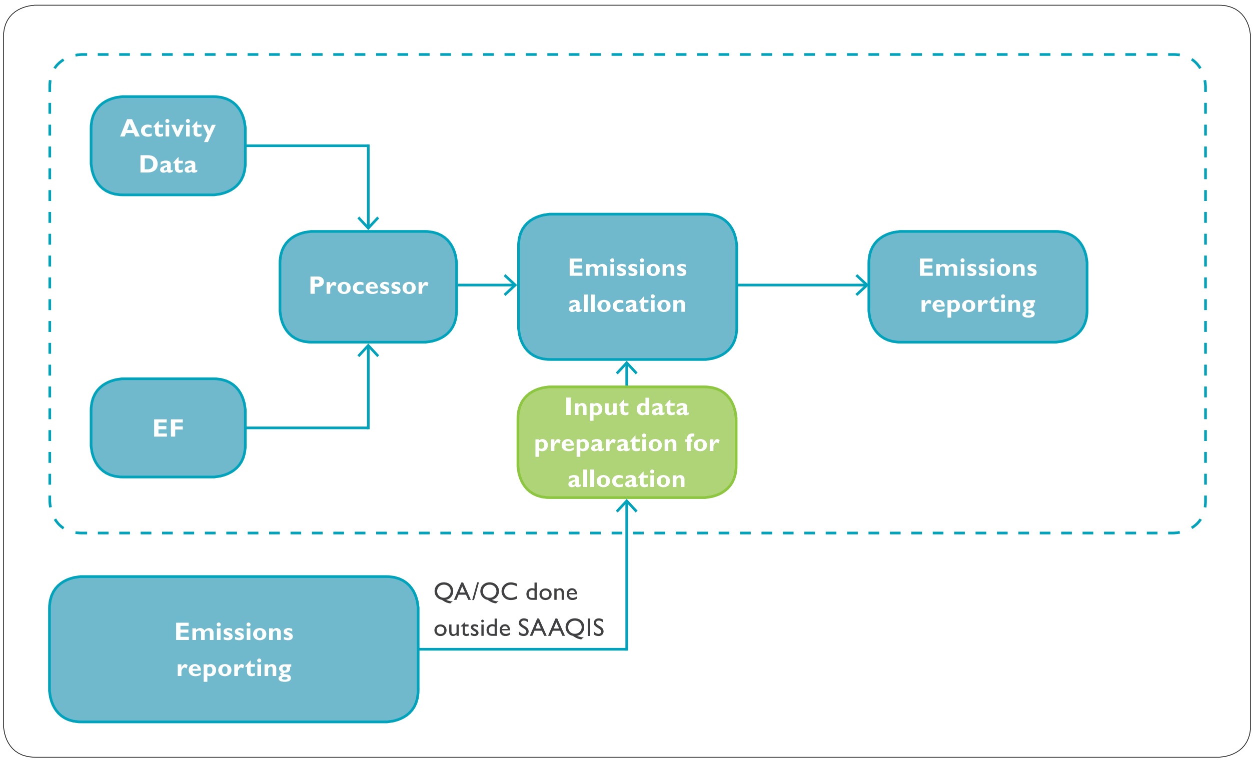



Figure A: Information flow in NAEIS.

of the NGHGIS which covers the GHG emissions inventory compilation process. The NGHGIS will be managed by a group of experts known as the National Inventory Unit (NIU). The NIU will include sector experts, quality assurance and control specialists, an inventory co-ordinator, etc. The unit will be managed through the DEA.

The NGHGIS will include:

- The formalization of a National Entity (the DEA) responsible for the preparation, planning, management, review, implementation and improvement of the inventory;
- Legal and collaborative arrangements between the National Entity and the institutions that are custodians of key source data;
- A process and plan for implementing quality assurance and quality control procedures;
- The alignment of the NGHGIS with the South African Standard Quality Assessment Framework;
- A process to ensure that the national inventory meets the standard inventory data quality indicators of accuracy, transparency, completeness, consistency and comparability; and
- A process for continual improvement of the national inventory.

### *Current inventory process*

In the 1990, 1994 and 2000 GHG inventories for South Africa activity and emission factor data were reported in the IPCC worksheets and the reports were compiled from this data. Supporting data and methodological details were not recorded, which made updating the inventory a very difficult and lengthy process. In the 2000 – 2010 GHG inventory more emphasis was placed on building up the annual data sheets and creating improved trend information. This led to better data records, but still very little supporting data and method details were kept. Also, in all previous inventories the quality control procedures and uncertainty estimates were limited. As South Africa moves forward, more emphasis has been placed on improving the documentation of inventory data and documents, as well as on uncertainty and quality control to improve the transparency of the inventory. The 2012 inventory has come a long way in addressing some of these issues.

The stages of the inventory update and improvement process (**Figure B**) were:

- Data collection, which involved:
  - assessing data requirements;
  - sourcing data from various stakeholders;
  - screening data and selecting the appropriate data sets; and
  - data quality control.
- Data input into the inventory database.
- Metadata input into the inventory database, which included:
  - documentation of people responsible for inputting the data;
  - specific data calculations;
  - data sources;
  - recalculations undertaken; and
  - links to data or reference files.
- Uncertainty analysis.
- Compilation of the inventory report.
- Quality control and quality assurance involving:
  - assessment of the quality of the inventory;
  - routine and consistent checks to ensure data integrity, correctness and completeness;
  - identification of errors and omissions both in the calculations and report compilation;
  - a public commenting process; and
  - an external review.

### *Institutional arrangements for inventory preparation*

The 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 the 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 C** gives an overview of the institutional arrangements for the compilation of the 2000 – 2012 GHG emissions inventory.

### *Organisation of report*

This report follows a standard NIR format in line with the UNFCCC Reporting Guidelines. **Chapter 1** is the introductory chapter which contains background information for South Africa, the country's inventory preparation and reporting process, key categories, a 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

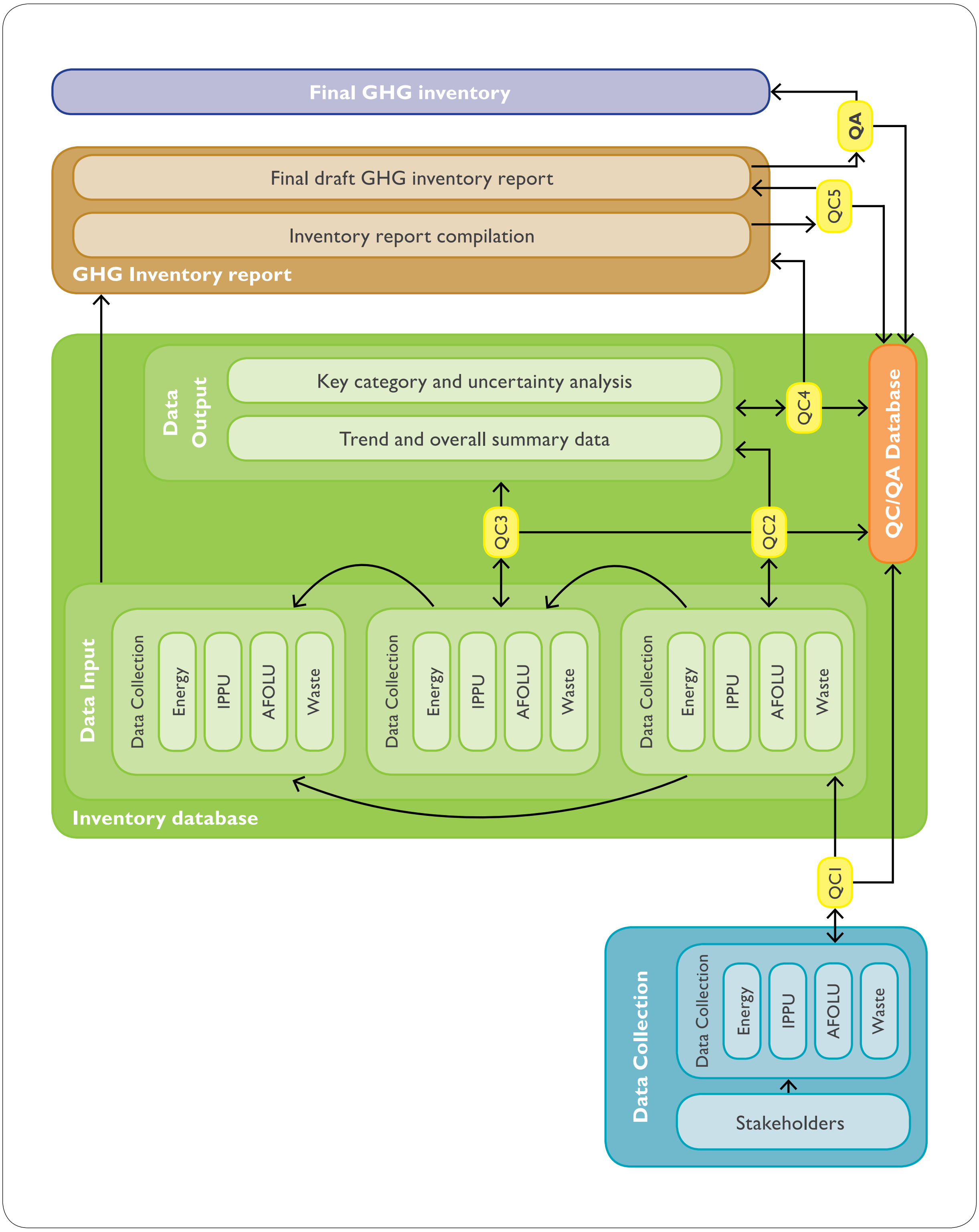



Figure B: Overview of the phases of the GHG inventory compilation and improvement process.

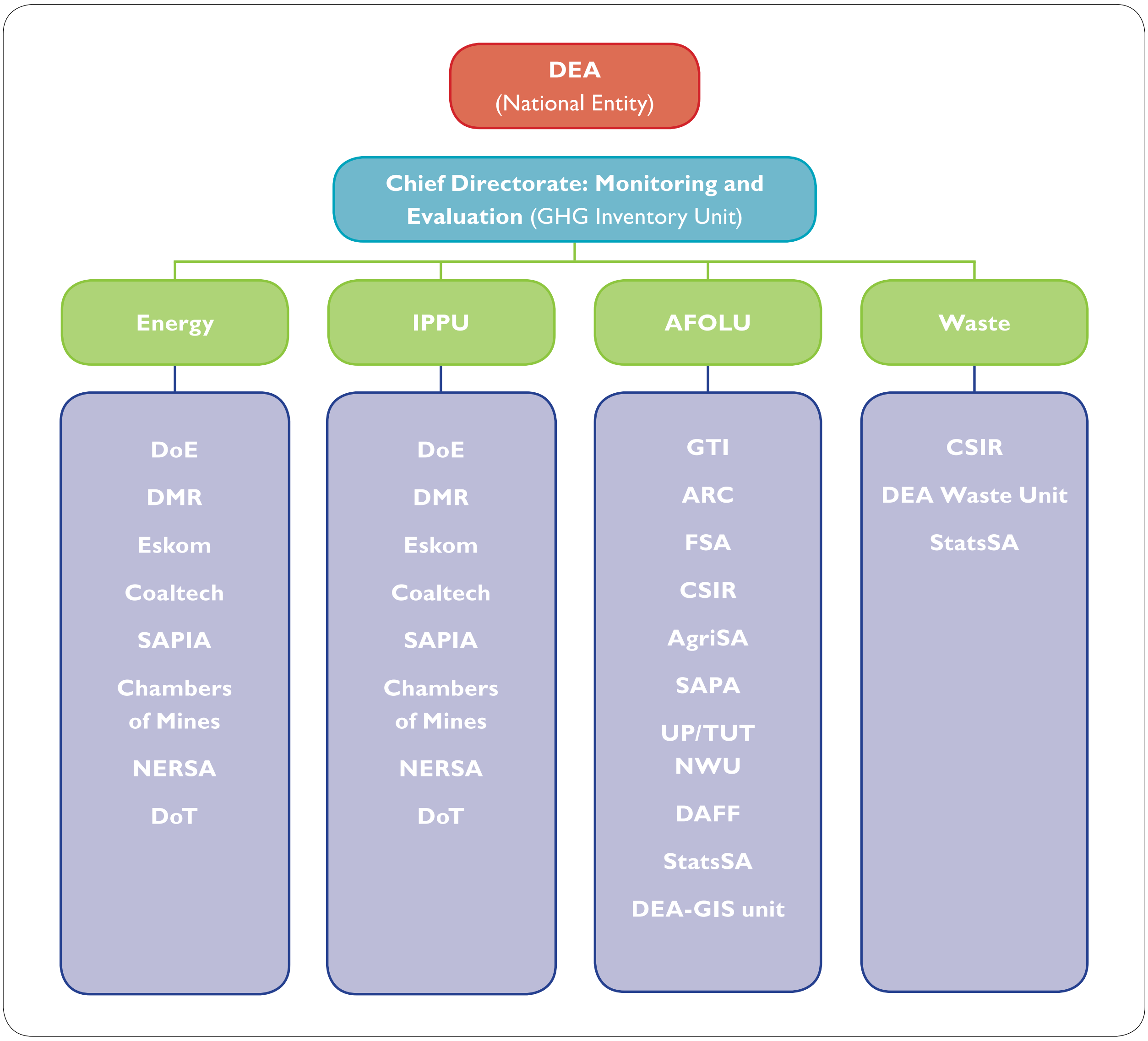



Figure C: Institutional arrangements for the compilation of the 2000 – 2012 inventories.

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.

## ES2 Summary of South Africa's GHG emissions

### *Overview of national emission and removal trends*

In 2012 the total GHG emissions in South Africa were estimated to be at 539 112 Gg$CO_2$eq (excl. FOLU) (**Table A**). Emissions (excl. FOLU) increased by 21.7% between 2000 and 2012. There were decreases of 0.7% between 2004 and 2005 and 1.6% between 2007 and 2008, with the highest decrease of 2.7% between 2010 and 2011. Including FOLU, which was estimated to be a net carbon sink, the total GHG emissions in 2012 were reduced to 518 297 Gg $CO_2$eq (**Table A**). Emissions including FOLU showed an increase of 19.3% over the 12 years from 434 304 Gg $CO_2$eq in 2000. The declines in 2005 (0.7 %), 2008 (0.5 %), 2009 (0.2%) and 2011 (2.9 %) were still evident.

### *Overview of source and sink category emission estimates and trends*

Emissions from the energy sector increased by 25.0% between 2000 and 2012, while the IPPU and waste sectors increased by 10.6% and 78.5%, respectively, over the same period (**Table B**). AFOLU emissions declined by 32.1%.

The energy sector contributed 77.3% to the total GHG inventory (excl. FOLU) in 2000 and this increased to 79.4% in 2012 (**Figure D**). There was a general increase in the energy sector contribution; however slight declines were evident in 2001, 2008 and 2011. The AFOLU sector (excl. FOLU) is the second-largest contributor, followed by the IPPU sector. AFOLU (excl. FOLU) contributed 12.3% in 2000, which declined to 9.6% in 2012, while in 2000

Table A: Trends in the national GHG emissions, including and excluding FOLU, between 2000 and 2012.

| | **Total** (excl. FOLU) | **Total** (incl. FOLU) |
|---|---|---|
| | (Gg $CO_2$ eq) | |
| 2000 | 443 133 | 434 304 |
| 2001 | 442 966 | 434 093 |
| 2002 | 456 953 | 445 545 |
| 2003 | 478 546 | 467 765 |
| 2004 | 497 630 | 488 744 |
| 2005 | 494 270 | 485 487 |
| 2006 | 502 897 | 491 708 |
| 2007 | 529 335 | 517 168 |
| 2008 | 520 834 | 514 763 |
| 2009 | 526 633 | 513 509 |
| 2010 | 544 758 | 529 391 |
| 2011 | 529 969 | 514 257 |
| 2012 | 539 112 | 518 297 |

Table B: Trends and levels in GHG emissions for 2000 and 2012 classified by sector

| | **Total** (excl. FOLU) | **Total** (incl. FOLU) | **Percentage change between 2000 and 2012** |
|---|---|---|---|
| | (Gg $CO_2$ eq) | | |
| Energy | 342 592 | 428 112 | 25.0% |
| IPPU | 33 563 | 37 129 | 10.6% |
| AFOLU | 45 860 | 31 128 | -32.1% |
| Waste | 12 288 | 21 928 | 78.5% |
| **Total (incl. FOLU)** | **434 304** | **518 297** | **19.3%** |

IPPU contributed 7.6%, which declined to 6.9% in 2012. The IPPU sector showed declines in annual emissions in 2003, 2007 to 2009 and 2012. The AFOLU sector (excl. FOLU) showed a general decline with small annual increases (of less than 5%) in 2002, 2006, 2008, 2010 and 2011. The waste sector showed a steady increase in its contribution from 2.7% in 2000 to 4.0% in 2012. Including the FOLU component in the AFOLU sector decreased the total GHG emissions to 518 297 Gg $CO_2$eq in 2012. This also changed the contribution from the energy, IPPU, AFOLU and waste sectors to 82.6%, 7.2%, 6.0% and 4.2%, respectively, in 2012 (**Figure D1** and **D2**).

The top-emitting categories in 2000 and 2012 (excl. FOLU) are shown in **Figure E**.

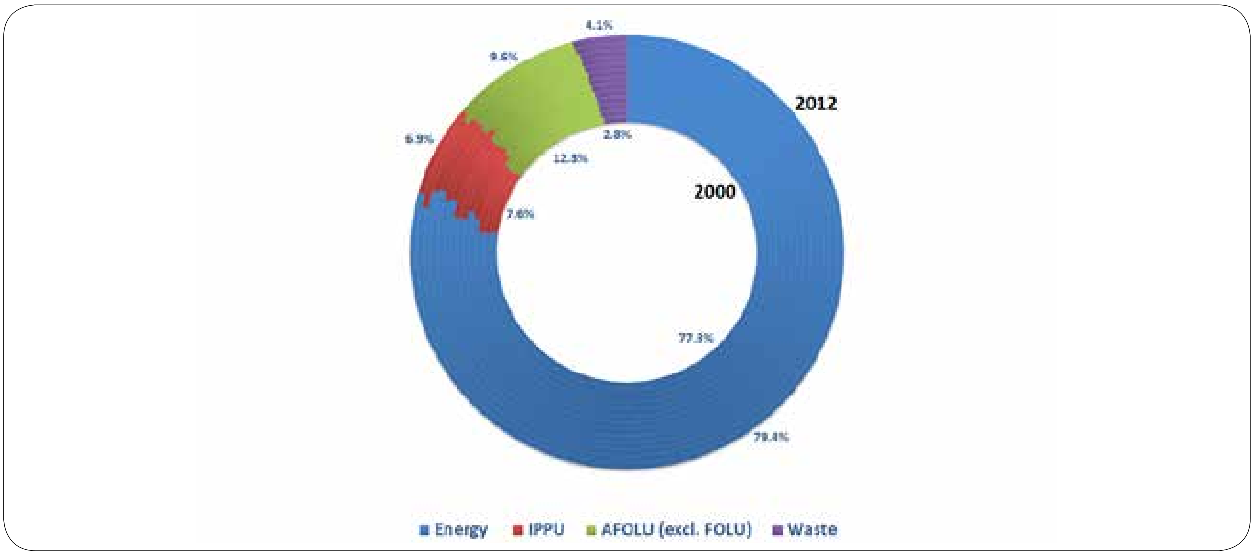



Figure D1: GHG emissions for South Africa between 2000 and 2012 by sector excluding FOLU.

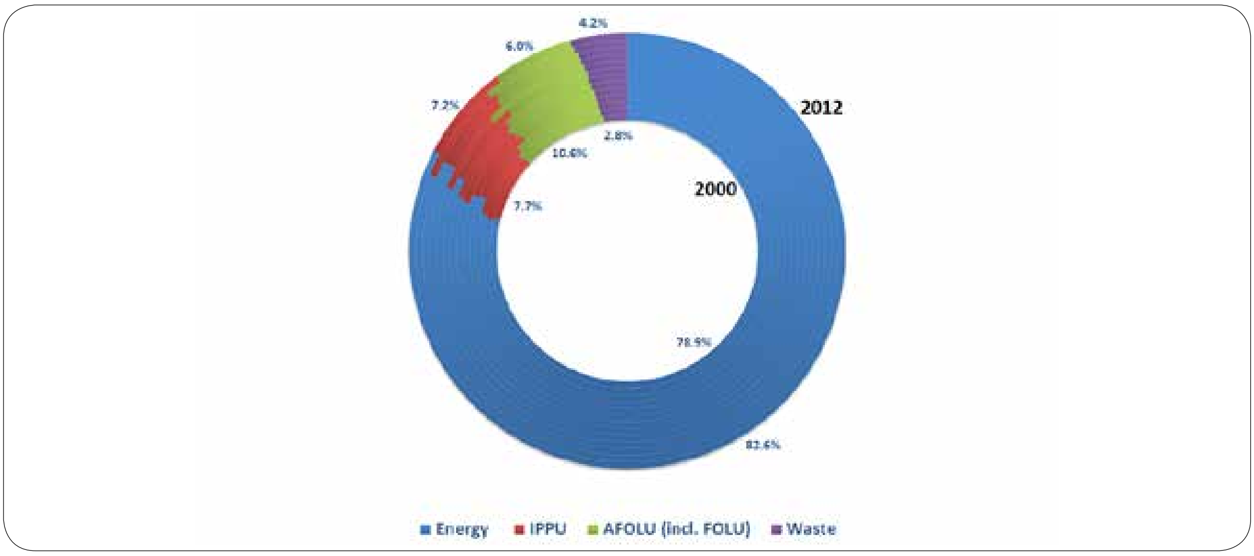



Figure D2: GHG emissions for South Africa between 2000 and 2012 by sector with FOLU included.

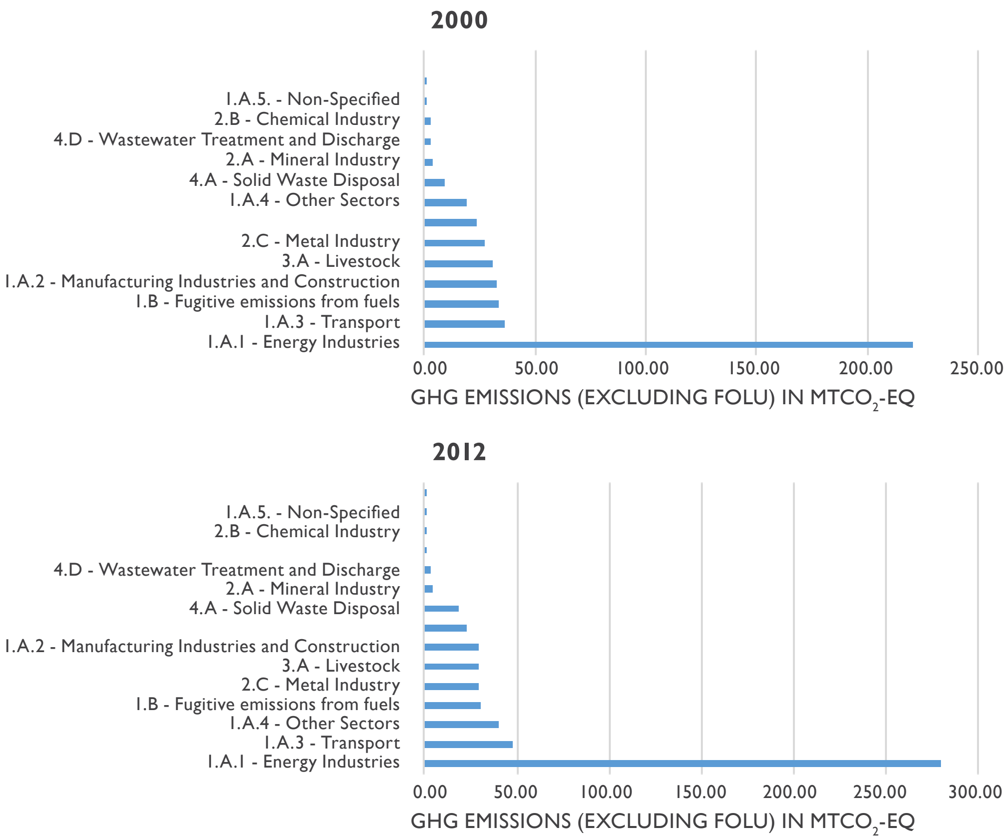



Figure E: The highest emitting categories in the South African GHG inventory (excl. FOLU) in 2000 (top) and 2012 (bottom).

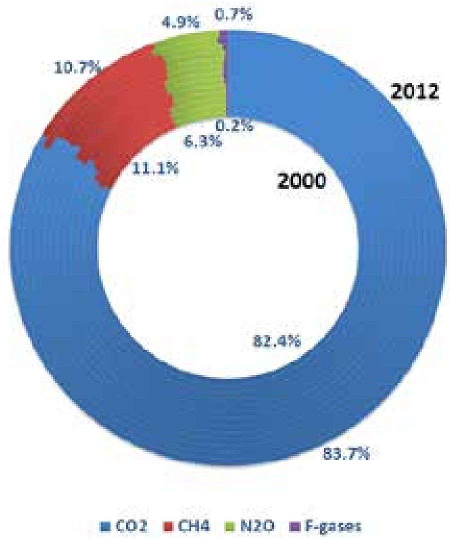



Figure F: Gas contribution to South Africa's GHG emissions between 2000 and 2012.

### *Overview of gas emission estimates and trends*

South Africa's GHG emissions in 2012 were dominated by $CO_2$ (83.7 %), followed by $CH_4$ (10.7%) and $N_2O$ (4.9%). F-gases contributed less than 1% (**Figure F**). $CO_2$ and $CH_4$ emissions excluding FOLU (incl. FOLU) increased by 23.9% (21.2 %) and 15.1% (14.6 %), respectively, between 2000 and 2012, while $N_2O$ emissions showed a decline of 5.6%. PFC emissions doubled over the 12-year period, while HFC's (only included from 2005) increased by 65.8% between 2005 and 2012.

### *Key categories*

Key categories refer to the emission sources that 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 2012 GHG inventories. The level assessment showed the key categories for 2012 (excluding FOLU[1]) to be *energy industries* (solid fuels) – *main activity electricity and heat, road transportation* (liquid fuels), *energy industries* (liquid fuels) – *manufacture of solid fuels and other energy industries, manufacturing industries and construction* (solid fuels), and *enteric fermentation - cattle*; while the trend assessment (base year being 2000) indicated the key categories were *other sectors* (solid fuels) – *residential, energy industries* (solid fuels) – *main activity electricity and heat production, manufacturing industries and construction* (solid fuels), energy industries (liquid fuels) – *manufacture of solid fuels and other energy industries*, and *enteric fermentation – cattle*. If the land sector is included then *land converted to forest land* becomes the fourth and first key categories in the level and trend assessments, respectively. Further details are provided in **Section 1.3.4** with full results for 2012 given in **Appendix B**.

## ES3 South Africa's indicators

**Figure G** presents South Africa's emissions intensity between 2000 and 2012. The carbon intensity of the economy has dropped steadily over the decade. This is largely due to growth in the services and financial sectors, a decline in the manufacturing sector and stagnation in the mining sector. The global economic crisis has had an impact on the carbon-intensity of the national energy supply even though there is generally stagnation elsewhere in the time series due to an unchanged energy supply mix.

## 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,

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.

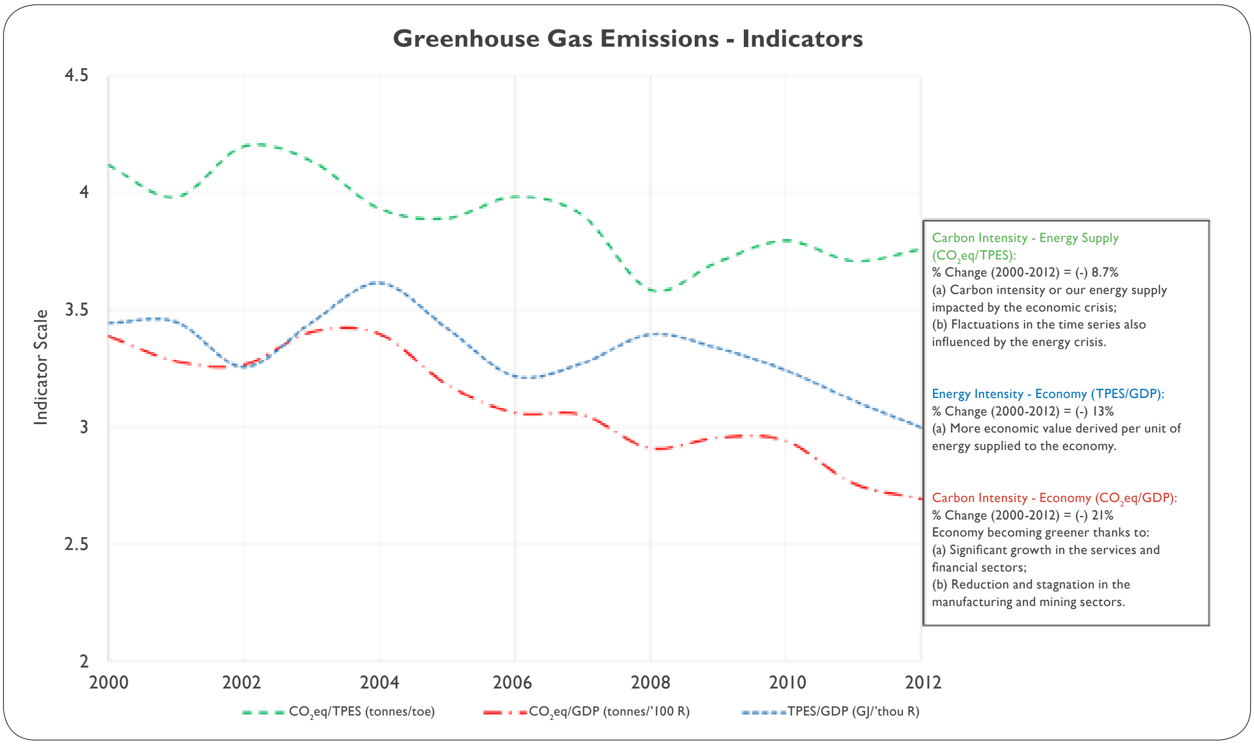



Figure G: South Africa's emissions intensity between 2000 and 2012 (Department of Environmental Affairs, 2014)

so that potential sources of inaccuracy can be qualified and possibly quantified. The 2010 inventory (Department of Environmental Affairs, 2014) did not incorporate an overall uncertainty assessment due to a lack of quantitative and qualitative uncertainty data. In this inventory there has been an attempt to incorporate an overall uncertainty assessment through the utilization of the IPCC uncertainty spread sheet. A trend uncertainty between the base year and 2012, as well as a combined uncertainty of activity data and emission factor uncertainty was determined using an Approach 1. This inventory includes uncertainty assessment for the energy and IPPU sectors only, but the other sectors will be included in the next inventory. The total uncertainty for the energy sector was determined to be 6.8%, with a trend uncertainty of 6.2%. The IPPU sector has an uncertainty of 30.8% (8.83% excluding section 2.F).

### *Quality control and quality assurance*

In accordance with IPCC requirements, the national GHG inventory preparation process must include quality control and quality assurance (QC/QA) procedures. The objective of quality checking is to improve the transparency, consistency, comparability, completeness, and accuracy of the national greenhouse gas inventory. QC procedures, performed by the compilers, were carried out at various stages throughout the inventory compilation process (**Figure B**). Quality checks were completed at four different levels, namely (a) inventory data (activity data, EF data, uncertainty, and recalculations), (b) database (data transcriptions and aggregations), (c) metadata (documentation of data, experts and supporting data), and (d) inventory report. Quality assurance was completed through a public review process as well as an independent review. The inventory was finalized once all comments from the quality assurance process were addressed.

Table C: Activities in the 2012 inventory which were not estimated (NE), included elsewhere (IE) or not occurring (NO).

| NE, IE or NO | Activity | Comments |
|---|---|---|
| NE | $CO_2$ and $CH_4$ fugitive emissions from oil and natural gas operations | Emissions from this source category will be included in the next inventory submission covering the period 2000-2014 |
| | $CO_2$, $CH_4$ and $N_2O$ from spontaneous combustion of coal seams | New research work on sources of emissions from this category will be used to report in the next emission inventory submission |
| | $CH_4$ emissions from abandoned mines | New research work on sources of emissions from this category will be used to report emissions in the next inventory submission |
| | Other process use of carbonates | |
| | Electronics industry | A study was to be undertaken in 2015 to understand emissions from this source category |
| | Indirect $N_2O$ emission due to nitrogen deposition | |
| | HWP from solid waste | This will be included in the next inventory |
| | $CO_2$, $CH_4$ and $N_2O$ emissions from combined heat and power (CHP) combustion systems | |
| | $CH_4$, $N_2O$ emissions from biological treatment of waste | |
| | $CO_2$, $CH_4$ and $N_2O$ emissions from incineration and open burning of waste | |
| | DOM emissions from croplands, grasslands, settlements and other lands | |
| IE | $CO_2$, $CH_4$ 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 was to be undertaken in 2015 and a progress report will be included in the next inventory submission |
| | $CO_2$, $CH_4$ and N2O emissions from off-road vehicles and other machinery | Fuel use associated with this source category is included in road transportation. A new study that was to be finalised in October 2015 on fuel apportionment to all demand sectors will help with accurate allocation of fuels. |
| | Ozone depleting substance replacements for fire protection and aerosols | Emissions from these sources are assumed to be accounted for in the Tier 1 methodology for quantification of HFC emissions |
| NO | Other product manufacture and use | |
| | Rice cultivation | This activity does not occur in South Africa |
| | $CO_2$, $CH_4$ and $N_2O$ emissions from Soda Ash Production | This activity does not occur in South Africa |
| | $CO_2$ from Carbon Capture and Storage | This activity does not occur in South Africa |
| | $CO_2$, $CH_4$ and $N_2O$ emissions from Adipic acid production | This activity does not occur in South Africa |
| | $CO_2$, $CH_4$ and $N_2O$ Caprolactam, Glyoxal and Glyoxylic acid production | This activity does not occur in South Africa |
| | Precursor emissions have only been estimated for biomass burning, and only for CO and NOx | Precursor emissions from all sources will be included in the next inventory |

### *Completeness of the national inventory*

The GHG emission inventory for South Africa is not complete, mainly due to data unavailability, and lack of data and estimation methodologies. **Table C** describes the activities identified by the IPCC 2006 Guidelines that were not estimated (NE), included elsewhere (IE) or not occurring (NO).

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. In the energy sector recalculation were required as activity data and emission factors were improved. Activity data was improved for *energy industries* (data obtained directly from national utility), *transport* (increased the use of SAPIA data) and *other sectors* (inclusion of SAMI data). Further, for coal country specific emission factors were applied and the $N_2O$ emission factor was corrected. Recalculations were complete for all years between 2000 and 2012 and the changes lead to a slight increase (1.5%) in energy emissions (**Table D**).

The IPPU emissions were recalculated due to updates in the iron and steel production emission factors, updated ferromanganese activity data, updated ODS and zinc production activity data. The recalculation meant a 20% reduction in the IPPU emissions in 2010 (**Table D**), mostly because of the emission factor updates in the iron and steel production calculations.

Significant updates were made in the AFOLU sector. In the agriculture sector small corrections were made to beef cattle and poultry population data, and emissions from game on privately owned parks was included. In the section on land use, new land-cover maps with a higher resolution were introduced, and emissions from DOM in forest lands and emissions from other lands were included. Updates to some of the biomass data were also made to incorporate data from the recent National Terrestrial Carbon Sinks report (Department of Environmental Affairs, 2015). The soil carbon methodology was updated to incorporate soil types, while the HWP data was updated based on the new KP Supplementary GP guidelines.

For the purpose of this report, the GHG emissions for the period 2000 to 2012 were recalculated using the updated activity data and emission factors so as to form a more consistent time series. 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 recalculations for the AFOLU sector had the largest impact on the total emissions (**Table D**) with a 32.5% and 29.2% increase on the sector estimates in 2000 and 2010, respectively. The majority of this change was due to the corrected HWP estimates (this falls under the IPCC category 3D other) and the updated land change maps. The increases in the AFOLU sector impacted the national total by 2.2% and 1.4% in 2000 and 2010, respectively (**Table D**). Small adjustments and recalculations were made in the energy, IPPU and waste sectors, which contributed 0.7%, 0.3% and 0.1% to the increase in the national total, respectively.

### *The Greenhouse Gas Improvement Programme (GHGIP)*

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. It has initiated a new programme called the National Greenhouse Gas Improvement Programme (GHGIP), which comprises 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 E** and **Table F** summarize some of the projects that are under implementation as part of the GHGIP.

Table D: Recalculated sector GHG emission estimates for 2000 and 2010 for South Africa.

| | | Initial emissions (Gg $CO_2$ eq) | Recalculated emissions (Gg $CO_2$ eq) | % change | % impact on national total (incl. FOLU) |
|---|---|---|---|---|---|
| Energy | 2000 | 337 381 | 342 592 | 1.5% | 1.2% |
| | 2010 | 428 368 | 435 117 | 1.6% | 1.6% |
| IPPU | 2000 | 44 907 | 33 563 | -25.3% | 2.6% |
| | 2010 | 44 350 | 35 463 | -20.0% | 2.0% |
| Total AFOLU | 2000 | 30 496 | 45 860 | 50.3% | 3.5% |
| | 2010 | 25 713 | 38 456 | 49.6% | 2.9% |
| 3A Livestock | 2000 | 31 118 | 31 162 | 0.1% | 0.01% |
| | 2010 | 28 986 | 29 412 | 1.5% | 0.1% |
| 3B Land | 2000 | -18 492 | -8 520 | 53.9% | 2.3% |
| | 2010 | -33 224 | -14 870 | 55.2% | 4.2% |
| 3C Aggregated sources and non-$CO_2$ emissions on land | 2000 | 23 656 | 23 526 | -0.5% | -0.0% |
| | 2010 | 22 802 | 23 577 | -3.4% | -0.2% |
| 3D Other | 2000 | -5 785 | -312 | -94.6% | 1.3% |
| | 2010 | -6 204 | -491 | -92.1% | 1.3% |
| Waste | 2000 | 12 433 | 12 288 | -1.2% | -0.03% |
| | 2010 | 19 806 | 20 354 | 2.8% | 0.13% |

Table E: 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 $CO_2$ emission factors for the Stationary | Eskom, Sasol, GIZ | October 2015 |
| Iron & steel | Using a combination of IPCC default factors and assumptions based on material flows | Combustion of Fuels in the Electricity | Mittal Steel, SAISI | December 2015 |
| Transport sector [implications for other sectors] | Using IPCC default emission factors | Generation Sector | DOT | September 2017 |
| Coal-to-liquids (CTL) | Allocation of emissions not transparently done, not accounting for all emissions | Shift towards a material balance approach | Sasol | December 2015 |
| Ferro-alloy production | Using a combination of IPCC default factors and assumptions based on material flows | Development of country-specific $CO_2$, $CH_4$, and $N_2O$ emission factors for road transportation. | Xstrata, Ferro-Alloy Producers' Association | May 2017 |
| Aluminium production | Using IPCC default emission factors | Tier 2 approach | BHP Billiton | December 2014 |
| Petroleum refining | Not accounting for all emission sources. Data time series inconsistencies | Shift towards a material balance approach | SAPIA in collaboration with all refineries | December 2015 |

Table F: Donor funded GHGIP projects

| Project | Partner | Objective | Outcome | Timelines |
|---|---|---|---|---|
| Development of a formal GHG National Inventory System | Norwegian Ministry of Foreign Affairs | Helping South Africa develop its national system | SA GHG inventories are documented and managed centrally | 2015-2017 |
| Stationary combustion EFs | GIZ, Eskom, Sasol (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, 2013/14] | Land-use change matrix developed for 36 IPCC land-use classes to detect changes | 2014-2015 |
| AFOLU sector activity data improvements | DFID-UK | To improve the activity data for agriculture, croplands and land-use change | Improved emission estimates for the AFOLU sector | 2014-2015 |
| Waste-sector activity data improvement project | African Development Bank (AfDB) | To improve waste-sector GHG emissions estimates and address data gaps | Waste-sector GHG inventory is complete, accurate and reflective of national circumstances | 2016-2017 |
| Compliance with the SASQAF | Statistics South Africa | Align GHG national inventory 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 |
| Survey on HFC consumption, production and application. | GEF | To collect information on main application areas for HFCs and PFCs as ODS substitutes | This will improve the estimation accuracy of emissions from this sector | 2016-2016 |
| Road Transport Modelling Study | GEF | To quantify information on Vehicle Kilometres Travelled (VKT) in the transport sector | This will improve the estimation accuracy of emissions from this sector | 2016-2017 |

## ES5 Conclusions and recommendations

The 2000 to 2012 GHG emissions results revealed an increase in emissions from the energy and waste sectors, and an increase in the sink for the AFOLU agriculture subsector. IPPU emissions increased and declined again over the 12 years. The compilation of the GHG inventory continues to be a challenge, especially in the availability of activity data for the computation of GHG emissions. The inclusion of the land subsector in the AFOLU sector caused a greater annual variation in the AFOLU emission numbers, but there was a general increase in the sink capacity of 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 IPPU emission estimates are largely derived from publicly available data from public institutions and sector-specific associations. Sourcing of information at the company level will enhance the accuracy of emission estimates and help reduce uncertainty associated with the estimates.

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-10 key categories each year. The land subsector was also an important component of this sector because it was estimated to be a sink. South Africa continues to require a more complete picture of this subsector and it is recommended that more country-specific data and carbon modelling be incorporated to move towards a Tier 2 or 3 approach. This subsector also has important mitigation options for the future, and understanding the sinks and sources will assist in determining its mitigation potential.

In the waste sector the emission estimates from both the solid waste and wastewater sources were largely computed using default values suggested in the IPCC 2006 Guidelines, which could lead to large margins of error for South Africa. South Africa needs to improve the data capture of the quantities of waste disposed into managed and unmanaged landfills, as well as update waste composition information and the mapping of all the wastewater discharge pathways. This sector would also benefit from the inclusion of more detailed economic data (e.g. annual growth) broken down by the different population groups. The assumption that GDP growth is evenly distributed across the different populations groups is highly misleading and exacerbates the margins of error.

# 1. INTRODUCTION

## 1.1 Climate change and GHG inventories

The Republic of South Africa ratified the UNFCCC and is therefore required to undertake several projects related to climate change. These include the preparation of greenhouse gas inventories, one of the outputs for the National Communications to the UNFCCC.

South Africa's first national GHG inventory was compiled in 1998 using activity data for 1990. The second national GHG inventory used 1994 data and was published in 2004. Both the 1990 and 1994 inventories were compiled based on the 1996 IPCC Guidelines.

The third national GHG inventory was compiled in 2009 using activity data from 2000. For that inventory the 2006 IPCC Guidelines were introduced. Those guidelines ensured accuracy, transparency and consistency. The 2006 IPCC Guidelines made significant changes, particularly on the restructuring of inventory sectors. Countries are not required by the UNFCCC to report their GHG emissions using the updated guidelines; however, it was decided to use the latest IPCC Guidelines to avoid difficulties converting from the 1996 to the 2006 guidelines in the future. In 2014 South Africa prepared its fourth national inventory, which included annual emission estimates for 2000 to 2010.

## 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 well-developed mining, transport, energy, manufacturing, tourism, agriculture, commercial timber and pulp production, and service sectors. It is a net exporter of energy, food, and telecommunications and other services to neighbouring countries. South Africa shares borders with six countries: Namibia, Botswana, Zimbabwe and Mozambique, which lie to the north, and Lesotho and Swaziland, which are landlocked within South Africa.

There are various factors that can influence a nation's GHG emissions, including government's infrastructure, population growth, geography, economic growth, energy consumption, technological development, climate and soils, agriculture, and land use management. South Africa contributes 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 democracy, with three tiers of government: national, provincial and local. Responsibilities affecting economic development, energy and natural resources, among others, are shared across the three tiers.

#### *1.2.1.2 Population Profile*

South Africa's population in 2013 was 52.98 million (Statistics SA, 2013). It had grown by 11.54% since 2001 to 2010 and the projected growth rate for 2010 to 2015 was 0.5% (Department of Environmental Affairs, 2011). International immigration is currently the main driving force of South Africa's population growth (Department of Environmental Affairs, 2014). Strong socio-economic and policy drivers of migration to 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. There are nine provinces: Eastern Cape, Free State, Gauteng, KwaZulu-Natal, Limpopo, Mpumalanga, Northern Cape, North West and Western Cape.

Gauteng is the most populated, with 24% of residents (Department of Environmental Affairs, 2014), followed by KwaZulu-Natal with 19.7%. The Northern Cape has the smallest population (2.2%) (Statistics SA, 2013). South Africa has 11 official languages, which displays its cultural diversity.

#### *1.2.1.3 Geopgraphic Profile*

South Africa is a medium-sized country, which covers roughly 124 929 847 hectares of the southernmost part of the African continent. It measures approximately 1 600 km from north to south, and is about the same from east to west. It lies between 22° and 35° south, flanked on the west by the Atlantic Ocean and on the east by the Indian Ocean (GCSI, 2009). The coastline is more than 2 500 km long, extending southwards from the desert border with Namibia in the northwest to Cape Agulhas, and then northwards to the Indian Ocean until it reaches the subtropical border with Mozambique in the northeast (GCSI, 2009). It has narrow coastal plateaus in the south and west which are edged by coastal mountain ranges. Further into the interior, an escarpment borders an extensive elevated plateau on which most of the central areas are 1 000 m above sea level. The main geographical features are the Drakensberg Mountains in the east, the Great Escarpment in the northeast and the Great Karoo in the centre (Department of Environmental Affairs, 2014).

#### *1.2.1.4 Economic and Industrial Profile*

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 (Department of Environmental Affairs, 2011). This increased to $380 billion (R2 835 087) in 2012 (Statistics SA, 2013). Between 2004 and 2007 the GDP grew at an annual rate of 4.6% to 5.6%, but in 2008 it slowed to 3.8% (**Table 1.1**). That was due to the global economic recession. In November 2009 South Africa showed that it had started to recover from the recession by achieving a growth of 0.9%. The hosting of the 2010 FIFA World Cup contributed significantly to the country's economy, helping it to register a 3.4% growth in the fourth quarter of 2010 (Statistics SA, 2013). In 2012, the agriculture, industry and service sectors accounted for 2.5%, 31.6% and 65.9% of GDP, respectively.

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.

Table 1.1: The GDP percentage growth in South Africa between 2000 and 2012 (Statistics SA, 2014).

| Year | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GDP % growth | 4.2 | 2.7 | 3.7 | 2.9 | 4.6 | 5.3 | 5.6 | 5.4 | 3.2 | -1.5 | 3.0 | 3.2 | 2.2 |

South Africa has an abundant supply of mineral resources. Its economy was originally built on natural resources, with agriculture and mining being the major components of the GDP. However, over the past few years thousands of jobs have been lost in the mining industry (Department of Environmental Affairs, 2011), nonetheless, South Africa's mining industry remains one of the country's main employers.

The transport sector is dominated by road travel. South Africa's car ownership ratio is higher than the world average, 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. Sixty-three percent of the country's commuters use minibus taxis, 22% use buses and 15% use trains (Department of Environmental Affairs, 2011). The minibus-taxi industry continues to grow annually.

With the growing population and economy, waste processing and disposal continue to be significant challenges. Households with adequate refuse removal services have remained at about 60% since 2006, but over 80% of these households are in urban areas. In rural areas, as little as 20% of households have access to these services.

#### *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. Its climate is generally warm temperate dry, however, there are exceptions, which create climatic diversity. There is a temperate Mediterranean-type climate in the southwest, a warm subtropical climate in the northeast, and a warm, dry desert environment in the central west and northwest. South Africa is a semi-arid region with an east-west rainfall gradient ranging from less than 250 mm to over 1000 mm per year (State of Environment Report, 2006). Most of the rainfall occurs in summer; however, the Western Cape receives most of its rainfall in winter (GCSI, 2009).

The relatively young geology in South African gives rise to high-nutrient soils. The Nama-Karoo biome of the central region comprises predominantly mudstones and sandstones of the Karoo Supergroup, while the Highveld grasslands are associated with high-nutrient soils of basalt and dolerite origin (Palmer & Ainslie, 2002). The Savannas of the Mpumalanga Lowveld are associated with Gabbros and granites (sandy, moderate-nutrient status) of the Bushveld Igneous Complex. The Cape Fold Mountains are siliceous rocks giving rise to litholic soils, while the Lesotho Highlands are basaltic giving rise to mollisols (Partridge, 1997).

The land cover in South Africa is dominated by low shrublands (33%), grasslands (20%) and woodlands or open bush (10%) (GeoTerraImage, 2015; see Appendix G). Natural forests are very small in South Africa, covering less than 0.5% of the land area. Settlements occupy approximately 2% of the land area (GeoTerraImage, 2015). Although 80% of South Africa's land surface area is used for agriculture and subsistence livelihoods, only about 11% has arable potential. The remaining 69% is used for grazing. Areas of moderate to high arable potential occur mainly in the eastern part of the country, in Mpumalanga and Gauteng, with scattered patches in KwaZulu-Natal, the Eastern Cape, and Limpopo. The agricultural sector is very diverse, ranging from intensive, large-scale commercial agricultural to low-intensity, small-scale subsistence farming. Roughly 11% of the land is formally cultivated, with a further 1.6% under subsistence farming. Maize and wheat are the dominant annual crops by area. Plantations are based on non-native trees, with the dominant species being Eucalyptus grandis.

Land in South Africa has enormous economic, social and environmental value, but a large proportion of the country's land surface is susceptible to degradation. Schoeman et al. (2013) showed that there was a 1.2% increase in transformed land between 1994 and 2005.

Cultivation and degradation of natural cover contributed 10.5% and 4.5%, respectively, to this transformation. The rest was due to urban land use and forestry. Cultivated areas over this period declined from 12.4% to 11.9%.

#### *1.2.1.6 Agriculture, Forestry and Fisheries Profile*

Agriculture, forestry and fisheries together accounted for less than 3% of GDP in 2006 (Department of Environmental Affairs, 2011). The agriculture 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, 26.7% was from field crops and 25.1% was 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 1.3% of the land area (GeoTerraImage, 2015). Timber contributes more than R16 billion to South Africa's economy, with an annual production of 2.2 million $m^3$ of commercial round wood (Department of Environmental Affairs, 2011). Exports are mainly converted, value-added products, with raw material exports making up only 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 and valued at approximately R4 billion to 5 billion annually (Department of Environmental Affairs, 2011).

### 1.2.2 Institutional arrangements for inventory preparation

In South Africa the DEA is the central co-ordinating and policy-making authority with respect to environmental conservation. The DEA is mandated by the Air Quality Act (Act 39 of 2004) to formulate, co-ordinate and monitor national environmental information, policies, programmes and legislation. The work of the 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 as a lead climate institution, the DEA is responsible for co-ordination and management of all climate change-related information, such as mitigation, adaption, monitoring and evaluation programmes, including the compilation and update of GHG inventories. The branch responsible for the management and co-ordination of GHG inventories at the DEA is the Climate Change and Air Quality Management branch, whose purpose is to improve air and atmospheric quality, as well as support, monitor and report international, national, provincial and local responses to climate change.

Although the 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. The major contributors are shown in **Table 1.2** to **1.5**.

At this stage there is a lack of well-defined institutional arrangements and an absence of legal and formal procedures for the compilation of GHG emission inventories. The structure and formalization of these institutional arrangements is currently being developed by the DEA so as to maintain a consistent and sustainable flow of data input for the inventory.

Table 1.2: Institutional arrangements in the energy sector

| Ministry / Agency | Role |
|---|---|
| Department of Energy (DoE) | The DEA utilises national energy balances published by the DoE to estimate energy emissions. |
| Department of Mineral Resources (DMR) | Provides energy-related information in the form of the South African Minerals Industry (SAMI) report. |
| Eskom | Provides information on GHG emissions associated with electricity generation. |
| Coaltech | Provides information on fugitive emissions associated with solid fuels. |
| South African Petroleum Industry Association (SAPIA) | Provides information for estimating GHG emissions from petroleum refining. |
| Chamber of Mines | Provides information for estimating GHG emissions from mining activities. |
| National Energy Regulator of South Africa (NERSA) | Provides information for estimating GHG emissions from independent power producers (IPPs). |
| Department of Transport | Provides information for estimating GHG emissions from the transport sector. |

Table 1.3: Institutional arrangements in the IPPU sector

| Ministry / Agency | Role |
|---|---|
| Business Unity South Africa (BUSA) and industry | Provide GHG information for the IPPU sector. |
| South African Iron and Steel Institute (SAISI) | Provides GHG information for the iron and steel industry. |
| Association of Cementitious Material Producers (ACMP) | Provides GHG information for the cement industry. |
| Ferro-Alloy Producers' Association (FAPA) | Provides activity data on ferroalloy production. |
| Department of Mineral Resources (DMR) | Provides industrial processes-related information in the form of the South African Minerals Industry (SAMI) reports. |
| Department of Transport | Provides information for estimating GHG emissions from the transport sector. |

Table 1.4: Institutional arrangements in the AFOLU sector

| Ministry / Agency | Role |
|---|---|
| GeoTerraImage | Provides maps for the land sector. |
| Agricultural Research Council (ARC) | Provides data and technical support when compiling GHG emissions for agriculture. |
| Forestry South Africa (FSA) | Provides data for the forestry sector. |
| Agri South Africa (AgriSA) | Provides technical support for compiling GHG emissions from the agriculture sector. |
| South African Poultry Association (SAPA) | Provides poultry population data. |
| Council for Scientific and Industrial Research (CSIR) | Provides technical support when compiling GHG emissions for land. |
| University of Pretoria (UP) and Tshwane University of Technology (TUT) | Undertake research related to agricultural emissions. |
| North-West University (NWU) | Provide support for the compilation of the AFOLU sector inventory. |
| Department of Agriculture, Forest-ry and Fisheries (DAFF) | Provides data, statistics and information on the AFOLU sector. |
| Statistics South Africa (Stats SA) | Provides statistical data for the AFOLU sector. |
| Department of Environmental Affairs (DEA) Geographic Information System (GIS) Unit | Provides an archiving system for forestry maps. |

Table 1.5: Institutional arrangements in the waste sector

| Ministry / Agency | Role |
|---|---|
| Council for Scientific and Industrial Research (CSIR) | Provides technical support when compiling GHG emissions for the waste sector. |
| DEA Waste Unit | Provides information on the waste sector. |
| Statistics South Africa (StatsSA) | Provides statistical parameters that can be applied when estimating GHG emissions from the waste sector |
| Department of Water Affairs (DWA) | Provides information on the country's wastewater treatment works. |

## 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 to ensure consistency, accuracy and transparency. To be consistent with previous inventories, this GHG inventory for 2012 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 the source category was considered as the main category, and on the availability of data.

The collection of data and information is still a challenge when compiling the GHG inventory for South Africa. 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 methods difficult. Where more disaggregated data and emission factors were available, a higher-tier method was used to improve on the previous inventory. South Africa's aim is to incorporate more country-specific data and move towards a Tier 2 or 3 approach for the key categories in particular.

The DEA is in the process of implementing a data management system that will manage all aspects of the inventory compilation process. The NGHGIS will include:

- The formalization of a National Entity (the DEA), which will include an inventory co-ordinator, sector-specific experts and an inventory compiler. This group will be responsible for the preparation, planning, management, review, implementation and improvement of the inventory;
- Legal and collaborative arrangements between the National Entity and the institutions that are custodians of key source data and that will provide the required data for each sector;
- A process and plan for implementing QA and QC procedures, including ensuring that the UNFCCC reporting and IPCC Guidelines have been properly implemented;
- The alignment of the NGHGIS with the South African Standard Quality Assessment Framework;
- A process to ensure that the national inventory meets the standard inventory data quality indicators of accuracy, transparency, completeness, consistency and comparability; and
- A process for continual improvements of the national inventory.

### 1.3.1 Data collection procedures and plans

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 (see **Section 1.6**).

The DEA is in the process of developing a data collection plan that will improve the accessibility of activity data. The data collection procedures will include guidance on collection, collation and processing existing data, as well as providing guidance for the generation of new data. A data collection plan is required to meet data quality objectives regarding timeliness, consistency, completeness, comparability, accuracy and transparency. It is also good practice to periodically review the data collection process to maintain the quality and to guide progressive and efficient inventory improvement.

The data collection plan will focus on providing guidance for three main aspects (**Figure 1.1**):

- Collection and collation of existing data:
    - o focus data collection on improving estimates for key categories which:

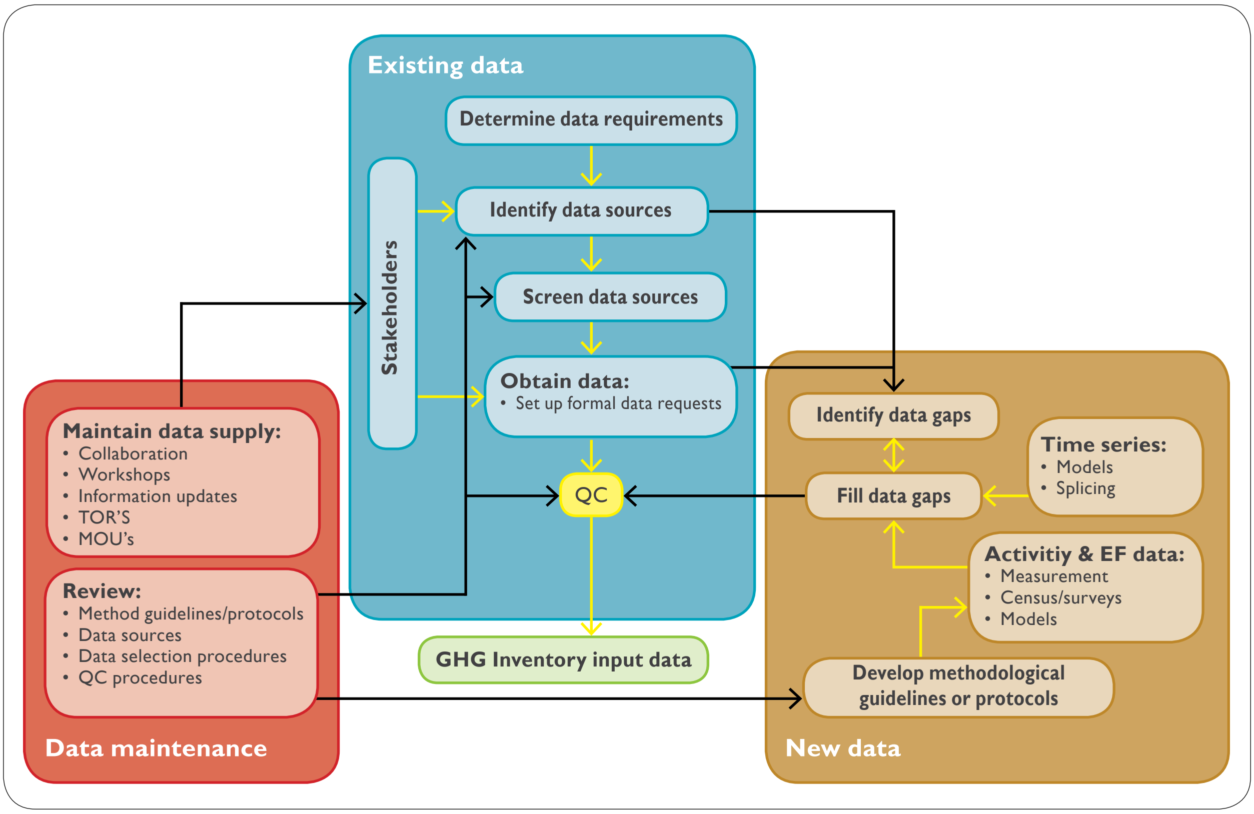



Figure 1.1: GHG inventory data collection procedure

  - are the largest,
  - have the greatest potential to change, or
  - have the greatest uncertainty;
- o choose data collection procedures that iteratively improve the quality of the inventory in line with the data quality objectives; and
- o collect data at a level of detail appropriate to the method used;

- Generation of new data:
  - o identify data gaps and work towards filling these gaps; and
  - o put in place data collection activities that lead to the continual improvement of data sets used in the inventory;
- Maintenance of data supply and collection procedures:
  - o introduce agreements with data suppliers to support consistent and continuing information flows; and
  - o review data collection activities and methodological needs on a regular basis.

### 1.3.2 Data archiving and storage

After the data has been through the data collection phase (collection, selection, generation, review and QC) it enters the GHG inventory database. In the past, each inventory was treated differently and separate worksheets were completed for each inventory. Furthermore, no documentation (of methodology or QC) or supporting data were recorded. The 2000 – 2010 inventory was the

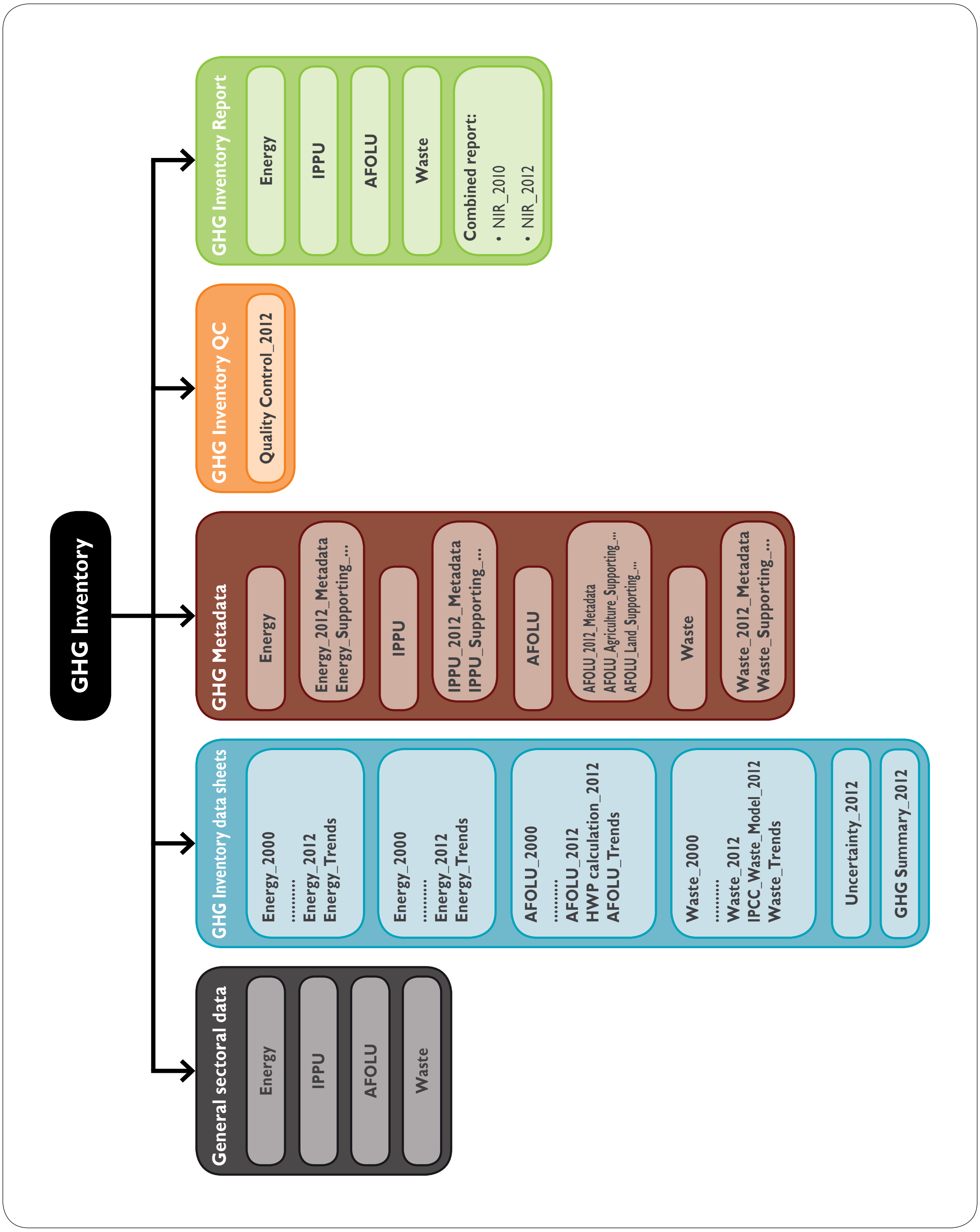



Figure 1.2: Configuration and files contained in the GHG inventory database.

first one in which an annual time series was included, and because of the increase in the amount of data there was a focus on setting up a proper inventory database where all the data could be kept. The database will also assist in streamlining future GHG inventory updates. In this 2000 – 2012 inventory there has been a focus on documentation, transparency and quality control. Additional spreadsheets for metadata and supporting documents, as well as quality control and uncertainty files have been added to the database.

The database consists of a series of Excel spreadsheets which are linked to ensure consistency and easy updating. The GHG Inventory database contains five folders (**Figure 1.2**):

- General sectoral data;
- GHG inventory data sheets;
- GHG metadata;
- GHG inventory QC; and
- GHG inventory report.

### 1.3.3 Brief description of methodologies and data sources

#### *1.3.3.1 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. For the current inventory, data were gathered for the following gases: $CO_2$, $CH_4$, and $N_2O$. Certain HFCs and PFCs were reported on in the IPPU sector and NOx and CO were estimated for biomass burning emissions.

This section provides an overview of the methods used to estimate GHG emissions in South Africa, and **Table 1.6** summarizes the tier method and type of emission factors used in the calculations.

After data were collected, the sources quality assured, and the unit conversions 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 in **Chapters 5** and **6**.

When calculating emissions, the expert is responsible for quality assurance and checks, but the calculations are also 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 methodologies for each sector and source category are presented in later chapters.

In January 2015 all countries will be mandated to use the 2006 IPCC Guidelines for the compilation and reporting of national GHG inventories under the UNFCCC reporting guidelines. In addition, non-annex I countries that are party to the convention shall use the GWP from the IPCC Second Assessment Report (SAR). In this current inventory, South Africa has chosen to use GWPs from the IPCC Third Assessment Report (TAR) (**Table 1.7**) so as to align with the 2006 IPCC Guidelines. Discussions are underway domestically to consider the possibility of using GWPs from the IPCC Fourth Assessment Report (FAR).

Table 1.6: Tier method (TM) and emission factor (EF) used in this inventory in the estimation of the emissions from the various sectors.

| GHG Source and Sink Category | $CO_2$ | | $CH_4$ | | $N_2O$ | | HFCs | | PFCs | | $SF_6$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TM | EF | TM | EF | TM | EF | TM | EF | TM | EF | TM | EF |
| **1. Energy** | | | | | | | | | | | | |
| A. Fuel combustion | | | | | | | | | | | | |
| 1. Energy industries | T1, T3 | T1, CS[a] | T1, T1 | DF[b] | T1, T1 | DF | | | | | | |
| 2. Manufacturing industries and construction | T1 | DF | T1 | DF | T1 | DF | | | | | | |
| 3. Transport | T1 | DF | T1 | DF | T1 | DF | | | | | | |
| 4. Other sectors | T1 | DF | T1 | DF | T1 | DF | | | | | | |
| 5. Non-specified | T1 | DF | T1 | DF | T1 | DF | | | | | | |
| B. Fugitive emissions from fuels | | | | | | | | | | | | |
| HFC-152a | T2 | CS | T2 | CS | | | | | | | | |
| | T3 | CS | | | | | | | | | | |
| | T3 | CS | T3 | CS | | | | | | | | |
| **2. Industrial processes** | | | | | | | | | | | | |
| A. Mineral products | T1 | DF | | | | | | | | | | |
| B. Chemical industry | T1, T3 | DF CS | T1 | DF | T1, T3 | DF | | | | | | |
| C. Metal industry | T2, T3 | T2, PS[c] | T1 | DF | | | | | T2 | CS | | |
| D. Non-energy products from fuels and solvents | T1 | DF | | | | | | | | | | |
| F. Product used as substitutes for ODS | | | | | | | T1 | DF | | | | |
| **3. AFOLU** | | | | | | | | | | | | |
| A. Livestock | | | | | | | | | | | | |
| 1. Enteric fermentation | | | T2 | CS | | | | | | | | |
| 2. Manure management | | | T2 | CS | T2 | DF | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B. Land | | | | | | | | | | | | |
| 1. Forest land | T1,<br>T2 | | CS<br>DF | | | | | | | | | |
| 2. Cropland | T1,<br>T2 | | CS<br>DF | | | | | | | | | |
| 3. Grassland | T1 | | CS<br>DF | | | | | | | | | |
| 4. Wetlands | | | T1 | DF | | | | | | | | |
| 5. Settlements | T1 | DF | | | | | | | | | | |
| 6. Other lands | T1 | DF | | | | | | | | | | |
| C. Aggregated sources and non-$CO_2$ emissions | | | | | | | | | | | | |
| 1. Emissions from biomass burning | T2 | CS | T2 | CS | T2 | CS | | | | | | |
| 2. Liming | T1 | DF | | | | | | | | | | |
| 3. Urea application | T1 | DF | | | | | | | | | | |
| 4. Direct $N_2O$ from managed soils | | | | | T1 | DF | | | | | | |
| 5. Indirect $N_2O$ from managed soils | | | | | T1 | DF | | | | | | |
| 6. Indirect $N_2O$ from manure management | | | | | T1 | DF | | | | | | |
| D. Other | | | | | | | | | | | | |
| 7. Harvested wood products | T1 | CS<br>DF | | | | | | | | | | |
| **4. Waste** | | | | | | | | | | | | |
| A. Solid waste disposal | | T1 | DF | | | | | | | | | |
| D. Wastewater treatment and discharge | | | T1,<br>T2 | CS<br>DF | T1 | DF | | | | | | |

a Country specific;

b Default factors

c Plant Specific emission factors

Table 1.7: 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 |

### 1.3.3.2 Data Sources

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

- Energy data:
    - 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);
    - Government Communications and 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 Minerals Industry (SAMI) report;
    - Department of Mineral Resources (DMR);
    - Department of Energy (DoE);
    - South African Iron and Steel Institute (SAISI);
    - Association of Cementitious Material Producers (ACMP); and
    - Direct communication with various industrial production plants.
- AFOLU:
    - Department of Agriculture, Forestry and Fisheries (DAFF);
    - Forest Resource Assessment (from DAFF and FAO);
    - Department of Environmental Affairs (DEA);
    - Forestry South Africa (FSA);
    - GeoTerraImage (GTI);
    - National Terrestrial Carbon Sinks Assessment (NTCSA) (DEA, 2015);
    - Food and Agriculture Organization (FAO);
    - Agricultural Research Council (ARC);
    - Tshwane University of Technology (TUT);
    - University of Pretoria (UP);
    - North West University, Potchefstroom (NWU);
    - Statistics South Africa;
    - Professional livestock associations and breed societies;
    - MODIS burnt area data.

- Waste:
  - Centre for Scientific and Industrial Research (CSIR);
  - Statistics SA;
  - World Resources Institute (WRI); and
  - DEA waste baseline study.

### 1.3.4 Brief description of key categories

The key categories are the most significant emission sources in South Africa. There are two approaches which can be used to determine the key categories; namely, the level approach and the trend approach. The former is used if only one year of data is available, while the latter can be used if there are two comparable years. The inventory provides emissions for more than one year; therefore both the level and trend assessments for key category analysis were performed.

The key categories have been assessed using the Approach 1 level (L1) and Approach 1 trend (T1) methodologies from the 2006 IPCC Guidelines (IPCC, 2006). The key category analysis identifies key categories of emissions and removals as those that sum to 95 per cent of the gross or net level of emissions and those that are within the top 95 per cent of the categories that contribute to the change between 2000 and 2012, or the trend of emissions. The key categories identified in 2012 are summarised in **Table 1.8**. In accordance with the 2006 IPCC Guidelines, the key category analysis is performed once for the inventory excluding the FOLU sector and then repeated for the inventory including the FOLU sector.

The level analysis excluding FOLU (**Table 1.9**) identifies the following major contributions to the net emissions for 2012:

- $CO_2$ emissions from solid fuels in *energy industries – main activity electricity and heat* (47.9%);
- $CO_2$ emissions from liquid fuels used in *road transportation* (8.5%);
- $CO_2$ emissions from liquid fuels in *energy industries – manufacture of solid fuels and other energy industries* (5.9%);
- $CO_2$ emissions from the use of solid fuels in *manufacturing industries and construction* (4.8%); and
- $CH_4$ emissions from *enteric fermentation from cattle* (4.2%).

Including FOLU in the level assessment (**Table 1.10**) shows the following key categories:

- $CO_2$ emissions from solid fuels in *energy industries – main activity electricity and heat* (43.5%);
- $CO_2$ emissions from liquid fuels used in *road transportation* (7.7%);
- $CO_2$ emissions from liquid fuels in *energy industries – manufacture of solid fuels and other energy industries* (5.4%);
- $CO_2$ removals from *land converted to forest land* (5.3%); and
- $CO_2$ emissions from the use of solid fuels in *manufacturing industries and construction* (4.4%).

**Table 1.11** identifies the key categories (excluding FOLU) having the largest relative influence on the trend, when compared with the average change in net emissions from 2000 to 2012:

- $CO_2$ emissions from solid fuels used in *other sectors – residential* (14.7%);
- $CO_2$ emissions from solid fuels used in *energy industries – main activity electricity and heat production* (13.0%);
- $CO_2$ emissions from solid fuels used in *manufacturing industries and construction* (12.3%);
- $CO_2$ emissions from liquid fuels used in *energy industries – manufacture of solid fuels and other energy industries* (8.3%); and

- $CH_4$ emissions from *enteric fermentation from cattle* (7.5%).

Including FOLU in the trend analysis (Table 1.12) also shows the following key categories:

- $CO_2$ removals from *land converted to forest land* (14.6%);
- $CO_2$ emissions from solid fuels used in *energy industries – main activity electricity and heat production* (14.1%);
- $CO_2$ emissions from solid fuels used in *other sectors – residential* (11.7%);
- $CO_2$ emissions from solid fuels used in *manufacturing industries and construction* (9.1%); and
- $CO_2$ emissions from liquid fuels used in *energy industries – manufacture of solid fuels and other energy industries* (6.0%).

The complete level and trend assessments are provided in **Appendix B**.

Table 1.8: Summary of South Africa's key categories for 2012 level assessment and the trend assessment for 2000 to 2012 (including and excluding FOLU activities).

| IPCC Category code | IPCC Category | Greenhouse gas | Criteria for identification |
|---|---|---|---|
| | **ENERGY** | | |
| 1.A.1.a | Energy Industries - Solid Fuels - Main activity electricity and heat production | $CO_2$ | L1,T1 |
| 1.A.1.b | Energy Industries - Liquid Fuels - Petroleum refining | $CO_2$ | L1,T1 |
| 1.A.1.c | Energy Industries - Liquid Fuels - Manufacture of solid fuels and other energy industries | $CO_2$ | L1,T1 |
| 1.A.2 | Manufacturing Industries and Construction - Solid Fuels | $CO_2$ | L1,T1 |
| 1.A.2 | Manufacturing Industries and Construction - Gaseous Fuels | $CO_2$ | L1 |
| 1.A.2 | Manufacturing Industries and Construction - Solid Fuels | $CO_2$ | L1,T1 |
| 1.A.2 | Manufacturing Industries and Construction - Liquid Fuels | $CO_2$ | L1,T1 |
| 1.A.3.a | Transport - Liquid Fuels - Civil Aviation | $CO_2$ | L1,T1 |
| 1.A.3.b | Transport - Liquid Fuels - Road Transportation | $CO_2$ | L1,T1 |
| 1.A.3.c | Transport - Liquid Fuels - Railways | $CO_2$ | T1 |
| 1.A.4.a | Other Sectors - Liquid Fuels - Commercial/Institutional | $CO_2$ | L1,T1 |
| 1.A.4.a | Other Sectors - Solid Fuels - Commercial/Institutional | $CO_2$ | L1,T1 |
| 1.A.4.b | Other Sectors - Solid Fuels - Residential | $CO_2$ | L1,T1 |
| 1.A.4.b | Other Sectors - Liquid Fuels - Residential | $CO_2$ | L1,T1 |
| 1.A.4.c | Other Sectors - Liquid Fuels - Agriculture/Forestry/Fishing/Fish farms | $CO_2$ | L1,T1 |

| IPCC Category code | IPCC Category | Greenhouse gas | Criteria for identification |
|---|---|---|---|
| | **IPPU** | | |
| 2.A.1 | Mineral industry - Cement production | $CO_2$ | L1 |
| 2.B. | Chemical industry - Industry X | $CO_2$ | T1 |
| 2.B. | Chemical industry - Industry F | $N_2O$ | T1 |
| 2.B. | Chemical industry - Industry K | $CO_2$ | T1 |
| 2.C.1 | Metal industry - Iron and Steel Production | $CO_2$ | L1,T1 |
| 2.C.2 | Metal industry - Ferroalloys Production | $CO_2$ | L1,T1 |
| 2.C.3 | Metal industry - Aluminium production | PFCs | T1 |
| 2.F.1 | Product uses as substitutes for ODS - Refrigeration and Air Conditioning | HFCs | T1 |
| | **AFOLU** | | |
| 3.A.1.a | Enteric Fermentation - Cattle | $CH_4$ | L1,T1 |
| 3.A.1.c | Enteric Fermentation - Sheep | $CH_4$ | L1,T1 |
| 3.A.1.d | Enteric Fermentation - Goats | $CH_4$ | T1 |
| 3.B.1.a | Forest land - Forest land Remaining Forest land | $CO_2$ | L1 |
| 3.B.1.b | Forest land - Land Converted to Forest land | $CO_2$ | L1,T1 |
| 3.B.2.a | Cropland - Cropland Remaining Cropland | $CO_2$ | T1 |
| 3.B.2.b | Cropland - Land Converted to Cropland | $CO_2$ | L1,T1 |
| 3.B.3.b | Grassland - Land Converted to Grassland | $CO_2$ | L1,T1 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - Urine and dung N deposits in PRP | $N_2O$ | L1,T1 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - Inorganic N application | $N_2O$ | T1 |
| 3.C.5 | Indirect $N_2O$ Emissions from managed soils - N leaching/runoff | $N_2O$ | L1,T1 |
| 3.C.5 | Indirect $N_2O$ Emissions from managed soils - N volatilization | $N_2O$ | T1 |
| | **WASTE** | | |
| 4.A | Solid Waste Disposal | $CH_4$ | L1,T1 |
| 4.D.1 | Wastewater Treatment and Discharge - Domestic | $CH_4$ | L1 |

Table 1.9: Level assessment results for 2012, excluding FOLU contributions. Only key categories are shown.

| IPCC code | IPCC Category | GHG | 2012 estimate (Gg $CO_2$ eq) | Level assessment (%) | Cumulative total (%) |
|---|---|---|---|---|---|
| 1.A.1,a | Energy Industries - Solid Fuels - Main activity electricity and heat production | $CO_2$ | 242 154.0 | 47.9 | 47.9 |
| 1.A.3.b | Transport - Liquid Fuels - Road Transportation | $CO_2$ | 42 929.6 | 8.5 | 56.4 |
| 1.A.1.c | Energy Industries - Liquid Fuels - Manufacture of solid fuels and other energy industries | $CO_2$ | 29 903.3 | 5.9 | 62.3 |
| 1.A.2 | Manufacturing Industries and Construction - Solid Fuels | $CO_2$ | 24 472.7 | 4.8 | 67.2 |
| 3.A.1.a | Enteric Fermentation – Cattle | $CH_4$ | 21 236.5 | 4.2 | 71.4 |
| 1.A.4.b | Other Sectors - Solid Fuels – Residential | $CO_2$ | 18 461.9 | 3.7 | 75.0 |
| 4.A | Solid Waste Disposal | $CH_4$ | 18 412.0 | 3.6 | 78.7 |
| 2.C.1 | Metal industry - Iron and Steel Production | $CO_2$ | 15 020.7 | 3.0 | 81.6 |
| 1.A.4.a | Other Sectors - Liquid Fuels - Commercial/Institutional | $CO_2$ | 12 685.4 | 2.5 | 84.1 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - Urine and dung N deposits in PRP | $N_2O$ | 11 815.0 | 2.3 | 86.5 |
| 2.C.2 | Metal industry - Ferroalloys Production | $CO_2$ | 11 623.8 | 2.3 | 88.8 |
| 2.A.1 | Mineral industry - Cement production | $CO_2$ | 3 844.5 | 0.8 | 89.5 |
| 3.A.1.c | Enteric Fermentation – Sheep | $CH_4$ | 3 783.5 | 0.7 | 90.3 |
| 1.A.3.a | Transport - Liquid Fuels - Civil Aviation | $CO_2$ | 3 466.4 | 0.7 | 91.0 |
| 1.A.4.a | Other Sectors - Solid Fuels - Commercial/Institutional | $CO_2$ | 3 434.8 | 0.7 | 91.7 |
| 1.A.4.c | Other Sectors - Liquid Fuels - Agriculture/Forestry/Fishing/Fish farms | $CO_2$ | 3 420.3 | 0.7 | 92.3 |
| 4.D.1 | Wastewater Treatment and Discharge - Domestic | $CH_4$ | 2 827.7 | 0.6 | 92.9 |

| IPCC code | IPCC Category | GHG | 2012 estimate (Gg $CO_2$ eq) | Level assessment (%) | Cumulative total (%) |
|---|---|---|---|---|---|
| 1.A.1.b | Energy Industries - Liquid Fuels - Petroleum refining | $CO_2$ | 2 802.4 | 0.6 | 93.4 |
| 1.A.2 | Manufacturing Industries and Construction - Gaseous Fuels | $CO_2$ | 2 497.5 | 0.5 | 93.9 |
| 3.C.5 | Indirect $N_2O$ Emissions from managed soils - N leaching/runoff | $N_2O$ | 2 330.0 | 0.5 | 94.4 |
| 1.A.4.b | Other Sectors - Liquid Fuels - Residential | $CO_2$ | 2 154.6 | 0.4 | 94.8 |
| 1.A.2 | Manufacturing Industries and Construction - Liquid Fuels | $CO_2$ | 2 114.0 | 0.4 | 95.2 |

Table 1.10: Level assessment results for 2012, including FOLU contributions. Only key categories are shown.

| IPCC code | IPCC Category | GHG | 2012 estimate (Gg $CO_2$ eq) | Level assessment (%) | Cumulative total (%) |
|---|---|---|---|---|---|
| 1.A.1,a | Energy Industries - Solid Fuels - Main activity electricity and heat production | $CO_2$ | 242 154.0 | 43.5 | 43.5 |
| 1.A.3.b | Transport - Liquid Fuels - Road Transportation | $CO_2$ | 42 929.6 | 7.7 | 51.2 |
| 1.A.1.c | Energy Industries - Liquid Fuels - Manufacture of solid fuels and other energy industries | $CO_2$ | 29 903.3 | 5.4 | 56.6 |
| 3.B.1.b | Forest land - Land Converted to Forest land | $CO_2$ | -29 490.8 | 5.3 | 61.9 |
| 1.A.2 | Manufacturing Industries and Construction - Solid Fuels | $CO_2$ | 24 472.7 | 4.4 | 66.3 |
| 3.A.1.a | Enteric Fermentation - Cattle | $CH_4$ | 21 236.5 | 3.8 | 70.1 |
| 1.A.4.b | Other Sectors - Solid Fuels - Residential | $CO_2$ | 18 461.9 | 3.3 | 73.4 |
| 4.A | Solid Waste Disposal | $CH_4$ | 18 412.0 | 3.3 | 76.8 |
| 2.C.1 | Metal industry - Iron and Steel Production | $CO_2$ | 15 020.7 | 2.7 | 79.5 |

| IPCC code | IPCC Category | GHG | 2012 estimate (Gg $CO_2$ eq) | Level assessment (%) | Cumulative total (%) |
|---|---|---|---|---|---|
| I.A.4.a | Other Sectors - Liquid Fuels - Commercial/Institutional | $CO_2$ | 12 685.4 | 2.3 | 81.7 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - Urine and dung N deposits in PRP | $N_2O$ | 11 815.0 | 2.1 | 83.9 |
| 2.C.2 | Metal industry - Ferroalloys Production | $CO_2$ | 11 623.8 | 2.1 | 85.9 |
| 3.B.3.b | Grassland - Land Converted to Grassland | $CO_2$ | 7 871.8 | 1.4 | 87.4 |
| 3.B.2.b | Cropland - Land Converted to Cropland | $CO_2$ | 5 721.0 | 1.0 | 88.4 |
| 3.B.1.a | Forest land - Forest land Remaining Forest land | $CO_2$ | -4 834.4 | 0.9 | 89.3 |
| 2.A.1 | Mineral industry - Cement production | $CO_2$ | 3 844.5 | 0.7 | 90.0 |
| 3.A.1.c | Enteric Fermentation - Sheep | $CH_4$ | 3 783.5 | 0.7 | 90.6 |
| I.A.3.a | Transport - Liquid Fuels - Civil Aviation | $CO_2$ | 3 466.4 | 0.6 | 91.3 |
| I.A.4.a | Other Sectors - Solid Fuels - Commercial/Institutional | $CO_2$ | 3 434.8 | 0.6 | 91.9 |
| I.A.4.c | Other Sectors - Liquid Fuels - Agriculture/Forestry/Fishing/Fish farms | $CO_2$ | 3 420.3 | 0.6 | 92.5 |
| 4.D.1 | Wastewater Treatment and Discharge - Domestic | $CH_4$ | 2 827.7 | 0.5 | 93.0 |
| I.A.1.b | Energy Industries - Liquid Fuels - Petroleum refining | $CO_2$ | 2 802.4 | 0.5 | 93.5 |
| I.A.2 | Manufacturing Industries and Construction - Gaseous Fuels | $CO_2$ | 2 497.5 | 0.4 | 93.9 |
| 3.C.5 | Indirect $N_2O$ Emissions from managed soils - N leaching/runoff | $N_2O$ | 2 330.0 | 0.4 | 94.4 |
| I.A.4.b | Other Sectors - Liquid Fuels - Residential | $CO_2$ | 2 154.6 | 0.4 | 94.8 |
| I.A.2 | Manufacturing Industries and Construction - Liquid Fuels | $CO_2$ | 2 114.0 | 0.4 | 95.1 |

Table 1.11: Trend assessment results for 2012 (with 2000 as the base year), excluding FOLU contributions. Only the key categories are shown.

| IPCC code | IPCC Category | GHG | 2000 Year estimate (Gg $CO_2$eq) | 2012 Year Estimate (Gg $CO_2$eq) | Trend Assessment | Contribution to trend (%) | Cumulative total (%) |
|---|---|---|---|---|---|---|---|
| 1.A.4.b | Other Sectors - Solid Fuels - Residential | $CO_2$ | 3 604.2 | 18 461.9 | **0.034** | 14.7 | 14.7 |
| 1.A.1,a | Energy Industries - Solid Fuels - Main activity electricity and heat production | $CO_2$ | 185 027.4 | 242 154.0 | **0.030** | 13.0 | 27.7 |
| 1.A.2 | Manufacturing Industries and Construction - Solid Fuels | $CO_2$ | 29 101.6 | 24 472.7 | **0.029** | 12.3 | 40.0 |
| 1.A.1.c | Energy Industries - Liquid Fuels - Manufacture of solid fuels and other energy industries | $CO_2$ | 30 454.7 | 29 903.3 | **0.019** | 8.3 | 48.3 |
| 3.A.1.a | Enteric Fermentation – Cattle | $CH_4$ | 22 819.4 | 21 236.5 | **0.017** | 7.5 | 55.8 |
| 4.A | Solid Waste Disposal | $CH_4$ | 9 367.6 | 18 412.0 | **0.017** | 7.1 | 62.9 |
| 2.C.1 | Metal industry - Iron and Steel Production | $CO_2$ | 16 410.5 | 15 020.7 | **0.013** | 5.6 | 68.5 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - Urine and dung N deposits in PRP | $N_2O$ | 13 180.8 | 11 815.0 | **0.011** | 4.8 | 73.3 |
| 1.A.4.a | Other Sectors - Liquid Fuels - Commercial/Institutional | $CO_2$ | 7 690.4 | 12 685.4 | **0.008** | 3.3 | 76.6 |
| 1.A.3.b | Transport - Liquid Fuels - Road Transportation | $CO_2$ | 32 623.3 | 42 929.6 | **0.006** | 2.5 | 79.2 |
| 2.C.2 | Metal industry - Ferroalloys Production | $CO_2$ | 8 079.1 | 11 623.8 | **0.004** | 1.7 | 80.8 |
| 1.A.4.b | Other Sectors - Liquid Fuels – Residential | $CO_2$ | 2 868.9 | 2 154.6 | **0.003** | 1.5 | 82.3 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2.F.1 | Product uses as substitutes for ODS - Refrigeration and Air Conditioning | HFCs | 0.0 | 1 396.1 | **0.003** | 1.5 | 83.8 |
| 3.A.1.c | Enteric Fermentation - Sheep | $CH_4$ | 4 169.0 | 3 783.5 | **0.003** | 1.5 | 85.3 |
| 1.A.4.a | Other Sectors - Solid Fuels - Commercial/Institutional | $CO_2$ | 1 811.2 | 3 434.8 | **0.003** | 1.2 | 86.5 |
| 1.A.1.b | Energy Industries - Liquid Fuels - Petroleum refining | $CO_2$ | 3 164.8 | 2 802.4 | **0.003** | 1.2 | 87.7 |
| 1.A.3.a | Transport - Liquid Fuels - Civil Aviation | $CO_2$ | 2 040.0 | 3 466.4 | **0.002** | 1.0 | 88.7 |
| 2.C.3 | Metal industry - Aluminium production | PFCs | 982.2 | 1 979.2 | **0.002** | 0.8 | 89.5 |
| 3.C.5 | Indirect $N_2O$ Emissions from managed soils - N leaching/runoff | $N_2O$ | 2 479.0 | 2 330.0 | **0.002** | 0.8 | 90.3 |
| 2.B | Chemical industry - Industry F | $N_2O$ | NS[a] | NS[a] | **0.002** | 0.8 | 91.0 |
| 1.A.4.c | Other Sectors - Liquid Fuels - Agriculture/Forestry/Fishing/Fish farms | $CO_2$ | 2 207.2 | 3 420.3 | **0.002** | 0.7 | 91.8 |
| 1.A.2 | Manufacturing Industries and Construction - Liquid Fuels | $CO_2$ | 1 186.1 | 2 114.0 | **0.002** | 0.7 | 92.4 |
| 3.C.5 | Indirect $N_2O$ Emissions from managed soils - N volatilization | $N_2O$ | 1 939.5 | 1 791.7 | **0.002** | 0.6 | 93.1 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - Inorganic N application | $N_2O$ | 1 934.7 | 2 000.1 | **0.001** | 0.4 | 93.5 |
| 2.B | Chemical industry - Industry X | $CO_2$ | NS[a] | NS[a] | **0.001** | 0.4 | 93.9 |
| 2.B | Chemical industry - Industry K | $CO_2$ | NS[a] | NS[a] | **0.001** | 0.4 | 94.3 |
| 3.A.1.d | Enteric Fermentation - Goats | $CH_4$ | 993.6 | 855.6 | **0.001** | 0.4 | 94.7 |
| 1.A.3.c | Transport - Liquid Fuels - Railways | $CO_2$ | 551.5 | 318.0 | **0.001** | 0.4 | 95.1 |

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

Table 1.12: Trend assessment results for 2012 (with 2000 as the base year), including FOLU contributions. Only the key categories are shown.

| IPCC code | IPCC Category | GHG | 2000 Year estimate (Gg $CO_2$eq) | 2012 Year Estimate (Gg $CO_2$eq) | Trend Assessment | Contri-bution to trend (%) | Cumula-tive total (%) |
|---|---|---|---|---|---|---|---|
| 3.B.1.b | Forest land - Land Converted to Forest land | $CO_2$ | -15339.9 | -29490.8 | **0.039** | 14.6 | 14.6 |
| 1.A.1,a | Energy Industries - Solid Fuels - Main activity electricity and heat production | $CO_2$ | 185027.4 | 242154.0 | **0.038** | 14.1 | 28.6 |
| 1.A.4.b | Other Sectors - Solid Fuels - Residential | $CO_2$ | 3604.2 | 18461.9 | **0.032** | 11.7 | 40.3 |
| 1.A.2 | Manufacturing Industries and Construction - Solid Fuels | $CO_2$ | 29101.6 | 24472.7 | **0.025** | 9.1 | 49.5 |
| 1.A.1.c | Energy Industries - Liquid Fuels - Manufacture of solid fuels and other energy industries | $CO_2$ | 30454.7 | 29903.3 | **0.016** | 6.0 | 55.4 |
| 4.A | Solid Waste Disposal | $CH_4$ | 9367.6 | 18412.0 | **0.016** | 5.8 | 61.3 |
| 3.A.1.a | Enteric Fermentation - Cattle | $CH_4$ | 22819.4 | 21236.5 | **0.015** | 5.4 | 66.7 |
| 2.C.1 | Metal industry - Iron and Steel Production | $CO_2$ | 16410.5 | 15020.7 | **0.011** | 4.1 | 70.8 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - Urine and dung N deposits in PRP | $N_2O$ | 13180.8 | 11815.0 | **0.009** | 3.5 | 74.3 |
| 1.A.4.a | Other Sectors - Liquid Fuels - Commercial/Institutional | $CO_2$ | 7690.4 | 12685.4 | **0.007** | 2.8 | 77.1 |
| 1.A.3.b | Transport - Liquid Fuels - Road Transportation | $CO_2$ | 32623.3 | 42929.6 | **0.007** | 2.7 | 79.8 |
| 2.C.2 | Metal industry - Ferroalloys Production | $CO_2$ | 8079.1 | 11623.8 | **0.004** | 1.5 | 81.3 |
| 3.B.3.b | Grassland - Land Converted to Grassland | $CO_2$ | 7904.1 | 7871.8 | **0.004** | 1.5 | 82.7 |
| 2.F.1 | Product uses as substitutes for ODS - Refrigeration and Air Conditioning | HFCs | 0.0 | 1396.1 | **0.003** | 1.2 | 83.9 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1.A.4.b | Other Sectors - Liquid Fuels – Residential | $CO_2$ | 2868.9 | 2154.6 | **0.003** | 1.1 | 85.0 |
| 3.A.1.c | Enteric Fermentation - Sheep | $CH_4$ | 4169.0 | 3783.5 | **0.003** | 1.1 | 86.1 |
| 3.B.2.b | Cropland - Land Converted to Cropland | $CO_2$ | 5721.7 | 5721.0 | **0.003** | 1.0 | 87.1 |
| 1.A.4.a | Other Sectors - Solid Fuels - Commercial/Institutional | $CO_2$ | 1811.2 | 3434.8 | **0.003** | 1.0 | 88.1 |
| 1.A.1.b | Energy Industries - Liquid Fuels - Petroleum refining | $CO_2$ | 3164.8 | 2802.4 | **0.002** | 0.9 | 89.0 |
| 1.A.3.a | Transport - Liquid Fuels - Civil Aviation | $CO_2$ | 2040.0 | 3466.4 | **0.002** | 0.8 | 89.8 |
| 3.B.2.a | Cropland - Cropland Remaining Cropland | $CO_2$ | -1241.6 | -104.9 | **0.002** | 0.7 | 90.6 |
| 2.C.3 | Metal industry - Aluminium production | PFCs | 982.2 | 1979.2 | **0.002** | 0.7 | 91.2 |
| 2.B | Chemical industry - Industry F | $N_2O$ | NS[a] | NS[a] | **0.002** | 0.6 | 91.8 |
| 1.A.4.c | Other Sectors - Liquid Fuels - Agriculture/Forestry/Fishing/Fish farms | $CO_2$ | 2207.2 | 3420.3 | **0.002** | 0.6 | 92.4 |
| 3.C.5 | Indirect $N_2O$ Emissions from managed soils - N leaching/runoff | $N_2O$ | 2479.0 | 2330.0 | **0.002** | 0.6 | 93.0 |
| 1.A.2 | Manufacturing Industries and Construction - Liquid Fuels | $CO_2$ | 1186.1 | 2114.0 | **0.002** | 0.6 | 93.6 |
| 3.C.5 | Indirect $N_2O$ Emissions from managed soils - N volatilization | $N_2O$ | 1939.5 | 1791.7 | **0.001** | 0.5 | 94.0 |
| 2.B.6 | Chemical industry - Industry K | $CO_2$ | NS[a] | NS[a] | **0.001** | 0.3 | 94.4 |
| 2.B.1 | Chemical industry - Industry X | $CO_2$ | NS[a] | NS[a] | **0.001** | 0.3 | 94.7 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - Inorganic N application | $N^2O$ | 1934.7 | 2000.1 | **0.001** | 0.3 | 95.0 |
| 3.A.1.d | Enteric Fermentation - Goats | $CH_4$ | 993.6 | 855.6 | **0.001** | 0.3 | 95.3 |

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

## 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 the transparency, consistency, comparability, completeness, and accuracy of the national GHG 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

The quality controls applied in this GHG inventory involved generic quality checks related to the calculations, data processing, and completeness and documents applicable to the inventory. The QC procedures applied in this inventory are summarised in **Table 1.13**.

Table 1.13: QC activity and procedures applied in this inventory

| QC Activity | Procedures |
|---|---|
| Activity data QC | • Check the temporal consistency of the activity data; and<br>• Check the consistency of the units. |
| EF data QC | • IPCC default EF:<br>o Check default EF applicability;<br>o Check temporal consistency; and<br>o Check the consistency of the units.<br>• Country specific EF:<br>o Check data sources for CS EF;<br>o Check whether QC procedures were conducted on the CS EF;<br>o Check QC of models;<br>o Compare CS EF to IPCC default EF; and<br>o Compare CS EF to other country EF |
| General data QC | • Check the data calculations:<br>o Reproduce a set of emission/removal calculations; and<br>o Check calculations with an approximation method.<br>• Check any recalculation data;<br>• Check the emission and removal data are correctly aggregated from lower reporting levels;<br>• Check that the data is compared to previous estimates;<br>• Check for consistency in the trend; and<br>• Check for completeness of each subcategory |
| Uncertainty QC | • Check that expert judgement is recorded; and<br>• Check uncertainty calculations |

| QC Activity | Procedures |
|---|---|
| Database QC | • Check that the data is in the database;<br>• Check for transcription errors;<br>• Check uncertainty is in the database;<br>• Check for transcription errors in uncertainty data;<br>• Check the correct units have been used in the database;<br>• Check the labels in the database are correct;<br>• Check for common data consistency between sectors and categories;<br>• Check the correct conversion factors are used;<br>• Check data aggregations are correct; and<br>• Check the uncertainty aggregations are correct. |
| Metadata QC | • Check all data details are documented;<br>• Check all uncertainty details are documented;<br>• Check all recalculation details are recorded;<br>• Check all supporting data and documents are attached; and<br>• Check details regarding experts are documented. |
| Report QC | • Check that the relevant activity data details are incorporated into the report;<br>• Check that the relevant EF data details are incorporated into the report;<br>• Check for data transcription errors between the database and the report;<br>• Check the references are properly cited;<br>• Check that expert judgements are reported;<br>• Check that uncertainty data in incorporated into the report;<br>• Check that completeness is documented;<br>• Check that comparisons have been made with previous estimates;<br>• Check that explanations are provided for any data differences; and<br>• Check that the QC/QA procedures have been documented. |

### 1.4.2 Quality assurance (QA)

The QA process was done by external reviewers who have a different technical perspective and who were not involved in the compilation process of the inventory, so they could conduct an unbiased review of the inventory. The external reviewers ensured that the inventory's results, assumptions and methods were reasonable. Furthermore, a public review process was undertaken to supplement the external review. The independent review process is demonstrated in **Figure 1.3**.

Essentially, the draft GHG inventory report was published for public comment in a Government Gazette. Parallel to the publication for public comment, an independent technical review of activity data, emission factors and methodologies used was undertaken by an 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, the DEA is preparing a revised three-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 the previous review undertaken for the 2000 – 2010 GHG 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 GHG 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 GHG 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.

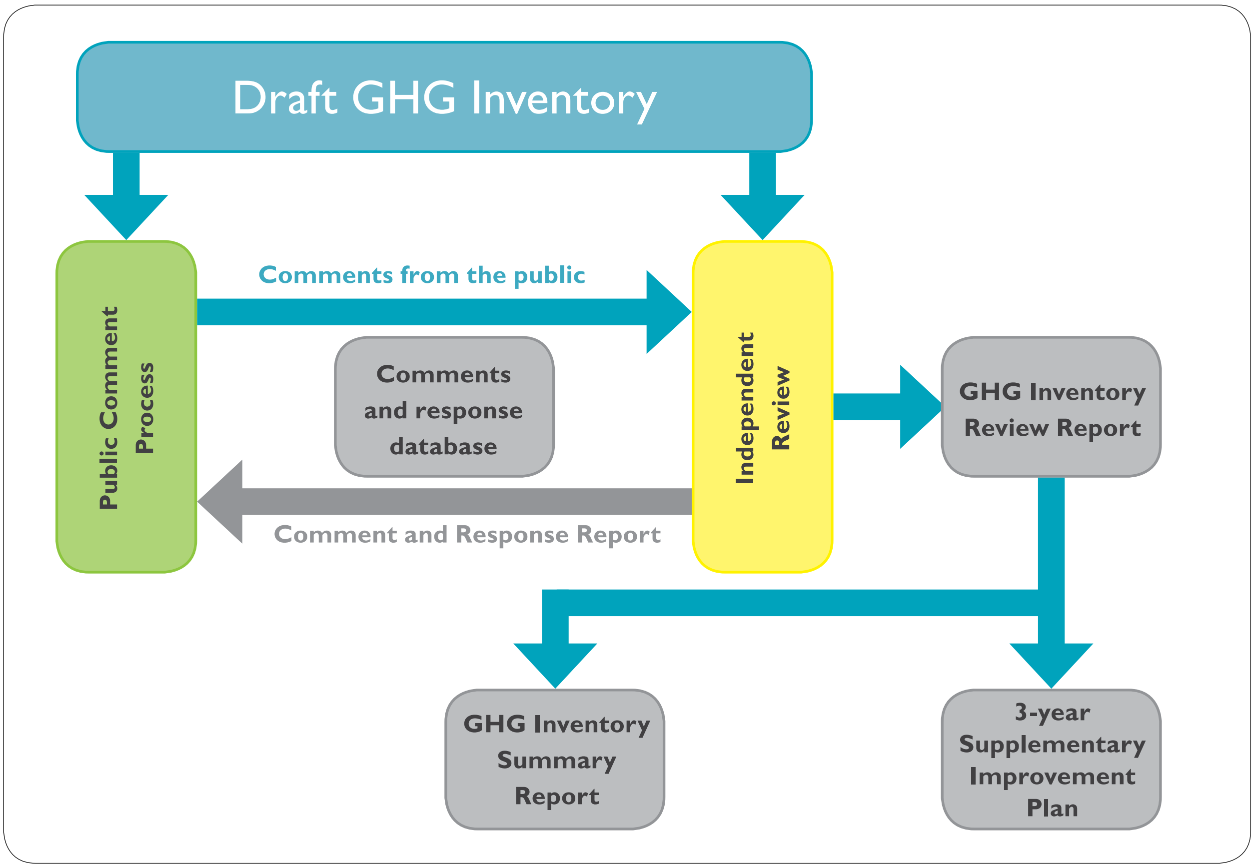



Figure 1.3: The independent review process for the 2000 – 2012 inventory.

## 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. 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.

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.

For this inventory an Approach 1 uncertainty analysis (assuming no correlation between the activity data) was applied to the energy and the IPPU sectors and the IPCC uncertainty tables were used. There were insufficient data to include AFOLU and waste sector uncertainties, however these will be included in the next inventory. The energy sector was determined to have an overall uncertainty of 6.5%, while the uncertainty introduced into the trend was 6.3%. The IPPU sector, on the other hand, had an uncertainty of 30.6%. These uncertainties are elevated due to the incorporation of sub-section 2F (product uses as substitutes for ozone-depleting substances) which has no emission estimates for the years 2000 to 2004 and then quite high emissions estimated in the years between 2005 and 2012. If this category is excluded from the uncertainty analysis then the total uncertainty drops to 8.8%, and the trend uncertainty is reduced to 4.74%. The detailed analyses are provided in **Appendix C**.

## 1.6 General assessment of completeness

The South African GHG emission inventory for the period 2000 – 2012 is not complete, mainly due to the lack of sufficient data. **Table 1.14** identifies the sources in the 2006 IPCC Guidelines which were not included in this inventory and the reason for their omissions is discussed further in the appropriate chapters.

Table 1.14: Activities in the 2012 inventory which are not estimated (NE), included elsewhere (IE) or not occurring (NO).

| NE, IE or NO | Activity | Comments |
|---|---|---|
| NE | $CO_2$ and $CH_4$ fugitive emissions from oil and natural gas operations | Emissions from this source category will be included in the next inventory submission covering the period 2000-2014 |
| | $CO_2$, $CH_4$ and $N_2O$ from spontaneous combustion of coal seams | New research work on sources of emissions from this category will be used to report emissions in the next inventory submission |
| | $CH_4$ emissions from abandoned mines | New research work on sources of emissions from this category will be used to report emissions in the next inventory submission |
| | Other process use of carbonates | |
| | Electronics industry | A study was to be undertaken in 2015 to understand emissions from this source category |
| | Indirect $N_2O$ emission due to nitrogen deposition | |
| | HWP from solid waste | This will be included in the next inventory |
| | $CO_2$, $CH_4$ and $N_2O$ emissions from Combined Heat and Power (CHP) combustion systems | |
| | $CH_4$, $N_2O$ emissions from biological treatment of waste | |
| | $CO_2$, $CH_4$ and $N_2O$ emissions from incineration and open burning of waste | |
| IE | $CO_2$, $CH_4$ and $N_2O$ emissions from water-borne navigation | Fuel consumption for this source category is included elsewhere. Accurate quantification of fuel consumption attributed to waterborne navigation was to be undertaken in 2015 and a progress report will be included in the next inventory submission |
| | $CO_2$, $CH_4$ and $N_2O$ emissions from off-road vehicles and other machinery | |
| | Ozone Depleting Substance replacements for fire protection and aerosols | |

| NE, IE or NO | Activity | Comments |
|---|---|---|
| NO | Other product manufacture and use | |
| | Rice cultivation | |
| | $CO_2$, $CH_4$ and $N_2O$ emissions from Soda Ash Production | |
| | $CO_2$ from Carbon Capture and Storage | |
| | $CO_2$, $CH_4$ and $N_2O$ emissions from Adipic acid production | |
| | $CO_2$, CH4 and $N_2O$ Caprolactam, Glyoxal and Glyoxylic acid production | |
| | Precursor emissions have only been estimated for biomass burning, and only for CO and NOx | |

# 2. TRENDS IN GHG EMISSIONS

## 2.1 Trends for aggregated GHG emissions

This chapter summarizes the trends in GHG emissions during the period 2000 to 2012, 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 2012 is provided in **Appendix A**.

In 2012 the total GHG emissions (excl. FOLU) in South Africa were estimated at 539 112 Gg $CO_2$eq, a slow increase of 21.7% since 2000 (443 133 Gg $CO_2$eq). The 2000 emissions were also 55.2% higher than the 1990 estimate of 347 346 Gg $CO_2$eq, 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) is 1.4% lower than the estimate from the previous 2010 inventory (Department of Environmental Affairs, 2015), which was 449 498 Gg $CO_2$eq (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 23.9% and 15.1% increase in $CO_2$ and $CH_4$ (in $CO_2$eq), respectively, between 2000 and 2012, and a decline of 5.6% in $N_2O$ emissions over that period. Fluorinated gases (F-gases) increased from 982 Gg $CO_2$eq in 2000 to 3 375 Gg $CO_2$eq in 2012, and their contribution to the total GHG emissions increased from 0.2% to 0.6% over the 12 years.

The land and HWP sub-sectors show annual variation, but are 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 434 304 Gg $CO_2$eq for 2000, which increased by 19.3% to 518 297 Gg $CO_2$eq in 2012 (**Figure 2.2**). The recalculated total GHG emission estimates for 2000 including the FOLU sector are 2.1% higher than the value reported in the National GHG Inventory for 2010 (Department of Environmental Affairs, 2014). This is due to the incorporation of more detailed land maps, improved soil carbon analysis, improved HWP data and the inclusion of other lands. Including FOLU in the total emissions leads to a slight increase in the $CO_2$ contribution from an average of 84.4% to 83.7% over the 12 years. The contributions from $CH_4$ and $N_2O$ increased by 0.5% and 0.2%, respectively; while the average contribution from F-gases remained the same (**Figure 2.2**).

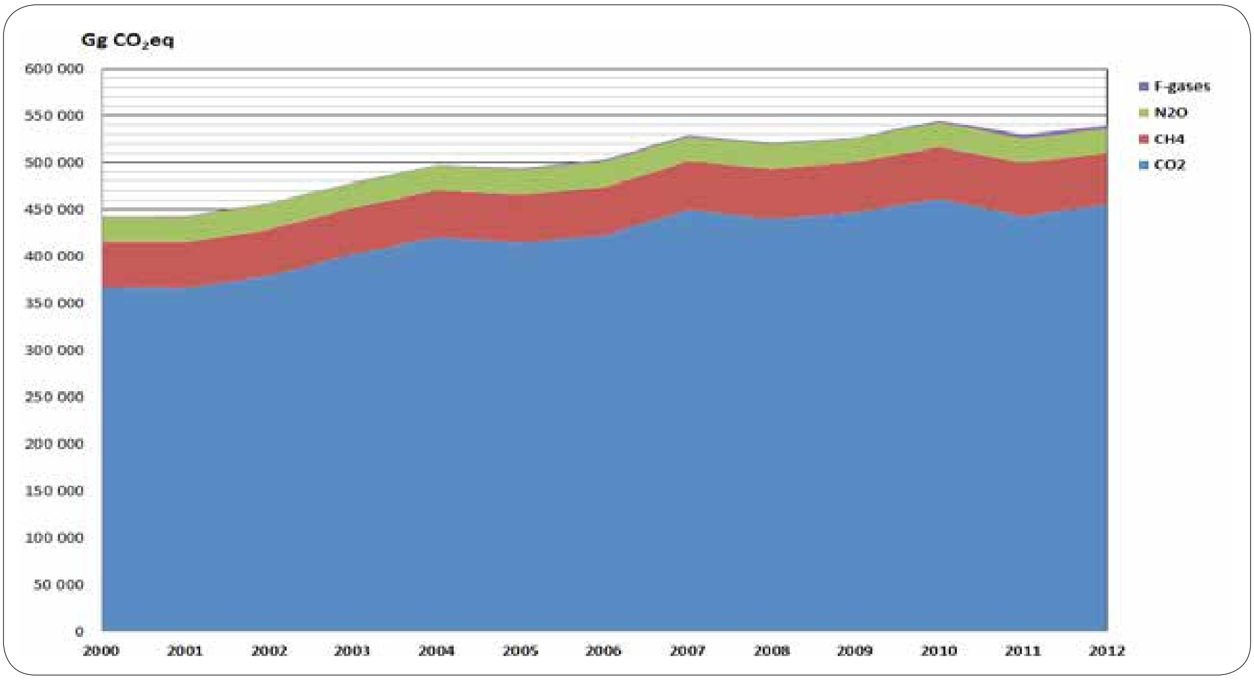



Figure 2.1: Greenhouse gases: Trend and emission levels (excl. FOLU), 2000 – 2012.

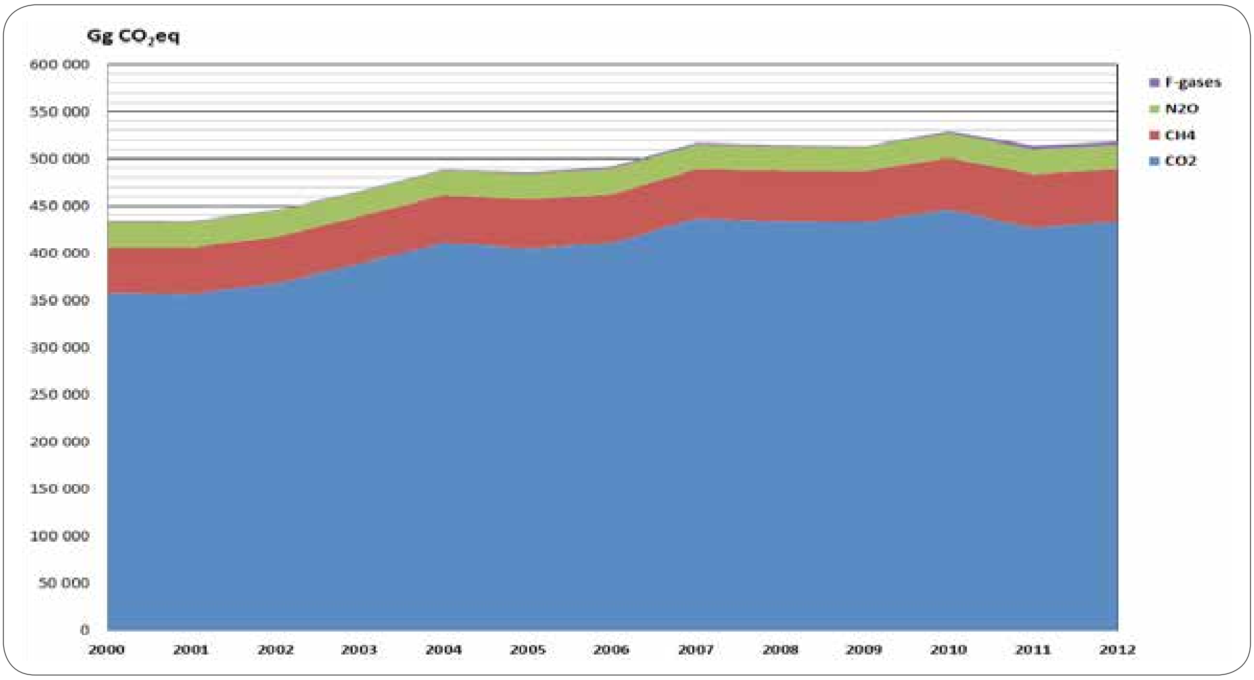



Figure 2.2: Greenhouse gases: Trend and emission levels (including FOLU sub-sectors), 2000 – 2012.

## 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 energy sector is by far the largest contributor to $CO_2$ emissions in South Africa, contributing an average of 91.9% between 2000 and 2012, and 92.5% in 2012. The categories *1A1 energy industries* (61.1 %), *1A3 transport* (10.3 %) and *1A4 other sectors* (8.8 %) were the major contributors to $CO_2$ emissions in 2012. The IPPU sector contribution declined from 8.4% in 2000 to 7.2% in 2012. The AFOLU sector (excl. FOLU) contributed an average of 0.2% towards the $CO_2$ emission budget over the 12 years.

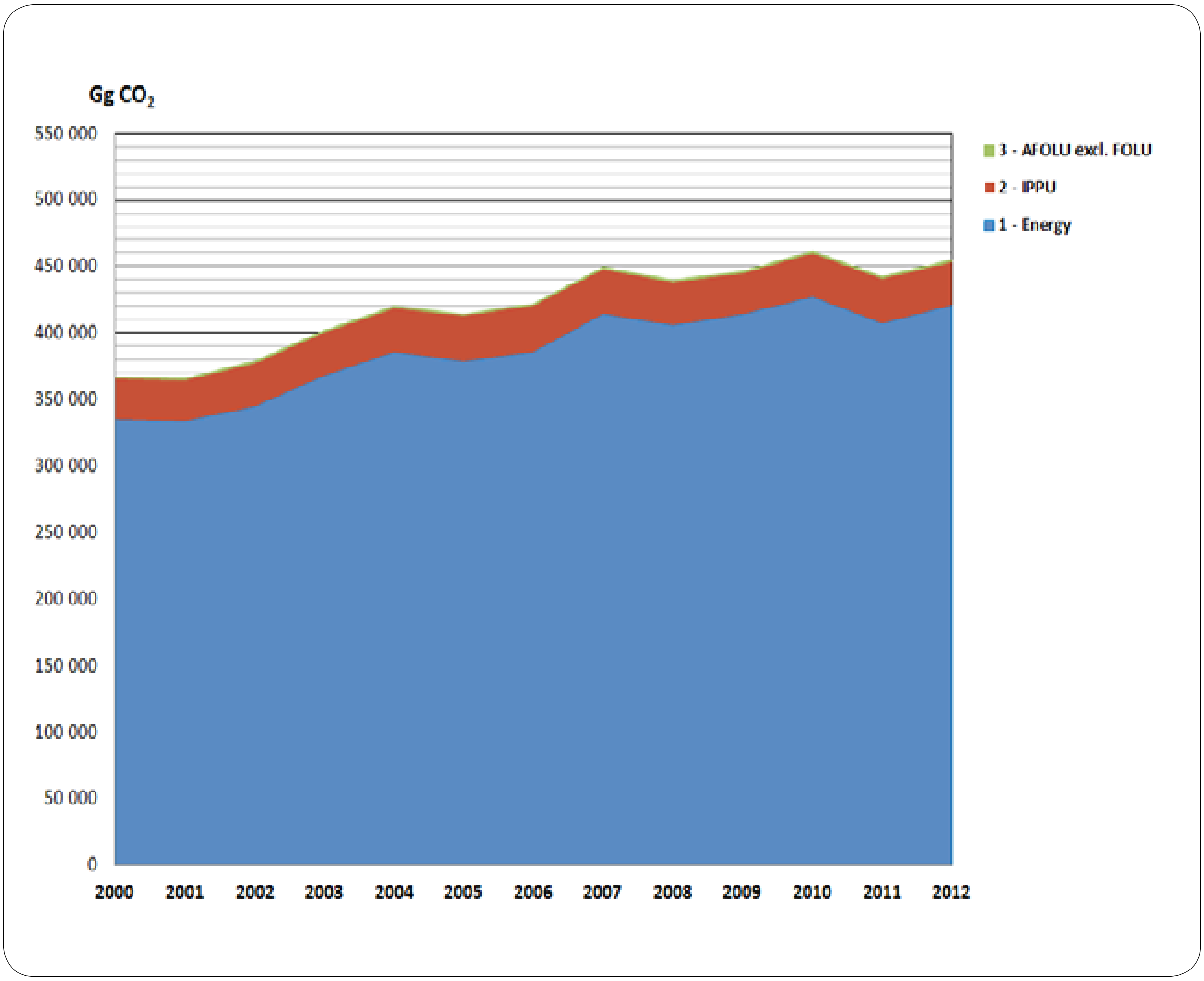



Figure 2.3: $CO_2$: Trend and emission levels of sectors (excl. FOLU), 2000 – 2012.

### 2.2.2 Methane

The sector contributions to the total $CH_4$ emissions (excl. FOLU) in South Africa are shown in **Figure 2.4**. National $CH_4$ emissions increased from 47 937 Gg $CO_2$eq (2 084 Gg $CH_4$) in 2000 to 55 168 Gg CO2eq (2 399 Gg $CH_4$) in 2012 (a 15.1% increase). The AFOLU livestock category and waste sectors were the major contributors, providing 50.5% and 38.3%, respectively, to the total $CH_4$ emissions in 2012. The contribution from livestock declined by 11.7%, while the contribution from the waste sector increased by a similar amount (14.1 %) over the period 2000 to 2012.

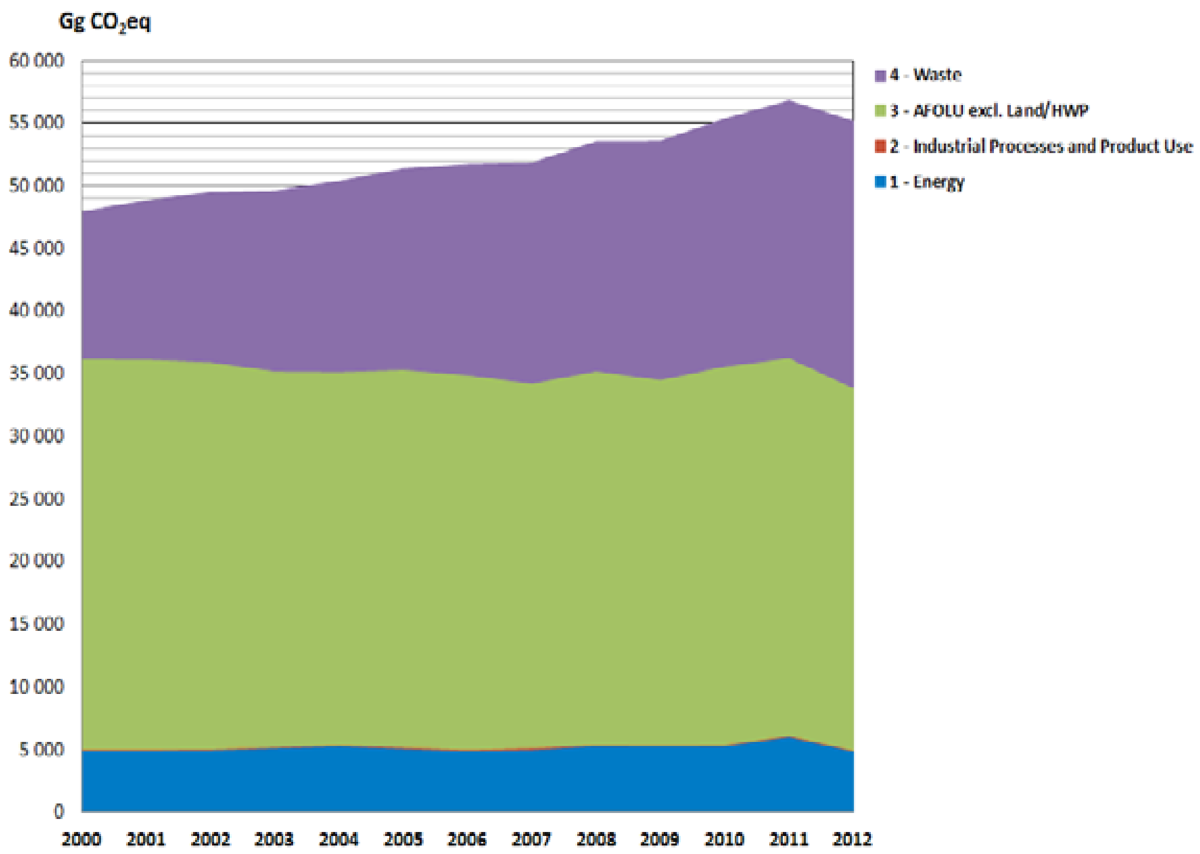



Figure 2.4: $CH_4$: Trend and emission levels of sectors (excl. FOLU), 2000 – 2012

### 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 declined by 5.5% over the 2000 to 2012 period from 27 162 Gg $CO_2$eq (88.4 Gg $N_2O$) to 25 645 Gg $CO_2$eq (86.6 Gg $N_2O$). The category *3C aggregated and non-$CO_2$ sources on land* (which includes emissions from managed soils and biomass burning) contributed an average of 80.5% to the total $N_2O$ emissions over the period 2000 to 2012, while the energy sector and livestock subsector (which includes manure management) contributed an average of 8.4% and 4.4%, respectively.

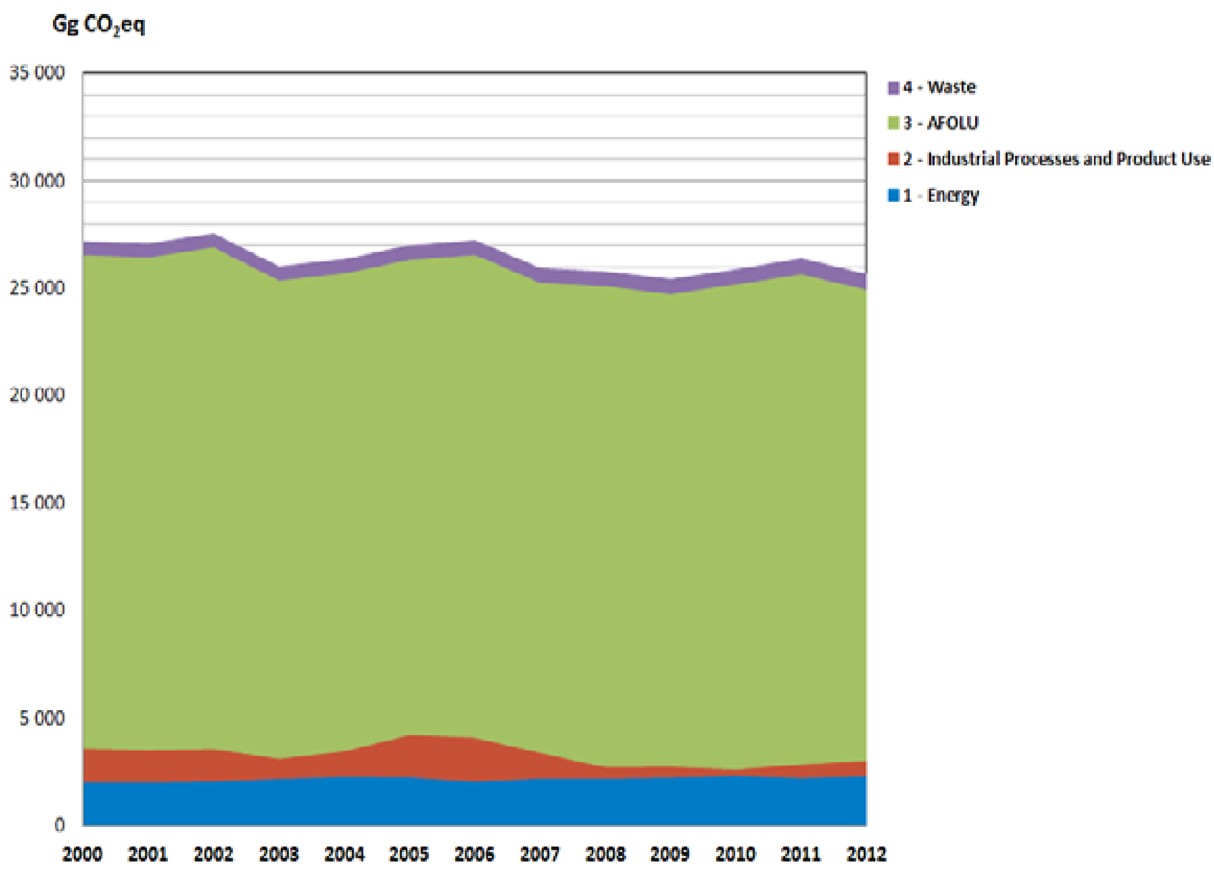



Figure 2.5: $N_2O$: Trend and emission levels of sectors, 2000 – 2012.

### 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 888 Gg $CO_2$eq and 4 160 Gg $CO_2$eq (**Figure 2.6**). HFC emissions in 2005 were estimated at 842 Gg $CO_2$eq and these increased to 2 096 Gg $CO_2$eq in 2010 and to 1 396 Gg $CO_2$eq in 2012. There is no data prior to 2005. PFC emissions were estimated at 982 Gg $CO_2$eq in 2000. This increased to 970 Gg $CO_2$eq in 2007, then declined to 108 Gg $CO_2$eq in 2009 and increased again to 1 979 Gg $CO_2$eq in 2012. There is a sharp decline in emissions from the metal industry between 2006 and 2009 and this is attributed to reduced production caused by electricity supply challenges and decreased demand following the economic crisis that occurred during 2008/2009. Increases in 2011 and 2012 were due to increased emissions from aluminium plants due to inefficient operations. The industry was used to control the electricity grid and had to switch on and off at short notice leading to large emissions of $C_2F_4$ and $CF_4$.

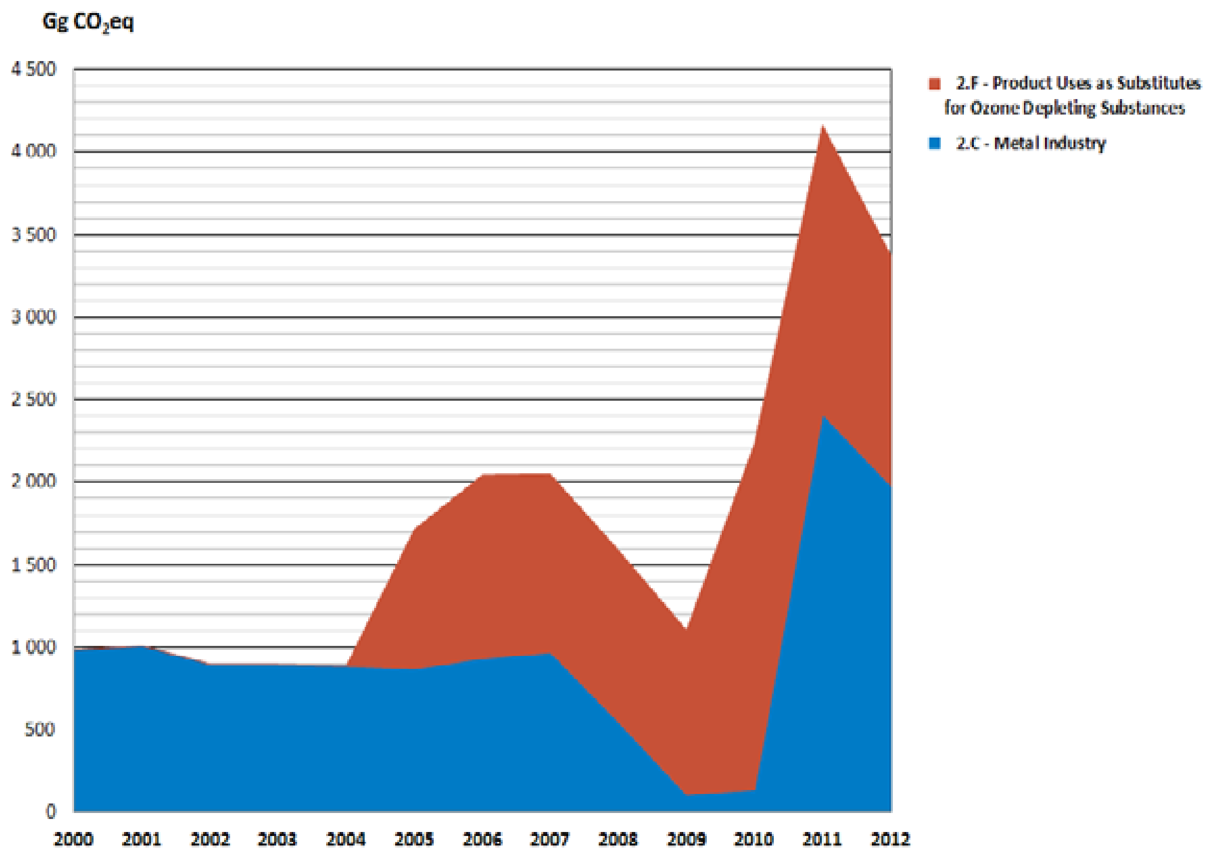



Figure 2.6: F-Gases: Trend and emission levels of sectors, 2000 – 2012.

## 2.3 Emission trends specified by source category

**Figure 2.7** provides an overview of emission trends per IPCC sector in Gg $CO_2$eq (excl. FOLU). The energy sector is the largest contributor to the total GHG emissions, providing 77.3% in 2000 and 79.4% in 2012. The AFOLU sector (excl. FOLU) and the IPPU sector contributed 9.6% and 6.9%, respectively, to the total GHG emissions in 2012. Their contributions decreased by 2.6% and 0.7%, respectively since 2000. The percentage contribution from the waste sector increased from 2.7% to 4.1% over the 12-year period. Including the full AFOLU sector reduces the total GHG emissions to 518 297 Gg $CO_2$eq (**Table 2.1**). The contribution from the AFOLU sector (incl. FOLU) declined from 10.5% in 2000 to 6.0% in 2012. Trends in emissions by sub-categories in each sector are described in more detail in **Chapters 3** to **6**.

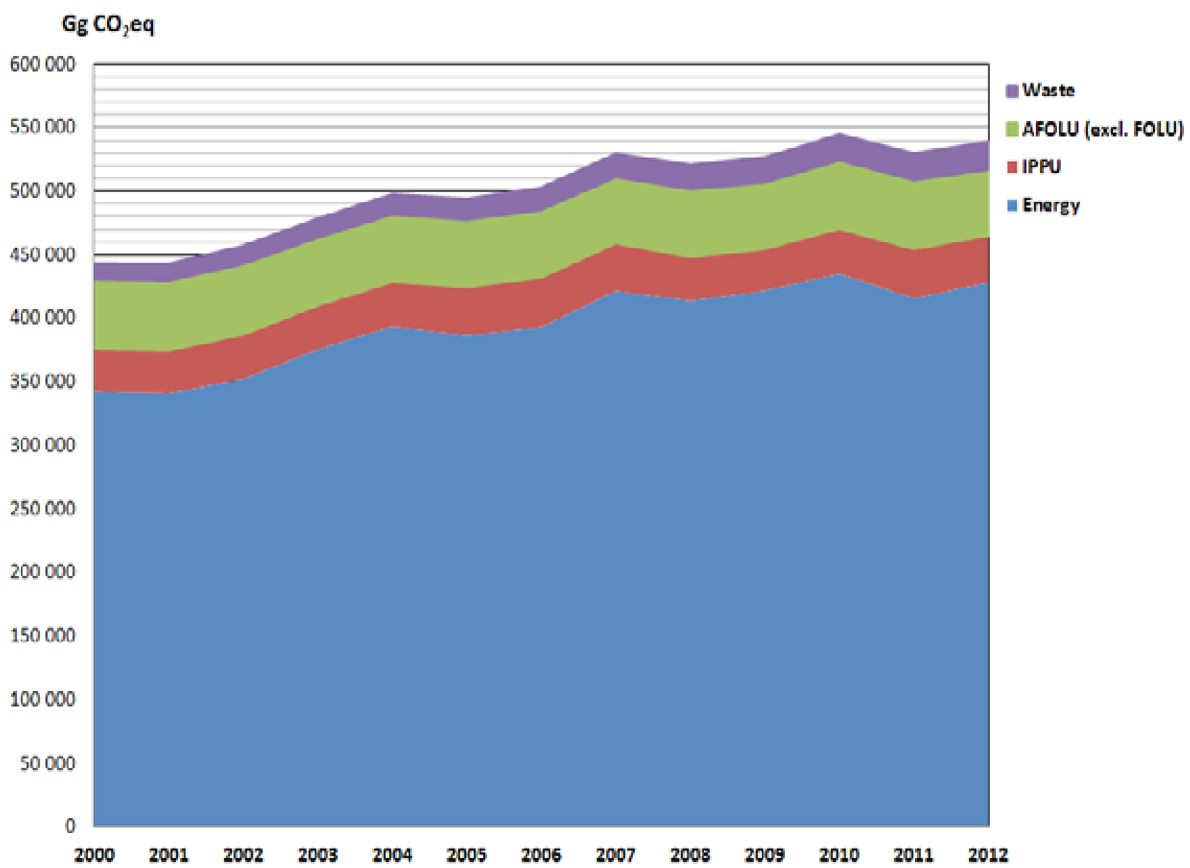



Figure 2.7: Total GHG: Trend and levels from sectors (excl. FOLU), 2000 – 2012.

Table 2.1: Trends and levels in GHG emissions for South Africa between 2000 and 2012.

| | Energy | IPPU | AFOLU (excl. FOLU) | AFOLU (incl. FOLU) | Waste | Total (excl. FOLU) | Total (incl. FOLU) |
|---|---|---|---|---|---|---|---|
| | (Gg $CO_2$ eq) | | | | | | |
| 2000 | 342 592 | 33 564 | 54 689 | 45 860 | 12 288 | 443 133 | 434 304 |
| 2001 | 341 338 | 33 737 | 54 686 | 45 813 | 13 205 | 442 966 | 434 093 |
| 2002 | 352 216 | 35 271 | 55 378 | 43 971 | 14 088 | 456 953 | 445 545 |
| 2003 | 375 718 | 34 759 | 53 145 | 42 342 | 14 947 | 478 546 | 467 765 |
| 2004 | 393 607 | 35 290 | 53 019 | 44 066 | 15 780 | 497 630 | 488 744 |
| 2005 | 386 587 | 38 262 | 52 830 | 44 047 | 16 591 | 494 270 | 485 487 |
| 2006 | 393 076 | 39 298 | 53 141 | 41 952 | 17 381 | 502 897 | 491 708 |
| 2007 | 421 753 | 37 505 | 53 141 | 39 758 | 18 152 | 529 335 | 517 168 |
| 2008 | 413 698 | 34 935 | 53 297 | 47 225 | 18 905 | 520 633 | 514 763 |
| 2009 | 421 834 | 33 026 | 52 150 | 39 011 | 19 639 | 526 649 | 513 509 |
| 2010 | 435 117 | 35 463 | 53 823 | 38 456 | 20 354 | 544 758 | 529 391 |
| 2011 | 415 843 | 38 888 | 54 087 | 38 376 | 21 151 | 529 969 | 514 257 |
| 2012 | 428 112 | 37 129 | 51 943 | 31 128 | 21 929 | 539 112 | 518 297 |
| *Change 2000 - 2012 (%)* | 24.9 | 10.6 | -5.0 | -32.1 | 78.5 | 21.7 | 19.3 |

## 2.4 Emission trends for indirect GHG

The trend in total emissions of carbon monoxide (CO) and nitrogen oxides (NOx) is shown in **Table 2.2**. These emissions are recorded only for biomass burning. An average of 1 458 Gg CO and 70 Gg NOx is estimated to have been produced from biomass burning over the period 2000 to 2012. The highest values were recorded in 2005.

Table 2.2: Precursor GHG: Trend and emission levels in CO and NOx (Gg of gas) from biomass burning, 2000 – 2012.

| Gas | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CO | 1 256 | 1 449 | 1 463 | 1 082 | 1 027 | 1 604 | 1 435 | 1 251 | 1 340 | 1 246 | 1 524 | 1 412 | 1 402 |
| NOx | 62 | 73 | 73 | 53 | 51 | 79 | 69 | 60 | 65 | 60 | 74 | 68 | 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 (DoE). The DoE is responsible for the management, processing, exploration, utilisation and development of South Africa's energy resources.

The DoE'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 the form of crude oil. Renewable energy comprises biomass and natural processes that can be used as energy sources. Biomass is used commercially in industry to produce process heat and in households for cooking and heating.

The 2004 White Paper on Renewable Energy indicated that the target for renewable energy should be 10 000 GWh by 2013. The DoE recently developed a biofuel strategy to contribute towards the production of renewable energy and to minimize South Africa's reliance on imported crude oil.

### 3.1.1 Energy demand

In terms of energy demand, South Africa is divided into six sectors: industry, agriculture, commerce, residential, transport and other. 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 Africa is dominated by coal (65.7%), followed by crude oil (21.6%), renewable and waste (7.6%) and natural gas (2.8%) (Department of Energy, 2010) (**Figure 3.1**).

#### *3.1.2.1 Coal*

Coal provides for about 65% of South Africa's primary energy needs (Department of Energy, 2016). South African coal is nearly all bituminous, with very little anthracite. It is generally of low quality with a high ash

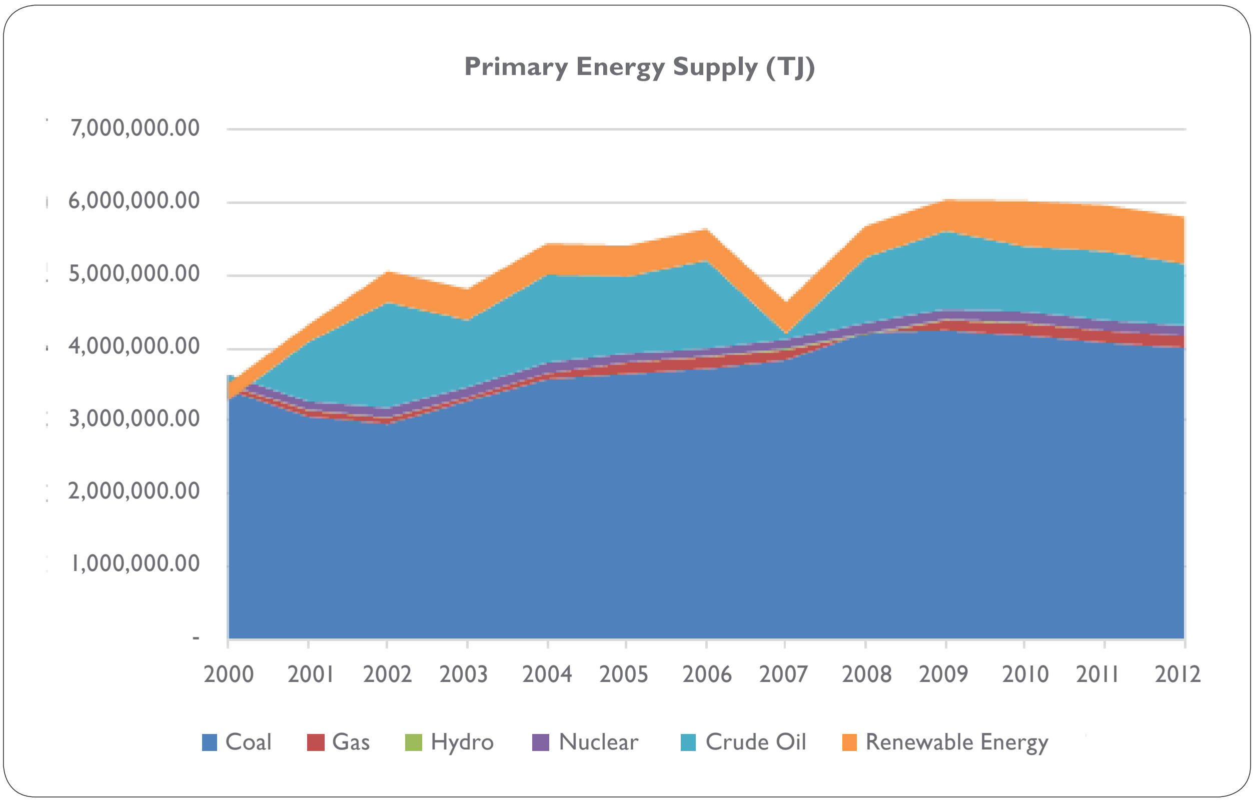



Figure 3.1: Sector 1 Energy: Trend in primary energy consumption in South Africa, 2000 – 2012.

content. The contribution of coal to the total primary energy supply decreased by 8% between 2000 and 2006, however this 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 30 156 Mt, representing 3.5% of total global reserves (SAMI, 2013). In 2012 the coal sector remained the largest revenue earner in the country. Local coal sales volume increased by 4.4 percent from 177.9 Mt in 2011 to 185.7 Mt in 2012 (**Table 34**). Electricity consumed 120.4 Mt (64.8 percent) of local sales, followed by the synthetic fuels sector 40.9 Mt (22 percent), industries 8.7 Mt (4.7 percent) and merchants and domestic 8 Mt or 4.3 percent) (SAMI, 2013).

#### *3.1.2.2 Nuclear*

Nuclear power contributes a small amount (1.9%) to South Africa's energy supply (Department of Energy, 2010). The Koeberg Nuclear Power Station, which is the only nuclear power station in Africa, has two 900 MW units supplying 1 800 MW to the national grid. It therefore provides a significant amount of South Africa's electricity (GCSI, 2009). The National Nuclear Regulator, as the main safety regulator responsible for protecting persons, property and the environment against nuclear damage, provides safety standards and regulations. Low- and intermediate-level waste from Koeberg is transported by road in steel and concrete containers to a remote disposal site at Vaalputs, 600 km away in the Kalahari

Desert. High-level waste, the spent fuel, is stored on-site in special pools equipped with high-density racking (Eskom, 2012). The total consumption of nuclear energy decreased by 1.4% for the period 2000 to 2009.

#### *3.1.2.3 Renewable Energy*

Renewable energy sources, other than biomass (the energy from plants and plant-derived materials), have not yet been exploited optimally in South Africa. Renewable energy and waste contribute a total of 7.6% to the energy supply (Department of Energy, 2010). Wind as an energy source contributes more than 4 GWh annually. Hydro and geothermal solar contribute a total of 0.2% and 0.1%, respectively, to the primary energy supply. Their contribution 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 with the same period in 2007, while the demand for diesel increased by 3.0% as industries scaled down operations because of the global economic recession (GCSI, 2009). The petrol price in South Africa is linked to international petrol markets in which use the United States dollar. This means the supply and demand of petroleum products on the international markets, combined with the rand-dollar exchange rate influence the domestic price.

#### *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 its crude oil requirements. Crude oil consumption increased from 17% in 2000 to 29% in 2002, but then declined 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 (in oil refineries), converting coal to liquid fuels and gas to liquid fuels, and turning natural gas into liquid fuels. Industry is the largest customer of refined petroleum products.

#### *3.1.2.6 Electricity*

South Africa's largest power producer, Eskom, generates 95% of the electricity in South Africa and about 45% of Africa's electricity (GCSI, 2009). Eskom generates, transmits and distributes electricity to industrial, mining, commercial, agricultural and residential customers and redistributors. Approximately 88% of South Africa's electricity is generated from coal-fired power stations, 6.5% from Koeberg Nuclear Power Station, and 2.3% from hydroelectric and other renewables (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 invested R170 billion in the transport system in the five-year period from 2005/06 to 2009/10, with R13.6 billion of the total allocated to improve public transport systems for the 2010 FIFA World Cup.

#### *3.1.3.1 Rail*

State-owned Transnet is a freight transport and logistics company. Transnet owns and operates the largest rail network on the continent. Of the 55 000km of track in sub-Saharan Africa, 40% of the operating network and 70% of the traffic are operated by Transnet. (Transnet Long-Term Planning Framework, 2016). The Gautrain Rapid Rail Link commenced operation in 2010. It has 80 km of routes, linking Sandton to OR Tambo International Airport, Johannesburg to Pretoria, and Rosebank to Johannesburg's Park Station. The aim of the Gautrain was to reduce the 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 which incorporates existing bus and minibus operators.

#### *3.1.3.3 Civil Aviation*

South Africa is home to more than 70% of the 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 25.0% between 2000 and 2012, and produced a total accumulated GHG estimate of 5 121 939 Gg $CO_2$eq over the 12-year period. An analysis of key categories was completed to determine the most significant emission sources in the energy sector. The majority of emissions are from *energy industries* (63.2 %) (**Figure 3.2**), followed by 10.7% from *transport* and 9.1% 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 to 2012 is the *main activity electricity and heat production*, which accounted for 54.6% (2 797 150 Gg $CO_2$eq) of the total accumulated emissions from the Energy sector. The second largest emitting subcategory was *manufacturing industries and construction* which accounted for 467 830 Gg $CO_2$eq over the period 2000 to 2012. The *transport* sector and *fugitive emissions from energy production* accounted for an accumulated amount of 549 896 Gg $CO_2$eq and 374 087 Gg $CO_2$eq (10.7% and 7.3% of the total emissions) respectively, between 2000 and 2012. The *manufacture of solid fuels and other energy industries* accounts for an accumulated 391 561 Gg $CO_2$eq of the total GHG emissions in the energy sector for the period 2000 to 2012. The residential and commercial sectors are both heavily reliant on electricity for meeting energy needs, contributing a total of 211 817 Gg $CO_2$eq and 189 211 Gg $CO_2$eq of emissions, respectively.

The total GHG emissions in the energy sector increased from 342 592 Gg$CO_2$eq in 2000 to 428 112 Gg $CO_2$eq in 2012 (**Figure 3.3**). The majority of emissions were from *main activity electricity and heat production* which accounted for a total of 54.6% of the total GHG emissions from the energy sector in 2012. Total GHG emissions increased between 2001 and 2004, mainly because of economic growth and development, which led to increased demand for electricity and fossil fuels. An expansion of industrial production during that period increased the demand for electricity and fossil fuels. Economic growth also increased the amount people travelled, leading to higher rates of consumption of petroleum fuels. GHG emissions decreased by 1.78% in 2005, which was followed by an increase in emissions until 2007. The largest annual increase (7.3%) was evident in 2007 (**Figure 3.4**). The largest decrease was seen in 2011 (4.4%).

**Table 3. 1** shows the contribution of the source categories in the energy sector to the total national GHG inventory.

In 1990 and 1994 the energy sector produced an estimated 260 886 Gg $CO_2$eq and 297 564 Gg $CO_2$eq, respectively. Between 1990 and 2000 there was an increase of 31.3% in total GHG emissions from the energy sector, and between 2000 and 2010 there was a further 27.0% increase (**Figure 3.5**). A small decline (1.6%) is evident between 2010 and 2012. It should be noted, however, 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.

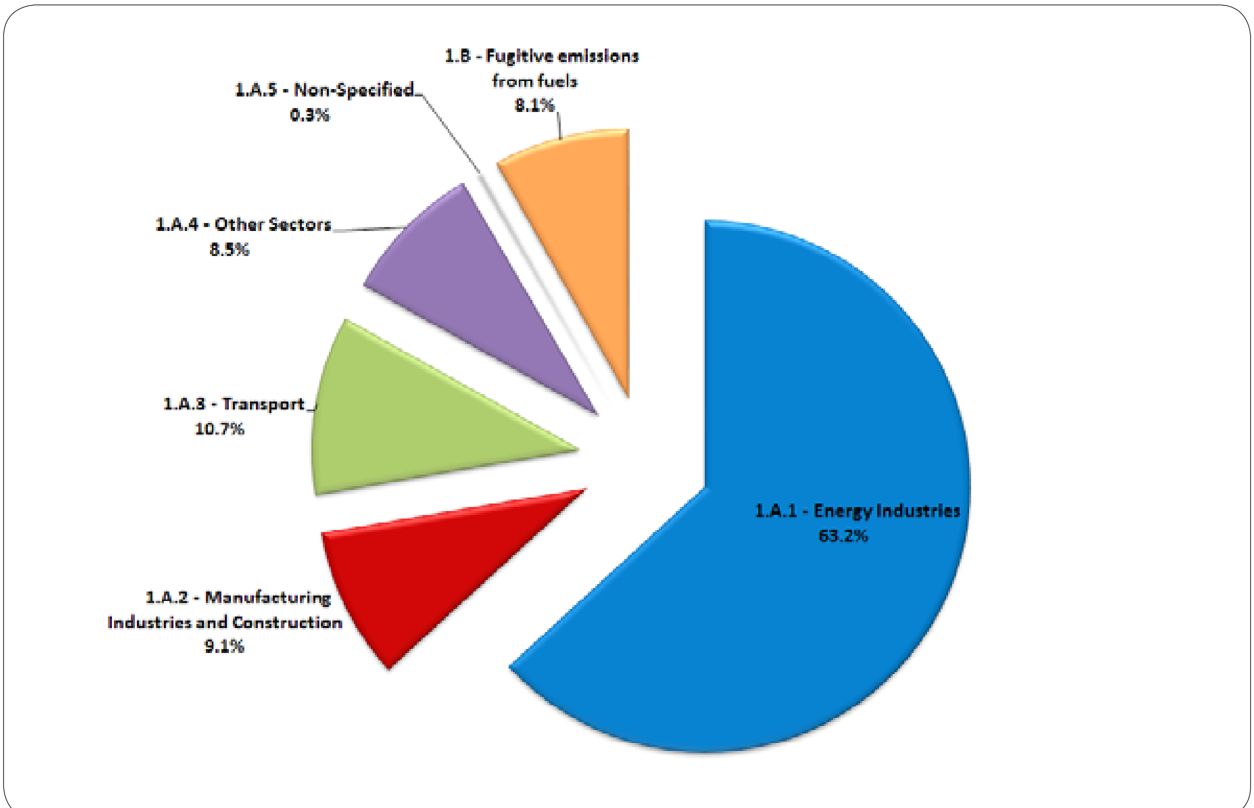



Figure 3.2: Sector 1 Energy: Average contribution of source categories to total energy sector GHG emissions, 2000 and 2012.

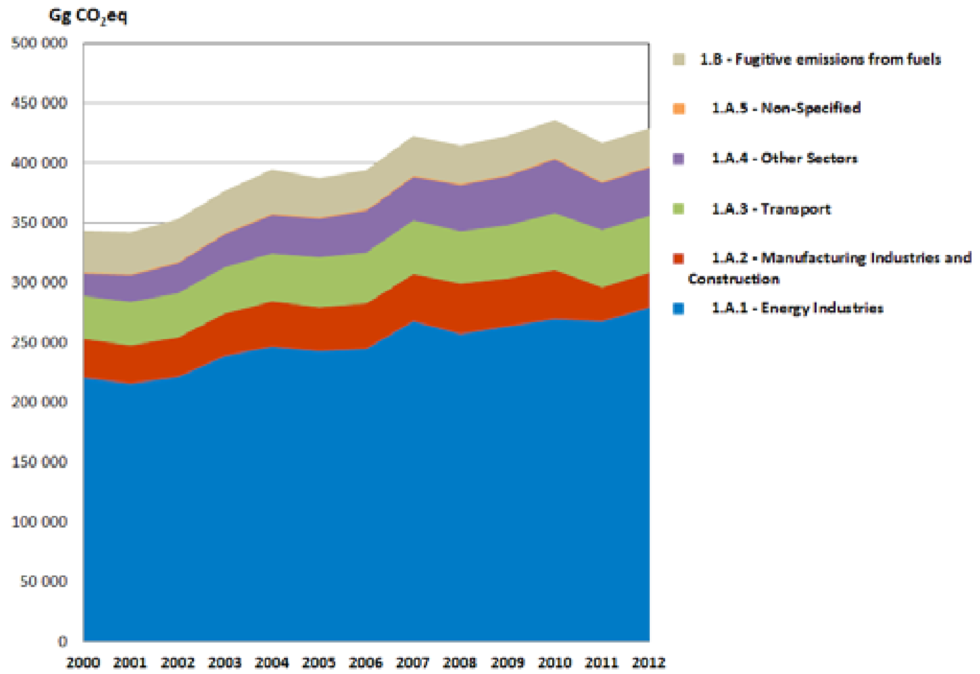



Figure 3.3: Sector 1 Energy: Trend and emission levels of source categories, 2000 – 2012.

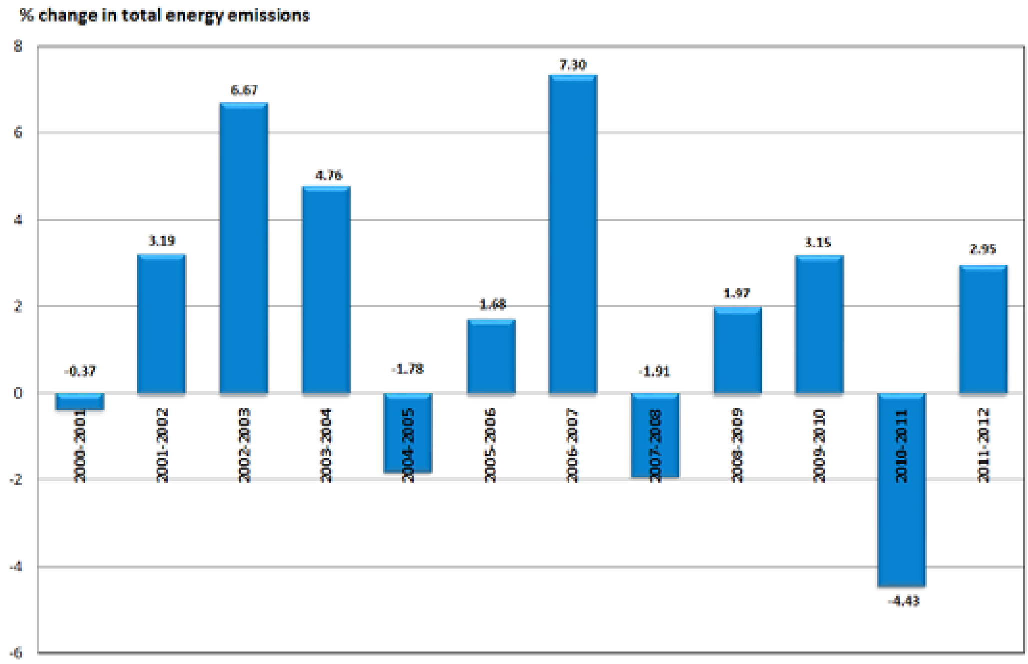



Figure 3.4: Sector 1 Energy: Annual change in total GHG emissions between 2000 and 2012.

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

| Period | Total $CO_2$ (Gg $CO_2$eq) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
| Electricity generation | 185 925 | 180 915 | 187 149 | 203 866 | 211 905 | 209 920 | 212 304 | 233 883 | 223 477 | 229 937 | 236 798 | 235 205 | 245 865 |
| Petroleum refining | 4 049 | 3 905 | 3 390 | 3 885 | 3 569 | 3 418 | 3 675 | 3 767 | 3 874 | 3 803 | 3 551 | 3 341 | 3 384 |
| Manufacture of solid fuels and other energy industries | 30 572 | 31 036 | 30 597 | 31 095 | 31 161 | 29 403 | 28 810 | 30 312 | 29 814 | 29 883 | 29 531 | 29 294 | 30 053 |
| Manufacturing industries and construction | 32 653 | 32 182 | 33 389 | 35 899 | 37 878 | 37 148 | 38 072 | 39 463 | 42 277 | 40 129 | 41 117 | 28 413 | 29 212 |
| Domestic aviation | 2 047 | 2 079 | 2 204 | 2 626 | 2 837 | 3 146 | 3 118 | 3 374 | 3 413 | 3 468 | 3 670 | 3 552 | 3 478 |
| Road transportation | 33 354 | 33 595 | 34 068 | 35 479 | 36 834 | 37 902 | 39 046 | 41 255 | 40 130 | 40 695 | 43 440 | 44 377 | 43 857 |
| Railway | 615 | 604 | 589 | 558 | 582 | 579 | 535 | 552 | 522 | 538 | 496 | 354 | 355 |
| Commercial/ institutional | 9 549 | 11 039 | 12 201 | 13 177 | 16 155 | 15 199 | 16 486 | 15 155 | 15 388 | 15 970 | 17 114 | 15 581 | 16 196 |
| Residential | 7 101 | 9 237 | 11 085 | 12 282 | 13 947 | 14 948 | 16 127 | 18 323 | 20 211 | 22 361 | 24 703 | 20 550 | 20 943 |
| Agriculture/ forestry/ fishing/ fish farms | 2 387 | 2 256 | 2 327 | 2 449 | 2 581 | 2 665 | 2 809 | 3 072 | 3 021 | 3 065 | 3 308 | 3 430 | 3 432 |
| Non specified | 989 | 984 | 983 | 1 015 | 1 045 | 1 062 | 1 073 | 1 100 | 1 053 | 1 076 | 1 139 | 1 138 | 1 114 |
| Fugitive emissions from coal mining | 2 003 | 2 161 | 1 961 | 2 118 | 2 167 | 2 181 | 2 180 | 2 205 | 2 245 | 2 230 | 2 266 | 2 986 | 1 760 |
| Fugitive emissions from natural gas | 752 | 753 | 955 | 1 458 | 1 379 | 1 160 | 1 133 | 1 133 | 1 138 | 1 243 | 964 | 786 | 642 |
| Fugitive emissions - other emissions from energy production | 30 597 | 31 039 | 31 317 | 29 812 | 31 568 | 27 854 | 27 708 | 28 160 | 27 134 | 27 435 | 27 019 | 26 836 | 27 821 |
| **Total GHG emissions (Gg CO2eq)** | **342 592** | **341 785** | **352 216** | **375 718** | **393 607** | **386 587** | **393 076** | **421 753** | **413 698** | **421 834** | **435 117** | **415 843** | **428 112** |

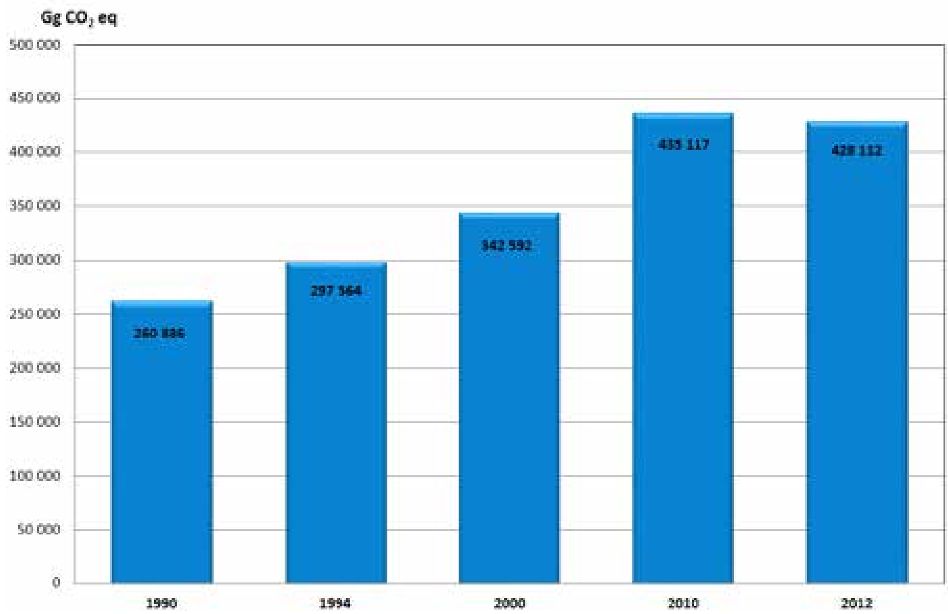



Figure 3.5: Sector 1 Energy: Trend and emission levels of total GHG's from the energy sector, 1990 – 2012.

### 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. 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, the 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 the energy sector have increased by 16.0% over the 12-year period between 2000 and 2012, mainly due to economic growth and development, and preparations for the 2010 FIFA World Cup.

According to Statistics South Africa, the growth rate of the economy slowed from 3.6% in 2002 to 1.9% in 2003. The slowdown was attributed to a contraction in the growth of the agricultural and manufacturing sectors. Despite the slowdown in economic growth, GHG emissions still increased by 3.19% in 2002 and 6.67% in 2003In 2004 GDP growth increased again to 3.7% and to 5% in 2005. GHG emissions increased by only 1.8% between 2005 and 2006. The reason for the slower rate of increase in emissions between 2004 and 2005 is unknown.

The annual rate of increase in GHG emissions was significantly lower between 2007 and 2009, with an increase of only 2.0% in 2009. In May 2009 South Africa officially entered an economic recession – the first in 17 years – sparked by the global economic recession that started towards the end of 2008. Until then, the country's economic growth and development had been 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. As a result of the recession, GHG emissions decreased enormously almost across all categories in the energy sector.

By November 2009, the economy had recovered, achieving a 0.9% growth, primarily because of growth in the manufacturing sector. Hosting the 2010 FIFA World Cup in June and July 2010 also contributed positively to the economy and, as a result, GHG emissions increased by 3.5% that year.

South Africa's economy is highly dependent on a reliable electricity supply. A decline in emissions between November 2007 and the end of January 2008 can be attributed to substantial disruptions in the electricity supply caused by a lack of adequate generating capacity.

In January 2006 the main power producer, Eskom, started experiencing difficulties meeting customer demand (NERSA, 2008). This situation deteriorated in late 2007 and early 2008 and Eskom 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, and households. The situation deteriorated to the extent that major mining operations had to close down on 24 January 2008 for safety considerations (NERSA, 2008).

### 3.2.2 Key sources

Level and trend key category analyses were completed for 2012 using 2000 as the base year. The level assessment shows that *energy industries* (solid fuels) – main activity electricity and heat production (1.A.1.a), *road transportation* (1.A.3.b), *energy industries* (liquid fuels) – *manufacture of solid fuels and other energy industries* (1.A.1.c), *manufacturing industries and construction* (solid fuels) (1.A.2), and *other sectors* (solid fuels) – *residential* (1.A.4.b) are the top subcategories in the energy sector. In the trend assessment, it is *other sectors* (solid fuels) – *residential* (1.A.4.b), *energy industries* (solid fuels) – *main activity electricity and heat production* (1.A.1.a), *manufacturing industries and construction* (solid fuels) (1.A.2), *energy industries* (liquid fuels) – *manufacture of solid fuels and other energy industries* (1.A.1.c) and *other sectors* (liquid fuels) – *commercial/institutional* that top the list (**Table 1.9**, **Table 1.11**). 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 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 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
  - 1A1c Manufacture of solid fuels and other energy industries
- 1A2 Manufacturing industries and construction
  - 1A2c Chemicals
  - 1A2m Non-specified sectors
- 1A3Transport sector
  - 1A3a Civil aviation
  - 1A3b Road transportation
  - 1A3c Railways
  - 1A3d Waterborne 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. Over the period 2000 to 2012 the $CO_2$ emissions were higher using the reference approach (**Appendix D**). Reporting has improved over the 12-year period and, as a result, the difference between the two approaches has declined from 56% in 2000 to 20% in 2012. There are a number of possible reasons for the discrepancy:

- Net calorific values (NCVs) used in the sectoral approach differ from those used in the reference approach. In power generation, NCVs in the sectoral approach vary over the 2000–2012 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 as use for synfuels production remains one of the key drivers of the differences observed between the two datasets.

A more detailed analysis of the discrepancies between the reference and sectoral approach will be included in the next submission.

### 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 emphasize the significance of separating energy and process emissions to prevent double counting 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. The sources considered include coal used in iron and steel production, the use of fuels as solvents, lubricants and waxes, and the 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 the manufacture 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 the mining, commercial and residential sectors (Department of Energy, 2009a). In the event of power disruptions, these sectors are more likely to be impacted. In the case of the manufacturing/industry, mining and commercial sectors, disruptions can result in reduced productivity. **Table 3.2** 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: Department of Energy, 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% | not available |
| **Total** | **100%** | **7.9 million** |

### *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, which are industrial companies that operate and produce their own electricity. The main energy industries include electricity and heat production, petroleum refining and the manufacture of solid or liquid fuels. This category includes electricity produced both by public and auto electricity producers.

The energy balances published by the DoE indicate the type of fuel and the quantity consumed. Electricity generation is the largest key GHG emission source in South Africa, mainly because it mainly uses bituminous coal which is abundantly available in the country. Eskom supplies more than 95% of South Africa's electricity needs (Department of Energy, 2009). It generates, transmits and distributes electricity to various sectors, such as the industrial, commercial, agricultural and residential sectors. The net maximum electricity generation capacity and electricity consumption for 2000 to 2012 is illustrated in **Table 3.3**.

Additional power stations are being built to meet the increasing demand for electricity in South Africa (Eskom, 2011). Eskom had planned to invest more than R300 billion in new generation, transmission and distribution capacity up to 2013. In 2008 Eskom's total sales of electricity were estimated at 239 109 GWh. Eskom introduced demand side management (DSM) in an effort to reduce electricity consumption by 3 000 MW by March 2011. The utility aims to increase this to 5 000 MW by March 2026. The 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 2008.

#### *3.3.3.1.2 Petroleum refining [1A1b]*

This source category includes combustion emissions from crude oil refining and excludes emissions from the manufacture of synthetic fuels from coal and natural gas. Combustion-related emissions from the 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

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 | 224 366 |
| 2009 | 40 506 | 214 850 |
| 2010 | 40 870 | 218 591 |
| 2011 | 40 900 | 224 446 |
| 2012 | 41 500 | 224 785 |

crude oil refining, and the production of coal-to-liquid fuels and gas-to-liquid fuels.

In 2000 and 2010 the total crude oil distillation capacity of South Africa's petroleum refineries was 700 000 bbl/d- and 703 000 bbl/d, 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 the fuel consumed by refineries is sourced directly from refineries. National energy balance data from the DoE is used to verify data reported by the petroleum industry.

#### *3.3.3.1.3 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 estimated cumulative coal consumption of the public electricity producer, Eskom, for the period 2000 to 2012 was 28 229 590 TJ. Consumption increased by 38.6% over this period (**Table 3.4**). The total estimated of cumulative GHG emissions from the public electricity producer was 2 736 516 Gg $CO_2$eq between 2000 and 2012.

In 2000, GHG emissions from the public electricity producer totalled 174 702 Gg $CO_2$eq. The main source of emissions in this category was the combustion of coal for electricity generation. The consumption of

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

| Period | Consumption | $CO_2$ | $CH_4$ | $N_2O$ | Total GHG |
|---|---|---|---|---|---|
| | (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 |
| 2011 | 2 426 965 | 233 189 | 57 | 1 072 | 234 318 |
| 2012 | 2 537 364 | 243 497 | 60 | 1 118 | 244 675 |

electricity increased marginally between 2000 and 2007 (Department of Energy, 2009a). The GHG emissions steadily increased throughout the same period from 174 702 Gg $CO_2$eq to 229 218 Gg $CO_2$eq in 2007. The main reason for the increase in GHG emissions during that period was robust economic growth, which increased the demand for electricity and fossil fuel consumption.

During 2003, Eskom's total electricity sales were 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 195 Mt $CO_2$eq. 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, compared with a peak of 31 928 MW in 2003.

In late 2007 and early 2008 the public electricity producer started to experienced difficulties supplying electricity and resorted to shedding customer loads. The load shedding had a negative impact on the key drivers of economic growth. GHG emissions from the public electricity producer decreased by 4.2% as a result of the electricity disruptions.

The global economic crisis in late 2008 also affected key drivers of growth such as manufacturing and mining sectors. **Table 3.2** above provides a breakdown of electricity use by sector as follows: Residential 17%, Agriculture 3%, Commercial 13%, Mining 15%, Industry/Manufacturing 38%, Transport (mainly railway) 3%, Exports 6%, and Own use of distributors 5% (Department of Energy, 2009a).

### Auto electricity producer

The total estimated accumulated GHG emissions for the period 2000 to 2012 in the auto electricity production category was 60 624 Gg $CO_2$eq. Overall, from 2000 to 2012, GHG emissions decreased by 89.4% (**Table 3.5**). Total GHG emissions from auto electricity producers in South Africa fluctuated significantly from year to year, showing decreases in 2001, 2004, 2005, 2008 and 2011, and increases in the other years. In 2003 the emissions increased by 59.9%. This may be attributed to the economic growth during that period which increased the demand for electricity. The global economic crisis could explain the 16.9% decline in GHG emissions during 2008.

#### *3.3.3.2.2 Petroleum refining [1A1b]*

The total cumulative consumption of fuels for petroleum refining for the period 2000 to 2012 was estimated at 709 696 TJ, with refinery gas contributing 76.6% in 2010. The total GHG emissions from petroleum refining was estimated at 4 049 Gg $CO_2$eq in 2000, decreasing to 3 384 Gg $CO_2$eq in 2012 (**Table 3.6**).

In 2000 refinery gas contributed 57.0% to the total GHG emissions in this category and this increased to 64.8% in 2012. Emissions from residual fuel oil decreased from contributing 16.6% in 2000 to only 9.1% in 2012. A shift from residual fuel oil to refinery gas in most refineries is the main driver of emissions reduction in this source category.

#### *3.3.3.2.3 Manufacture of solid fuels and other energy industries [1A1c]*

Total GHG emissions from the manufacture of solid fuels and other energy industries was 30 572 Gg $CO_2$eq in 2000, with a slight decline of 1.7% over the 12-year period

Table 3.5: Sector 1 Energy: Summary of GHG emissions from auto electricity producers, 2000 – 2012.

| Period | 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 | 51.53 | 11 224 |
| 2001 | 47 346 | 4 557 | 1.09 | 21.02 | 4 579 |
| 2002 | 51 311 | 4 939 | 1.18 | 22.78 | 4 963 |
| 2003 | 82 036 | 7 896 | 1.89 | 36.42 | 7 934 |
| 2004 | 64 333 | 6 192 | 1.48 | 28.56 | 6 222 |
| 2005 | 28 029 | 2 698 | 0.64 | 12.44 | 2 711 |
| 2006 | 39 627 | 3 814 | 0.91 | 17.59 | 3 833 |
| 2007 | 48 233 | 4 642 | 1.11 | 21.46 | 4 665 |
| 2008 | 40 066 | 3 856 | 0.92 | 17.79 | 3 875 |
| 2009 | 44 149 | 4 294 | 1.02 | 19.60 | 4 270 |
| 2010 | 44 171 | 4 251 | 1.02 | 19.61 | 4 272 |
| 2011 | 9 164 | 882 | 0.21 | 4.07 | 886 |
| 2012 | 12 305 | 1 184 | 0.28 | 5.46 | 1 190 |

Table 3.6: Sector 1 Energy: Summary of consumption of fuels and GHG emissions in the petroleum refining category (1A1b), 2000 – 2012.

| Period | Consumption (TJ) | $CO_2$ (Gg) | $CH_4$ (Gg $CO_2$ eq) | $N_2O$ (Gg $CO_2$ eq) | Total GHG (Gg $CO_2$ eq) |
|---|---|---|---|---|---|
| **2000** | 59 637 | 4 043 | 2.27 | 4.7 | 4 049 |
| **2001** | 57 599 | 3 898 | 2.43 | 4.65 | 3 905 |
| **2002** | 50 679 | 3 385 | 1.81 | 3.6 | 3 390 |
| **2003** | 57 486 | 3 879 | 2.12 | 4.27 | 3 885 |
| **2004** | 53 292 | 3 563 | 1.88 | 3.70 | 3 569 |
| **2005** | 51 609 | 3 413 | 1.77 | 3.40 | 3 418 |
| **2006** | 55 122 | 3 669 | 1.96 | 3.90 | 3 675 |
| **2007** | 56 073 | 3 761 | 2.03 | 4.04 | 3 767 |
| **2008** | 57 870 | 3 868 | 2.08 | 4.11 | 3 874 |
| **2009** | 56 524 | 3 797 | 2.07 | 4.15 | 3 803 |
| **2010** | 52 519 | 3 546 | 1.91 | 3.83 | 3 551 |
| **2011** | 50 234 | 3 336 | 1.76 | 3.43 | 3 341 |
| **2012** | 51 049 | 3 379 | 1.77 | 3.43 | 3 384 |

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), 2000 – 2012

| Period | $CO_2$ (Gg) | $CH_4$ (Gg $CO_2$ eq) | $N_2O$ (Gg $CO_2$ eq) | Total GHG (Gg $CO_2$ eq) |
|---|---|---|---|---|
| **2000** | 30 454 | 11.64 | 105 | 30 571 |
| **2001** | 30 915 | 12.85 | 108 | 31 036 |
| **2002** | 30 479 | 11.66 | 106 | 30 597 |
| **2003** | 30 970 | 12.44 | 112 | 31 094 |
| **2004** | 31 041 | 11.82 | 107 | 31 160 |
| **2005** | 29 290 | 11.09 | 102 | 29 403 |
| **2006** | 28 699 | 10.90 | 100 | 28 810 |
| **2007** | 30 194 | 11.64 | 106 | 30 312 |
| **2008** | 29 699 | 11.32 | 104 | 29 814 |
| **2009** | 29 767 | 11.36 | 105 | 29 883 |
| **2010** | 29 415 | 10.95 | 105 | 29 531 |
| **2011** | 29 179 | 10.67 | 105 | 29 294 |
| **2012** | 29 903 | 8.42 | 142 | 30 053 |

to 30 053 Gg $CO_2$eq in 2012 (**Table 3.7**). Emissions remained fairly constant over the period 2000 to 2012, with annual changes ranging between -5.6% and 5.2%. $CO_2$ emissions contributed 99.6% to the total GHG emissions from this category.

### 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 *manufacture 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 producer for the period 2000 to 2012. Activity data for auto electricity producers was sourced from the energy balance for the period 2000-2006 and extrapolated for the period 2007-2012.Using the technique recommended by the 2006 IPCC Guidelines. To convert fuel quantities into energy units for public electricity generation, the net calorific values estimated by the national utility annually were applied. A country-specific average NCV of 0.0192 TJ/tonne was used to convert fuel quantities into energy units and this was sourced from Eskom's 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 approach was used with default emission factors sourced from the 2006 IPCC Guidelines. Furthermore, default factors from these guidelines were applied for the estimation of 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]

Activity data for petroleum refining was sourced directly from petroleum refineries. IPCC methodologies were applied for the filling of data gaps to ensure completeness and consistency in the data time series. IPCC 2006 default EFs (IPCC, 2006) were used (**Table 3.9**).

#### 3.3.3.4.3 Manufacture of solid fuels and other energy industries [1A1c]

GHG emissions results for this category were sourced from manufacturing plants (PetroSA and Sasol), and thus 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 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 and 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 2012 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*

For the 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 DMR's SAMI publication 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 was 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 followed for the compilation of this inventory and 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 as the national energy balances and SAPIA reports. For this inventory report improvements were made by collecting data directly from the national utility and the petroleum refineries. The $N_2O$ emission factor for coal was corrected. In the previous inventory a value of 3 kg

$TJ^{-1}$ was applied but the source of the data could not be traced so the default IPCC emission factor was applied. As more accurate activity data was collected for all sources and emission factors updated, the emissions within the energy industries sector had to be recalculated back to 2000. The recalculation improved the accuracy of the 2000 GHG emissions result for the energy sector.

#### 3.3.3.8 Source-specific Planned Improvements and Recommendations

##### 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 calculations by applying country-specific emission factors for this sector will improve the national GHG inventory estimate. Other improvements for this category would be to:

- formalise the data collection process to ensure continuous collection of data and time-series consistency;
- Collect plant specific data for coal combusted;
- Obtain more detailed information from the national power producer to assist in the explanation of trends throughout the reporting period;
- Obtain a list of auto power producers and obtain data directly from the producers. This is important going forward since growth is expected within this sector.

Finally, for purposes of completion, future inventories should consider the collection and reporting of SF6 for this category. In addition to the improvements identified above, the DEA is in the process of promulgating legislation - The National GHG Reporting Regulations. The purpose of these Regulations is to introduce a single national reporting system for the transparent reporting of greenhouse gas emissions, which will be used -

- to update and maintain a National Greenhouse Gas Inventory;
- for the Republic of South Africa to meet its reporting obligations under the United Framework Convention on Climate Change and instrument treaties to which it is bound; and
- to inform the formulation and implementation of legislation and policy.

Data providers operating within the Energy, IPPU and Waste sectors will be required to regularly report emissions data to DEA on an annual basis, provided that the reporting thresholds are met. It is envisaged that the implementation of these reporting regulations will enhance accuracy, completeness and transparency moving forward.

##### 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.

##### 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. 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 comprise 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 (Department of Energy, 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 used in the construction sector include 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 estimated cumulative total GHG emissions in the category *manufacturing industries and construction* for the 12-year period was 467 832 Gg $CO_2$eq. GHG emissions were estimated to be 32 653 Gg $CO_2$eq in 2000 and these decreased by 10.5% to 29 212 Gg $CO_2$eq in 2012 (**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, a 1% increase from liquid fuels and a 3.5% decline in the contribution from solid fuels over the 12-year period.

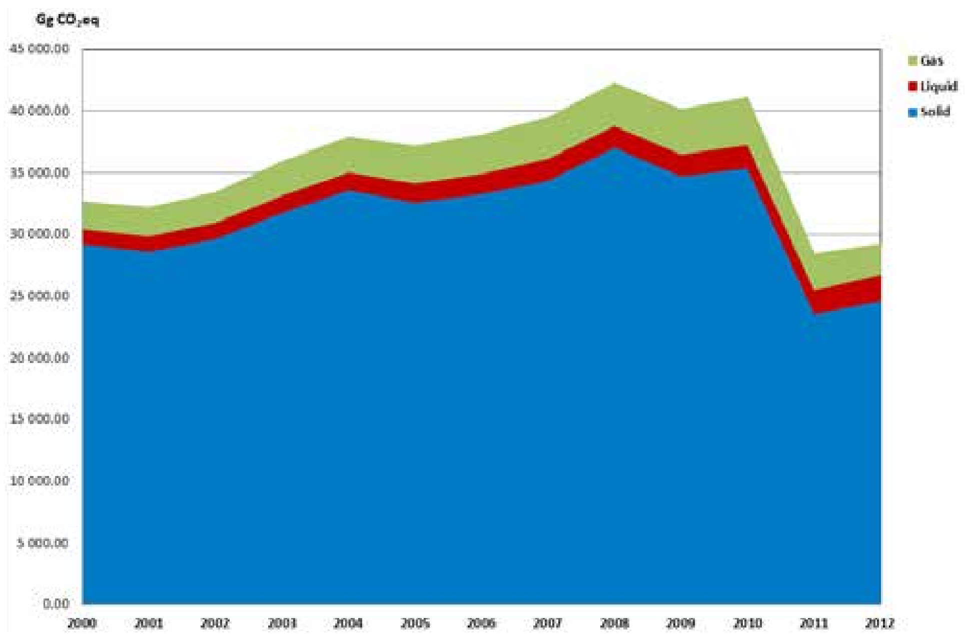



Figure 3.6: Sector 1 Energy: Trend in sources of total GHG emissions from fuel used in the manufacturing industries and construction category (1A2), 2000 - 2012.

GHG emissions from this category increased by 7.5% in 2003, but decreased by 1.9% in 2005. In 2009 GHG emissions from this category decreased by 5.1%, which might have been a result of the global economic crisis that started in late 2008.

The real value added by the construction sector increased at an annual rate of 10.6% in the second quarter of 2008, lower than the rate of 14.9% recorded in the first quarter of 2008. That reduced growth reflected deteriorating conditions in the residential and non-residential building sectors, as developers experienced a strain of higher interest rates and escalating inflationary pressures.

#### 3.3.4.3 *Methodological Issues*

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

#### 3.3.4.4 *Data Sources*

For the manufacturing industries and construction sector data for solid fuels for the period 2000 to 2007 were sourced from the DoE's energy digest, for the period 2007 to 2010 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 the SAMI report. **Table 3.10** shows the total fuel consumption in this category for the period

Table 3.10: Sector 1 Energy: Fuel consumption (TJ) in the manufacturing industries and construction category, 2000 – 2012.

| 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 | 353 465 |
| 2002 | 606 | 10 410 | 187 | 113 | 6 161 | 306 401 | 43 048 | 366 927 |
| 2003 | 626 | 11 069 | 185 | 107 | 6 276 | 328 424 | 48 749 | 395 436 |
| 2004 | 649 | 11 702 | 199 | 108 | 6 382 | 347 344 | 50 361 | 416 745 |
| 2005 | 619 | 12 367 | 171 | 106 | 7 038 | 337 162 | 53 166 | 410 629 |
| 2006 | 601 | 13 271 | 166 | 116 | 7 245 | 344 183 | 56 038 | 421 621 |
| 2007 | 567 | 14 870 | 164 | 122 | 7 707 | 355 304 | 58 908 | 437 643 |
| 2008 | 433 | 14 877 | 164 | 118 | 7 475 | 383 032 | 61 778 | 467 877 |
| 2009 | 444 | 14 877 | 207 | 105 | 7 602 | 359 011 | 64 645 | 446 892 |
| 2010 | 469 | 16 129 | 219 | 111 | 8 044 | 365 687 | 68 406 | 459 066 |
| 2011 | 473 | 17 107 | 167 | 138 | 7 536 | 243 904 | 51 382 | 320 707 |
| 2012 | 383 | 17 163 | 198 | 126 | 9 807 | 254 262 | 44 518 | 326 458 |

2000 to 2012. An NCV of 0.0243 TJ/tonne was used to convert fuel quantities into energy units (Department of Energy, 2009a). To avoid double counting fuel activity data, the fuel consumption associated with petroleum refining (1A1b) was subtracted from the fuel consumption activity data sourced for 1A2.

##### 3.3.4.4.1 Emission factors

A country-specific emission factors for $CO_2$ for sub-bituminous coal was applied (see **section 3.3.3.4**). This Country-Specific EF was used for all years going back to 2000. For all other fuels the IPCC 2006 default emission factors were used to estimate 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 3.11: Sector 1 Energy: Emission factors used in the manufacturing industries and construction category (Source: 2006 IPCC Guidelines).

| Type of Fuel | Emission factor (kg $TJ^{-1}$) | | |
|---|---|---|---|
| | $CO_2$ | $CH_4$ | $N_20$ |
| Sub-bituminous coal | 96 250 | 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 to 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 to 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 SAMI report. An independent reviewer was appointed to assess the quality of the inventory, determine the conformity of the procedures followed for the compilation of the inventory and identify areas of improvements.

#### 3.3.4.7 Source-specific Recalculations

In the previous 2000 GHG inventory, activity data for this category were sourced from the energy balances published by the DoE. For this inventory a combination of the energy digest and the SAMI report was used as a source of activity data for solid fuels, and SAPIA was 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. Country specific $CO_2$ emissions were also included for coal consumption. The $N_2O$ emission factor for coal was corrected. In the previous inventory a value of 3 kg $TJ^{-1}$ was applied but the source of the data could not be traced so the default IPCC emission factor was applied. Recalculations were therefore completed for all years between 2000 and 2012.

#### 3.3.4.8 Source-specific Planned Improvements and Recommendations

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

### 3.3.5 Transport [1A3]

According to the 2006 IPCC Guidelines, estimates of GHG emissions from mobile combustion refers to major transport activities such as road, off-road, air, railways and waterborne 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 and heat production category and not under the transport category. The diversity of sources and combustion takes into consideration the age of the fleet, maintenance, the sulphur content of the fuel used and patterns of use of the various transport modes. The GHG inventory includes 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 [1A3a]

Civil aviation emissions are produced from the combustion of jet fuel (jet kerosene and jet gasoline) and aviation gasoline. Aircraft engine emissions (ground emissions and cruise emissions) are roughly composed of 70% $CO_2$, less than 30% water and 1.0% of other components (NOx, CO, SOx, NMVOCs, particulates, and 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 reported separately under the other category or the memo item multilateral operations.

**International aviation (international bunkers) [1A3aI]**

GHG emissions from aircraft that returned from an international destination or were 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 [1A3b]

According to the 2006 IPCC Guidelines, road transport emissions include 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 are also included in this category. The DoE's energy balances list the fuels under road transport as diesel, gasoline, other kerosene, residual fuel oil and LPG. Road transport was responsible for the largest fuel consumed in the transport sector (79.1% in 2012). Motor gas contributed 64.9% of the road transport fuel consumption in 2010, followed by gas/diesel oil (35%). Between 2000 and 2012 there was an increase in the percentage contribution of gas/diesel oil to road transport consumption (80.1%), and a corresponding decline of 12.7% in the contribution from motor gasoline (**Figure 3.7**). This can be attributed to the efficiency and affordability of diesel compared with motor gasoline.

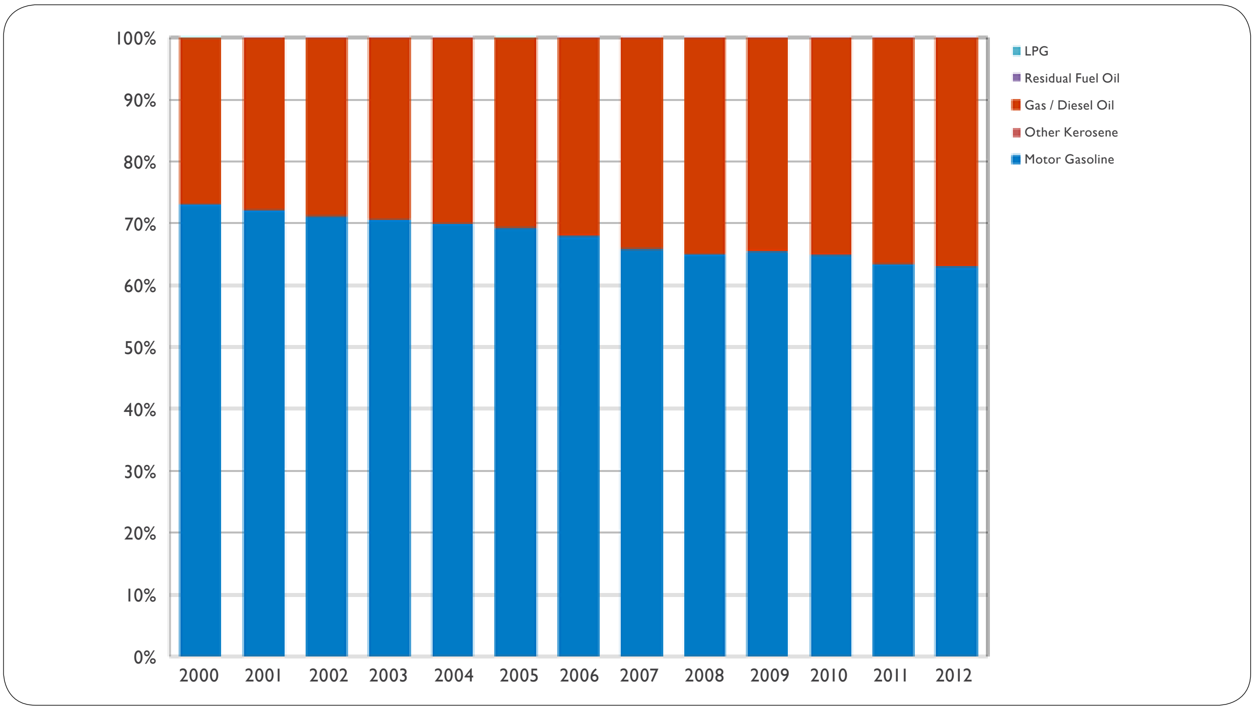



Figure 3.7: Sector 1 Energy: Percentage contribution of the various fuel types to fuel consumption in the road transport category (1A3b), 2000 – 2012.

### *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 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 Waterborne navigation [1A3d]*

According to the 2006 IPCC Guidelines, waterborne navigation sources include emissions from the use of fossil fuels in all waterborne transport, from recreational craft to large ocean cargo ships, but exclude fishing vessels. Fishing vessels are accounted for under the other sector, in the fishing subcategory. The vessels are driven primarily by large, medium to slow diesel engines and sometimes by steam or gas turbines.

### International waterborne navigation (international bunkers) [1A3d1]

International waterborne navigation GHG emissions include fuels used by vessels of all flags that are engaged in international waterborne navigation. 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, and excludes consumption by fishing vessels. International waterborne 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. This is not consistent with the 2006 IPCC Guidelines, which require marine bunkers to be reported separately from the national totals. In the future, improved data on marine activities will assist in improving the accuracy of emissions estimates for both waterborne navigation and marine bunkers.

#### 3.3.5.2 Overview of Shares and Trends in Emission

It was estimated that for the period 2000 to 2012, the total cumulative GHG emissions from transport activities was 549 923 Gg $CO_2$eq. GHG emissions from transport activities have increased by 32.4%, from 36 016 Gg $CO_2$eq in 2000 to 47 690 Gg $CO_2$eq in 2012 (Figure 3.8). $CO_2$ emissions from all modes contributed the most to the GHG emissions, while the $CH_4$ and $N_2O$ emission contributions were relatively small (**Figure 3.9**).

Road transport contributed 92.0% towards the total transport GHG emissions in 2012 (43 857 Gg $CO_2$ eq), while 7.3% was from domestic civil aviation and less than 1% from railways. The increase in GHG emissions in the transport sector can be attributed to the increase in motor vehicle 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. This decrease was linked to the global economic crisis. Motor vehicle sales decreased by a further 10.5% in 2009; however in November 2009 the economy started to recover, achieving growth of 0.9%. This growth was accompanied by an increase in GHG emissions by 1.4%.

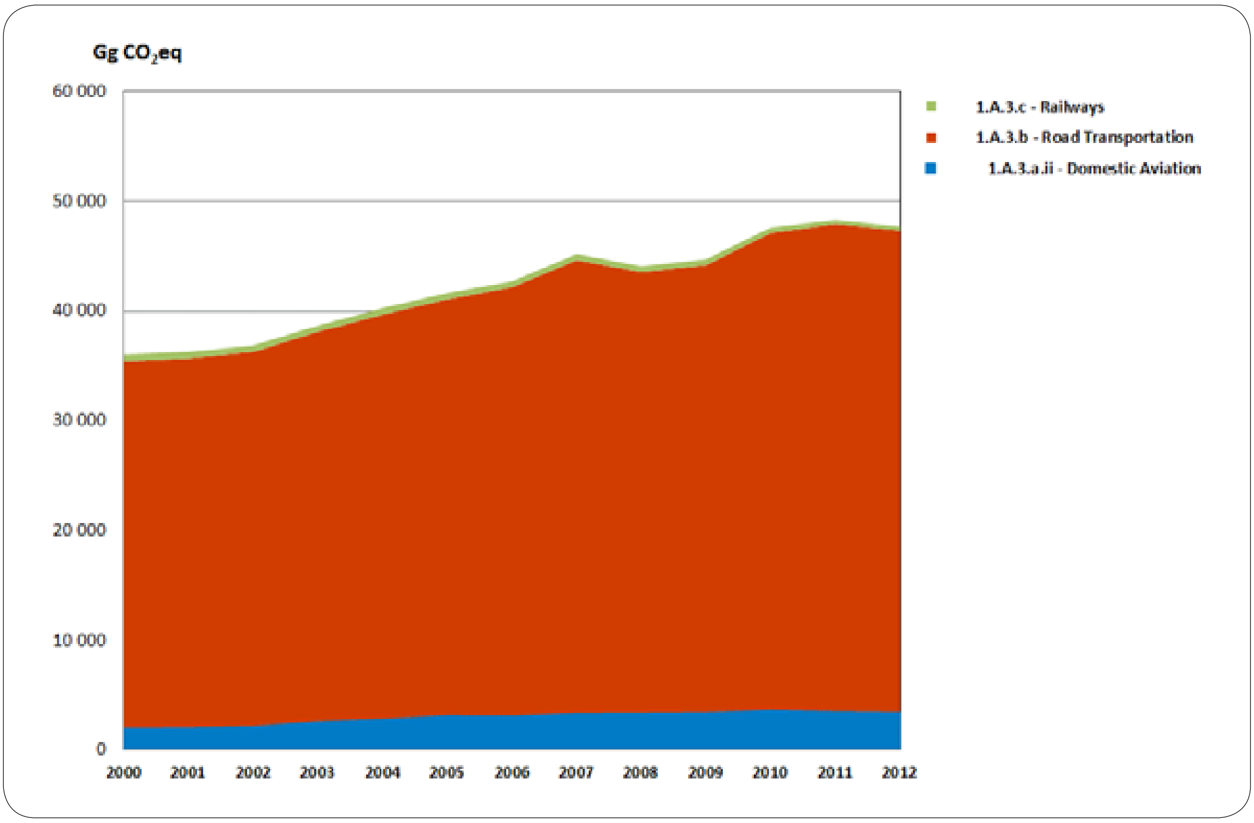



Figure 3.8: Sector 1 Energy: Trend in total GHG emissions from the transport sector, 2000 – 2012.

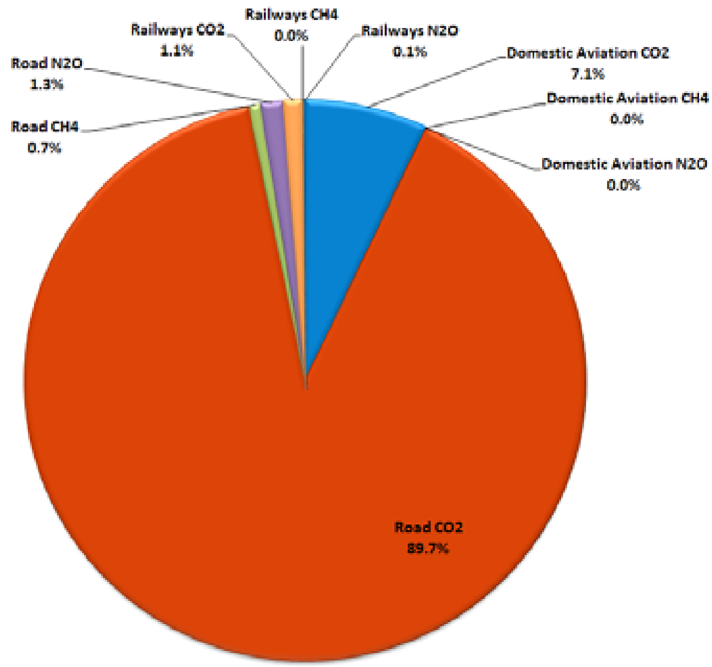



Figure 3.9: Sector 1 Energy: Percentage contribution of $CO_2$, $CH_4$ and $N_2O$ from the transport sector, average over 2000 – 2012 period.

*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 is 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 consist mainly of liquid fuels. The most dominant fuel is motor gasoline (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 grown steadily, however, 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 economy.

The primary driver for the transport sector is GDP growth. For road passenger travel, GDP growth means an increase in the number of commuters and an increase in personal wealth, both in terms of the number of wealthier people and the size of people's expendable incomes. This results in more money being available to purchase cars and for leisure activities, which, in turn, increases the demand for transport and transport fuel.

In terms of civil aviation, there has been 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).

Passengers travelling by commuter rail increased to 646.2 million in the financial year 2008/09, a 9% increase on

2008/09 (Stats SA, 2007). Passenger kilometres travelled by trains also increased by 9% to 16.9 billion kilometres in 2008/09.

Annual growth in GHG emissions from the transport sector slowed between 2003 and 2004, from 4.9% to 4.1%. This was mainly because the price of oil was at the narrow range of approximately $22/28/bbl, however in the year 2005 the price of oil escalated significantly.

According to SAPIA, the factors that influenced the escalating crude oil price in 2005 were the following:

- 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 United States and China;
- A particular shortage of sweet (low-sulphur) crudes due to a lack of refining capacity to process sour (high-sulphur) crudes into the requisite product qualities needed by world markets;
- Political tensions in certain crude oil-producing countries; and
- The petrol price in South Africa is linked to the price of petrol in US dollars and to certain other international petrol markets.

The local prices of petroleum products are affected by the ZAR-USD exchange rate and the dollar price of crude oil. It is important to note that in late 2001 when the exchange rate rose above R12 to the dollar and the oil price was about $20/bbl, crude oil cost some R240/bbl, and in 2004 when the rand strengthened to R6 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/bbl and at a rate of R6, 5 to the dollar, the cost became R423/bbl, a very significant rise.

In 2007, aggregate sales of major petroleum products showed a strong increase of 7.3% in the first quarter 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 of 2007, 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%, which was attributed to the global economic crisis that occurred in 2008 and 2009. Total sales of major petroleum products showed an increase of 4% in the first quarter of 2008 compared with 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%, respectively, 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 South Africa's economy recovered from the recession and in 2010 the country successfully hosted the FIFA World Cup.

#### International aviation (international bunkers) [1A3aI]

It was estimated that for the period 2000 to 2012 the total cumulative GHG emissions from international aviation activities was 33 075 Gg $CO_2$eq. **Table 3.12** provides a summary of GHG emissions for the period 2000 to 2012 from international aviation. Over the 12-year assessment period, GHG emissions emanating from international aviation have decreased by 18.8%. However in 2006 and 2010 GHG emissions increased by 10.7% and 5.8%, respectively. The increase in 2010 could be attributed to the fact that South Africa hosted the FIFA World Cup and international travel increased as a result.

Table 3.12: Sector 1 Energy: Summary of GHG emissions from international aviation (international bunkers), 2000 – 2012.

| Period | $CO_2$ | $CH_4$ | $N_2O$ | Total GHG |
|---|---|---|---|---|
| | (Gg) | (Gg $CO_2$ eq) | (Gg $CO_2$ eq) | (Gg $CO_2$ eq) |
| 2000 | 2 972 | 3.12 | 7.43 | 2 983 |
| 2001 | 2 708 | 2.84 | 6.77 | 2 718 |
| 2002 | 2 687 | 2.82 | 6.72 | 2 697 |
| 2003 | 2 584 | 2.71 | 6.46 | 2 593 |
| 2004 | 2 316 | 2.43 | 5.79 | 2 324 |
| 2005 | 2 267 | 2.38 | 5.67 | 2 275 |
| 2006 | 2 510 | 2.63 | 6.28 | 2 519 |
| 2007 | 2 557 | 2.68 | 6.39 | 2 566 |
| 2008 | 2 478 | 2.60 | 6.20 | 2 487 |
| 2009 | 2 423 | 2.54 | 6.06 | 2 431 |
| 2010 | 2 564 | 2.69 | 6.41 | 2 573 |
| 2011 | 2 482 | 2.60 | 6.21 | 2 491 |
| 2012 | 2 414 | 2.53 | 6.04 | 2 422 |

### *3.3.5.3 Methodological Issues*

NCVs, which were applied in the transport sector to convert fuel quantities into energy units, were sourced from the DoE (**Table 3.13**).

Table 3.13: Net Calorific Values for the transport Sector (Source: Department of Energy 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 |
| Bitumen | 80 700 |

#### *3.3.5.3.1 Civil Aviation [1A3a]*

The main challenge in this category was splitting the fuel consumption of international and domestic flights. The 2006 IPCC Guidelines (p.3.78) propose that international/ domestic splits should be determined on the basis of departure and landing locations for each flight stage and not by the nationality of the airline. The energy balances published by the DoE note that splits for international/ national have been made, but the methodology is not described. Furthermore, the energy balances do not give details on whether military aviation activities are included, but, this may be due to confidentiality issues. The Tier 1 methodology was used for to calculate 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 the fuel combusted, whereas the kilometre approach (distance travelled by vehicle type) is appropriate for $CH_4$ and $N_2O$. Hence, in order to use a higher-tier approach for calculating road transport emissions, a better understanding of the fuel sold and vehicle kilometres travelled is required for the entire South African vehicle fleet. This data was not available for the entire 12-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 Guidelines were used. The use of a 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 SAPIA's annual reports (**Table 3.14**). The 2006 IPCC Guidelines (p. 3.78) require 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 fuel used for military aviation activities. It is not indicated in data sources, therefore, military aviation emissions are thought to be accounted for under domestic aviation. In the D0E's energy balances civil aviation fuels include gasworks gas, aviation gasoline and jet kerosene.

**International aviation (international bunkers) [1A3al]**

The energy balances published by the DoE were the main source of data for the amount of fuel consumed (**Table 3.14**). They did not indicate whether aviation fuel consumption figures included military aviation activities (these might have been excluded for security reasons).

##### *3.3.5.4.2 Road transport [1A3b]*

SAPIA annual reports were the main sources of activity data for the transport sector (**Table 3.15**). 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 a proper understanding of fuel consumption.

##### *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 (SAPIA, 2008) was used to disaggregate actual diesel consumption for the rail transport sector. An assumption was made that the split of diesel consumption for rail activities was constant for the whole time series (2000 – 2012), which may not necessarily be accurate. To improve accuracy in the future, data should be collected at the subcategory 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**

Table 3.14: Sector 1 Energy: Fuel consumption (TJ) in the transport sector, 2000 – 2012.

| | 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 |
| 2011 | 745 | 48 775 | 388 678 | 214 | 222 390 | 97 | 0 | 5 514.30 |
| 2012 | 1070 | 47 433 | 380 588 | 173 | 223 123 | 116 | 0 | 5638.72 |

Table 3.15: Sector 1 Energy: Fuel consumption (TJ) in the international aviation category, 2000 – 2012.

| 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 |
| 2011 | 34 711 |
| 2012 | 33 755 |

subsector. As a result, emissions from this sub-category are "implied elsewhere" (IE). Hence, to improve transparency in reporting and the accuracy of 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 to estimate 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 transport sector emission calculations (Source: 2006 IPCC Guidelines).

| Type of Fuel | Emission factor (kg $TJ^{-1}$) | | |
|---|---|---|---|
| | $CO_2$ | $CH_4$ | $N_20$ |
| Motor gasoline | 69 300 | 33 | 3.2 |
| Other kerosene | 71 900 | 3 | 0.6 |
| Gas/ diesel oil | 74 100 | 3.9 | 3.9 |
| Gas/ diesel oil (railways) | 74 100 | 4.15 | 28.6 |
| Residual fuel oil | 77 400 | 3 | 0.6 |
| Aviation gasoline | 70 000 | 3 | 0.6 |
| Jet kerosene | 71 500 | 3 | 0.6 |

### 3.3.5.5 Uncertainty and Time-series Consistency

#### *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 is 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 $N_2O$ are relatively high and are likely to be a factor of 2 to 3%. They also depend on the following: fleet age distribution; uncertainties in the 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 converters), to mention a few.

Activity data were another primary source of uncertainty in the emission estimates. 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 transport because less fuel is consumed. Also 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. Therefore, the uncertainties around waterborne navigation emission estimates are related to the difficulty 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 2000 GHG inventory, the activity data for this category was sourced from the energy balances published by the DoE. For this inventory (2000 – 2012) the energy balances were used as a source of activity data, but the SAPIA report on the impact of liquid fuels on air pollution (SAPIA, 2008) was used to disaggregate fuel consumption into the various users. This resulted in the recalculation of GHG emissions for these years so as to reduce the uncertainty of the emission estimates.

#### 3.3.5.8 Source-specific Planned Improvements and Recommendations

This category is a key category and it is essential that further work is done to move toward the use of a higher tier emissions estimation methodology.

##### *3.3.5.8.1 Road transport [1A3b]*

The road transport 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 calculations by using bottom-up method and applying country-specific emission factors for this sector will improve the national GHG inventory estimate. Planned improvements for Road Transportation include:

Collection of information on Vehicle Kilometres Travelled (VKT) in the transport sector and to development of a modelling tool for the transport sector. Collecting information on VKT will improve the estimation accuracy of emissions from this category. This project will ensure that emissions estimated from the transport sector are more accurate and will involve (a) bottom-up fuel consumption and VKT for road transportation by vehicle type, (b) bottom-up fuel consumption by vehicle type and (c) a model to ensure sustainability of this work.

Development of country-specific Road Transport Emission Factors for $CO_2$, $CH_4$ and $N_2O$. This study will enable estimation and compilation of the Greenhouse Gas Emissions Inventory for road transportation using country-specific emission factors, thus improving the accuracy in the estimation of emissions from this category by moving to a Tier 2 methodology. The implementation of this project will involve (a) Detailed measurement of the carbon content of $CO_2$ for Petrol and Diesel; and (b) measurement of $CH_4$ and $N_2O$ emission factors by vehicle type.

##### *3.3.5.8.2 Civil aviation [1A3a]*

Improvement of emission estimation for this category requires an understanding of aviation parameters, including the number of landings/take-offs (LTOs), fuel use and the approaches used to distinguish between domestic/international flights. This would ensure the use of higher-tier approaches 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).

It is also recommended that a more detailed description of the methodology for splitting domestic and international fuel consumption be included in the next inventory report.

##### *3.3.5.8.3 Road transport [1A3b]*

To improve road transport emission estimates, calculations should include the ability to compare emission estimates using fuel consumption and kilometres travelled (based on travel data). This requires more knowledge of South Africa's fleet profile, and also an understanding of how much fuel is consumed in the road transport sector as a whole. Furthermore, the development of local emission factors by fuel and vehicle-type will enhance the accuracy of the emission estimation.

##### *3.3.5.8.4 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 a Tier 2 approach, locomotives category-level data are needed. These approaches require that railway, locomotive companies or the relevant transport authorities provide fuel consumption data. The use of representative locally estimated data is likely to improve accuracy although uncertainties will remain large.

##### *3.3.5.8.5 Water-borne navigation [1A3d]*

The provision of data by waterborne navigation is vital for the accurate estimation of emissions from this category. Complete and accurate data that 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 includes commercial/institutional buildings, as well as government, information technology, retail, tourism and services. There are great opportunities for improved energy efficiency in the buildings of this category. This category consumes 14.8% of South Africa's total final energy demand (Department of Energy, 2008). Fuels included are 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).

##### *3.3.6.1.2 Residential [1A4b]*

The residential sector includes fuel combustion in households. Fuels consumed in this category are 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.

##### *3.3.6.1.3 Agriculture/ forestry/ fishing/ fish farms [1A4c]*

The GHG emissions in this category include fuel combustion from agriculture (including large modern farms and small traditional subsistence farms), forestry, fishing and fish farms. Fuels included in this category are 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 energy balance data (Department of Energy, 2009), sub-bituminous coal was used only in 2000.

#### *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/institutional category for the period 2000 to 2012 was 189 211 Gg $CO_2$eq. Emissions increased by 69.6 % over the 12 year period from 9 549 Gg $CO_2$ eq in 2000 to 16 196 Gg $CO_2$eq in 2012 (**Figure 3.13**). Emissions were dominated by $CO_2$ emissions, with a small percentage of $CH_4$ and $N_2O$.

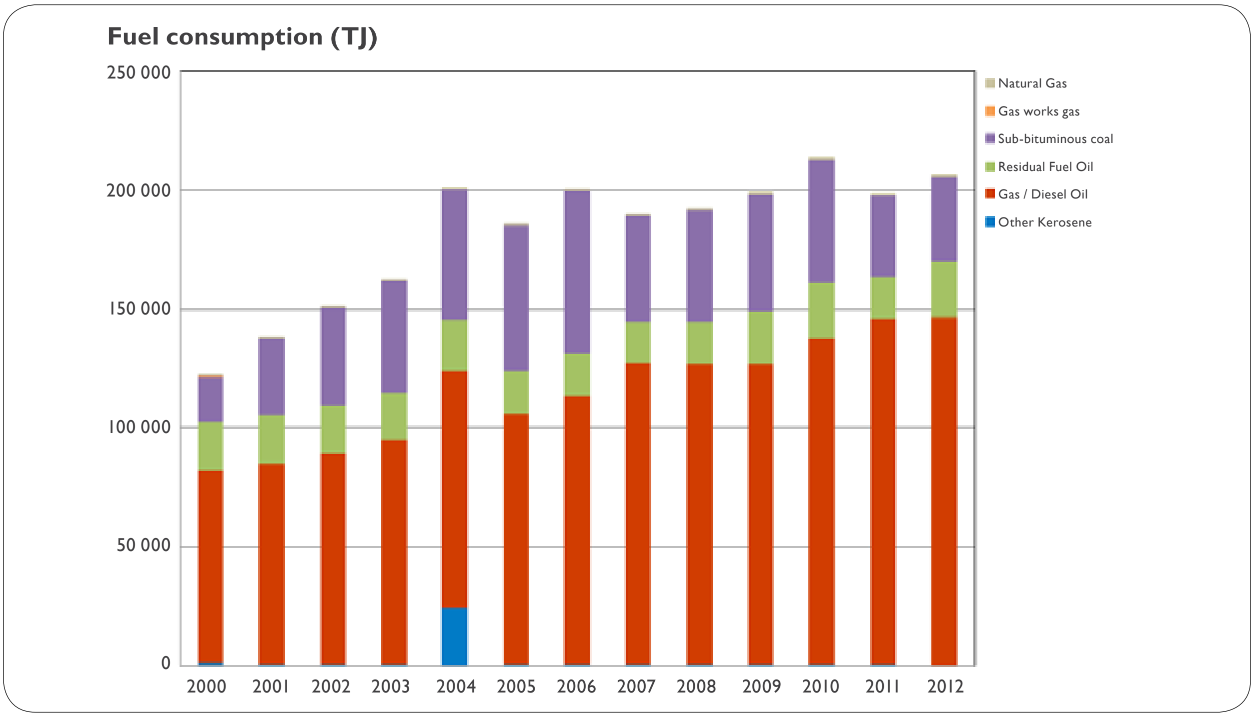



Figure 3.10: Sector 1 Energy: Fuel consumption in the commercial/institutional category, 2000 – 2012.

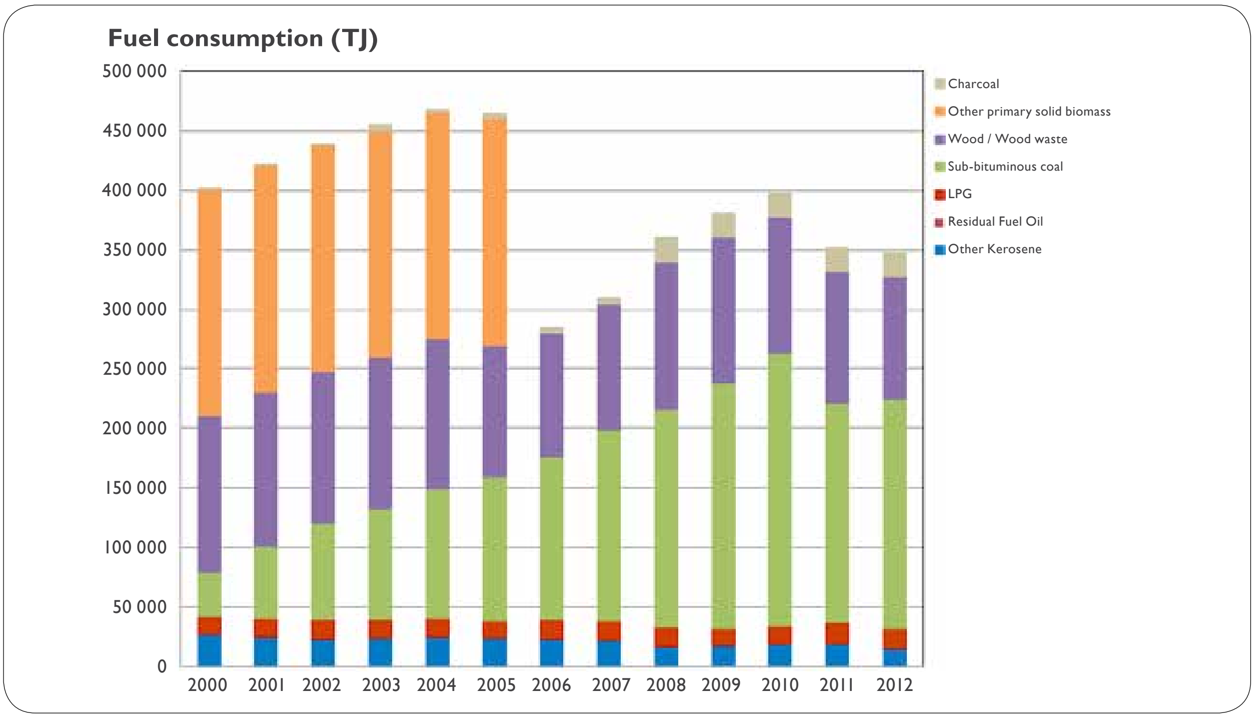



Figure 3.11: Sector 1 Energy: Trend in fuel consumption in the residential category, 2000 – 2012.

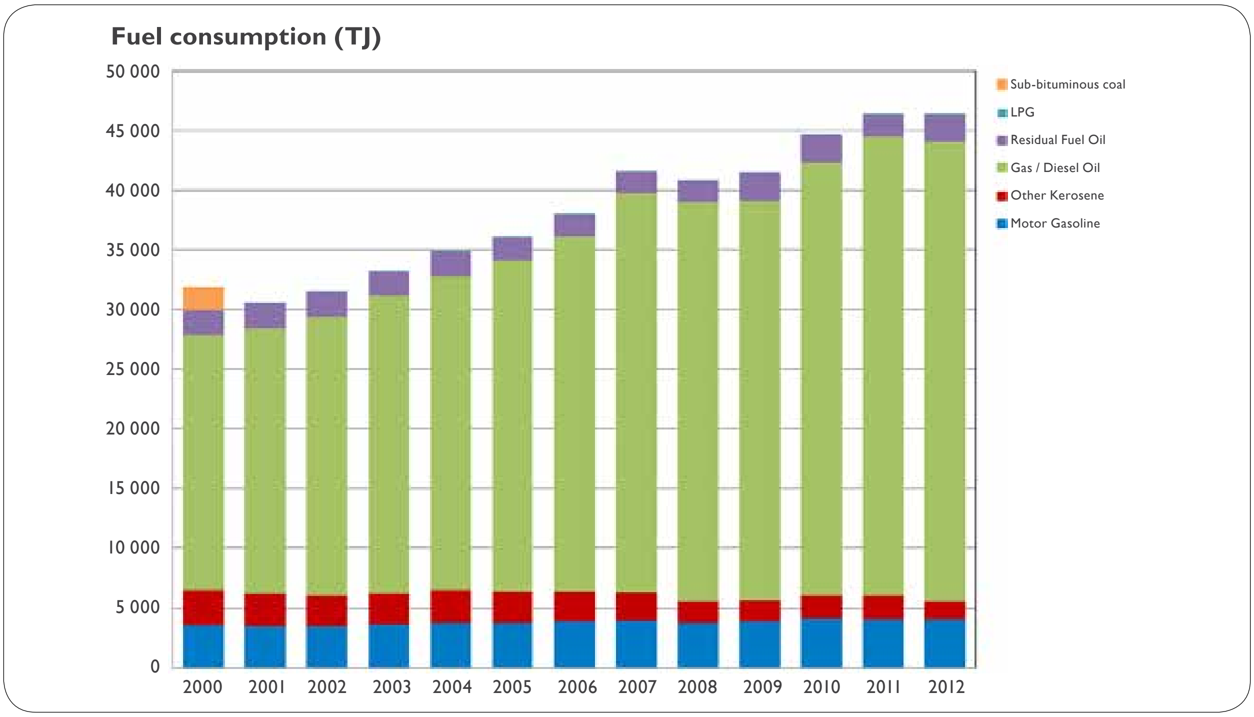



Figure 3.12: Sector 1 Energy: Trend in fuel consumption in the agriculture/forestry/fishing category, 2000 – 2012.

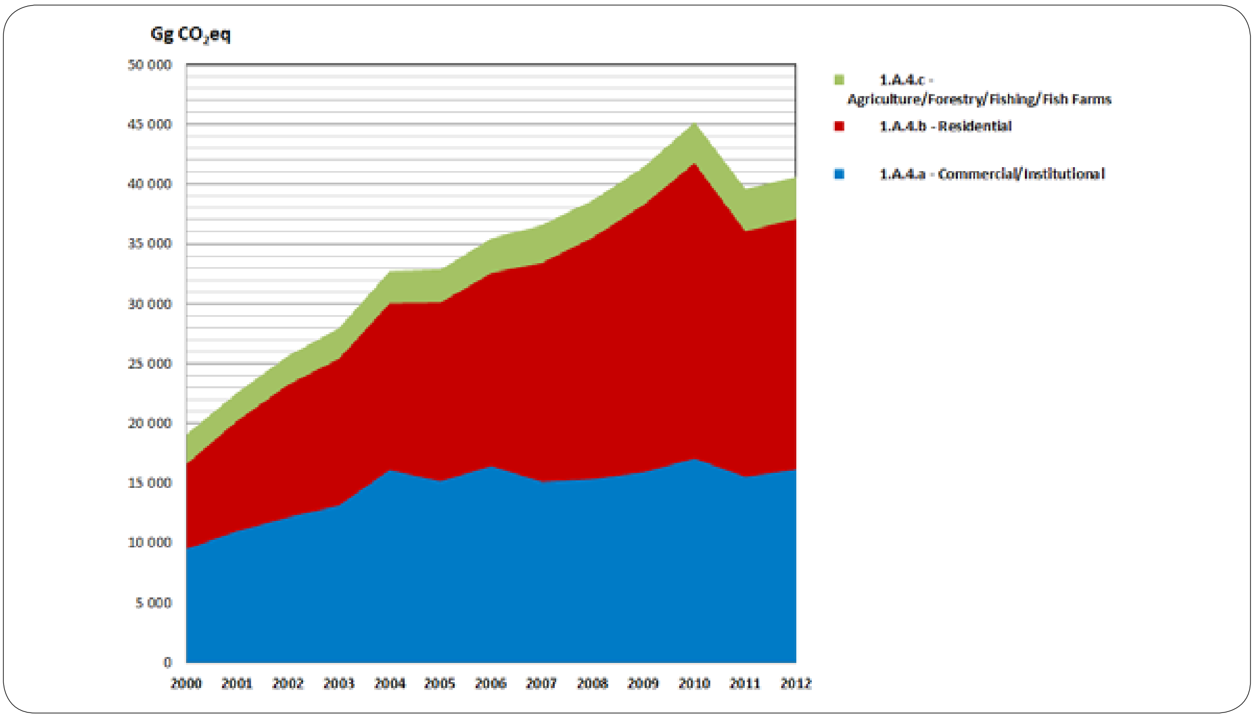



Figure 3.13: Sector 1 Energy: Trend in total GHG emissions from other sectors, 2000 – 2012.

In 2001 GHG emissions in this category increased by 15.6% compared with the previous year, and continued to increase annually from 2002 to 2003. 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. There was a decline in emissions 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. GHG emissions in 2011 decreased by 9%, followed by an increase of 3.9% in 2012.

### *3.3.6.2.2 Residential [1A4b]*

The estimation of total GHG emissions in the residential category for the period 2000 to 2012 was 211 817 Gg $CO_2$eq. Emissions in the residential sector have increased more than threefold from 7 101 Gg $CO_2$eq in 2000 to 20 943 Gg $CO_2$eq in 2012 (**Figure 3.13**). The increase was attributed mainly to population growth and economic growth (70.44% in 2000 to 75% in 2009). The GHG emissions in this category increased annually. The South African residential category consumes 20% of the total energy supply; this includes 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) (Department of Energy, 2009b). By 2009, 75% of households (9 245 357 households) were electrified (Department of Energy, 2009b).

It has been recorded that more than 10 million electrified households in South Africa have been 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. The 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.

GHG emissions in this category increased annually, however in 2011 there was a decline of 16.8%. 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 with the previous year.

### *3.3.6.2.3 Agriculture/ forestry/ fishing/ fish farms [1A4c]*

Primary agriculture contributes approximately 3.2% to the GDP of South Africa and provides almost 9% of formal employment. The majority of the energy for agriculture is sourced from diesel and vegetable waste (Department of Energy, 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 (Department of Energy, 2010). The estimated total GHG emissions of the agriculture/forestry/fishing/fish farms category for the period 2000 to 2012 was 36 801 Gg $CO_2$eq. GHG emissions increased from 2 387 Gg $CO_2$eq in 2000 to 3 432 Gg $CO_2$ eq in 2012, with annual increases of up to 9.3%. Decreases occurred in 2001 and 2008 (**Figure 3.13**). GHG emissions in 2008, during the global economic crisis, decreased by 1.7%, while in 2010 GHG emissions peaked, increasing by 7.9%.

There was a decline in emissions between 2000 and 2001. The contribution of the agriculture/forestry/fishing/fish farms category to the GDP also decreased by 3.3% during the same period. In 2008 the sector's GHG emissions decreased by 1.7%, accompanied by a massive GDP contribution of 16.1% in the same period. However, in 2009 its contribution to the GDP decreased to 0.3% and the GHG emissions increased by 1.46%., mainly because of the global economic crisis in 2008/09.

### 3.3.6.3 Methodological Issues

The Tier 1 approach was used to estimate emissions from all the other sectors. To estimate the total GHG emissions of 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 category was sourced from the DoE's energy digest reports, the DMR's SAMI 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 the period 20007 to 2010, the SAMI report was used to extrapolate the consumption of solid fuels for this category. An NCV of 0.0243 TJ/tonne was used to convert fuel quantities into energy units (Department of Energy, 2009a).

#### 3.3.6.4.2 Residential [1A4b]

Data on fuel consumption in the residential sector was obtained from the DoE's energy digest reports, the DMR's SAMI report, the FAO and SAPIA. The DoE energy reports were used to source solid fuels for the period 2000 to 2006, for the period 2007 to 2010), the SAMI report was used to extrapolate the consumption of solid fuels for this category. An NCV of 0.0243 TJ/tonne was used to convert fuel quantities into energy units (Department of Energy, 2009a).

#### 3.3.6.4.3 Agriculture/ forestry/ fishing/ fish farms [1A4c]

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

#### 3.3.6.4.4 Emission factors

A country specific emission factor for $CO_2$ for sub-bituminous coal was applied (***see section 3.3.3.4***). This country specific EF was used for all years going back to 2000. For all other fuels the 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 $TJ^{-1}$) | | |
|---|---|---|---|
| | $CO_2$ | $CH_4$ | $N_20$ |
| Motor gasoline | 69 300 | 3 | 0.6 |
| Other kerosene | 71 900 | 3 | 0.6 |
| Gas/ diesel oil | 74 100 | 3 | 0.6 |
| Residual fuel oil | 77 400 | 3 | 0.6 |
| LPG | 63 100 | 1 | 0.1 |
| Sub-bituminous coal | 96 250 | 1 | 1.5 |
| Gaswork 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 to 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 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 published by the DoE. For this inventory a combination of sources of activity data were used, including the DoE's energy digest, the DMR's SAMI report, SAPIA and the FAO. 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. Further, the N2O emission factor for coal was corrected. In the previous inventory a value of 3 kg $TJ^{-1}$ was applied but the source of the data could not be traced so the default IPCC emission factor was applied. The results for the published 2000 GHG inventory had to be recalculated as a result of the availability of more robust activity data.

#### 3.3.6.8 Source-specific Planned Improvements and Recommendations

There are several opportunities for improvement in this category including the collection of additional activity data, identification and disaggregation of contributing sources in each section, and the development of source specific methodologies.

##### 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 co-operate in the provision of data for the purposes of inventories. A regulatory framework should be established and implemented to ensure that sectors provide the 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 if data were collected 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 the 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 were 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 includes emissions from fuel combustion in stationary sources that are not specified elsewhere. The only fuel 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 12.7% in total GHG emissions between 2000 and 2012. Emissions were estimated at 989 Gg $CO_2$eq in 2000 and 1 114 Gg $CO_2$eq in 2012 (**Table 3.18**). There was a slight decline of 0.71% between 2000 and 2002 and a 4.23% decline in 2008.

### 3.3.7.3 Methodologica 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 were sourced from the DoE's energy digest reports (solid fuels and natural gas), the SAMI report to extrapolate activity data for solid fuels for the period 2007 to 2012, 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 (Department of Energy, 2009a).

Table 3.18: Sector 1 Energy: Trend in consumption and GHG emissions from the non-specified sector, 2000 – 2012.

| Period | Consumption (TJ) | $CO_2$ (Gg) | $CH_4$ (Gg $CO_2$eq) | $N_2O$ (Gg $CO_2$eq) | Total GHG (Gg $CO_2$eq) |
|---|---|---|---|---|---|
| 2000 | 14 222 | 986 | 1.07 | 2.54 | 989 |
| 2001 | 14 145 | 980 | 1.06 | 2.53 | 984 |
| 2002 | 14 138 | 980 | 1.06 | 2.53 | 983 |
| 2003 | 14 592 | 1 011 | 1.01 | 2.59 | 1 015 |
| 2004 | 15 027 | 1 041 | 1.13 | 2.69 | 1 045 |
| 2005 | 15 274 | 1 058 | 1.15 | 2.73 | 1 062 |
| 2006 | 15 430 | 1 069 | 1.16 | 2.76 | 1 073 |
| 2007 | 15 811 | 1 096 | 1.19 | 2.83 | 1 100 |
| 2008 | 15 142 | 1 049 | 1.14 | 2.71 | 1 053 |
| 2009 | 15 476 | 1 072 | 1.16 | 2.77 | 1 076 |
| 2010 | 16 376 | 1 135 | 1.23 | 2.93 | 1 139 |
| 2011 | 16 365 | 1 134 | 1.23 | 2.93 | 1 138 |
| 2012 | 16 025 | 1 111 | 1.2 | 2.87 | 1 114 |

##### 3.3.7.4.1 Emission factors

IPCC default emission factors from the 2006 IPCC Guidelines were used to estimate GHG emissions from the 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 $TJ^{-1}$) | | |
|---|---|---|---|
| | $CO_2$ | $CH_4$ | $N_2 0$ |
| 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 an 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 followed for the compilation of this inventory and identify areas of improvements.

#### 3.3.7.7 *Source-specific Recalculations*

In the 2000 GHG inventory, the non-specified category was excluded from the estimations. For this inventory the DoE's energy digest and SAPIA were used as sources of 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, and 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 GHGs 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, the fugitive emissions considered were from the following sources:

- Coal mining, including both surface and underground mining;
- Coal processing;
- The storage of coal and wastes; and
- The 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 causes 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 operations are low. In addition, methane can continue to be emitted from abandoned coal mines after mining has ceased.

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

- ***Mining emissions:*** The release of gas during the breakage of coal and the surrounding strata during mining operations
- ***Post-mining emissions:*** Emissions released during the handling, processing and transportation of coal. Coal continues to emit gas even after it has been mined, but at a much slower rate than during coal breakage stage.
- ***Low-temperature oxidation:*** Emissions are released when coal is exposed to oxygen in air; the coal oxidizes to slowly produce $CO_2$.
- ***Uncontrolled combustion:*** Uncontrolled combustion occurs 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. It may be anthropogenic or occur naturally.

### 3.4.1.2 Overview of Shares and Trends in Emissions

#### 3.4.1.2.1 1B1a Coal mining and handling [1B1a]

In 2000 South African mines produced 217.5 Mt of coal and the fugitive emissions in that period were 2 003 Gg $CO_2$eq. In 2004, 242.82 Mt of coal were produced, of which 146.27 Mt were consumed locally and the fugitive emissions were equivalent to 2 141 Gg $CO_2$eq. In 2005, 245 Mt of coal were produced, and 174 Mt was consumed locally. In 2006, 246 Mt were produced and the fugitive emissions accounted for 2 154 Gg $CO_2$eq. In 2007, 247.7 Mt of coal were produced (with a value of R14.69 billion) and 2 179 Gg $CO_2$eq of fugitive emissions were produced.

Total GHG fugitive emissions from coal mining decreased from 2 003 Gg $CO_2$eq in 2000 to 1 760 Gg $CO_2$eq in 2012 (**Table 3.20**). GHG emissions in this category increased by 49.1% between 2000 and 2011, then declined in 2012. The increase is mainly due to the increased demand for coal, particularly for electricity generation. Since opencast mining dominates overall coal production, $CH_4$ emissions have remained relatively stable over the 2000 to 2012 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 2012.

| Period | $CO_2$ Gg | $CH_4$ (Gg $CO_2$eq) | Total GHG (Gg $CO_2$eq) |
|---|---|---|---|
| 2000 | 24 | 1 979 | 2 003 |
| 2001 | 23 | 2 137 | 2 161 |
| 2002 | 23 | 1 938 | 1 961 |
| 2003 | 25 | 2 093 | 2 118 |
| 2004 | 25 | 2 141 | 2 167 |
| 2005 | 26 | 2 155 | 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 |
| 2011 | 35 | 2 951 | 2 986 |
| 2012 | 21 | 1 739 | 1 760 |

### 3.4.1.3 Methodologica Issues

#### 3.4.1.3.1 1B1a Coal mining and handling [1B1a]

A Tier 2 approach was used to calculate fugitive emissions from coal mining and handling. Fugitive emission estimates were based on coal production data. Coal waste dumps were also considered as an emission source. This methodology requires 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 remained constant throughout 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 SAMI report compiled by the DMR (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, therefore, has estimated emissions related to this activity.

### 3.4.1.5 Uncertainty and Time-series Consistency

The major source of uncertainty in this category is activity data on coal production statistics. According to the 2006 IPCC Guidelines, country-specific tonnages are likely to have an uncertainty in the 1 to 2% range, but if raw coal data are not available, then the uncertainty will increase to about ±5%, when converting from saleable coal

Table 3.21: Sector 1 Energy: Coal mining activity data for the period 2000 to 2012.

| 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 |
| 2011 | 153 430 367 | 113 400 000 |
| 2012 | 152 430 368 | 118 800 000 |

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 |

production data. The data are also influenced by moisture content, which is usually present at levels between 5 and 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 followed for the compilation of this inventory and identify areas of improvements.

#### 3.4.1.7 Source-specific Recalculations

Emissions were recalculated for 2000 using country-specific EFs. The recalculation resulted in the reduction of emissions from 40 Mt $CO_2$eq to 2 Mt $CO_2$eq, 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 the 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 emissions 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 flaring was equivalent to 13 496 Gg $CO_2$ for the period 2000 to 2012. Emissions decreased by 20% from 752 Gg $CO_2$eq in 2000 to 642 Gg $CO_2$eq in 2012 (**Table 3.23**).

#### *3.4.2.3 Methodologica Issues*

Fugitive emissions are a direct source of GHGs due to the release of $CH_4$ and formation $CO_2$ ($CO_2$ produced in 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, $CO_2$ emissions from venting and flaring have been estimated using real continuous monitoring results and therefore no emission factors were used.

#### *3.4.2.4 Data Sources*

This is the first time this subcategory has been accounted for in the national GHG inventory. Data on oil and natural gas emissions were obtained directly from refineries and, to a lesser extent, from the energy digest reports (Department of Energy, 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 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 the completeness of the accounting of emissions from this subsector, 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 Category Description*

According to the 2006 IPCC Guidelines (p.4.35), *other emissions from energy production* refers to emissions from geothermal energy production and other energy production not included in the 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.

Table 3.23: Sector 1 Energy: Total GHG emissions from venting and flaring for the period 2000 – 2012.

| Year | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gg $CO_2$eq | 752 | 753 | 955 | 1 458 | 1 379 | 1 160 | 1 133 | 1 133 | 1 138 | 1 243 | 964 | 786 | 642 |

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 374 300 Gg $CO_2$eq for the period 2000 to 2012. Emissions fluctuated throughout the 12 year period (**Table 3.24**).

### 3.4.3.3 Methodologica 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: 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 identify areas of improvement.

### 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.

Table 3.24: Sector 1 Energy: Total GHG emissions from the category other emissions from energy production (1B3), 2000 – 2012.

| Year | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gg $CO_2$eq | 30 597 | 31 039 | 31 317 | 29 812 | 31 568 | 27 854 | 27 708 | 28 160 | 27 134 | 27 435 | 27 019 | 26 836 | 27 821 |

# 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 emission sources are releases from industrial processes that chemically or physically transform raw material (e.g. ammonia products manufactured from fossil fuels). GHG emissions released during these processes are $CO_2$, $CH_4$, $N_2O$, HFCs, $SF_6$ and PFCs. Also included in the IPPU sector are GHG emissions used in products such as refrigerators, foams and aerosol cans.

The estimation of GHG emissions from non-energy sources is often difficult because they are widespread and diverse. The difficulties in the allocation of GHG emissions between fuel combustion and industrial processes arise when by-product fuels or waste gases are transferred from the manufacturing site and combusted elsewhere in different activities. The largest source of emissions in the IPPU sector in South Africa is 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 late 2008, economic growth had been 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 recession, GHG emissions during that period decreased enormously across almost 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 2000, there was 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 12-year reporting period (**Figure 4.1**). Accumulated emissions totalled 467 127 Gg $CO_2$eq. IPPU sector emissions increased annually by an average of 2.7% between 2000 and 2006 due to robust economic growth during this time, which led to an increased demand for products. Between 2006 and 2009 there was a decline of 16% (from 39 298 Gg $CO_2$eq to 37 128 Gg $CO_2$eq) in the IPPU emissions. This decrease was mainly due to the global economic recession and the electricity crisis that occurred in South Africa during that period. In 2010 emissions increased again by 7.4%. The economy was beginning to recover from the global recession. Another reason for the increase in GHG emissions in 2010 was that South Africa hosted the 2010 FIFA World Cup and, as a result, an increase in demand for commodities was experienced.

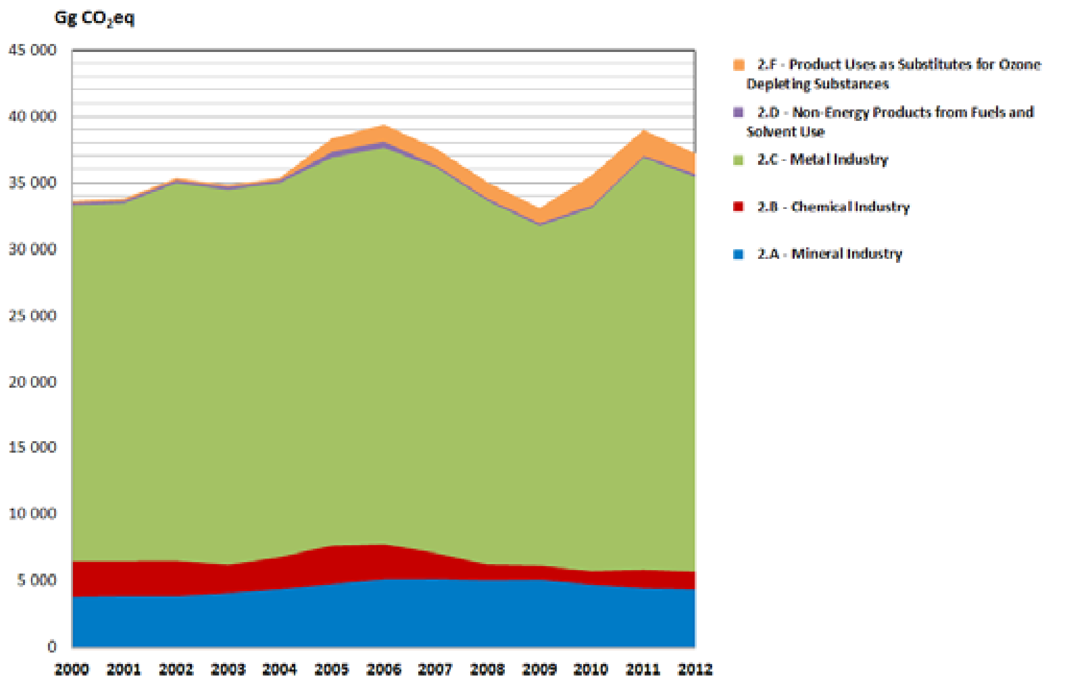



Figure 4.1: Sector 2 IPPU: Trend and emission levels of source categories, 2000 – 2012.

The most significant source of emissions in the IPPU sector was the metal industries subsector, which contributed between 79.9% and 80.5% over the period 2000 to 2012. The biggest contributor in 2012 to the metal industry emissions was the iron and steel industry (50.5%). $CO_2$ emissions constituted between 92.2% and 88.7% of the total IPPU emissions between 2000 and 2012, while HFCs and PFCs contributed an average of 2.2% and 2.7% respectively (**Figure 4.2**).

### 4.1.2 Key sources

The major key category in the IPPU sector in terms of emissions is *iron and steel production* (2.C.1). The other key categories are *ferroalloys production* (2.C.2), *product uses as substitutes for ODS* (2.F.1), *aluminium production* (2.C.3) and *chemical industries* (2.B) (see **Table 1.9** and **Table 1.11**). These are similar findings to the key category analysis performed in the 2010 inventory.

### 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

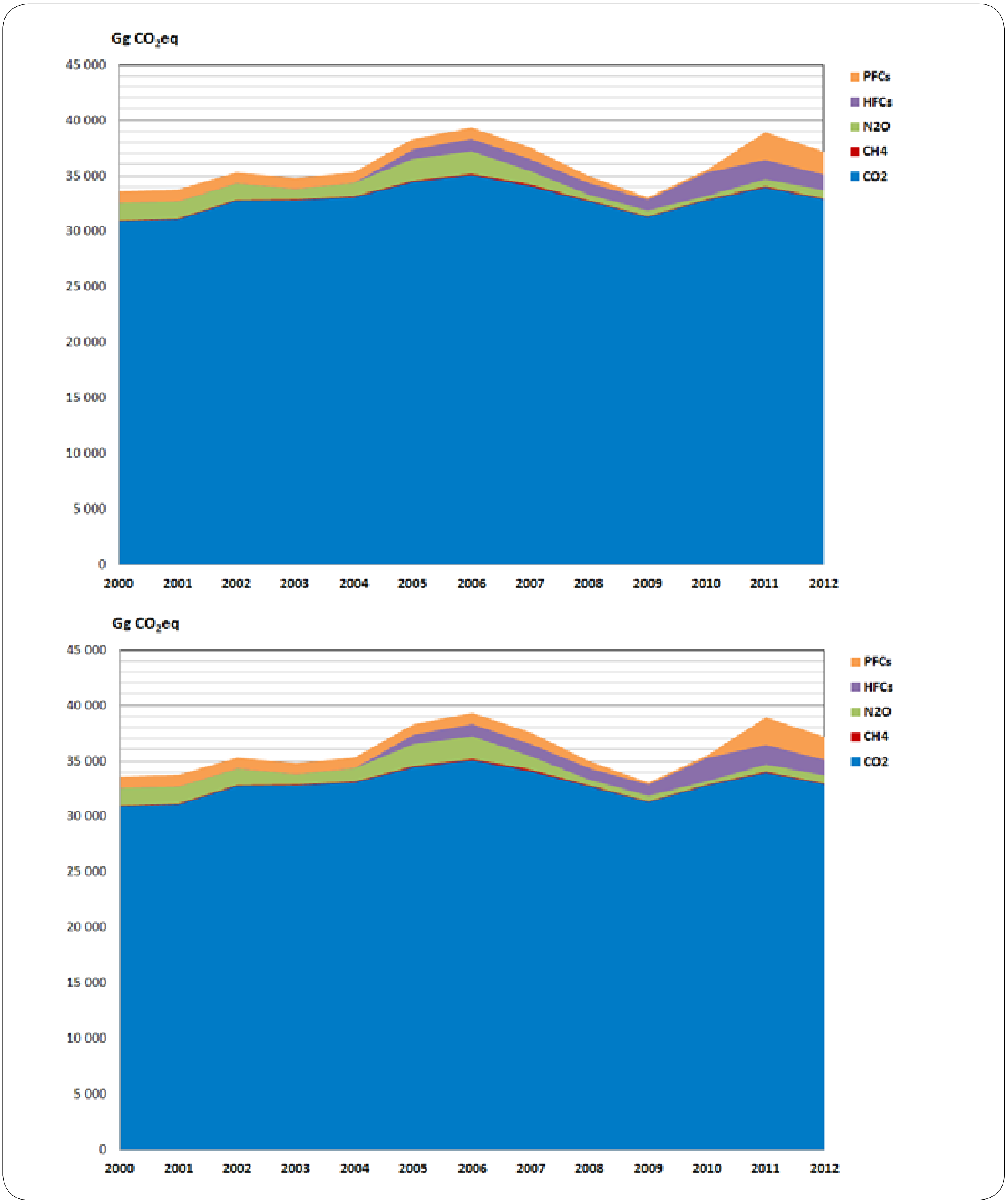



Figure 4.2: Sector 2 IPPU: Trend and emission levels of the various greenhouse gases, 2000 – 2012.

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 emissions. Therefore it is imperative to ensure that all the sources that have been identified are allocated to the appropriate sources. In the compilation of GHG emissions from the IPPU sector, 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 includes (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 are 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 that have not been included in the inventory will give direction on the disproportionate amount of effort required for 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. |

| Category | Definition of category | Justification for exclusion |
|---|---|---|
| **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 $SF_6$ and PFCs from other product uses 2G3 $N_2O$ | 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

Mineral production emissions are mainly process-related GHG emissions resulting from the use of carbonate raw materials. The mineral production category is divided into five subcategories; cement production, lime production, glass production, process uses of carbonates, and other mineral products processes. For this inventory report, emissions are reported for three subcategories: 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, which has a clinker content of >95%, is described by the class CEM I. CEM II cements can be 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 limestone. CEM III cements have a lower clinker content and are also split into subgroups: A (35 – 64% clinker) and B (20 – 34% clinker). South Africa's 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 Africa region, such as 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 50% of the cement produced goes to the 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, e.g., it is used as a neutralizing and coagulating agent in chemical, hydrometallurgical and water treatment processes and a fluxing agent in pyrometallurgical processes. Pyrometallurgical quicklime sales have been increasing, while the demand for quicklime in the chemical industry has been 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 ($Na2CO_3$). Glass makers do not produce glass only from raw materials, they also use a certain amount of recycled scrap glass (cullet). The chemical composition of glass is 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 2012 were 59 472 Gg $CO_2$eq. Emissions increased by 35% between 2000 and 2007 to 5 217 Gg $CO_2$eq, after which emissions slowly declined (by 15.8%) to 4 411 Gg $CO_2$eq in 2012 (**Figure 4.3**). Over the 12-year period the emissions from the mineral industries increased by 14.7%. The most significant GHG emission sources in 2012 were cement production (contributing 87.2% of total GHG emissions), followed by lime production (10.3%). GHG emissions from glass production accounted for only 2.6% of the total emissions.

#### 4.2.2.1 Cement Production [2A1]

The GHG emissions from cement production increased from 3 347 Gg $CO_2$eq in 2000 to 4 583 Gg $CO_2$eq in 2007, after which emissions declined to 3 845 Gg $CO_2$eq in 2012. Cement production in South Africa increased significantly from the period 2000 to 2007 as a result of economic growth. There was a 2.0%, 7.1%, 5.8% and 2.5% decrease in emissions in 2008, 2010, 2011 and 2012, respectively. In 2009 the South African economy went into recession and the GDP 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, increased inflation and the introduction of the National Credit Act (DMR, 2009/2010). One 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). Demand for cement since 2009 has continued to increase. In 2012, the DMR

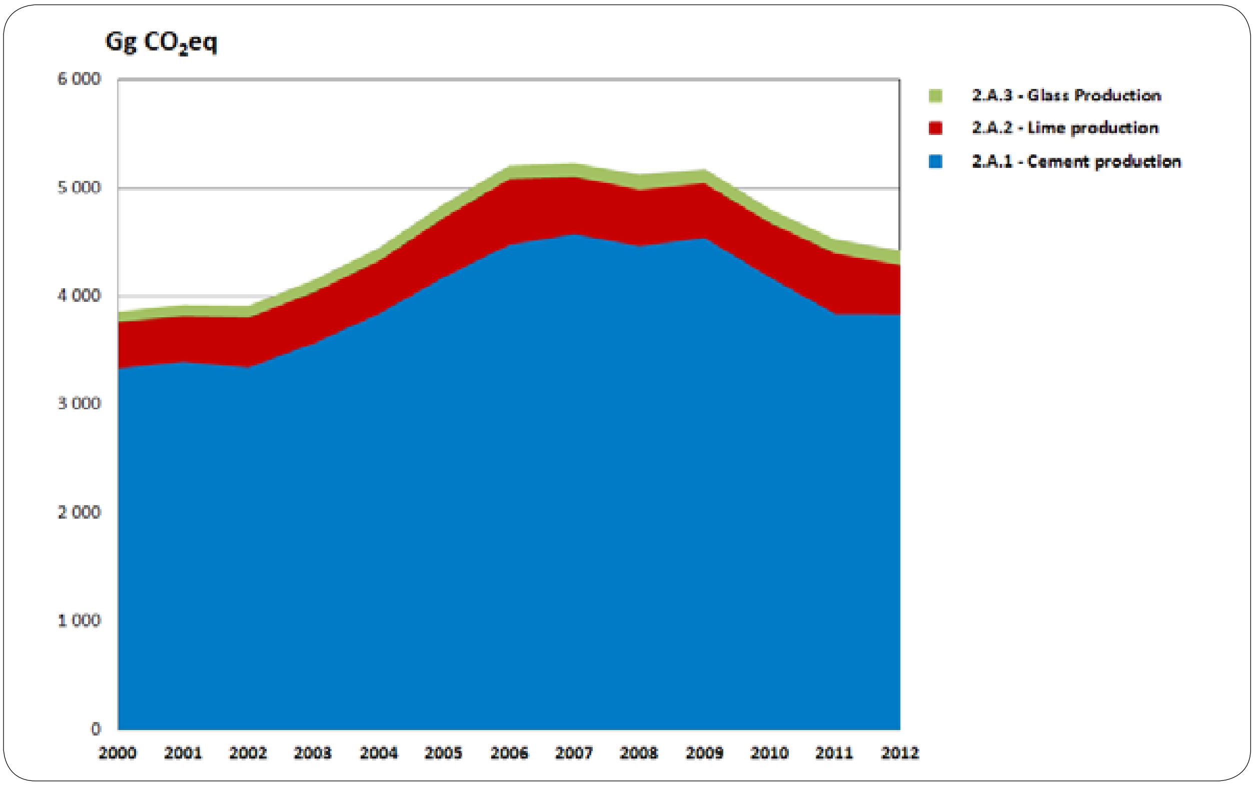



Figure 4.3: Sector 2 IPPU: Trend and emission levels in the mineral industries, 2000 – 2012.

estimated that cement imports increased by 62% in 2012 compared with 2011 imports (DMR 2013). Hence, despite an increase in cement demand, emissions have declined by 15% between 2009 and 2012 because clinker is being imported.

#### *4.2.2.2 Lime Production [2A2]*

The demand for lime production in South Africa is mainly linked to developments and investments in the steel and metallurgical industries (DMR Report R85/2010). The local sales volume of lime decreased by 21% in 2012, compared with the previous year, to 1.2 Mt due to a decrease in demand for quicklime for the steel and alloys industries. According to media reports, South African steelmakers collectively produced 6.9 Mt in 2012 compared with 7.5 Mt the previous year, dropping in the world steel-production rankings from 21 to 22. The total sales volume of quicklime for pyrometallurgical and chemical applications decreased by 22% to 1.11 Mt owing to subdued demand from the steel industry, and sales value decreased by 14% to R1.1 billion (DMR 2013). The total cumulative estimation of GHG emissions from lime production for the period 2000 to 2012 was 6 480 Gg $CO_2$eq.

The fluctuations in lime production were directly linked to developments and investments in the 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 increased by 6.3% between 2000 and 2012, which is mainly due to an increase in the number of infrastructure projects and the 2010 FIFA World Cup preparation.

#### *4.2.2.3 Glass Production [2A3]*

South Africa's glass production emissions increased consistently from 2001 to 2005 and again in 2007 to 2008. In 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. GHG emissions picked up again in 2011 (1.9%) and 2012 (7.5%). Over the 12-year period there was a 53.2% increase in emissions from glass production. 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 2012 was 1 295 Gg $CO_2$eq.

### 4.2.3 Methodological issues

#### *4.2.3.1 Cement Production [2A1]*

A Tier 2 approach, based on plant-level data, was used to determine the emissions from cement production.

#### *4.2.3.2 Lime Production [2A2]*

The production of lime involves various steps, which include the 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 report (2012/2013). Based on the IPCC's default method, an emission factor that assumes an 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 national level glass production was also determined from industry supplied activity data.

### 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 declined in South Africa between 2008 and 2012. With the decline in domestic demand of cement due to economic recession and the electricity crisis, the cement production industry had to reduce production. Local cement production declined by 14 % between 2008 and 2012. In 2009 Sephaku Cement entered the local cement production market, adding an estimated 1.2 Mt of production capacity to the market (SAMI, 2012/2013).

##### *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 CO2 by weight (IPCC, 2006, p. 2.11). The emission factor for $CO_2$, provided by IPCC 2006 Guidelines, is 0.52 tonnes of $CO_2$ per tonne clinker. The IPCC default emission factors were used to estimate the total emissions. The country-specific clinker fraction for the period 2000 to 2012 ranged between 69% - 76% (**Table 4.3**).

Table 4.2: Sector 2 IPPU: Activity data for cement, lime and glass Production, 2000 – 2012.

| Period | Cement Production | Quicklime | Hydrated lime | Total Glass Produced | Recycled Glass |
|---|---|---|---|---|---|
| | Tonnes | Tonnes | Tonnes | Tonnes | Tonnes |
| 2000 | 6 436 640 | 532 100 | 46 270 | 561 754 | 189 957 |
| 2001 | 6 551 695 | 522 910 | 45 470 | 624 156 | 202 227 |
| 2002 | 6 451 258 | 572 369 | 49 771 | 667 110 | 225 382 |
| 2003 | 6 879 106 | 586 969 | 51 041 | 702 008 | 245 359 |
| 2004 | 7 404 575 | 608 056 | 52 874 | 726 644 | 247 182 |
| 2005 | 8 054 255 | 685 860 | 59 640 | 775 839 | 264 026 |
| 2006 | 8 627 144 | 755 302 | 65 678 | 808 328 | 299 474 |
| 2007 | 8 812 852 | 660 772 | 57 458 | 858 382 | 333 444 |
| 2008 | 8 603 568 | 648 462 | 56 388 | 978 488 | 391 620 |
| 2009 | 8 749 099 | 626 465 | 54 475 | 993 784 | 444 949 |
| 2010 | 8 051 414 | 626 777 | 54 502 | 1 009 043 | 489 622 |
| 2011 | 7 402 299 | 700 000 | 55 000 | 1 019 755 | 489 482 |
| 2012 | 7 393 325 | 564 000 | 51 000 | 1 095 264 | 525 730 |

Table 4.3: Sector 2 IPPU: Clinker fraction for the period 2000 – 2012.

| Year | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 | 0.69 | 0.69 |

#### 4.2.4.2 Lime Production [2A2]

The DMR publishes data on limestone and dolomite production in South Africa in the SAMI report (DMR, 2012/2013). The SAMI provides a breakdown of limestone demand; 80% goes to cement manufacturing and the remaining 20% goes to metallurgical, agricultural and other uses. No data was 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 to 98% CaO content, and hydraulic lime, which has a range of 62 to 92% CaO. The GHG emission factor for high-calcium lime (0.75 tonnes $CO_2$/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 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 a typical raw material mixture, according 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 to 7%. Since a tier 2 method with plant–level information was used there is no need to account for imports and exports, therefore a low uncertainty (1%) was assumed.

#### 4.2.5.2 Lime Production [2A2]

The only available data for lime production was sourced from the SAMI report; 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 to 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 at +/- 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 SAMI reports. 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 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 2009 SAMI reported production as 5 027 293 tonnes and the industry reported 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 were categorised according to IPCC categorization. An independent reviewer was appointed to assess the quality of the inventory, determine the conformity of the procedures followed for the compilation of this inventory and identify areas of improvement.

### 4.2.7 Source-specific recalculations

No recalculations were performed for cement production, lime production or glass production.

### 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 must 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 DMR, 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. GHG emissions from the following chemical production processes were reported: 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: 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, in explosives of various types and as a refrigerant.

#### 4.3.1.2 Nitric Acid Production [2B2]

Nitric acid is a raw material 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 used mainly in paint manufacture, paper, plastics, rubber, ceramics, fabrics, floor coverings, printing ink, among others. According 2006 IPCC Guidelines (p. 3.47), there are three processes in titanium dioxide production that result in GHG emissions, namely, a) titanium slag production in electric furnaces; b) synthetic rutile production using the Becher Process and c) rutile $TiO_2$ production through the 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 carbon black production include natural gas, petroleum and coal. The use of these fossil fuels may involve the combustion of hydrocarbon content for heat rising and the production of secondary fuels (IPCC, 2006, p.3.56). GHG missions from the combustion of fuels obtained from feed stocks should be allocated to the source category in the IPPU sector, however, where the fuels are not used within the source category but are transferred out of the process for combustion elsewhere, these emissions should be reported in the appropriate energy sector source category (IPCC, 2006, p. 3.56). Commonly, the largest percentage of carbon black is used in the tyre and rubber industry, and the rest is used as pigment in applications such as ink and carbon dry-cell batteries.

### 4.3.2 Trends in emissions

The chemical industries subsector contains confidential information, so, following the IPCC Guidelines for reporting confidential information, no disaggregated 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 emissions totalling 26 034 Gg $CO_2$eq over the period 2000 to 2012. Emissions from this category fluctuated considerably over the 12-year period, with a maximum of 2 889 Gg $CO_2$eq in 2005 and a minimum of 1 011 Gg $CO_2$eq in 2010 (**Figure 4.4**: Sector 2 IPPU: Trend and emission levels in the chemical industries between 2000 and 2012).

Overall there was a 50.8% decline in GHG emissions from this category over the 12-year period, largely due to $N_2O$ emission reductions in nitric acid production.

### 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 of 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.

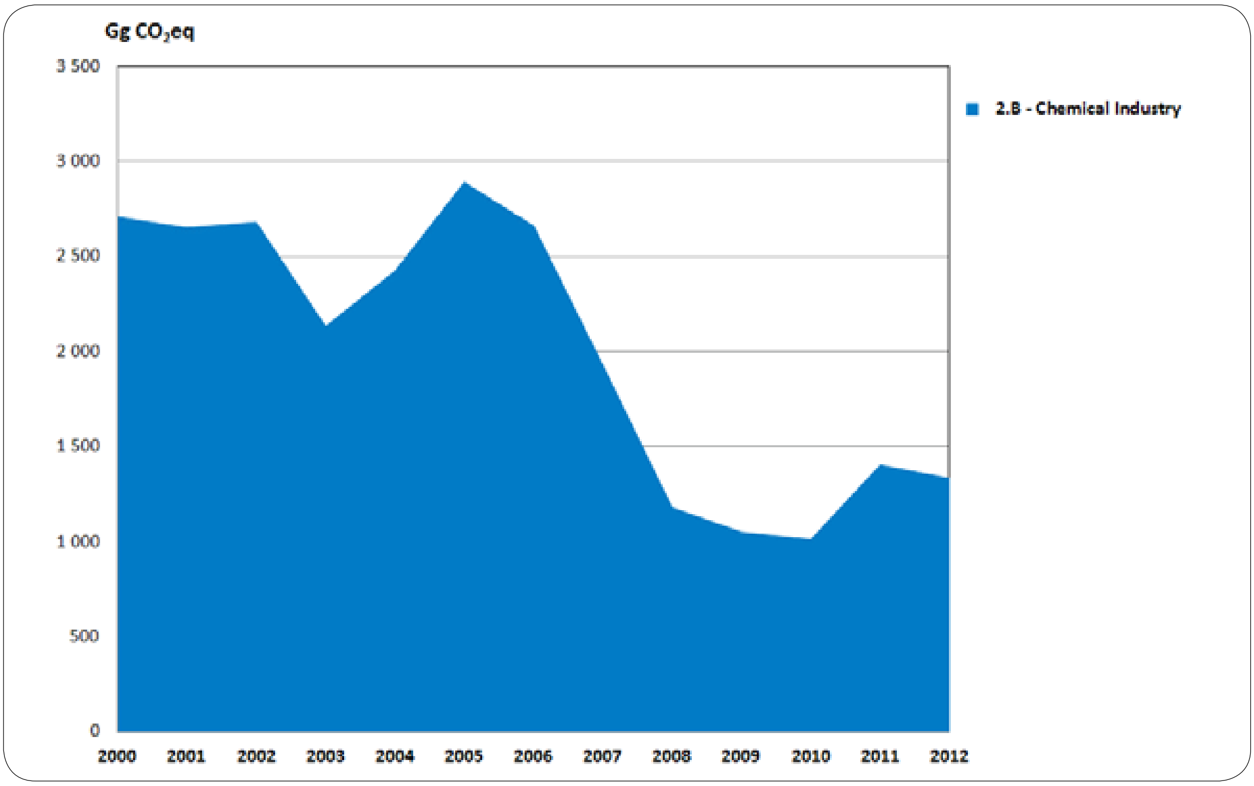



Figure 4.4: Sector 2 IPPU: Trend and emission levels in the chemical industries between 2000 and 2012.

#### *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 2000 were not provided for; therefore it was assumed that the GHG emissions for 2001 were similar to the GHG emissions for 2000.

#### 4.3.4.2 Nitric Acid Production [2B2]

The amount of nitric acid emissions released was sourced from all nitric acid production plants. The GHG emissions were calculated based on continuous monitoring (tier 3 approach). Sasol emissions were also included.

#### 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 were sourced from the titanium dioxide production plants. Emission estimates were 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 carbon black 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 Guidelines (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 for two reasons: a) $N_2O$ may be generated in the gauze reactor section of nitric acid production as an unintended reaction by-product; and b) the exhaust gas may or may not be treated for NOx control and the NOx abatement system may or may not reduce the $N_2O$ concentration of the treated gas. The uncertainty measures of default emission factors are +/- 2%. The IPCC guidelines suggest that where uncertainty values are not available from other sources, as is the case for this inventory, this default value of ±2 percent should be applied to the activity data (IPCC 2006, Vol 3, Chpt. 3, pg. 3.25). For emission factors the default uncertainty range between 10% and 40% for a tier 2 approach (IPCC 2006, Vol 3, Chpt. 3, and pg. 3.23, Table 3.3). Since a tier 3 approach was applied in this inventory the lower uncertainty value of 10% was assumed.

#### 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 QC 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

No recalculations were performed.

### 4.3.8 Source-specific planned improvements and recommendations

For ammonia, nitric acid, carbide and titanium production it is recommended that the 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 include the production of iron and steel, ferroalloys, aluminium, lead, and zinc. Estimates were made for emissions of $CO_2$ from the manufacture 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 emission 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 steel-making 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 includes: 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 Ferroalloy 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, 2013). South Africa is also the largest producer of iron and manganese ores, and an important supplier of ferromanganese, ferrosilicon and silicon metal (SAMI, 2013).

#### *4.4.1.3 Aluminium Production [2C3]*

According to the 2006 IPCC Guidelines, aluminium production is realised via 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;
- Perfluorocarbon (PFC) emissions of CF4 and $C_2F_6$ during anode effects. Also emitted are smaller amounts of process emissions, CO, $SO_2$, and NMVOCs. $SF_6$ 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 constitutes approximately 7% of the primary production; and
- Direct smelting, which eliminates the sintering step and constitutes 22% of 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.
- The pyrometallurgical process: this involves the utilization of an 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.
- The electrolytic: this is a hydrometallurgical technique, during which zinc sulphide is calcinated, resulting in the production of zinc oxide. The 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 367 785 Gg $CO_2$eq between 2000 and 2012. The major contributor over this period was *iron and steel production* (55.4 %), followed by *ferroalloy production* (36.0 %) and *aluminium production* (8.0 %) (**Figure 4.5**). In 2000 almost half (47.1%) of the total GHG emissions (in Gg $CO_2$eq) from *aluminium production* were PFC emissions. This rose to 65.0% in 2011 and 2012 due to the closure of the Soderberg and Side-Worked Pre-Bake processes in 2009. The Aluminium plants released large amounts of $C_2F_4$ and $CF_4$ during 2011 and 2012 due to inefficient operations (switching on and off at short notice) as they were used to control the electricity grid.

Total emissions in the *metal industry* increased between 2000 and 2006, with a sharp decline (14.2 %) between 2006 and 2009 (**Figure 4.6**). This decrease was evident in the three major contributing industries, with emissions from iron and steel production showing a decline of 25.7%, aluminium production emissions declined by 39.6% and zinc production emissions declined by 4.4% over this period. Ferroalloy industry emissions increased in most years, except in 2008 and 2012, when they declined by 0.6% and 5.0% respectively. These declines could be attributed to reduced production caused by electricity supply challenges and decreased demand following the economic crisis that occurred during 2008/2009. Between 2009 and 2012 total GHG emissions from the metal industries increased by 16.2%, from 27 328 Gg $CO_2$eq in 2009 to 29 721 Gg $CO_2$eq in 2012. Although emissions from zinc production were relatively small, emissions decreased by 100% between 2009 and 2012 due to the closure of zinc production facilities in South Africa.

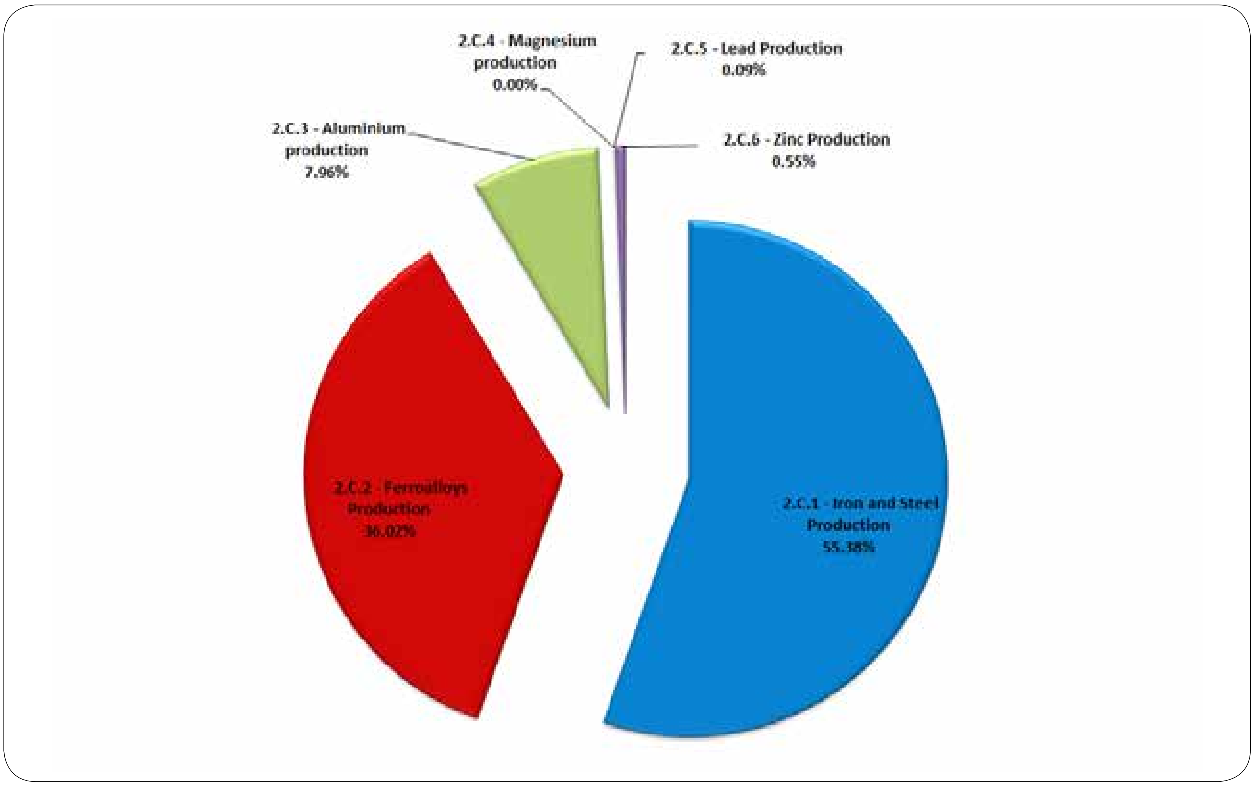



Figure 4.5: Sector 2 IPPU: Trend and emission levels in the chemical industries between 2000 and 2012.

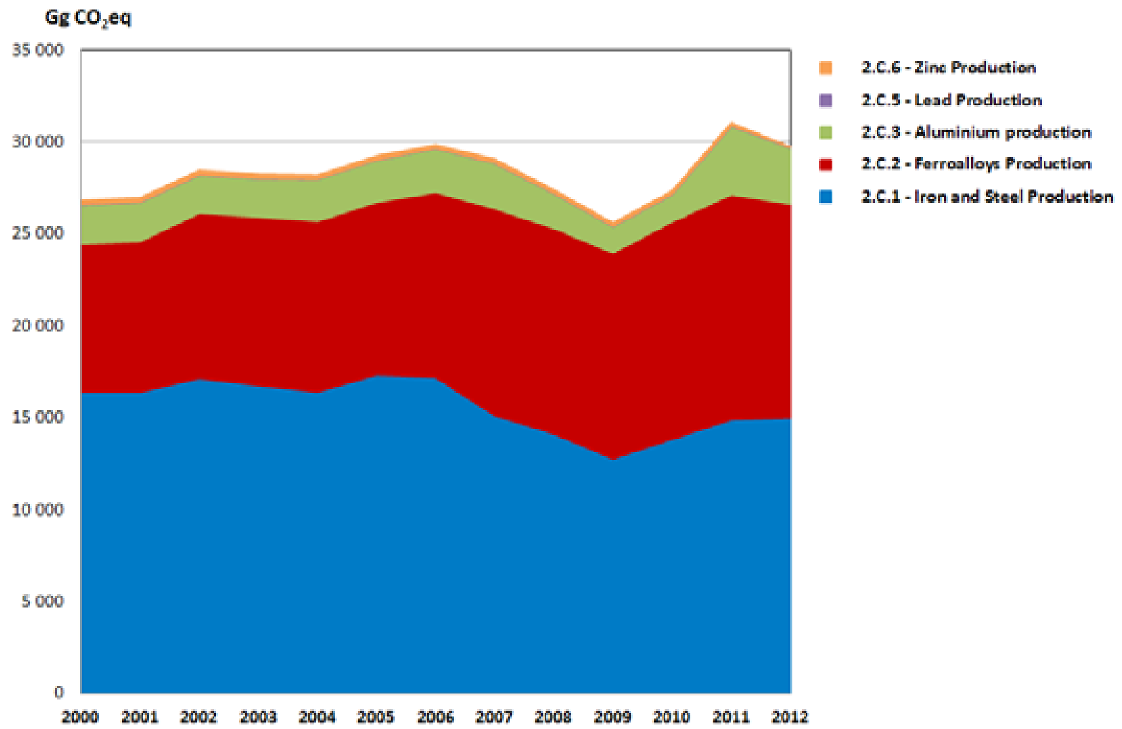



Figure 4.6: Sector 2 IPPU: Trend and emission levels in the metal industry, 2000 – 2012.

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 1.0% over this period. In 2009, GHG emissions from zinc production increased by 4.9%, and this was attributed to new mine developments, such as the Pering Mine and the Anglo American Black Mountain mine and Gamsberg project (DMR, 2009).

Over the 12-year period emissions from iron and steel, lead and zinc production declined (8.5%, 30.3% and 100%, respectively), while emissions increased by 45.9% and 43.9% from the aluminium and ferroalloy industries, respectively.

### 4.4.3 Methodology

#### *4.4.3.1 Iron and Steel Production [2C1]*

A combination of the Tier 1 and Tier 2 approaches (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 of energy and process emissions emanating from the use of coke was not done due to a lack of disaggregated information on coke consumption. Hence, energy-related emissions from iron and steel production have been accounted for through the application of default IPCC emission factors.

Table 4.4: Sector 2 IPPU: Activity data for the various metal industries, 2000 – 2012.

| | Consumption (tons) | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **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 | 3 991 686 | 3 904 276 |
| | 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 | 3 554 803 | 3 904 276 |
| | 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 | 4 603 558 | 4 599 015 |
| | 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 | 1 414 164 | 1 493 420 |
| | 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 | 570 129 | 677 891 |
| **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 | 3 422 000 | 3 063 000 |
| | Manganese alloys (7% C) | 596 873 | 523 844 | 618 954 | 607 362 | 611 914 | 570 574 | 656 235 | 698 654 | 502 631 | 274 923 | 473 000 | 714 000 | 706 000 |
| | Manganese alloys (1% C) | 310 400 | 259 176 | 315 802 | 313 152 | 373 928 | 275 324 | 277 703 | 327 794 | 259 014 | 117 683 | 317 000 | 350 000 | 177 000 |
| | 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 | 126 000 | 83 000 |
| | Silicon metal | 40 600 | 39 400 | 42 500 | 48 500 | 50 500 | 53 500 | 53 300 | 50 300 | 51 800 | 38 600 | 46 400 | 58 800 | 53 000 |
| **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 | 812 209 | 666 790 |
| | Soderberg | 89 572 | 85 973 | 82 749 | 89 037 | 88 644 | 86 529 | 90 082 | 91 334 | 22 722 | 0 | 0 | 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 | 812 209 | 666 790 |
| | SWPB | 9 980 | 9 763 | 9 192 | 10 084 | 9 784 | 10 002 | 9 974 | 9 925 | 804 | 0 | 0 | 0 | 0 |
| | VSS | 79 592 | 76 210 | 73 557 | 78 952 | 78 860 | 76 527 | 80 108 | 81 409 | 21 917 | 0 | 0 | 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 | 54 460 | 52 489 |
| **Zinc production** | Zinc | 113 000 | 110 000 | 113 000 | 113 000 | 105 000 | 104 000 | 90 000 | 101 000 | 82 000 | 86 000 | 85 100 | 72 000 | 0 |

### *4.4.3.2 Ferroalloy Production [2C2]*

Ferrochromium production emissions are based on plant-level data (tier 3 method), while the rest of the Ferroalloys are based on T1 approach.

### *4.4.3.3 Aluminium Production [2C3]*

A Tier 3 methodology where the amount of $CF_4$ and C2F6 produced are tracked were used to determine emissions in this category.

### *4.4.3.4 Lead Production [2C5]*

Emissions from lead production were estimated using a Tier 1 approach. 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 SAISI (2008) provided data for iron and steel production, while production data for all the other metals were obtained from the SAMI report (Department of Minerals and Energy, 2013).

### *4.4.4.1 Iron and Steel Production[2C1]*

The SAISI provided data for iron and steel production (**Table 4.4**).

#### *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 4.5**) and these were based on actual process analysis at the respective plants. The country-specific emission factor for electric arc furnace (EAF) production is slightly higher than the IPCC default value; this emission factor was, however, not used for the estimation of GHG emissions from EAF because was based on a small sample and needs further investigation before it can be applied. The country-specific emission factor for Direct Reduced Iron (DRI) production is more than twice the default factor (**Table 4.5**). This country specific factor was used for estimating GHG emissions as it was based on a comprehensive carbon balance analysis. Differences in feedstock material and origin results in higher emission factors compared with the IPCC default emission factor values, which assume consistent feedstock conditions across countries. The *Other* category values were based on production by the Corex process. This process is 50% Basic Oxygen Furnace and 50% Electric Arch Furnace, therefore, a weighted emission factor (0.77 t $CO_2$/ t production) accounting for these two processes was applied to the *Other* category.

Table 4.5: 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 Companies; IPCC 2006 Guidelines).

| Type of Technology | $CO_2$ Emission factor (tonne $CO_2$ / 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 the SAMI report (**Table 4.4**). For ferromanganese production the 7% C values were taken to be the high and medium carbon ferromanganese and the 1% C values were the other manganese alloys (DMR, 2014; Tables 77 and 78). IPCC default emission factors were used for ferroalloy production (**Table 4.6.**), except for ferrochromium production where a tier 3 approach was used. A tier 3 method was also applied for aluminium production. 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.

Table 4.6: Sector 2 IPPU: Emission factors for ferroalloy production (Source: 2006 IPCC Guidelines).

| Ferroalloy Type | $CO_2$ (tonnes per ferroalloys tonne production) | $CH_4$ |
|---|---|---|
| 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 |

### 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% (IPCC 2006, Vol 3, Chpt 4, pg. 4.40, Table 4.9). The same range of uncertainty is associated with the Tier 1 approach for ferroalloy production emission factors. For this inventory the maximum default uncertainty for T1 of 25% was assumed for the EF. There is a default 5% uncertainty on the activity data (IPCC 2006, Table 4.9). Even though a tier 3 approach was used for aluminium production emission no data was collected on uncertainty. The default uncertainty for $CF_4$ and $C_2F_6$ range from -99% to +380% (IPCC 2006, Vol 3, Chpt 4, page 4.54, Table 4.15). Since a country specific approach was used the uncertainty is expected to be lower than the tier 1 default uncertainties, therefore 190% (half the default uncertainty) was applied for the uncertainty on these emission factors.

### 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 followed for the compilation of this inventory and identify areas of improvement.

### 4.4.7 Source-specific recalculations

Recalculation were completed for all years between 2000 and 2012 due to the following improvements and updates:

- Zinc production:
  - Updated zinc production data between 2004 and 2010;
- Ferroalloys:
  - Updated ferromanganese activity data for 2010;
- Steel and iron production:
  - Emission factor for EAF was stated to be 2.1 tonnes $CO_2$/tonne product, but the source of the data could not be verified so the IPCC default factor (0.08 tonnes $CO_2$/tonne product) was used instead;
  - Due to changes in the EAF emission factor

so the emission factor for the Corex process (listed as other technologies in the steel and iron production category) was also adjusted; and

- Emission factor for pig iron reduction was corrected to the IPCC default value (1.35 tonne $CO_2$/tonne product) as the value of 1.65 tonnes $CO_2$/tonne product could not be verified.

### 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. In order to reduce uncertainty in the Ferroalloy production emissions it is recommended that site specific data is urgently acquired. For reducing uncertainty in the cement production emissions it is important for the DMR to work together with the cement production industry to ensure consistent reporting of data.

## 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 NMVOCs, which can be oxidized and released into the atmosphere. According to the 2006 IPCC Guidelines (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 transport applications. Lubricants are divided into two types, namely, motor and industrial oils, and greases that differ in physical characteristics. Paraffin wax is used in 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* category fluctuated between 196 Gg $CO_2$eq and 246 Gg $CO_2$eq between 2000 and 2004, and hovered around 230 Gg $CO_2$eq between 2007 and 2010, with a peak in emissions (504 Gg $CO_2$eq) occurring in 2006 (**Figure 4.7**).

Emissions from lubricant use contributed between 93.5% and 99.1% of 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% is grease.

### 4.5.4 Data sources

The source of activity data for solvents was the energy balance tables published annually by the DoE (Department of Energy (DoE), 2008. Energy Balances Statistics. Department of Energy, http://www.energy.gov. za/files/energyStats_frame.html. [Accessed November 2012]).

#### *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.

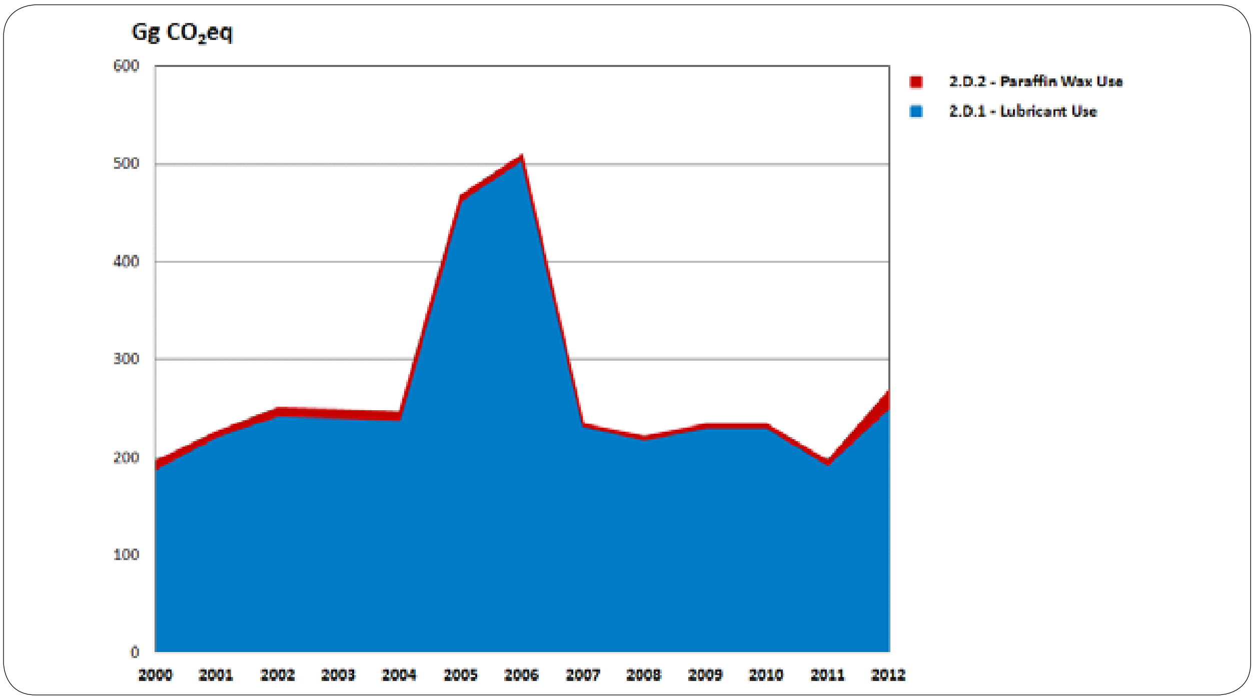



Figure 4.7: Sector 2 IPPU: Trend and emission levels from the non-energy products from fuels and solvent use category, 2000 – 2012.

Table 4.7: 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 |
| 2011 | 13 130 | 260 |
| 2012 | 17 085 | 1 188 |

### 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 to 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 followed for the compilation of this inventory and to identify areas of improvement.

### 4.5.7 Source-specific recalculations

No source-specific recalculations were performed.

### 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 would 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. 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, tobacco expansion applications, and as solvents in the manufacture of adhesives, coatings and inks).

### 4.6.1 Overview of shares and trends in emissions

Total $CO_2$eq emissions from HFC's increased from 842 Gg $CO_2$eq in 2005 to 2 096 Gg $CO_2$eq in 2010, then declined again to 1 396 in 2012 (**Figure 4.8**). There was no available data for the years prior to 2005. HFC-134a is the biggest contributor (average contribution of 80.8%) and HFC-143a contributing an average of 8.9%.

### 4.6.2 Methodological issues

The Tier 1 approach was used to estimate emissions from substitutes for ozone-depleting substances. The calculation of GHG emissions was done through a calculator provided by the IPCC. It was assumed that the equipment lifespan was 15 years and the emission factor from the installed base was 15%. These assumptions were based on the defaults from the 2006 IPCC Guidelines.

### 4.6.3 Data sources

Activity data for ODS substitutes were sourced from the ODS database managed by the DEA. The ODS database registers imports and exports of ODS substances and their replacements. The activity data has been updated and improved since the last inventory. 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, therefore, it is not possible to give default uncertainties for these sources. However, procedures should be put in

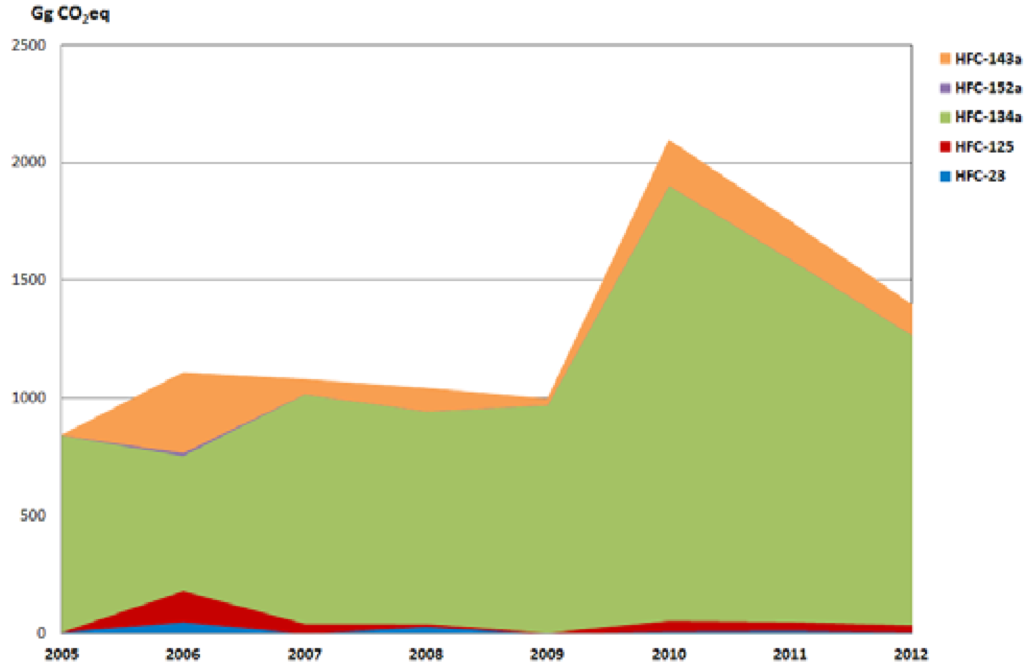



Figure 4.8: Sector 2 IPPU: Trends and emission levels of HFC's, 2005 – 2012.

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 distributors was confirmed with the International Trade Administration Commission (ITAC), which is responsible for issuing import/export permits. In addition, the yearly import/export ODS figures were compared with import/export data obtained from the South African Revenue Service (SARS).

### 4.6.6 Source-specific recalculations

Due to updated activity data recalculations were completed for this category for all years between 2000 and 2012.

### 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 the collection of data at the 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)
- Other
  - Harvested wood products (IPCC Section 3D1)

Emissions from fuel combustion in this sector are not included here as these fall under the *agriculture/forestry/fisheries* subsector (see **Section 3.3.6.1.3**) in the energy sector. Categories not included in this report are *rice cultivation* (3C7), and *other* (3C8, 3D2), as they are not applicable to South Africa. 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 Tier 1 approach to the mineral soil carbon pool, while organic soils are not reported on as the area of organic soils in South Africa was estimated to be insignificant.

Emissions from ruminants in privately owned game parks has been included as these are suggested to be managed lands as the game are fed. Game in national parks are not included as they are considered unmanaged.

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 of 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 12 year period, but overall there appeared to be an increase in the sink. Total GHG emissions from livestock declined by 5.6%, from 31 162 Gg $CO_2$eq in 2000 to 29 413 Gg $CO_2$eq in 2012. The decline was attributed mainly to the decreasing cattle, sheep and goat populations. The land component is estimated to be a sink, varying between 4 651 Gg $CO_2$eq and 20 570 Gg $CO_2$eq (**Table 5.1**). The variation was caused mainly by changes in carbon stocks in forest lands due to variation in carbon losses (fire and fuelwood losses).

Emissions from *aggregated and non-$CO_2$ emission sources* varied by a maximum of 9.1% over the 12 year period. The fluctuations in this category are driven mainly by changes in biomass burning, liming and urea application. HWP estimates indicate that this subsector is a small sink of $CO_2$, varying between a minimum of 312 Gg $CO_2$eq (2000) and a maximum of 1 187 Gg $CO_2$eq (2004). In 2011 this subsector was a small source of $CO_2$. As with the land and aggregated and non-$CO_2$ emission sources, the sink does not show any trend.

The recalculated 2010 estimate in this inventory was 49.6% higher than the previous inventory estimate of 25 713 Gg $CO_2$eq (Department of Environmental Affairs, 2014). The change was attributed mainly to the use of updated land cover change maps and corrected HWP estimates. The HWP estimates were reduced by an average of 94% compared with the 2010 inventory due

Table 5.1: Sector 3 - AFOLU: Trends in emissions and removals (Gg $CO_2$eq) from the AFOLU sector, 2000 – 2012.

| | 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** | **45 860** | 31 162 | -8 521 | 23 527 | -312 |
| **2001** | **45 813** | 31 003 | -8 205 | 23 683 | -675 |
| **2002** | **43 971** | 30 771 | -10 597 | 24 607 | -817 |
| **2003** | **42 342** | 30 194 | -11 777 | 22 951 | -927 |
| **2004** | **44 066** | 30 039 | -7 701 | 22 980 | -1 185 |
| **2005** | **44 047** | 29 998 | -8 561 | 22 832 | -197 |
| **2006** | **41 952** | 29 956 | -10 285 | 23 186 | -882 |
| **2007** | **39 758** | 29 325 | -11 582 | 22 600 | -581 |
| **2008** | **47 225** | 29 969 | -5 259 | 23 327 | -781 |
| **2009** | **39 011** | 29 412 | -13 019 | 22 738 | -98 |
| **2010** | **38 456** | 30 245 | -14 870 | 23 578 | -490 |
| **2011** | **38 376** | 30 349 | -15 779 | 23 738 | 82 |
| **2012** | **31 128** | 29 413 | -20 346 | 22 530 | -512 |

to corrections and improved methodology.

In all years $CH_4$ emissions contributed the most to the total AFOLU emissions (***Figure 5.1***: Sector 3 AFOLU: Percentage contribution of the various GHG to the total AFOLU inventory, 2000 – 2012.), but this contribution declined from 46.32% in 2000 to 38.5% in 2012. *Enteric fermentation* contributed an average of 92.4% of the $CH_4$. The contribution from $N_2O$ fluctuated annually but was in the range of 32.5% to 38.9% with an average of 68.8% of this coming from *direct $N_2O$ emissions from managed soils.*

### 5.2.2 Key sources

A level and trend key category analysis including the AFOLU sector was carried out on the 2012 data (**Appendix B**). Both of these assessments showed that the main key categories in this sector are *land converted to forest land* (3.B.1.b), *enteric fermentation* (from cattle (3.A.1.a)), *direct $N_2O$ from managed soils – urine and dung deposits in PRP* (3.C.4), *land converted to grasslands* (3.B.2.b) and *land converted to croplands* (3.B.2.b) (**Table 1.10**, **Table 1.12**). It should be noted that the key category assessment is incomplete due to the incomplete reporting of all sources.

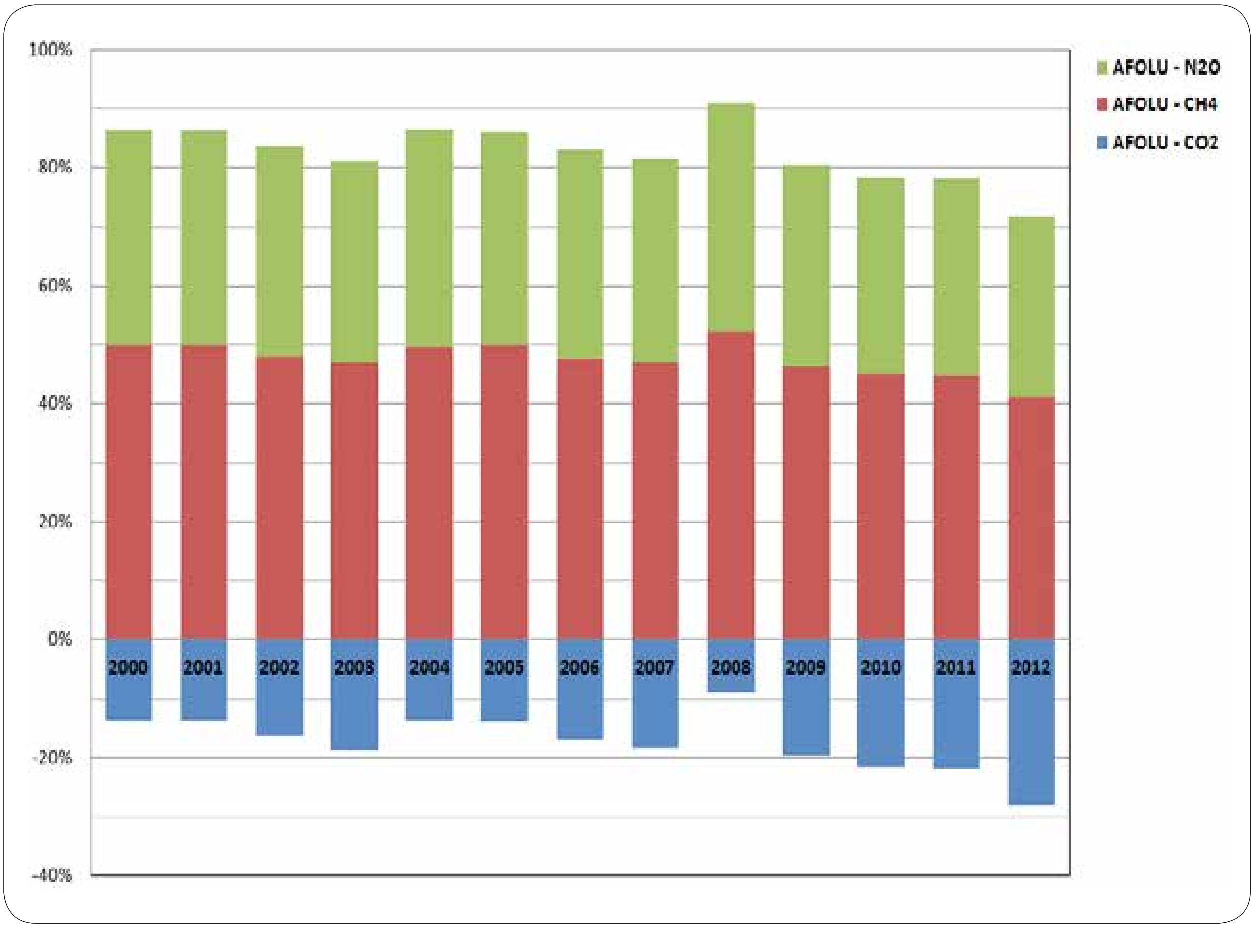



Figure 5.1: Sector 3 AFOLU: Percentage contribution of the various GHG to the total AFOLU inventory, 2000 – 2012.

### 5.2.3 Recalculations

In the livestock subsector, minor corrections were made to the beef and dairy cattle population numbers, as well as the poultry population numbers. Also emissions from game on privately owned game parks were included using activity data and emission factors supplied by Du Toit et al. (2013d). Due to these updated activity data and emission factors the annual livestock emissions since 2000 were recalculated.

In the land category there were several updates:

- New land-use change maps were incorporated (for 1990 and 2013/2014);
- Biomass data was updated;
- DOM was incorporated for forest lands;
- Estimates from other lands were included;
- Changes in soil carbon methodology to include soil type; and
- Corrected and updated HWP methodology.

These recalculations were completed for all yeas since 2000 and all updates and improvements are discussed in the sections below.

## 5.3 Livestock [3A]

### 5.3.1 Overview of shares and trends in emissions

The GHG emissions from livestock produced a total of 29 413 Gg $CO_2$eq in 2012. This was a 5.6% decline from the 2000 emissions (31 162 Gg $CO_2$eq) (**Figure 5.2**: Sector 3 AFOLU: Trends in GHG emissions from the livestock category, 2000 – 2012.).

The total accumulated emissions since 2000 stand at 332 075 Gg $CO_2$eq. Emissions declined annually between 2000 and 2007, and increased by 2.2% in 2008. There was also an increase of 3.0% between 2009 and 2011. Enteric fermentation accounted for an average of 93.3% of the GHG emissions from livestock, while the rest was from manure management. Emissions from manure management showed an increase in emissions of 18.2% between 2000 (1 872 Gg $CO_2$eq) and 2012 (2 214 Gg $CO_2$eq). This increase was 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.

### 5.3.2 Overview of trends in activity data

The total annual livestock population increased by 29.8% between 2000 and 2012, mainly due to growth in the poultry industry. If poultry numbers are excluded, then there was a general decline (of 6.1%) in the remaining livestock population over the 12-year period (**Figure 5.3**: Sector 3 AFOLU - Livestock: Trends in livestock population numbers, 2000 – 2012.).

The commercial beef cattle population fluctuated slightly around an average of 7 million (with a low of 6.85 million in 2002, and a high of 7.34 million in 2001), while the communal beef population fluctuated around 5.4 million (± 0.27 million). The dairy cattle population declined between 2000 and 2004 (25.6%), increased between 2004 and 2010 (31.4%), and declined by 7.5% between 2010 and 2012. Sheep and goat populations declined by 9.2% and 13.9%, respectively, and swine by 4.1% between 2000 and 2012. The annual average poultry population increased by 48.4%, from 100 million in 2000 to 149 million in 2012 (**Figure 5.3**: Sector 3 AFOLU - Livestock: Trends in livestock population numbers, 2000 – 2012.).

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. The game

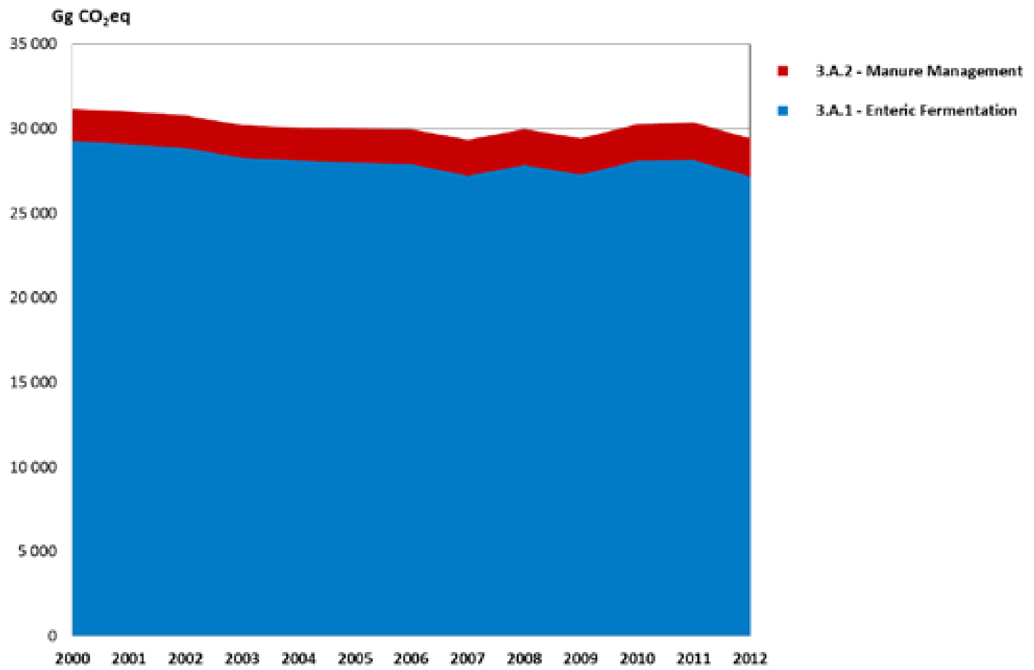



Figure 5.2: Sector 3 AFOLU: Trends in GHG emissions from the livestock category, 2000 – 2012.

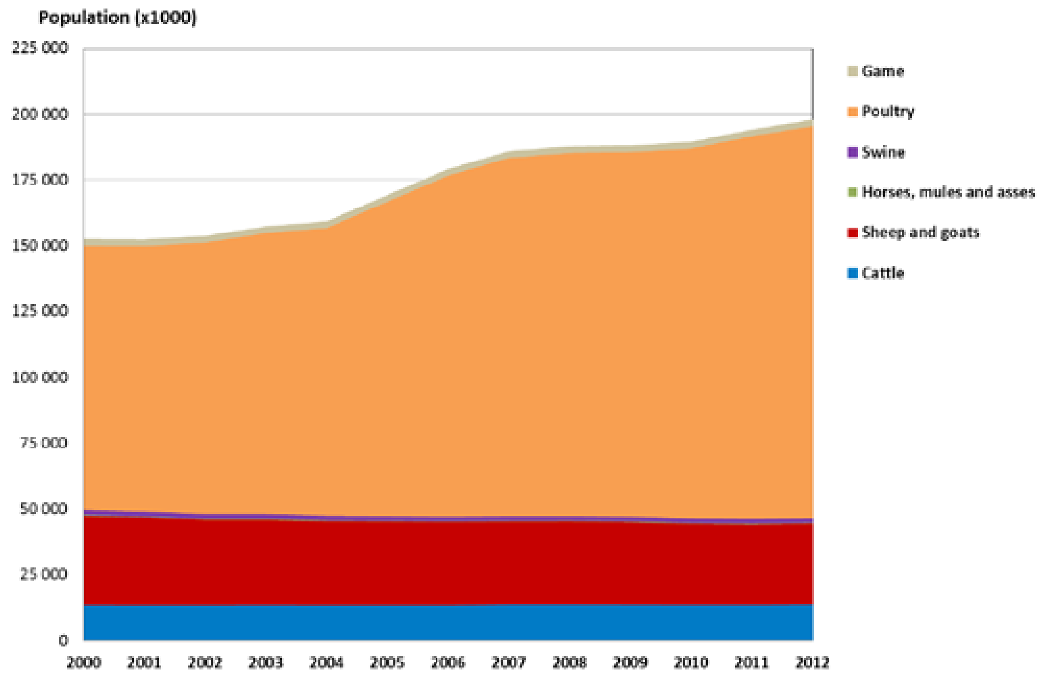



Figure 5.3: Sector 3 AFOLU - Livestock: Trends in livestock population numbers, 2000 – 2012.

population in privately owned game parks was estimated at 2 285 000 (Du Toit et al., 2013d). This was kept constant each year due to a lack of data.

### 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, and is released mainly through eructation and normal respiration, and a small quantity as flatus (Bull *et al.*, 2005; Chhabra *et al.*, 2009; Baggot *et al.*, 2006; IPCC, 1997; IPCC, 2006). 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 abilities, namely ruminants (cattle, sheep, and goats), pseudo-ruminants (horses, donkeys) and monogastric animals (pigs) (DAFF, 2010).

South Africa does not have any managed camels or ilamas so these were excluded from the emissions. Buffalo and other game are not managed per say, but are found in significant numbers in game parks (both national and private). This inventory includes a first estimate of emissions from game in private parks. This number is not complete as not all ruminant species were included due to a lack of emission factor data. Furthermore, an estimate from the game population kept in national parks has not been included due to a lack of population data.

Enteric fermentation emissions from poultry were 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 from 29 290 Gg $CO_2$eq in 2000 to 27 198 Gg $CO_2$eq in 2012 (**Figure 5.4**: Sector 3 AFOLU - Livestock: Trend and emission levels of enteric fermentation emissions in the livestock categories, 2000 – 2012.), mainly due to a decline in population numbers. Emissions declined in most years except for an increase of 2.3% between 2007 and 2008, as well as a 3.0% increase between 2009 and 2010. In these years there was an increase in enteric fermentation emissions from cattle, which was attributed to an increase in the number of mature cows and heifers and a reduction in the calf population (**Figure 5.5**: Sector 3 AFOLU - Livestock: Trend in cattle herd composition, 2000 – 2012.). Mature cows and heifers have a higher emission factor than calves due to a well-developed gut. Cattle are the largest contributors to the enteric fermentation emissions (78.1% in 2012), with 9.2% from dairy cattle, 13.9% from sheep and 3.2% from goats in 2012 (**Figure 5.6**: Sector 3 AFOLU – Livestock: Contribution of the livestock categories to the enteric fermentation emissions in 2012.).

#### *5.3.3.3 Methodological Issues*

The proportion of intake that is converted into methane is dependent on 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.

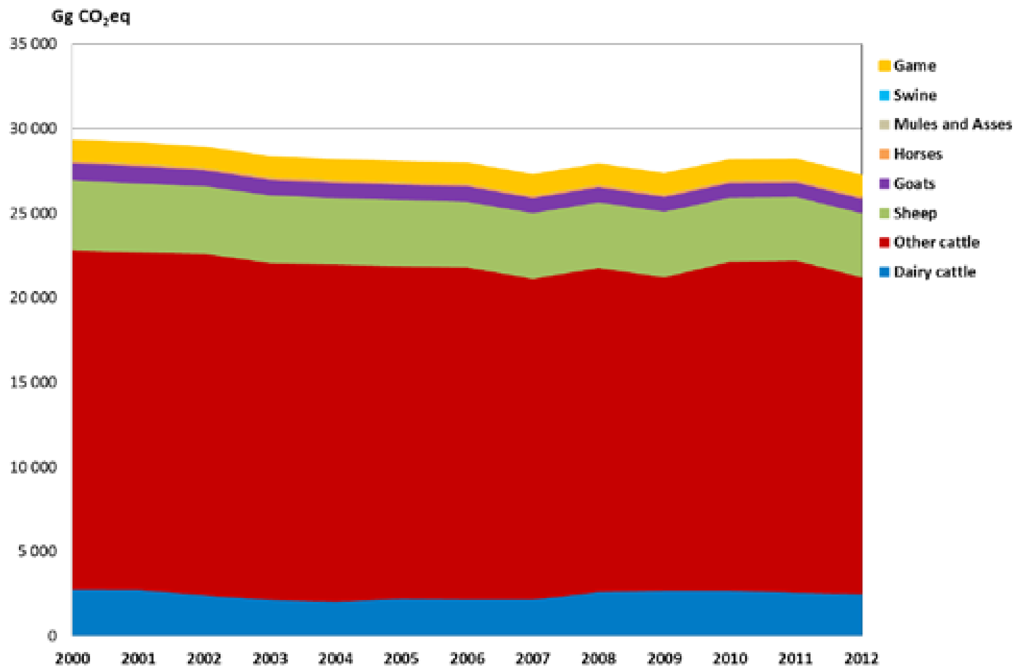



Figure 5.4: Sector 3 AFOLU - Livestock: Trend and emission levels of enteric fermentation emissions in the livestock categories, 2000 – 2012.

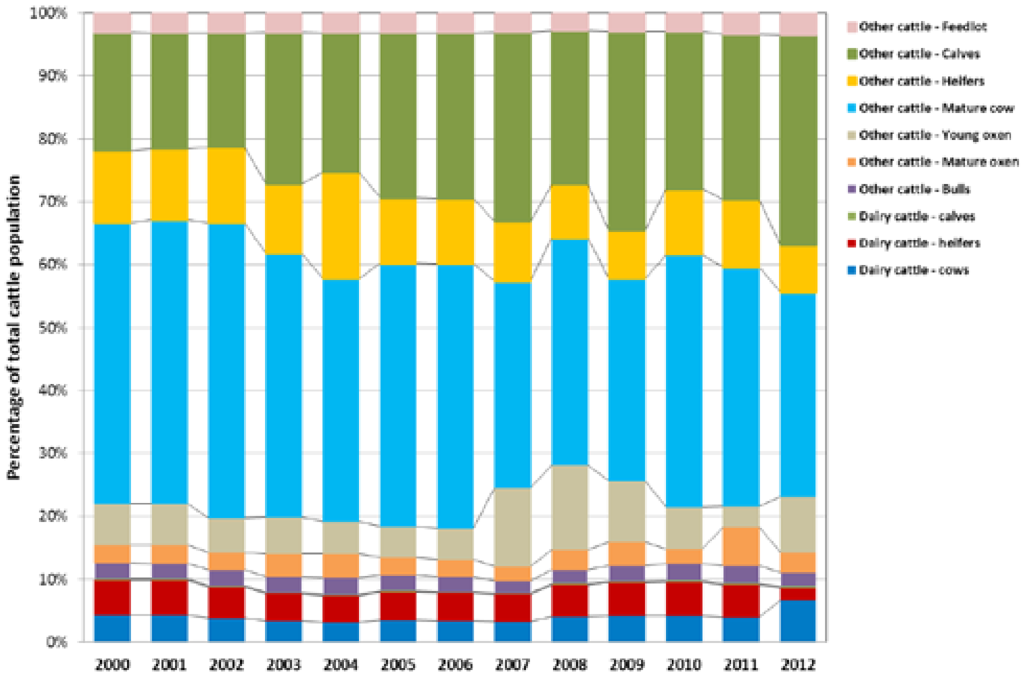



Figure 5.5: Sector 3 AFOLU - Livestock: Trend in cattle herd composition, 2000 – 2012.

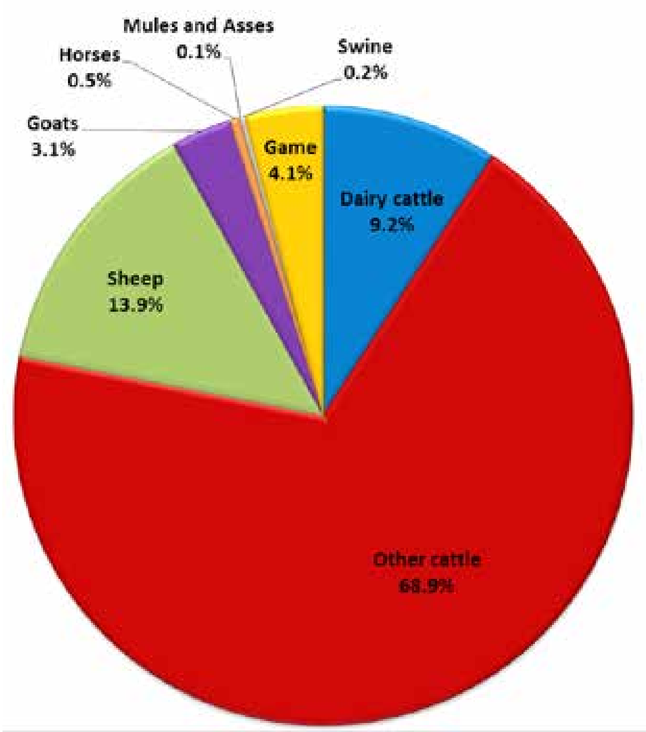



Figure 5.6: Sector 3 AFOLU – Livestock: Contribution of the livestock categories to the enteric fermentation emissions in 2012.

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

$CH_4$ emission = ΣEFi (kg $CH_4$ animal$^{-1}$) * [number of animals for livestock category *i*]

(Eq. 5.1)

### *5.3.3.3.1 Dairy cattle [3A1AI]*

EFs 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

(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 EFs 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:

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

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 are 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):

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

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 dry matter intake (DMI) 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:

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

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):

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

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]*

CH4 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):

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

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 the 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.

*5.3.3.3.7. Game [3A1J]*

EF's for ruminant game species were taken directly from Du Toit *et al.* (2013d). For hippopotamus and rhinoceros, the EFs were based on the daily methane emissions of elephants (0.1 g $CH_4$/kg LW/day) as was done in Du Toit *et al.* (2013).

### 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 E**) 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. For other cattle the feedlot cattle need to be separated out as feedlot cattle have a different emission factor. Annual feedlot cattle numbers were obtained from the South African Feedlot Association (SA Feedlot Association, 2013; Ford, Dave, 2013. Pers. Comm.). Data was only available for the years 2008 to 2012, so an average of 420 000 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). The feedlot population was assumed to consist of calves, heifers and young oxen in

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 | Game |
|---|---|---|---|---|---|---|---|---|---|---|
| | | TMR[a]-based | Pasture-based | | | | | | | |
| Sub-category | Commercial | Lactating cow | Lactating cow | Bulls | Non-wool ewe | Buck | Boars | | | Elephant |
| | | Lactating Heifer | Lactating Heifer | Cows | Non-wool ram | Doe | Sows | | | Giraffe |
| | | Dry cow | Dry cow | Heifers | Non-wool lamb | Kids | Piglets | | | Eland |
| | | Pregnant heifers | Pregnant heifers | Ox | Wool ewe | Angora | Baconers | | | Buffalo |
| | | Heifers >1 yr | Heifers >1 yr | Young ox | Wool ram | Milk goat | Porkers | | | Zebra |
| | | Heifers 6-12 mths | Heifers 6-12 mths | Calves | Wool lamb | | | | | Kudu |
| | | Heifers 2-6months | Heifers 2-6months | Feedlot | | | | | | Waterbuck |
| | | Calves < 2 months | Calves < 2 months | | | | | | | Blue Wilde-beest |
| | | | | | | | | | | Black Wilde-beest |
| | | | | | | | | | | Tsessebe |
| | | | | | | | | | | Blesbok |
| | | | | | | | | | | Warthog |
| | | | | | | | | | | Impala |
| | | | | | | | | | | Springbok |
| | | | | | | | | | | Hippopotamus |
| | | | | | | | | | | Rhinoceros |
| | 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

an equal split. Therefore the total commercial calf, young oxen and heifer population numbers from the Abstracts of Agricultural Statistics (DAFF, 2012) were reduced by a third of the feedlot population for that year and then the feedlot category was added into the population.

The herd composition data from Du Toit *et al.* (2013a, 2013b, 2013c) was applied to the national dairy, sheep and goat population numbers to obtain the herd composition sub-categories for these livestock. 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).

Due to a lack of data over time on herd composition it was assumed that the composition remained constant between 2000 and 2010. In future this assumption needs to be addressed by improving the monitoring of livestock herd composition. Altering the composition of the herd is a possible, although small, mitigation action therefore improved monitoring of herd composition is required in the future to address this assumption.

The total communal cattle population was determined from the difference in the total cattle population data provided in **Table 58** of the Abstracts of Agricultural Statistics (2013) and the total commercial dairy and other cattle provided in **Table 59** of the Abstracts. All the communal cattle were assumed to be other cattle. The communal population was assumed to have the same herd composition (excluding feedlot cattle) as the commercial population. The total communal population numbers for sheep, goats and swine was obtained by using the ratio of commercial to communal population from the quarterly census numbers which have been recorded by DAFF from 1996 onwards. The ratios were 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.

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. Population data for all game animals was taken from Du Toit et al. (2013d). All livestock population numbers are provided in **Appendix E**.

##### *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 subcategories were combined a weighted average TAM (based on population numbers) was calculated for the livestock subcategories used in this inventory. For game the live weight data was taken from Du Toit *et al.* (2013d) except for hippo and rhino. The live weight for hippo and rhino were taken to be the average weight provided in Clauss et al. (2003). For rhino it was the average weight of both black and white rhino.

##### *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, as well for game. The EFs were taken from Du Toit *et al.* (2013a, 2013b, 2013c, 2013d) (**Table 5.3** and **Table 5.4**), 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 EFs 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 subcategories, so in these cases a weighted average EF was calculated for the livestock subcategories used in this inventory. Du Toit *et al.* (2013a, 2013b, 2013c, 2013d) calculated the emission factors for the year 2010. In this inventory, we assumed that the EFs remained constant between 2000 and 2010. IPCC 2006 default EFs were used for horses, 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) | Calculated $EF_{enteric}$ (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 | | |

| Livestock category | Livestock sub-category | TAM (kg) | Calculated $EF_{enteric}$ | IPCC default EF (kg/head/year) | |
|---|---|---|---|---|---|
| | | | (kg/head/year) | Africa | Oceania |
| 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 |

Table 5.4: Sector 3 AFOLU – Livestock: Weights and methane EF's for game animals.

| Livestock category | Livestock sub-category | TAM (kg) | $EF_{enteric}$ (kg/head/year) |
|---|---|---|---|
| Game | Elephant | 2436 | 81.0 |
| | Giraffe | 826 | 136 |
| | Eland | 528 | 93.7 |
| | Buffalo | 466 | 113 |
| | Zebra | 266 | 13.9 |
| | Kudu | 155 | 31.3 |
| | Waterbuck | 150 | 35.9 |
| | Blue wildebeest | 153 | 24.8 |
| | Black wildebeest | 106 | 14.3 |
| | Tsessebe | 105 | 13.8 |
| | Blesbok | 62 | 9.1 |
| | Warthog | 59 | 2.2 |
| | Impala | 42 | 7.4 |
| | Springbok | 28 | 4.7 |
| | Hippopotamus | 1453 | 47.5 |
| | Rhinoceros | 5452 | 62.2 |

**Comparison of methane EF with IPCC defaults**

A comparison of the calculated methane EFs for cattle, sheep, goats and swine and the IPCC default factors is provided in **Table 5.5**. The EFs were seen to be in the same range as the Oceania or developed-country EFs, 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 South Africa in 2010 was 14.5 kg $day^{-1}$, which is much higher than the 1.3 kg $day^{-1}$ given for Africa (**Table 5.5**). The cattle weights in South Africa 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 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.

### *5.3.3.5 Uncertainty and Time-series Consistency*

Uncertainty in livestock population numbers is around 10% (Meissner, pers. Comm., 2015) except for dairy and swine population data which is slightly higher (15%). Emission factor uncertainty has not been calculated but the IPCC suggests the uncertainty for Tier 2 EF is around 20%. Overall uncertainty for enteric fermentation for the various livestock was therefore determined to be between 9% and 20%. Time-series consistency was ensured by using consistent methods for the 12 year period, as well as for the recalculations in 2000.

Table 5.5: 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 – TMR | 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 | Lactating cows | 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 |

### *5.3.3.6 Source-specific QA/QC and Verification*

Population data was obtained for a 40-year period for cattle, sheep, goats and swine, and trends were checked. There were no sudden changes in the data. For poultry, a 12-year trend was monitored. Population numbers were also checked against FAO data and numbers from the individual livestock organizations for the year 2012. These numbers were found to vary slightly, however, the variation for all livestock was smaller than the uncertainty on the national population numbers, and 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. 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. 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 followed for the compilation of this inventory and identify areas of improvement.

### *5.3.3.7 Source-specific Recalculations*

The other cattle population data was recalculated for all years between 2000 and 2012, as it was determined that feedlot cattle were already incorporated into the commercial population data. Also, the ratio of communal to commercial cattle was adjusted based on data from the Abstracts of Agricultural Statistics (2013). In this inventory, emissions from ruminant game in privately owned game parks were estimated. There were not in the previous inventory. Due to limited population data the numbers and emissions for game were kept constant between 2000 and 2012, so a constant emission from game was added to all years.

##### *5.3.3.8 Source-specific Planned Improvements and Recommendations*

There are no 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. 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 the storage and treatment of manure, before using it as farm manure or burning it 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 South Africa and were therefore not included in the report. There is a large population of game in South Africa, but a lack of data hinders the inclusion of their emissions. National population data for ruminant game is lacking, however, there is population data for game kept in privately owned parks. Du Toit *et al.* (2013) determined that manure $CH_4$ emissions from game were very low and therefore no emission factors were reported. This inventory thus assumes zero manure $CH_4$ emissions from game.

The majority of manure in South Africa is produced and left in the pastures while grazing, with only a small amount of manure is being managed in South Africa. $N_2O$ manure emissions are reported for managed manure on dairy, swine, feedlot and poultry. 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 2 214 Gg $CO_2$eq in 2012, which was an increase from the 1 872 Gg $CO_2$eq produced in 2000 (**Figure 5.7**: Sector 3 AFOLU – Livestock: Total manure management trend and emission levels from source categories, 2000 – 2012.).

Manure emissions showed the greatest increase between 2004 and 2007, with annual increases of 4.0%, 2.6% and 2.8% during this period. There was also another large increase between 2010 and 2011. Emissions generally increased annually, with the only decline (0.5%) occurring between 2002 and 2003. These increases are due to increased $N_2O$ emissions from poultry manure, but $N_2O$ emission from feedlot manure also contributed to the increase between 2010 and 2011. This was mostly related to increases in population numbers during that time.

Methane emissions accounted for 38.5% of manure emissions in 2012, with its contribution slowly declining from 46.2% in 2000. Manure $CH_4$ emissions showed peaks in 2001 (875 Gg $CO_2$eq) and in 2009 (870 Gg $CO_2$eq) (**Figure 5.8**: Sector 3 AFOLU – Livestock: Manure management $CH_4$ trend and emission levels from source categories, 2000 – 2012.). The largest contributor to the $CH_4$ emissions were swine (68.9% in 2012), followed by dairy cattle (18.1% in 2012). The contribution of $CH_4$ from dairy cattle manure management decreased by 1.6% since 2000, while the contribution from swine manure declined by 1.9% over the same period.

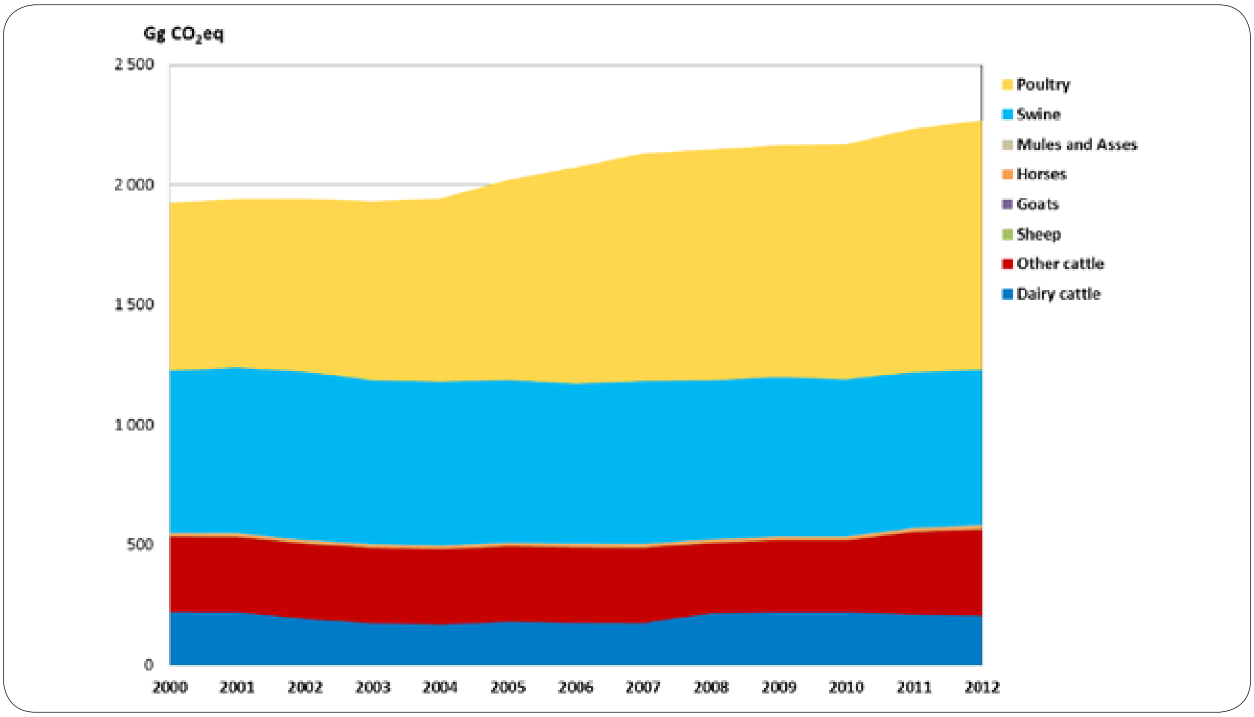



Figure 5.7: Sector 3 AFOLU – Livestock: Total manure management trend and emission levels from source categories, 2000 – 2012.

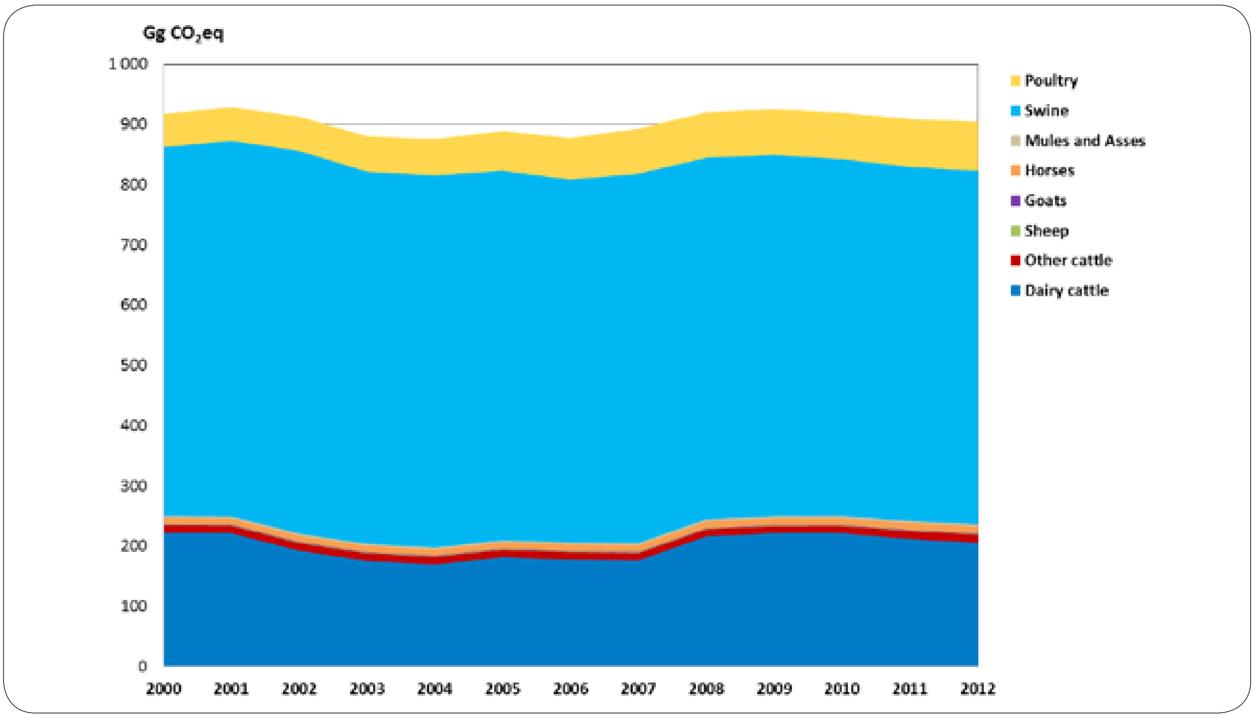



Figure 5.8: Sector 3 AFOLU – Livestock: Manure management $CH_4$ trend and emission levels from source categories, 2000 – 2012.

$N_2O$ dominated the manure emissions, contributing 57.5% in 2012. The contribution has slowly increased since 2000 (when it contributed 53.8%). $N_2O$ emissions from manure management increased from 1 007 Gg $CO_2$eq (2000) to 1 362 Gg $CO_2$eq (2012), mainly due to the increased manure from poultry. Poultry contribution has increased from 63.8% in 2000 to 70.1% in 2012, while the contribution from cattle feedlots declined by 4.4% over the same period (**Figure 5.9**: Sector 3 AFOLU – Livestock: Manure management $N_2O$ trend an emission levels from source categories, 2000 – 2012.). Swine manure $N_2O$ emissions declined by 4.1% between 2000 and 2012.

The total emissions from poultry manure increased by 48.6% between 2000 and 2012, and their contribution to manure emissions increased from 36.2% to 45.7%.

#### *5.3.4.3 Methodological Issues*

The methane produced from manure management of dairy cattle, beef cattle and feedlot cattle was 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 $1.4 \times 10^{-5}$ kg $CH_4$ (kg DM manure)$^{-1}$ based on Gonzalez-Avalos and Ruiz-Suarez (2001).

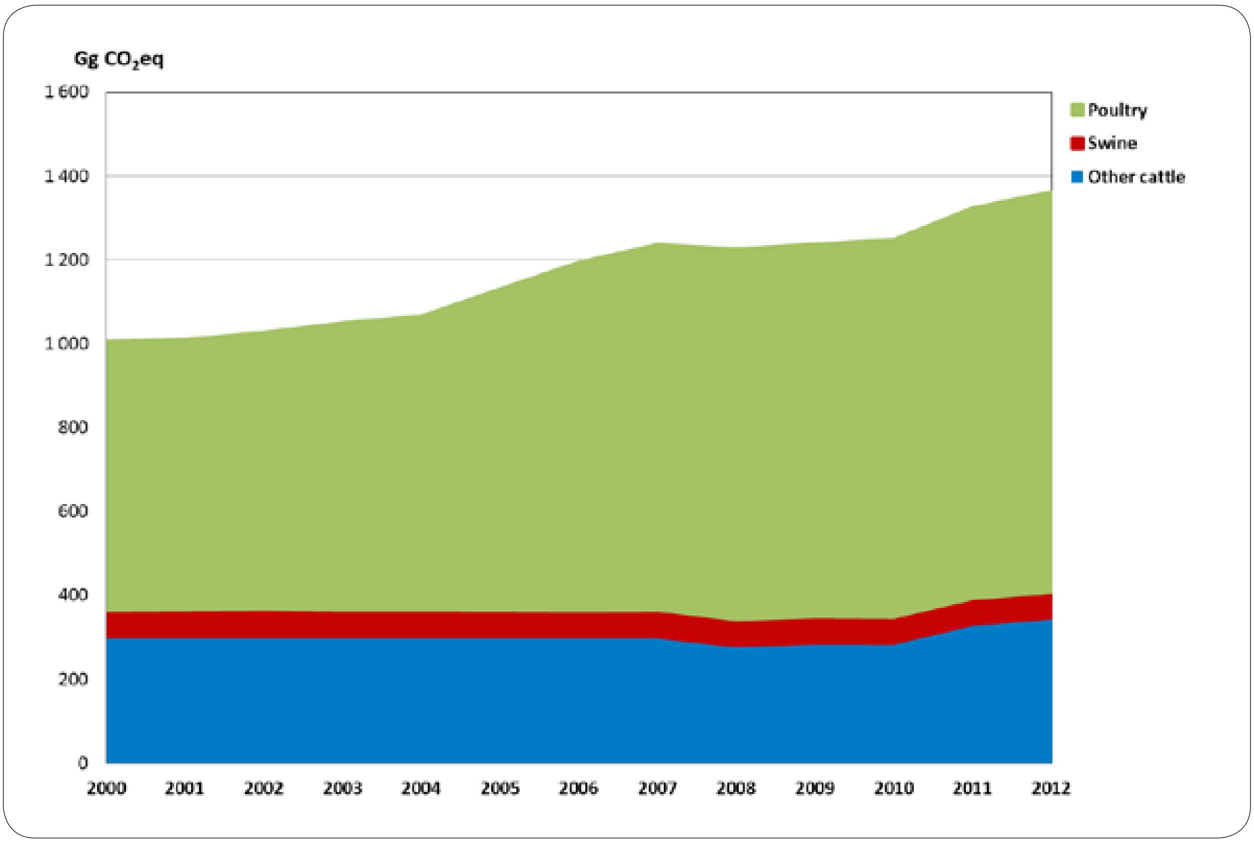



Figure 5.9: Sector 3 AFOLU – Livestock: Manure management $N_2O$ trend an emission levels from source categories, 2000 – 2012.

#### *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:

$$EF = (VS \times Bo \times MCF \times p\quad) \times 365 \qquad \text{(Eq. 5.8)}$$

Where:

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

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

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):

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

Where:

I = Intake as calculated under enteric emissions (**Section 5.3.3.3**);

MEF = Manure emissions factor (kg $CH_4$ (kg DM manure)$^{-1}$).

**Feedlot cattle**

The IPCC default methane conversion factor 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 B0 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):

$$EF = (VS \times Bo \times MCF \times p\quad) \times 365$$

(Eq. 5.11)

Where:

VS = Volatile solid production (kg $head^{-1}$ $year^{-1}$);

Bo = 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 was 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).

**Game [Other - 3A2j]**

$CH_4$ emissions from game manure were assumed to be zero as Du Toit *et al.* (2013d) indicated that emissions were minimal and did not report any EFs.

##### *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 were insufficient data to extend these calculations from 2010 to the period 2000 to 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 5.3.3.4.1** and the typical animal masses (TAMs) are provided in **Table 5.3**: Sector 3 AFOLU – Livestock: Livestock weights, methane EF's and IPCC 2006 default EF's. Poultry were also included in the manure management emission calculations. The total number of layers and slaughtered broilers was obtained from the South African 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 average number of broiler growing cycles (per annum), using an equation similar to that used by New Zealand (Ministry of Agriculture and Forestry, 2011):

$$AAP = NAPA/R \quad \text{(Eq. 5.13)}$$

NAPA is the number of animals produced annually, which was taken to be the number of broilers slaughtered; and R is the average number of broiler growing cycles per annum (R = 8, Du Toit *et al.*, 2013). It has been noted that New Zealand changed their methodology from using the growing cycle to using the number of days alive. It indicated that the former method was leading to an overestimation. However, for South Africa, using the growing cycle brings the population numbers more in line with data from the census that was carried out between 2000 and 2013. Communal layers and 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 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 5.6**), 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 or daily spread (Du Toit *et al.*, 2013c; **Table 5.6**). All cattle feedlot manure and poultry manure is managed as drylot (Du Toit et al., 2013a; DAFF, 2010).

#### *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 5.7**) were taken from Du Toit *et al.* (2013a, 2013b, 2013c) and the methods are described in **Section 5.3.3.3**. In the case of sheep, goats and swine there were additional livestock subcategories in Du Toit *et al.* (2013a, 2013b, 2013c) (see **Appendix E**) and in these cases a weighted average emission factor was calculated. IPCC 2006 Africa default values were used for horses and donkeys.

**<u>Comparison of manure EF's and IPCC defaults</u>**

A comparison of the calculated manure emission factors with IPCC default values is given in **Table 5.7**. 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. Poultry manure EF for $N_2O$ was lower than all default values.

Table 5.6: Sector 3 AFOLU – Livestock: Manure management system usage (%) for different livestock categories, 2000 – 2012 (Source: DAFF, 2010; Du Toit et al., 2013a and 2013b).

| Livestock Category | Sub-category | Lagoon | Liquid / slurry | Drylot | Daily spread | Compost | Pasture |
|---|---|---|---|---|---|---|---|
| Country specific clinker fraction | 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 |

##### *5.3.4.4.3 $N_2O$ activity data and Emission factors*

Nitrogen excretion rates (Nrate) were obtained from the Africa default values (IPCC, 2006, Table 10.19) while the annual N excretion for livestock Nex 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 5.6**) 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).

Table 5.7: Sector 3 AFOLU – Livestock: CH4 manure EF's for the various livestock compared with 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 | Sub-category | Lagoon (kg/h/year) | Liquid / slurry Africa | Drylot Oceania | Daily spread (kg/head/year) |
|---|---|---|---|---|---|
| Dairy - TMR | Lactating cows | 14.800 | 1 | 29 | 8.8 |
| | Lactating heifers | 14.700 | | | |
| | Dry cows | 1.470 | | | |
| | Pregnant heifers | 1.240 | | | |
| | Heifers > 1 year | 1.190 | | | |
| | Heifers 6 – 12 months | 0.750 | | | |
| | Heifers 2 – 6 months | 0.370 | | | |
| | Calves | 0.210 | | | |
| Dairy - pasture | Lactating cows | 4.980 | 1 | 29 | 8.8 |
| | Lactating heifers | 4.800 | | | |
| | Dry cows | 1.110 | | | |
| | Pregnant heifers | 0.880 | | | |
| | Heifers > 1 year | 0.780 | | | |
| | Heifers 6 – 12 months | 0.580 | | | |
| | Heifers 2 – 6 months | 0.400 | | | |
| | Calves | 0.320 | | | |
| Other cattle - commercial | Bulls | 0.022 | 1 | 2 | 0.04 |
| | Cows | 0.018 | | | |
| | Heifers | 0.016 | | | |
| | Ox | 0.018 | | | |
| | Young ox | 0.012 | | | |
| | Calves | 0.012 | | | |
| | Feedlot | 0.870 | | | 2.91 |
| Other cattle - communal | Bulls | 0.017 | 1 | 2 | 0.04 |
| | Cows | 0.015 | | | |
| | Heifers | 0.013 | | | |
| | Ox | 0.015 | | | |
| | Young ox | 0.010 | | | |
| | Calves | 0.010 | | | |
| Sheep - commercial | Non-wool ewe | 0.003 | 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 | | | |

| Livestock Category | Sub-category | Lagoon (kg/h/year) | Liquid / slurry Africa | Drylot Oceania | Daily spread (kg/head/year) |
|---|---|---|---|---|---|
| **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 | |

#### 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 Bo estimates is ±15%. For volatile solids 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. The uncertainty on the $CH_4$ EF is ± 20% (IPCC 2006 Guidelines). The uncertainty on the default EFs for horses, mules and asses is ± 30%.

The default Nrate values were used for Africa and these had an uncertainty of ±50%. Uncertainty on management system usage data is estimated to be between 25% and 50% (IPCC 2006 Guidelines). The drylot EF has an uncertainty of a factor of 2.

Overall uncertainties for the various livestock for manure $CH_4$ were determined to be between 12% and 20%, whereas for manure $N_2O$ uncertainty is around 220% due to the large uncertainties on EF's.

##### 5.3.4.5.2 Time-series consistency

Time-series consistency was ensured by the use of consistent methods and full recalculations in the 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 5.7**), 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 followed for the compilation of this inventory and to identify areas of improvements.

#### 5.3.4.7 Source-specific Recalculations

Recalculations were completed for all years between 2000 and 2012 with the updated population data for other cattle and poultry. Poultry data were adjusted for all years based on new information and to bring the numbers more in line with the annual census data. Game manure emissions were considered for all years, but the emissions were assumed to be zero, so no changes were made for this.

#### 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. Another 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 South Africa were determined so that actual data could be used instead of the value calculated using IPCC 2006 default values.

## 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), other lands (3.B.6), and the relevant land-use change categories. The $N_2O$ emissions from the land sector were estimated in the *aggregated and non-$CO_2$ emission sources on land* section and $CH_4$ emissions from wetlands were also included, following the methodology in the previous inventories (Department of Environmental Affairs and Tourism, 2009 & Department of Environmental Affairs, 2014). All other emissions in the land category were assumed to be negligible.

According to the maps developed in section 5.4.4 (GeoTerraImage, 2015) the land cover in South Africa in 2014 was dominated by low shrubland (33.5%) and grasslands (20.7%). Natural forests are very small in South Africa covering less than 0.5% of the land area, while settlements occupy approximately 2.3%. Agricultural activities cover about 11.2% of the land area, with maize and wheat being the dominant annual crops by area. Perennial crops (orchards and viticulture) contribute less than 0.5% towards the cropland land area. Plantations are based on non-native trees, the dominant species being *Eucalyptus grandis*, and they cover about 1.5% of the land area (Forestry South Africa, 2012).

Classifying the South African soils into the six main types provided by the IPCC shows that the high-activity clay mineral soil dominates (>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 sandy mineral soil and low-activity clay mineral soil. Sandy minerals predominate over the Northern Cape, North West 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. 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, in some parts of Mpumalanga and over the 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.

The inventory makes use of available data in this sector, however there are still large data gaps. The inventory would benefit from a detailed gap analysis which includes not only a clear description of current data and data gaps, but also a detailed proposals for how these data gaps may be filled in the future (potentially with reference to organisations collecting data, surveys that could be expanded to collect additional data, etc.).

### 5.4.2 Overview of shares and trends

#### *5.4.2.1 Land Cover Trends*

Land-cover change was determined as discussed in **Section 5.4.4** and results show that between 1990 and 2014 the Forest land (which includes woodlands and open bush) and settlements increased by 15.4% and 6.7% respectively. Wetlands decreased by 17.6%, while grasslands and croplands declined by 6.2% and 1.6% respectively (**Figure 5.10**).[2] These numbers, however, should be considered in light of the limitations discussed in **Section 5.4.4.4**.

2 A cautionary note: there are three basic factors that may have influenced land-cover change results and associated statistics, namely land-cover mapping accuracies, seasonal / climatic conditions under which the original source imagery was acquired, and the level of (landscape) detail that is being compared over time. These influencing factors are discussed in detail in **Appendix G** (**section 14.2**).

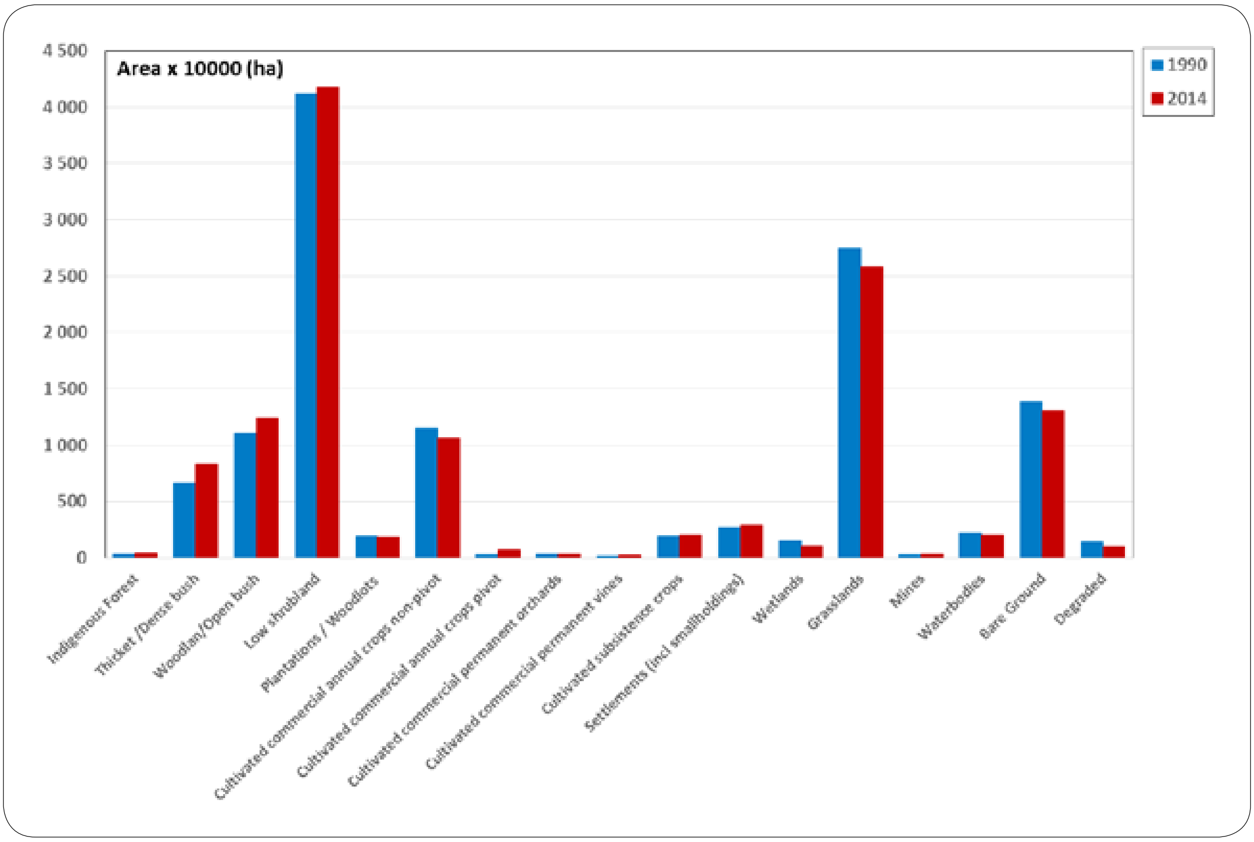



Figure 5.10: Sector 3 AFOLU - Land: Comparison of land areas and the change between 1990 and 2013-2014.

### *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 12 year period (**Figure 5.11**). The biomass and soil carbon pools contribute the most to the Land sector (**Figure 5.12**), however the DOM pool is incomplete

Forest land (3B1) comprised emissions and removals from the above and below ground, soil carbon and DOM pools for the *forest land remaining forest land* and *land converted to forest land* sub-categories. Forest lands include plantations, natural forests, thickets, and woodland/open bush. Carbon stock changes due to wood harvesting, fuelwood consumption, and disturbance (including fires) were all included. The forest land category was estimated to be a net sink for $CO_2$ in all years between 2000 and 2012, varying between a low of 18 988 Gg $CO_2$ (2008) and a high of 34 325 Gg $CO_2$. The *land converted to forest land* subcategory accounted for 85.9% of the forest land $CO_2$ in 2012 and this is mainly due to the land conversions accumulating in this category until the 23 year period is reached. Furthermore, due to a lack of data the carbon losses could not be separated between *land remaining land* and *converted land*. Therefore all losses were allocated to land remaining land, leading to the converted lands having a higher sink.

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 (viticulture, orchards), and cultivated subsistence crops. Cropland had an emission of 4 480 Gg $CO_2$

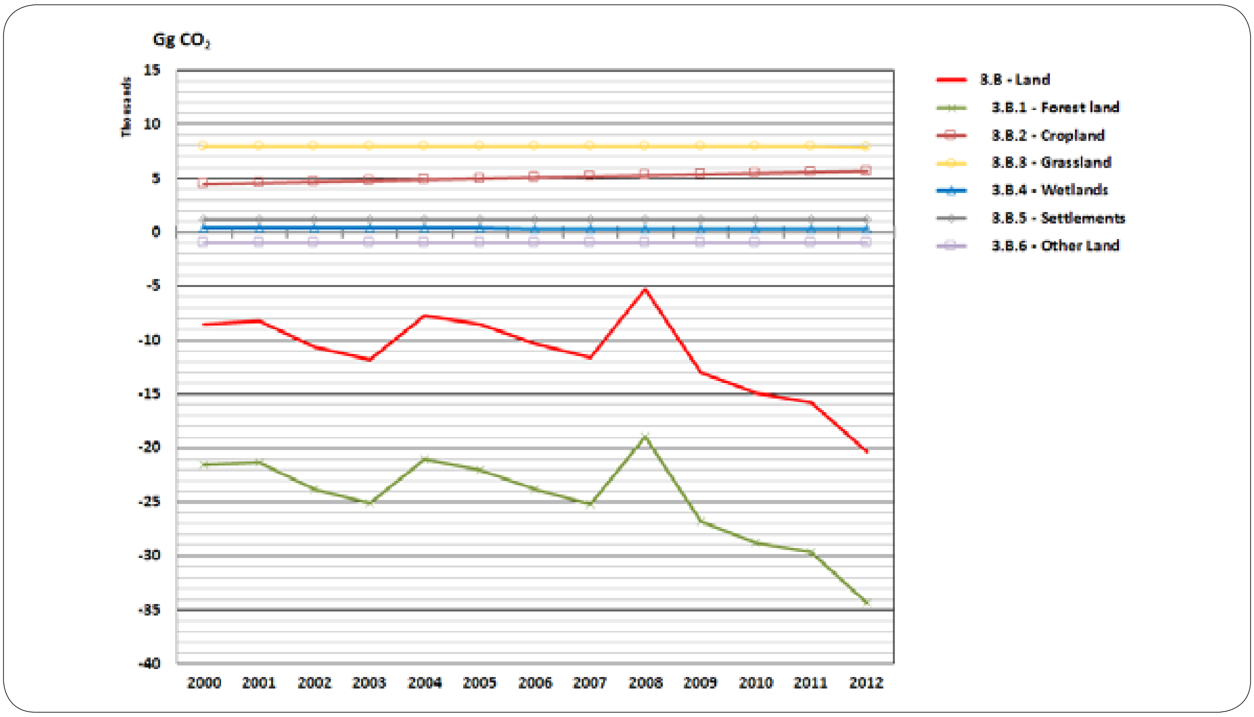



Figure 5.11: Sector 3 AFOLU – Land: Trend in emissions and sinks (in Gg $CO_2$) in the Land sub-sector between 2000 and 2012, differentiated by sub-category.

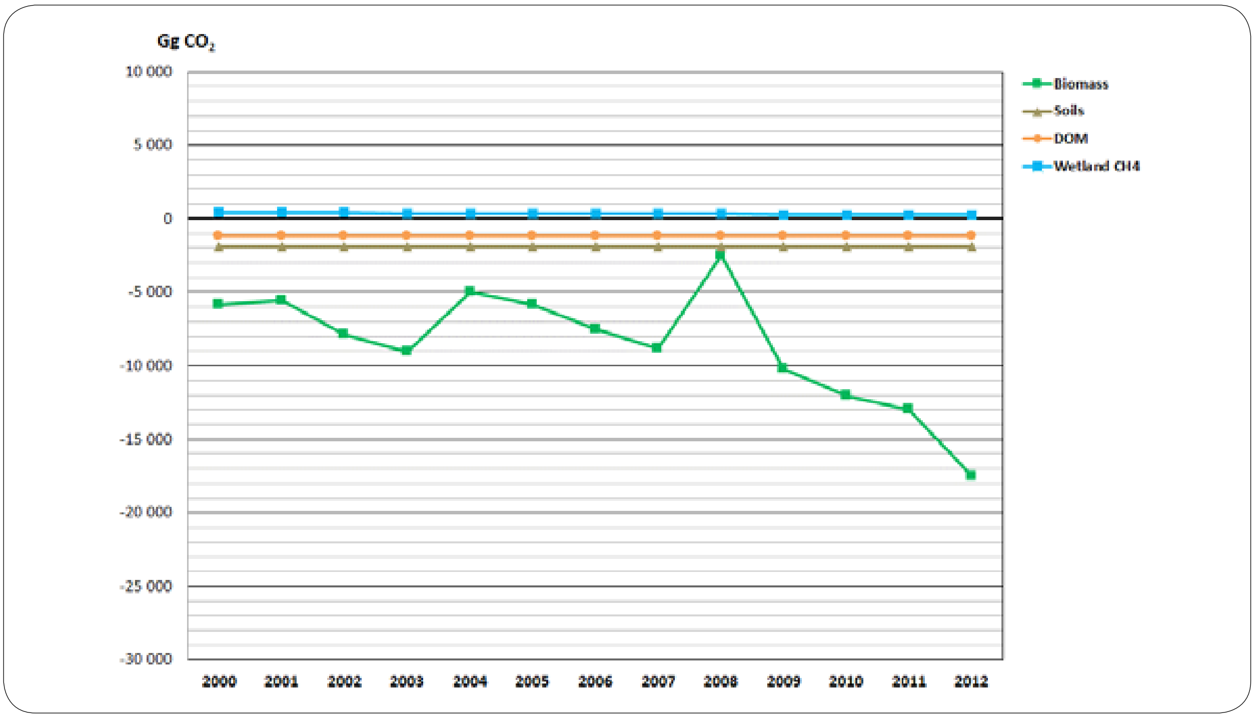



Figure 5.12: Sector 3 AFOLU – Land: Trend in emissions and sinks (in Gg $CO_2$) in the Land sub-sector between 2000 and 2012, differentiated by source category.

in 2000 and this increased to 5 616 Gg $CO_2$ in 2012. *Croplands remaining croplands* are generally assumed to be in balance, however there were some conversions between the different crop types which lead to a sink in this category which declined to 104 Gg $CO_2$ from 1 242 Gg $CO_2$ in 2000.

Grasslands (3B3) comprised emissions and removals from the biomass and soil carbon pools for *grasslands remaining grasslands* and *land converted to grasslands* subcategories. The grassland category only includes grassland vegetation. The *grassland remaining grasslands* subcategory, following the Tier 1 methodology, are assumed to be in balance, while land converted to grasslands were a source of 7 904 Gg $CO_2$ annually.

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 429 Gg $CO_2$eq in 2000 to 267 Gg $CO_2$eq in 2012. Wetlands included wetlands and water bodies.

The Settlements category (3B5) comprises the *settlements remaining settlements* and *land converted to settlements* subcategories. 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 small source (1 195 Gg $CO_2$ per year).

Other lands (3B6) comprised emissions and removals from the biomass and soil carbon pools for *other lands remaining other lands* and *land converted to other lands* subcategories. The other lands category includes low shrublands, bare ground and degraded land. *Other lands remaining other lands* do not have any $CO_2$ emissions or uptakes, while *land converted to other lands* was shown to be a sink of 960 Gg $CO_2$ per year.

### 5.4.3 General methodology

South Africa followed a Tier 1 approach and in Forest lands a Tier 2 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.

It was assumed that no conversions occurred before 1990, so land converted to another land category would remain, and accumulate, in the converted category for 23 years. The IPCC default period is 20 years, but it is stated that if the change period extends beyond this then the time period can be adjusted. In this inventory the maps spanned a 23 year period therefore D = T = 23 years.

The inventory comprises the six land classes recommended by the 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 six land classes had several subdivisions (**Table 5.8**). These divisions are further explained in **Section 5.4.5**.

The sub-divisions in this inventory differ slightly from those in the 2010 inventory. The main reason for this change was because in the previous inventory the maps suggested large changes between bare ground and Nama-Karoo and Succulent-Karoo vegetation. The fact that the biome borders used to identify these areas are static may have had an influence on these numbers and led to errors in change over time. In this current inventory, the map resolution was increased from 1 km to 30m and the biome categories were removed. More detail on the classification is provided in **Section 5.4.5**. Area per category was estimated using a wall-to-wall approach, where the entire land surface of South Africa was classified into one of the six land class. Land areas were determined from the maps described in **Section 5.4.4**.

Annual carbon stock changes in biomass 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 the *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. For plantations the Tier 2 approach was applied. 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 2 approach was used. Changes in biomass carbon stocks were estimated from IPCC 2006 Equations 2.15 and 2.16. Carbon stock changes in dead organic matter were estimated with the stock-difference method (Tier 1), according to Equation 2.19 and 2.23 of the IPCC 2006 Guidelines. 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, volume 4, p. 2.34).

If an IPCC default factor is required, 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 IPCC category for South Africa based on long term climate data (Moeletsi *et al.*, 2013).

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

| IPCC Land Class | SA Sub-category in 2010 inventory | Reclassification in this inventory |
|---|---|---|
| Forest Land | Natural Forests | Indigenous Forests |
| | Plantations (Eucalyptus, Softwoods, Acacia, Other sp.) | Plantations/woodlots |
| | Thicket | Thicket/ Dense bush |
| | Woodland/savannas | Woodland/ Open bush |
| Cropland | Annual commercial crops | Cultivated commercial annual crops (pivot, non-pivot) |
| | Perennial crops (viticulture, orchards) | Cultivated commercial perennial crops (viti-culture, orchards) |
| | Annual semi-commercial/subsistence crops | Cultivated subsistence crops |
| | Sugarcane | |
| Grassland | Grassland<br>Fynbos | Grasslands |
| Settlements | Settlements | Settlements |
| | Mines | Mines |
| Wetlands | Wetlands | Wetlands |
| | Water bodies | Water bodies |
| Other Lands | Nama Karoo<br>Succulent Karoo<br>Bare ground | Low shrublands<br>Bare ground<br>Degraded land |
| | Other | |

### 5.4.4 Method for obtaining land-cover matrix

The South African National Land-Cover Dataset 1990[3] and 2013-14[4], developed by GeoTerraImage (GTI), were used for this study to determine long-term changes in land cover and their associated impacts. The 1990 and 2013-14 National Land-Cover Datasets were derived from multi-seasonal Landsat 5 and Landsat 8 imagery with 30 x 30 m raster cells, respectively. The 1990 National Land-Cover Dataset made use of imagery from 1989 to 1991, while the 2013-14 National Land-Cover Dataset used 2013 to 2014 imagery. Both datasets were developed as 35 and 17 classes. The 35-class land cover, which included biome-level information (Fynbos, Nama-Karoo and Succulent-Karoo, where applicable) for indigenous forest, thicket/ dense bush, Woodland/open bush, shrubland, grasslands and bare ground was further summarised into 17 classes to remove the biomes (see **Table 5.7**). Details of the land-cover datasets can be found in (**Appendix G**).

The accuracy of the 2013-14 Land-Cover Dataset was calculated at 83% based on 6 415 sample points. It was determined that the accuracy is unlikely to be the result of chance occurrence, with a high Kappa score of 80.87. The 1990 dataset did not have an accuracy assessment conducted on it as there was no historical reference to use. The assumption was that the same modelling procedures were used to compile the 1990 dataset as was used for the 2013-14 dataset, therefore, the accuracy assessment calculated for the 2013-14 dataset would apply to the 1990 dataset.

Landsat 5 and 8 imagery with a 30m resolution was acquired for the 1990 and 2013-14 datasets from the United States Geological Survey (USGS, http://glovis.usgs.gov/). Seasonal images were acquired to characterise seasonal variations of foundation-based landscapes, which include; trees, grass, water and bare ground. Spectral indices were derived from existing algorithms including, the Normalised Difference Vegetation Index (NDVI), Normalised Difference Water Index (NDWI) and GTI custom-derived algorithms. ERDAS Imagine © was used for all modelling. All modelling was conducted using the foundation classes. Terrain modifications were conducted to minimise terrain-shadowing effects resulting from seasonal variations. Thereafter, the spectrally-modified dataset was merged into a single national dataset with the various classes. A detailed description of the modelling process can be obtained from the GTI report (2014, 2015) in **Appendix G**.

#### *5.4.4.1 Data Sources*

Details of the source imagery used to develop the land cover maps for South Africa for 1990 and 2013-2014 are given in the GTI report (2014, 2015) provided in **Appendix G**.

#### *5.4.4.2 Land Cover and Modelling Grid Resolution*

The Landsat 5 and 8 modelling was based on 30 x 30 m pixels, while the geographic masks were pre-defined in the GTI data libraries.

#### *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

3 © GEOTERRAIMAGE - 2015

4 © GEOTERRAIMAGE - 2014

- Approach 3 extends the information available from Approach 2 by allowing land use conversions to be tracked in a spatially explicit way.

The maps developed for this inventory allowed for a Tier 2 methodology (IPCC, 2006) to represent areas of land cover and change, and to develop the land cover-change matrix. The matrix was developed by intersecting the 1990 land-cover map with the 2013-14 land-cover map. All methodological details are provided in the GTI land-cover change report (2015) in **Appendix G**.

##### *5.4.4.3.1 Land use changes*

The resulting land use change matrix, including transitions, between 1990 and 2013-14 are shown in **Table 5.9**.

##### *5.4.4.3.2 Derivation of annual land-use changes*

The annual land cover changes between 1990 and 2013-2014 were calculated on a proportional basis, via linear interpolation, and are shown in **Table 5.10**. In the future additional data can be used to redistribute the annual change over the years.

Table 5.9: Sector 3 AFOLU – Land: Land-use matrix for the change between 1990 and 2013-14 (ha) 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 (including the transitions since 1990).

| Initial/ Final | Forest land | Crop-lands | Grass-lands | Settle-ments | Wet-lands | Other lands | Σ reduc-tions | Σ addi-tions – Σ reduc-tions |
|---|---|---|---|---|---|---|---|---|
| **Forest land** | 14 275 143 | 443 513 | 2 824 017 | 185 925 | 105 633 | 2 119 071 | 5 678 158 | 3 075 446 |
| **Crop-lands** | 651 525 | 12 020 271 | 904 354 | 78 603 | 42 821 | 493 488 | 2 170 791 | -221 986 |
| **Grass-lands** | 5 049 249 | 946 522 | 16 594 524 | 244 892 | 184 331 | 4 471 448 | 10 896 442 | -1 696 993 |
| **Settle-ments** | 146 716 | 51 986 | 149 644 | 2 641 451 | 6 621 | 38 259 | 393 226 | 202 576 |
| **Wet-lands** | 291 891 | 79 294 | 442 552 | 6 994 | 2 642 354 | 265 096 | 1 085 826 | -656 661 |
| **Other lands** | 2 614 223 | 427 490 | 4 878 884 | 79 388 | 89 759 | 48 441 893 | 8 089 743 | -702 381 |
| **Σ addi-tions** | **8 753 603** | **1 948 804** | **9 199 449** | **595 801** | **429 165** | **7 387 362** | | |
| **Σ land use cate-gory** | **23 028 746** | **13 969 075** | **25 793 973** | **3 237 252** | **3 071 518** | **55 829 255** | | |
| **Total area** | **124 929 820** | | | | | | | |

Table 5.10: Sector 3 AFOLU – Land: Annual land cover changes between the various land classes.

| Initial/ Final | Forest land | Croplands | Grasslands | Settlements | Wetlands | Other lands |
|---|---|---|---|---|---|---|
| Forest land | | 148 115 | 122 783 | 281 627 | 4 593 | 22 005 |
| Croplands | 28 327 | | 39 320 | 110 965 | 1 862 | 4 735 |
| Grasslands | 219 533 | 41 153 | | 10 647 | 8 014 | 194 411 |
| Settlements | 6 379 | 7 811 | 6 506 | | 288 | 741 |
| Wetlands | 12 691 | 13 897 | 19 241 | 34 440 | | 7 421 |
| Other lands | 113 662 | 121 434 | 212 125 | 341 739 | 3 903 | |

#### *5.4.4.4 Limitations and Cautionary Notes on Change Assessment*

Cloud-free images from Landsat were used as far as possible. Where this was not possible, regions were corrected by merging cloud affected YoA with cloud free ToA. The process of masking was found to be acceptable by GTI.

The seasonal representation and range of monthly acquisition dates is generally better for the 1990 land-cover dataset, than used for the 2013-14 dataset, despite the same average number of acquisition dates per frame for the two datasets. This is because the 2013-14 dataset was limited to what cloud free imagery was recorded between April 2013 and the designated March 2014 cut-off, whereas the 1990 dataset had access to a wider range of imagery from 1989 to 1993. This greater seasonal representation may have influenced the modelling results in terms of the distribution and extent of some of the natural vegetation classes (excluding indigenous forests), since a better seasonal profile was often possible in 1990 compared to 2014 in some image frame locations.

The 1990 period appears to have been generally wetter than the 2013-14 period in most regions, as observed through the increase in observable surface water features in 1990. This is especially evident in the pans across the central regions of the Free State and Northern Cape, where many pans are water filled in 1990 and dry in 2013-14. These differences will reflect as changes between the two assessment periods but do not necessarily represent a permanent loss of water bodies over the ± 24 year period, but rather a seasonal (or climatic) induced difference. This fact needs to be noted during modelling and interpretation of land-cover change results.

The wetter conditions prevalent in the 1990 dataset have allowed the wetland modelling to be extended across the full national coverage, unlike the drier 2013-14 image data which restricted wetland modelling to the wetter eastern and southern regions. These differences will reflect as changes between the two assessment periods but do not necessarily represent a permanent loss of wetlands over the ± 24 year period, but rather a seasonal (or climatic) induced difference. This fact needs to be noted during modelling and interpretation of land-cover change results.

The wetter conditions prevalent in the 1990 dataset may have influenced the boundary between low-shrub (i.e. Karoo type) and Highveld grassland vegetation, since the 1990 grassland/low shrub transition in the western Free State region appears to have shifted generally to the west compared to 2013-14, which may be a result of a greater grass component being present in the Karoo/ grass transition zone in 1990.

The (Highveld, montane and coastal) grassland correction procedures applied to the 1990 dataset are considered to be slightly more accurate than those applied to the

2013-14 data, as a result of both modified procedures used and better image seasonal representation in 1990. It is therefore potentially possible that some of the 'grassland' to 'open woody vegetation' changes in these regions may be a result of the improved grassland delineation in 1990 and not actual bush cover increases in 2013-14.

Changes in the extent of urban areas between 1990 and 2013-14 may not be as locally significant as maybe expected, since the *total built-up footprint* defined in the "settlements" class in both the 1990 and 2013-14 datasets *includes* peripheral smallholding areas around the main built-up areas; and these tend to be the first land-use that is converted to formal urban areas, before further expansion into natural and cultivated lands.

It should also be noted that all land conversions as provided by the land change map were included due to the limited time period to assess the change maps. In the next inventory a full assessment of the land change classes will be completed.

#### *5.4.4.5 Comparison with Land Cover Data for 2010 Inventory*

For the purpose of this inventory a comparison was made between the 2010 national land cover data from the previous inventory (Department of Environmental Affairs, 2014) and the new 2013-14 land cover map used in this inventory (Table 5.11). Croplands, settlements and other land areas were much larger in the 2010 classification, while forest land area was reduced by 44.3%. Indigenous forest area remained fairly consistent, while the thicket/dense bush and woodland/open bush varied significantly. This is partly because of the re-classification of the classes and the removal of the biome boundaries. Plantation areas were reduced, which was expected as plantations were overestimated in the 2010 map. The map area for plantations is now more consistent with areas reported by Forestry South Africa (FSA, 2012). Grassland areas are consistent, but the removal of the Fynbos boundary resulted in the Fynbos being reclassified into the other land classes and it was thus moved out of the grassland category. A portion of the Fynbos was classified into low shrubland, which is partly the reason for the increase in the *Other land* category.

#### *5.4.4.6 QA/QC and Verification*

GTI calculated the accuracy of the 2013-14 land-cover dataset with the multi-seasonal Landsat 8 imagery. The results indicated an overall map and mean map accuracy of 82.53% and 88.36%, respectively. A total of 6 415 sample points were used to determine the accuracy. In addition, the Kappa Index of 80.87 indicates that results are unlikely to be from a chance occurrence. All classes recorded above 70% user accuracy (UA) and producer accuracy (PA) except for dense bush/thicket (53.74% UA), woodland/open bush (60.84% UA; 54.13 PA), low shrubland/other (61.82 PA) and grasslands (69.82 PA). Detailed results can be found in the GTI report (**Appendix G**).

#### *5.4.4.7 Time-series Consistency*

It is important that there is a consistent time-series in the preparation of the 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.

Landsat imagery was used for both the 1990 and 2013-14 datasets to specifically ensure time-series consistency. In addition, the resolution of Landsat imagery was improved compared to the MODIS datasets used in previous studies. The methods and procedures used to develop the 1990 and 2013-14 datasets remained consistent. The

Table 5.11: Sector 3 AFOLU – Land: Comparison between the land areas from the 2010 inventory and the updated areas in this 2012 inventory.

| IPCC category | Vegetation class (2010) | Area (ha) | Vegetation class (2013-14) | Area (ha) | Change relative to 2010 (%) |
|---|---|---|---|---|---|
| Forest Land | Indigenous Forest | 477 889 | Indigenous Forest | 428 444 | |
| | Thicket | 2 876 607 | Thicket /Dense bush | 8 291 669 | |
| | Woodlands/Savanna | 35 854 791 | Woodland/Open bush | 12 434 932 | |
| | Plantations | 2 146 347 | Plantations / Woodlots | 1 873 701 | |
| **Sub-total** | | 41 355 634 | | 23 028 746 | -44.32% |
| Cropland | Annual commercial crops non-pivot | 6 445 523 | Commercial annual crops non-pivot | 10 610 838 | |
| | Annual commercial crops pivot | 426 973 | Commercial annual crops pivot | 782 049 | |
| | Permanent crops orchard | 181 835 | Commercial permanent orchards | 346 950 | |
| | Permanent crops viticulture | 235 113 | Commercial permanent vines | 188 711 | |
| | Annual semi-commercial / subsistence crops | 1 020 776 | Cultivated subsistence crops | 2 040 527 | |
| | Sugarcane | 313 613 | | | |
| **Sub-total** | | 8 623 833 | | 13 969 075 | 61.98% |
| Grassland | Grassland | 24 852 654 | Grasslands | 25 793 973 | |
| | Fynbos | 5 909 183 | | | |
| **Sub-total** | | 30 761 837 | | 25 793 973 | -16.15% |
| Settle-ments | Settlements | 1 822 753 | Settlements (Incl. smallholdings) | 2 908 280 | |
| | Mines | 179 324 | Mines | 328 973 | |
| **Sub-total** | | 2 002 077 | | 3 237 252 | 61.69% |
| Wetlands | Wetlands | 1 138 322 | Wetlands | 1 025 900 | |
| | Water Bodies | 1 716 648 | Water bodies | 2 045 618 | |
| **Sub-total** | | 2 854 970 | | 3 071 518 | 7.58% |
| Other lands | Bare Ground | 22 663 354 | Bare Ground | 13 057 933 | |
| | Other | 922 077 | | | |
| | Nama-Karoo | 9 280 573 | Low shrubland | 41 827 260 | |
| | Succulent Karoo | 3 598 410 | | | |
| | | | Degraded | 944 061 | |
| **Sub-total** | | 36 464 414 | | 55 829 255 | 53.11% |

main variation in the development of the two land-cover datasets was the use of Landsat 5 and Landsat 8. All other aspects in this development remained consistent.

#### 5.4.4.8 Planned Improvements

The land-cover maps were developed as a desktop 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 a GHG Inventory Improvement Programme and, although there are no specific plans in place currently, it is recommended that under this programme a stratified sampling approach which can be used to validate these, and future, land-cover maps be investigated for future inventory updates.

### 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 falls 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 to 1.0 hectares with tree crown cover (or equivalent stocking level) of more than 10 to 30%, with trees with the potential to reach a minimum height of 2 to 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 to 30% or tree height of 2 to 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 the forest area must be greater than 0.5 hectares. Under this definition, indigenous forests include woodlands which have a tree canopy cover of 10 to 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 subcategories were therefore included within forest land:

- Natural forests:
    - Natural/semi-natural indigenous forest, dominated by tall trees, where tree canopy heights are typically > ± 5m and tree canopy densities are typically > ± 75 %, often with multiple understory vegetation canopies.
- Plantations:
    - All areas of systematically planted man-managed tree resources, 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/dense bush:
  - Natural/semi-natural tree- and/or bush-dominated areas, where typically canopy heights are between 2 –and 5 m, and canopy density is typically > ± 75%, but may include localised sparser areas down to ± 60%. Includes dense bush, thicket, closed woodland, tall, dense shrubs, scrub forest and mangrove swamps. Can include self-seeded bush encroachment areas if sufficient canopy density.
- Woodland/open bush:
  - Natural/semi-natural tree- and/or bush-dominated areas, where typically canopy heights are between ± 2 and 5 m, and canopy densities typically between 40 and 75%, but may include localised sparser areas down to ± 15 to 20%. Includes sparse, open bushland and woodland, including transitional wooded grassland areas. Can include self-seeded bush encroachment areas if canopy density is within indicated range.

#### 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 subcategories in croplands were:

- Annual commercial crops:
  - Commercial annuals (rain fed or non-pivot) - Cultivated lands used primarily for the production of rain-fed, annual crops for commercial markets. Typically represented by large field units, often in dense local or regional clusters. In most cases the defined cultivated extent represents the actual cultivated or potentially extent. Includes Sugarcane crops.
  - Commercial pivot (irrigated or pivot) - Cultivated lands used primarily for the production of centre pivot irrigated, annual crops for commercial markets. In most cases the defined cultivated extent represents the actual cultivated or potentially extent. Includes sugarcane crops.
- Perennial crops:
  - Permanent orchards - Cultivated lands used primarily for the production of both rain-fed and irrigated permanent orchard crops for commercial markets. Includes both tree, shrub and non-woody crops, such as citrus, tea, coffee, grapes, lavender and pineapples etc. In most cases the defined cultivated extent represents the actual cultivated or potentially extent.
  - Permanent vines - Cultivated lands used primarily for the production of both rain-fed and irrigated permanent vine (grape) crops for commercial markets. In most cases the defined cultivated extent represents the actual cultivated or potential extent.
- Subsistence crops:
  - Those that do not meet the threshold for annual commercial crops and are found in and around local housing areas;
  - Cultivated lands used primarily for the production of rain-fed, annual crops for local markets and / or home use. Typically represented by small field units, often in dense local or regional clusters. The defined area may include intra-field areas of non-cultivated land, which may be degraded or use-impacted, if the individual field units are too small to be defined as separate features.

#### 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 silvo-pastural systems, consistent with national definitions. It is defined as natural/semi-natural grass-dominated areas, where typically the tree and/or bush canopy densities are < ± 20 %, but may include localised denser areas up to ± 40%, (regardless of canopy heights). Includes open grassland, and sparse bushland and woodland areas, including transitional wooded grasslands. May include planted pasture (i.e. grazing) if not irrigated. "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. Irrigated pastures will typically be classified as cultivated, and urban parks and golf courses etc. under urban.

#### 5.4.5.4 Settlements

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. The mining activity footprint includes extraction pits, tailings, waste dumps, flooded pits and associated surface infrastructure such as roads and buildings (unless otherwise indicated), for both active and abandoned mining activities. This class may also include open cast pits, sand mines, quarries and borrow pits etc.

#### 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:

- Water bodies:
    - Areas occupied by (generally permanent) open water. The category includes both natural and man-made water bodies 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 vegetation can be either rooted or floating. Wetlands may be either daily (i.e. coastal), temporarily seasonal or permanently wet and/or saturated. Vegetation is predominately herbaceous. Includes, but is not limited to, wetlands associated with seeps/springs, marshes, floodplains, lakes / pans, swamps, estuaries, and some riparian areas.

#### 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. This category included the following:

- Bare ground:
    - Bare, non-vegetated ground, with little or very sparse vegetation cover (i.e. typically < ± 5 to 10 % vegetation cover), occurring as a result of either natural or man-induced processes. Includes, but is not limited to, natural rock exposures, dry river beds, dry pans, coastal dunes and beaches, sand and rocky desert areas, very sparse low shrublands and grasslands, erosion areas, and major road networks etc.

May also include long-term wildfire scars in some mountainous areas in the Western Cape.

- Degraded land:
    - Sparsely vegetated areas, occurring as a result of man-induced processes, which show significantly lower overall vegetation cover compared to surrounding, natural undisturbed areas. Includes, but is not limited to, natural rock exposures, dry river beds, dry pans, coastal dunes and beaches, sand and rocky desert areas, very sparse low shrublands and grasslands, erosion areas, and major road networks etc.
- Low shrublands:
    - Natural/semi-natural low shrub-dominated areas, typically with ≤ 2m canopy height. Includes a range of canopy densities encompassing sparse to dense canopy covers. Very sparse covers may be associated with the bare ground class. Typically associated with low, woody shrub, Karoo-type vegetation communities, although can also represent locally degraded vegetation areas where there is a significantly reduced vegetation cover in comparison to surrounding, less impacted vegetation cover, including long-term wildfire scars in some mountainous areas in the Western Cape. Note that taller tree/bush/shrub communities within this vegetation type are typically classified separately as one of the other tree- or bush-dominated cover classes.

#### *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 South Africa 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 1990 – 2013-14;
    - The resolution of the maps was increased from 1km to 30m.
- Reclassification of land classes:
    - In this inventory the biome boundaries were removed so that Karoo and Fynbos vegetation were not distinguished. Instead all vegetation from these classes were classified into the other vegetation categories.
    - In the previous inventory Fynbos vegetation was classed in the grassland category, but with the new reclassification and distribution of Fynbos into the other land categories, the grassland category consisted only of grasslands.
    - Sugar cane was incorporated into annual crops.
    - A small degraded land category was included.
- Land-conversion data:
    - The category other lands was also included and sinks and removals from this category were incorporated in this inventory.
    - Converted land was accumulated over the 23 year period.
- Activity data:
    - Updated biomass data for indigenous forests, woodland/open bush, orchards and vineyards were incorporated;
    - Cropland methodology was corrected and updated with new biomass data;
    - DOM was included for forest lands; and

- Soil type was included into the soil carbon data.

- HWP:
  - Emissions and removals from the HWP category were corrected and the methodology was updated following the recent KP Supplementary GPG.

Specific recalculations completed for each land class are discussed in detail under the specific sections below. All recalculations were completed for the years 2000 to 2012.

## 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, DOM and mineral soils. The category included indigenous forests, plantations/woodlots, thickets/dense bush, and woodlands/open bush. As in the previous inventory the plantations were sub-divided into Eucalyptus sp., softwood sp., acacia (wattle) and other plantation species. Softwoods were further divided into sawlogs, pulp and other as the growth and expansion factors of these plantations differed. The majority of the *Eucalyptus* plantations are used for pulp so the Eucalyptus species were not split by use, but *Eucalyptus grandis* and *Other Eucalyptus* species were separated.

Changes in biomass include wood removal, fuelwood collection, and losses due to disturbance. Harvested wood was included for plantations, while fuelwood collection was estimated for all forest land subcategories. In plantations, disturbance from fires and other disturbances was included, while for all other subcategories 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.

This category reports emissions and removals from the categories forest land remaining forest land and land converted to forest land (new forest established, via afforestation or natural succession, on areas previously used for other land-use classes). In 2012 the total sink from forests amounted to 34 325 Gg $CO_2$, which was up from the 21 565 Gg $CO_2$ in 2000. Land converted to forest land contributed the largest portion to the forest category (**Figure 5.13**) due to changes in biomass and soil carbon. The annual fluctuations in this category are due mainly to changes in biomass losses (due to harvesting, fuelwood removals and disturbance losses). In 2004 there was a reduction in the sink compared to 2003 and this was due mainly to an increase in disturbance losses that year. Harvested wood was also higher in 2004 compared to 2003. There was also an increase in losses due to disturbance in 2007 and 2008, which declined in 2009. These increases in carbon losses led to a sink in the forest land remaining forest land during 2008. This sink is however also partly due to the inability to allocate carbon losses between land remaining land and converted land. The increased sink in 2012 is due to a combination of reduced harvested wood, fuelwood and disturbance. Conversion of grasslands and other lands to forest lands are estimated to be the largest contributors to the land converted to forest land $CO_2$ sink. Of the 2012 sink, 90.2% was contributed by the biomass pool, while the rest was from the SOC and DOM pools (**Figure 5.14**).


Figure 5.13: Sector 3 AFOLU – Land: Trend in emissions and sinks (in Gg $CO_2$) in the forest land between 2000 and 2012, differentiated by sub-category.

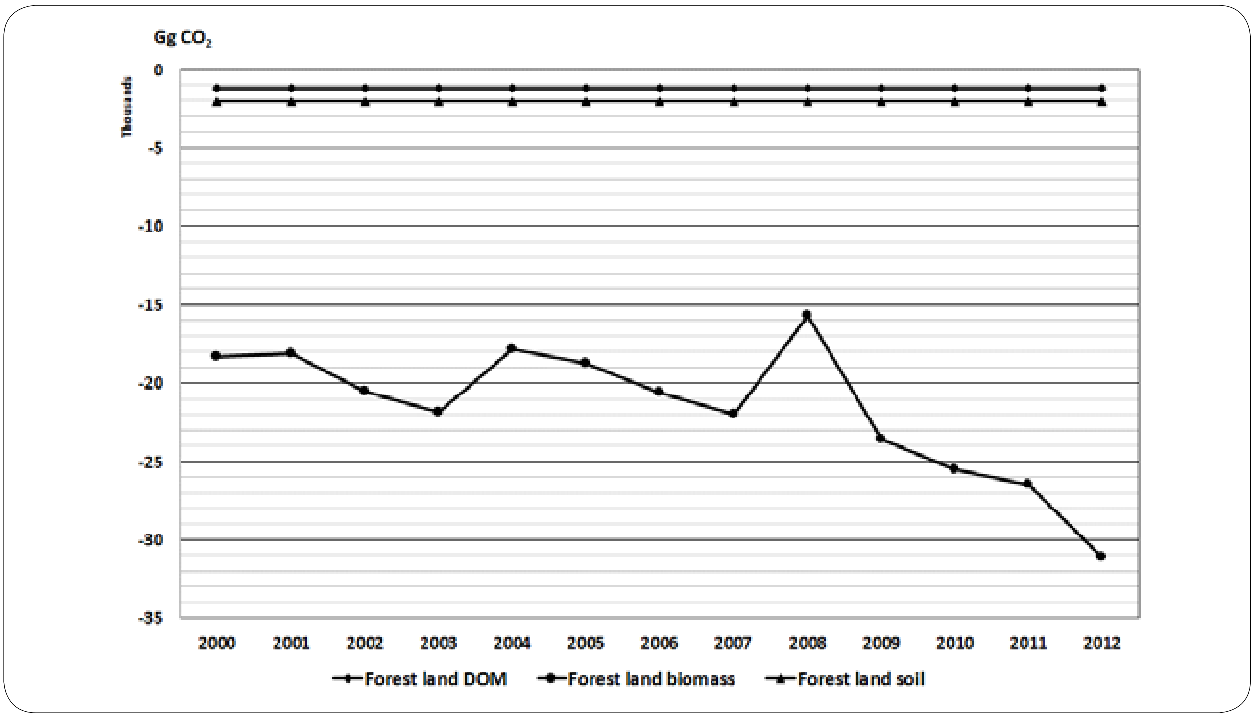



Figure 5.14: Sector 3 AFOLU – Land: Trend in emissions and sinks (in Gg $CO_2$) in the forest land between 2000 and 2012, differentiated by source category.

### 5.4.7.2 *Methodological Issues*

*5.4.7.2.1 Biomass*

**Forest land remaining forest land**

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):

$$\Delta CG = \sum (A_i * G_{TOTALi} * CF_i) \qquad \text{(Eq. 5.14)}$$

Where for $G_{TOTAL}$ a Tier 1 approach was used for natural vegetation classes (Eq. 5.15), while a Tier 2/3 approach was applied to the plantations (Eq. 5.16)

$$G_{TOTALi} = \sum [G_{Wi} * (1+R)] \qquad \text{(Eq. 5.15)}$$

$$G_{TOTALi} = \sum [I_v * BCEF_I * (1+R)] \qquad \text{(Eq. 5.16)}$$

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)$^{-1}$)

Iv = average net annual increment for specific vegetatio type ($m^3$ $ha^{-1}$ $yr^{-1}$);

BCEFI = biomass conversion and expansion factor for conversion of net annual increment in volume to above-ground biomass growth ((t AG biomass growth ($m^3$ net annual increment)$^{-1}$);

CFi = Carbon fraction of dry matter for forest category *i* (t C (t dm)$^{-1}$)

In the previous inventory a dead wood component was included in Eq. 5.15 as it was indicated that the carbon losses from the live biomass would be overestimated as the fuel wood removals include dead wood. In this inventory estimates for the DOM pool were included therefore, instead of including a dead wood component in the carbon gains the fuelwood removals were adjusted for dead wood so only removals of live wood were included here.

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):

$$L_{wood\text{-}removals} = [H * BCEF_S * (1+R) * CF \qquad \text{(Eq. 5.17)}$$

Where:

H = annual wood removals ($m^3$ $yr^{-1}$)

BCEFS = biomass conversion and expansion factor for conversion of removals in merchantable volume to total biomass removals (including bark), (t biomass removed ($m^3$ of removals)$^{-1}$)

R = ratio of below-ground biomass to above-ground biomass (t dm below-ground (t dm above-ground)$^{-1}$).

CF = Carbon fraction of dry matter (t C (t dm)$^{-1}$)

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

$$L_{fuelwood} = [FG_{trees} * BCEF_R * (1+R) + FG_{part} * D] * CF \qquad \text{(Eq. 5.18)}$$

Where:

$FG_{trees}$ = annual volume of fuelwood removal of whole trees (m$^3$ yr$^{-1}$)

$FG_{part}$ = annual volume of fuelwood removal as tree parts (m$^3$ yr$^{-1}$)

$BCEF_R$ = biomass conversion and expansion factor for conversion of removals in merchantable volume to biomass removals (including bark), (t biomass removal (m$^3$ of removals)$^{-1}$)

R = ratio of below-ground biomass to above-ground biomass (t dm below-ground (t dm above-ground)$^{-1}$)

D = basic wood density (t dm m$^{-3}$)

CF = carbon fraction of dry matter (t C (t dm)$^{-1}$)

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

$$L_{disturbances} = A_{disturbance} * B_W * (1+R) * CF * fd \qquad \text{(Eq. 5.19)}$$

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 woodlands/ open bush the loss of carbon from disturbance (fires only) was calculated using the biomass burning equation (IPCC 2006, Equation 2.27, p. 2.42):

$$L_{fire} = A * M_B * C_f * G_{ef} * 10^{-3} * (12/44) \qquad \text{(Eq. 5.20)}$$

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 ($\Delta C$) 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. 21)

**Land converted to forest land**

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 in the first year of conversion. 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/open bush 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 Dead organic matter*

**Forest land remaining forest land**

The dead organic matter (DOM) pool comprises deadwood and litter. For this inventory a Tier 1 approach was introduced as the DOM pool is not a key category. Under the Tier 1 method the DOM pool in land remaining in the same land use category are reported to have zero changes in carbon stocks or carbon emissions (IPCC, 2006, Chapter 2, p 2.21).

**Land converted to forest land**

For the Tier 1 approach it is assumed that on land converted to forest land the build-up of litter and deadwood occurs linearly from zero (in the non-forest land-use categories) over a transition period. The transition period for this inventory was taken as 23 years (transition period of the land-cover maps), as IPCC Guidelines indicate that if the transition time (T) is longer than the default 20 years (D) then the value for T should be used. Annual change in carbon stocks in deadwood or litter (tonnes C $yr^{-1}$) was calculated using the following equation (Equation 2.23 in the IPCC 2006 Guidelines):

$$\Delta C_{DOM} = [(C_n - C_o) * A_{on}] / T_{on}$$

(Eq. 5.22)

Where:

$C_n$ = dead wood/litter stock under the new land-use category (tonnes C $ha^{-1}$);

$C_o$ = dead wood/litter stock under the old land-use category (tonnes C $ha^{-1}$);

$A_{on}$ = area undergoing conversion from old to new-land use category (ha);

$T_{on}$ = time period of the transition from old to new land-use category (yr.) (23 years for this inventory).

*5.4.7.2.3 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, Volume 4, p. 2.30). Land areas were stratified by default soil types (see **Section 5.4.1**) in order to obtain SOC reference values (for warm temperate dry conditions). These were then multiplied by stock change factors by using formulation B of Equation 2.25:

$$\Delta C_{Mineral} = \sum[\{(SOC_{REF}*F_{LU}*F_{MG}*F_I)_0 - (SOC_{REF}*F_{LU}*F_{MG}*F_I*A)_{(0-T)}\}*A]/D \quad \text{(Eq. 5.23)}$$

Where:

$SOC_{REF}$ = the reference carbon stock (t C $ha^{-1}$) for each soil type;

FLU = stock change factor for land-use system for a particular land-use (dimensionless);

FMG = stock change factor for management regime (dimensionless);

FI = 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 (transition period of 23 years was used for this inventory).

### 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 5.4.4**.

*5.4.7.3.1 Biomass*

**Biomass gains**

Annual biomass growth data for plantations was calculated from mean annual increment (MAI) data provided by Forestry SA. These values were multiplied by the BCEF's from Dovey and Smith (2005) (0.522 for softwoods; 0.558 for *Eucalyptus grandis*; 0.741 for other *Eucalyptus* species; 0.909 for *Acacia* species; and an average of 0.68 for other species) to obtain the increment in t dm $ha^{-1}$. These $BCEF_I$ values fall within the IPCC 2006 default range of 0.4 – 0.9 t biomass ($m^3$ wood volume)$^{-1}$ for dry subtropical plantations with a growing stock between 100 and 200 $m^3$ (IPCC 2006, Table 4.5).

Midgley and Seydack (2006) reported that growth was 1% of AGB for indigenous forests. The AGB value in the previous inventory was 81 t dm $ha^{-1}$ (IPCC GPG 2003), however in this inventory a value of 150 t dm $ha^{-1}$ was applied based on the outputs of the recently completed NTCSA (Department of Environmental Affairs, 2015) (see **Appendix F**). The report provided validation for these data outputs. This value is at the upper limit of the IPCC default values for subtropical systems in Africa (20 – 200 t dm $ha^{-1}$) with the subtropical dry forest having a value of 130-140 t dm $ha^{-1}$ (IPCC, 2003). The 1% growth rate of 1.5 t dm $ha^{-1}$ $yr^{-1}$ is also much more in line with IPCC default values for subtropical systems (Table 4.12; IPCC 2006 Guidelines) than the 0.8 t dm $ha^{-1}$ from the previous inventory.

Data for thickets remain unchanged from the previous inventory. 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). Mills and Cowling (2006) reported growth rates for above ground biomass of 0.04 to 0.131 g C $m^{-2}$ $yr^{-1}$ (or 0.85 to 2.76 t dm $ha^{-1}$) in thickets which provides an average estimate of 1.8 t dm ha $yr^{-1}$ as used in the previous inventory. For woodland/open bush a growth value of 0.9 t $ha^{-1}$ $yr^{-1}$ was also taken from the previous inventory (Department of Environmental Affairs, 2013).

A root-to-shoot ratio of 0.24 for woodland/open shrubs and forests taken from the Global Forest Resource Assessment for South Africa (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). All of these are consistent with the values used in the 2010 inventory (Department of Environmental Affairs, 2014). In the GFRASA (2010) thickets are classed as other woodlands and these are indicated to have a root-to-shoot ratio of 0.48.

The IPCC 2006 default value of 0.47 t C per t $dm^{-1}$ (IPCC 2006, Table 4.3) was used for the carbon fraction of dry matter of all Forest lands.

### Losses due to wood harvesting

Loss of carbon due to wood harvesting was only determined for plantations using FSA data (FSA, 2012) (**Table 5.12**) as wood harvesting does not occur in woodlands/open bush, thickets or indigenous forests. The wood harvested for fuelwood was not included here as it was included under fuelwood removals. The industry conversion factors provided were used to convert between tonnes and $m^3$. The $BCEF_S$ were taken to be the same as the $BCEF_I$ values described above Section as the IPCC 2006 default values (IPCC 2006, Table 4.5) indicate this to be the case.

Table 5.12: Sector 3 AFOLU – Land: Annual wood harvest data (m3/yr) from plantations between 2000 and 2012 (source: FSA, 2012).

| | Softwood-sawlogs | Softwood – pulp | Softwood – other sp. | Euc. grandis | Other Eucs | Wattle | Other sp. |
|---|---|---|---|---|---|---|---|
| 2000 | 4 086 816 | 3 574 970 | 147 184 | 4 510 395 | 2 951 744 | 1 205 401 | 34 992 |
| 2001 | 4 041 832 | 3 058 964 | 126 713 | 4 695 726 | 3 466 830 | 953 701 | 20 742 |
| 2002 | 4 041 765 | 3 126 909 | 135 942 | 5 035 023 | 2 993 119 | 992 205 | 60 023 |
| 2003 | 4 857 374 | 3 402 798 | 122 055 | 5 471 160 | 4 155 741 | 960 728 | 18 665 |
| 2004 | 5 040 134 | 2 765 001 | 155 901 | 7 529 361 | 3 512 057 | 993 457 | 48 305 |
| 2005 | 5 224 656 | 3 751 951 | 199 081 | 7 529 566 | 3 893 000 | 1 084 651 | 27 658 |
| 2006 | 5 507 744 | 3 636 937 | 184 414 | 8 722 087 | 3 263 045 | 1 176 582 | 42 648 |
| 2007 | 5 115 671 | 3 759 857 | 127 443 | 6 399 489 | 3 659 702 | 954 447 | 7 515 |
| 2008 | 4 894 655 | 3 837 417 | 109 575 | 6 822 931 | 3 386 144 | 796 124 | 18 746 |
| 2009 | 4 145 537 | 3 421 600 | 94 450 | 6 837 481 | 3 125 173 | 928 456 | 21 027 |
| 2010 | 3 744 396 | 3 343 702 | 100 615 | 5 372 218 | 3 733 368 | 900 317 | 36 038 |
| 2011 | 3 916 832 | 3 534 944 | 106 087 | 5 757 557 | 3 779 164 | 1 070 608 | 48 537 |
| 2012 | 4 411 143 | 3 308 541 | 99 550 | 5 411 542 | 3 634 810 | 980 161 | 42 180 |

**Losses due to fuelwood removal**

Fuelwood removal was estimated for all sub divisions within the Forest land class. For plantations FSA (2012) provided annual data on wood removed for firewood/ charcoal (**Table 5.13**).

For natural forests, woodlands and shrublands data at a national scale is limited. Fuelwood consumption, therefore, was calculated by obtaining an average fuelwood consumption rate per household (Shackleton, 1998; Shackleton & Shackleton, 2004; Madubansi & Shackleton, 2007; Matsika **et al.**, 2013) and combining this with the number of households that use fuelwood (Statistics SA). A small percentage of the wood collected is deadwood, so this amount needs to be removed from fuelwood consumption, as only live wood removals are to be accounted for in this section. Shackleton (1998) calculated that annual deadwood production was 1.7% of total biomass. It was assumed that all pre-existing deadwood had been collected the previous year, so only the deadwood produced in the current year is collected. Therefore deadwood is assumed to be 1.7% of fuelwood consumption. The fuelwood consumption numbers are within the range of the value provided by the FAO. The fuelwood consumption estimates show a decline since 2000, but Damm and Triebel (2008) suggested that fuelwood consumption was stabilizing and may decline in the future. 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 woodlands/open bush with no removal from forests and thickets. For woodland/savannas the BCEF of 2.1 t biomass removed ($m^3$ of removals)$^{-1}$ was taken from the previous inventory. This was determined from the BEF and wood density data in the GFRASA (2005). This value is high compared to the plantation data, but little data is available to determine the BCEF for woodlands. Data is being collected to improve this value in the next inventory. This higher value could be leading to an underestimation

Table 5.13: Sector 3 AFOLU – Land: Annual removal of fuelwood (m3/yr) from plantations between 2000 and 2012 (source: FSA, 2012).

| | Softwoods | Euc. grandis | Other Eucs | Wattle | Other sp. |
|---|---|---|---|---|---|
| **2000** | 18 855 | 42 082 | 18 933 | 80 944 | 5 165 |
| **2001** | 21 523 | 95 890 | 21 093 | 94 991 | 6 268 |
| **2002** | 22 356 | 56 000 | 34 234 | 113 718 | 2 427 |
| **2003** | 20 148 | 53 439 | 36 821 | 101 730 | 2 822 |
| **2004** | 24 333 | 78 488 | 61 713 | 99 400 | 998 |
| **2005** | 39 772 | 51 053 | 37 221 | 134 037 | 2 289 |
| **2006** | 42 661 | 82 002 | 35 939 | 130 150 | 292 |
| **2007** | 26 537 | 93 077 | 51 850 | 132 358 | 1 674 |
| **2008** | 28 396 | 75 649 | 44 144 | 122 114 | 0 |
| **2009** | 38 669 | 105 093 | 43 624 | 123 065 | 1 727 |
| **2010** | 21 051 | 94 642 | 37 541 | 127 498 | 0 |
| **2011** | 25 448 | 139 666 | 18 019 | 116 852 | 0 |
| **2012** | 23 654 | 144 275 | 18 568 | 118 228 | 0 |

of the forest sink. During wood collection the trees are not destroyed, but are left to continue to grow. Therefore roots were not removed during fuelwood harvesting (i.e. root: shoot ratio was set to zero).

**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 the FSA also recorded whether the plantations in a 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 hardwood (fd = 0.636) and softwood (fd = 0.489) species. These averages were kept constant over the 10-year period as the FSA stop reporting this data in 2000. The AGB (BW) data obtained from the NTCSA (Department of Environmental Affairs, 2015) only provided a value for plantations as a whole (97 t dm ha-1). To estimate biomass data for each plantation type the growing stock (by volume) data from GFRASA (2010) was combined with the BCEFS (Chhabra *et al.*, 2002). The values ranged between 70 t dm $ha^{-1}$ and 132 t dm ha-1 which are within the range estimated in the NTCSA (Department of Environmental Affairs, 2015).

The amount of carbon lost due to fire disturbance in woodlands/open bush was determined as discussed in **Section 5.4.7.2.1**. Natural forests and thickets were assumed not to burn. The MB, Cf and emission factors are provided and discussed in **Section 5.5.2**.

##### *5.4.7.3.2 Dead organic matter*

For the tier 1 approach the default litter values should be considered, however these values are very high relative to estimates obtained from the literature for South Africa. The NTCSA (Department of Environmental Affairs, 2015) provided the values of 121 ± 49 g C $m^{-2}$, 900 ± 50 g C $m^{-2}$ and 254 ± 52 g C $m^{-2}$ for woodlands, forests and thickets respectively (Shea *et al.*, 1996; Weider and Wright, 1995; Powell, 2009). These values were used in the inventory as opposed to the default values.

##### *5.4.7.3.3 Mineral soils*

The long term climate in South Africa was classified according to the IPCC climate classes and 99.7% of South Africa falls within the "warm temperate dry" category (Moeletsi *et al.*, 2013). Therefore there was no stratification by climate in this inventory. Soils were also classified according to the six IPCC classes (Moeletsi et al., 2013), so the land classes (for 1990 and 2013/14) were stratified by soil type so that the reference carbon stock ($SOC_{REF}$) could be determined. As in the previous inventory, the IPCC default $SOC_{REF}$ values were applied (IPCC 2006, Volume 4, p. 2.31, Table 2.3), however, the next inventory should include country-specific SOC reference values. The soil carbon values for the various vegetation types determined from the NTCSA (Department of Environmental Affairs, 2015),which ranged between 3.8 and 37.95 t C $ha^{-1}$, were compared to the IPCC SOC reference values and found to be in a similar range. Reference values are expected to be slightly higher as it is the carbon in natural systems where no conversions have taken place. 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). Stock change factors were determined for each crop type by using data reported in Moeletsi *et al.* (2013) and the NTCSA (Department of Environmental Affairs, 2015) (**Table 5.14**). For settlements a stock change factor of 0.8 was used (Department of Environmental Affairs, 2015). The area converted is the total area converted since 1990.

Table 5.14: Sector 3 AFOLU – Land: Relative stock change factors (± error) for different management activities on croplands (Source: Department of Environmental Affairs, 2015; Moeletsi et al., 2013).

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

a long term cultivated;
b perennial/tree crop;
c frequent tillage;
d no till;
e medium inputs;
f low inputs;
g from NTCSA (Department of Environmental Affairs, 2015).

### 5.4.7.4 Uncertainties and Time-series Consistency

#### 5.4.7.4.1 Uncertainties

A full assessment of the uncertainties in the forest land category have not yet been completed, and will be undertaken in the next inventory. Much of the uncertainty associated with the land component relates to the mapping and area of each land type. These are discussed in **Section 5.4.4**. The statistics from the FSA have a high confidence rating (80%) with an uncertainty range from -11% to 3% based on a comparison with the RSA yearbook (Department of Environmental Affairs and Tourism, 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 AGB growth increment in natural forests and woodlands could not be determined, but for thickets the uncertainty is 1.8 ± 0.96 t dm $ha^{-1}$. The uncertainty in BCEF could not be determined; however, IPCC 2006 Guidelines suggest that it can reach up to 30%. Default root-to-shoot ratios for forests and woodlands 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 the FAO were not provided, but it 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, p 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, so the variation on the activity data was large (see **Appendix F**) and requires more vigorous analysis to determine the uncertainty. It is suggested that a more detailed uncertainty analysis be done on the data.

#### 5.4.7.4.2 Time-series consistency

The same sources of data and land-cover maps were used throughout the 12-year period so as to provide a consistent time series of data.

### 5.4.7.5 Source-specific QA/QC and Verification

The land area in the land-cover maps were compared to previous data sets and explanations for the various changes have been provided. The land areas were checked and summed across all land-use categories to ensure that the total area in the inventory remained constant over the time series. Where possible, the activity data was compared to literature, previous inventories and to default values. The biomass data was compared to the biomass and NPP data from the NTCSA (Department of Environmental Affairs, 2015) outputs. It was noted that the inventory produces biomass growth values at the low end of the NPP range and that savannas are estimated to have a higher NPP than thickets, however as more detail is included in the next inventory so these differences are expected to be reduced. Further assessments will be completed in the next inventory. Soil carbon data was also compared to the NTCSA outputs.

As validation the plantation data was compared to a more detailed study by Alembong (2015). This inventory overestimates the gains and also the losses from plantations. This could be due to a difference in plantation areas being used. However, Alembong (2015) estimated the overall carbon gains in plantations in 2011 to be 857 300 t C, while the inventory estimates 558 223 t C. These values are within a similar range and more detailed will be incorporated into the next inventory to reduce these differences.

Wood removed due to harvesting were cross-checked with the input data for HWP. There was also a cross-check between the wood removed for fuelwood and the fuelwood consumption data used in the energy sector. The amount of wood harvested was compared to the FAO data. All general QC procedures discussed in **Section 1.4.1** were carried out on this category to ensure consistency in the data. 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 to 2012 as new higher resolution maps were incorporated. There was also a reclassification of the woodland/open bush category. These changes impacted the *area of forest land remaining forest land* as well as *land converted to forest land*. Minor updates were made to the activity data and the DOM pool was included. Land classes were also stratified by soil type to improve the soil carbon data.

### 5.4.7.7 Category-specific Planned Improvements and Recommendations

Due to a lack of disaggregation within the land classes average growth increments for the ecosystems were taken from the literature. These could be over-estimated as there is little information on whether these growth increments are for regenerating or mature systems. It is therefore recommended that more detailed age class data be incorporated into future inventories to get a more accurate carbon gain values for the forest land.

Another important recommendation is to assess and update the BCEF for fuelwood data. A reduction in uncertainty in this area would lead to improved data for the forest land category.

The next inventory plans to make use of the recently released IPCC 2006 version of the Agriculture and Land Use (ALU) software. This software allows spatial data to be integrated with ground based data. For the forest land category the plan is to incorporate more detail regarding the forests and their age classes and management. Data from Alembong (2015) will be obtained and incorporated where possible. A complete uncertainty analysis on the land data is also planned for the next inventory and the

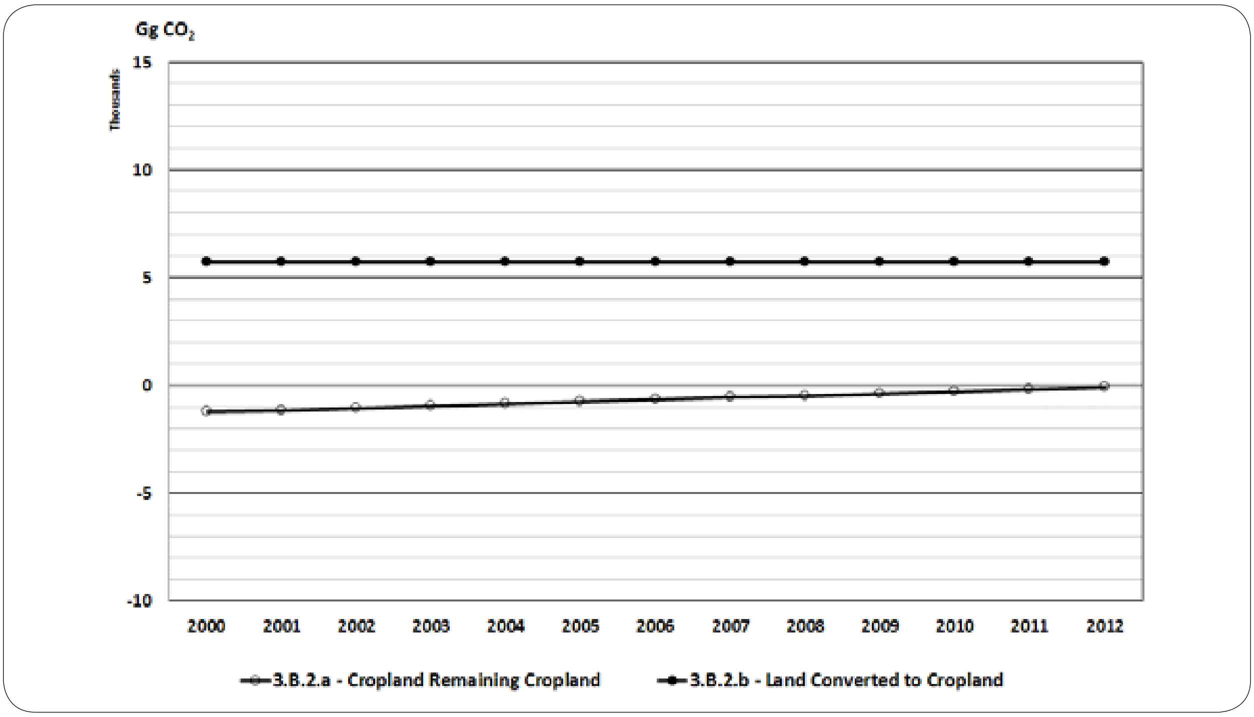



Figure 5.15: Sector 3 AFOLU – Land: Trend in emissions and sinks (in Gg $CO_2$) in Croplands between 2000 and 2012, differentiated by sub-category.

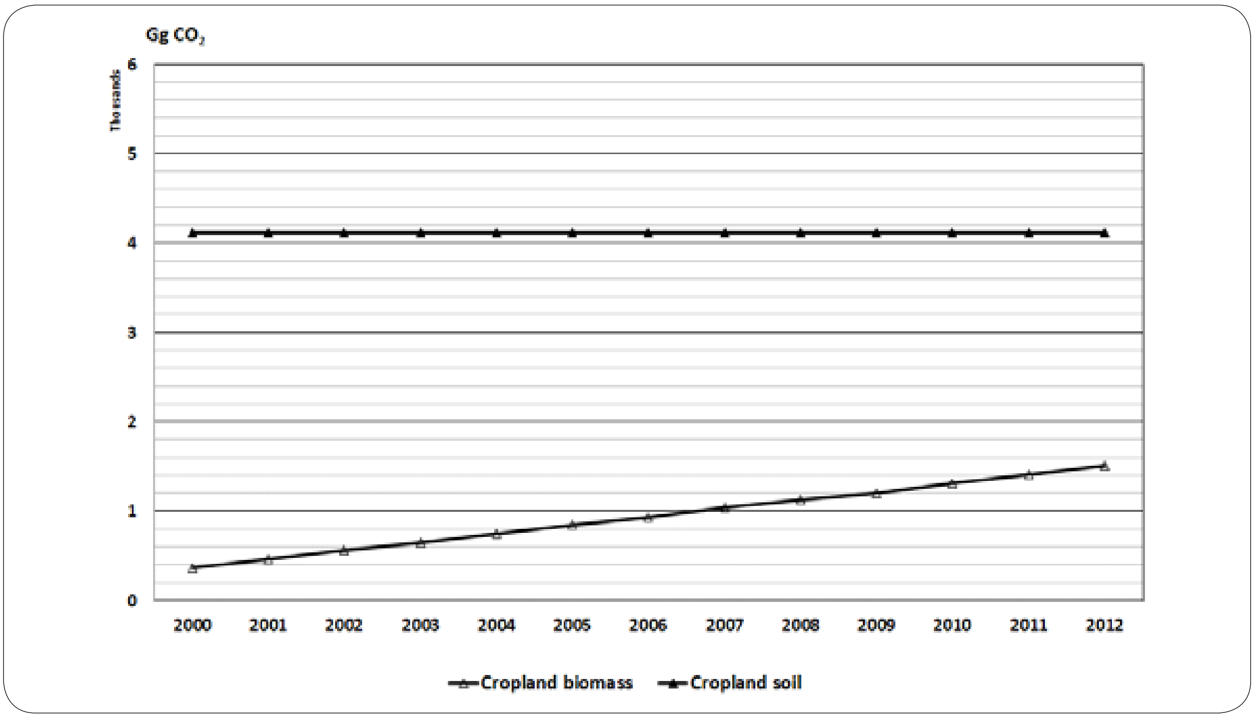



Figure 5.16: Sector 3 AFOLU – Land: Trend in emissions and sinks (in Gg $CO_2$) in Croplands between 2000 and 2012, differentiated by source category.

ALU software will also be able to assist with this. The other advantage of the ALU software is that it provides a place for all the metadata and data sources to be stored.

Going forward it is suggested that a stock-based approach be investigated for use in the inventory. This could be based on the carbon stock maps generated during the NTCSA (Department of Environmental Affairs, 2015) together with stock estimates for plantations and other forms of agriculture or production areas. The carbon stock estimates for indigenous landscapes could be updated on an annual or biannual time-scale using the model developed for the NTCSA. A stock-based approach allows a more complete evaluation of the change in stocks over time, compared to the current flux / process based approach that may not be complete.

### 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, and viticulture. 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 23-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 therefore all calculations include transitions since 1990.

For *Cropland remaining cropland*, the Tier 1 assumption is that for annual cropland there is no change in biomass carbon stocks after the first year (GPG-AFOLU, section 5.2.1, IPCC, 2006a). The rationale is that the increase in biomass stocks in a single year is equal to the biomass losses from harvest and mortality in that same year. For perennial cropland, there is a change in carbon stocks associated with a land-use change. Where there has been land-use change between the *Cropland* subcategories, carbon stock changes are reported under *Cropland remaining cropland. Cropland remaining cropland* was estimated to be a sink of $CO_2$, declining from 1 241 Gg $CO_2$ in 2000 to 104 Gg $CO_2$ in 2012 (**Figure 5.15**). The sink is due to conversions between annual and perennial cropland categories and changes in soil carbon. *Land converted to cropland* was a source of $CO_2$ (5 721 Gg $CO_2$ per year) (**Figure 5.16**). The source remained constant as a constant annual change was derived over the mapping period between 2000 and 2013-14. It is assumed that equilibrium is reached after a year of conversion therefore even though the land converted to cropland area increased every year the change in biomass is only determined for the annual area converted. The largest contributors to the $CO_2$ source in this category were conversions from grasslands to croplands. SOC was the largest contributor to this category (**Figure 5.16**). For Croplands the DOM was not estimated, but is not considered as a major contributor to this category.

#### *5.4.8.2 Methodological Issues*

##### *5.4.8.2.1 Biomass*

**Cropland remaining cropland**

According to the 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. Perennial woody crops (e.g. tree crops) accumulate biomass for a finite period until they are removed through harvest or reach a steady state where there is no net accumulation of carbon in biomass because growth rates have slowed and incremental gains from growth are offset by losses from natural mortality or pruning. After this period, perennial woody crops are replaced by new ones and carbon stored in biomass is released to the atmosphere. Default annual loss rate is equal to biomass stocks at replacement. Biomass stock changes in perennials were calculated as follows:

$$\Delta CB = A * (\Delta CG - \Delta C)$$

(Eq. 5.24)

Where

$\Delta CB$ = annual change in carbon stocks in biomass (tonnes C $yr^{-1}$);

$A$ = annual area of cropland (ha);

$\Delta CG$ = annual growth rate of perennial woody biomass (tonnes C $ha^{-1}$ $yr^{-1}$);

$\Delta CL$ = annual carbon stock in biomass removed (tonnes C $ha^{-1}$ $yr^{-1}$)

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.

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 was 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. 5.25)

Where:

$\Delta C_B$ = annual change in carbon stocks in biomass (t C $yr^{-1}$);

$\Delta C_G$ = 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 $ha^{-1}$);

$\Delta A_{TO\_OTHER}$ = annual area of land converted to cropland (ha);

$CF$ = carbon fraction of dry matter (t C/t $dm^{-1}$);

$\Delta C_L$ = 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 5.4.7.2.3**. The land areas for the various categories were obtained from the land-use change maps (GeoTerraImage, 2015) and described in **Section 5.4.4**. For the *croplands remaining croplands* category this included conversions between croplands, and for the *land converted to croplands* category the land area included all converted land since 1990.

### 5.4.8.3 Data Sources

#### 5.4.8.3.1 Biomass

**Croplands remaining croplands**

The areas of the various *croplands remaining croplands* and *land converted to croplands* were obtained from the updated land-use maps developed by GeoTerraImage (2015) and are discussed in detail in **Section 5.4.4**. For *croplands remaining croplands* the area is multiplied by a carbon gain and loss. Default net accumulation rates and biomass stocks were considered for perennial crops, however according to data from the NTCSA (Department of Environmental Affairs, 2015) these values are high. The DEA (2015) report provided biomass carbon for cultivated land in general, therefore to obtain a value for orchards and vineyards the above-ground carbon (woody and herbaceous) layers from this study were integrated into ArcGIS 10 and extrapolated based on the 2013/14 land-cover dataset. This provided a value of 59 t dm $ha^{-1}$ $yr^{-1}$ for orchards and a value of 22 t dm $ha^{-1}$ $yr^{-1}$ for vineyards (see **Appendix F**). There is not a lot of data available for validation but the National Inventory Report for Greece has a value of 48 – 54 t dm $ha^{-1}$ for orchards and for vineyards biomass data of 14 – 17.8 t dm $ha^{-1}$ are reported in the USA (Morande, 2015). These suggest that the calculated AGB from the DEA (2015) report are reasonable and were therefore applied in this inventory. Considering statistics for orchards and vineyards (Hortgro, 2015) the age distribution of the crops is shown to be up to 18 years plus and 25 years plus for various orchard types and up to 25 years plus for vineyards. Based on this it was assumed that on average the orchards and vines grow for 25 years. This is a broad assumption, and may be an underestimate, as the category is for orchards in general. More cropland detail and age class distribution will be included in the next inventory so these assumptions and estimates can be improved on. Biomass was assumed to accumulate linearly for the entire 25 year period, therefore, the growth rate was calculated as the biomass divided by age. These derived growth rates (1.16 t dm $ha^{-1}$ for orchards and 0.44 t dm $ha^{-1}$ for vineyards) are much lower than the IPCC default values, but similarly low growth rates have been used by other countries (National Inventory Report, New Zealand). For losses the area harvested was difficult to determine. The South African Wine Industry Statistics Report (2015) provides the area of uprooted vineyards and this was taken to be the area for loss. The biomass stock was multiplied by this area to calculate the carbon loss for vineyards. The activity data available for orchards does not provide information on areas of perennial cropland temporarily destocked; therefore, no losses in carbon stock due to temporary destocking could be calculated at this stage and can be considered in future inventories if data becomes available.

**Land converted to cropland**

It is assumed that land is cleared before it is converted to a crop, therefore the biomass stock immediately after conversion is assumed to be zero. Indigenous forest AGB are provided in **section 5.4.7.3.1**. For thickets and dense bush the 60 t dm $ha^{-1}$ (Mills et al., 2005; Mills and Cowling, 2006; Lechmere-Oertel, 2003) used in the previous inventory was applied. This was within the range provided by the NTCSA (Department of Environmental Affairs, 2015). This study reported an average value of 50 t dm $ha^{-1}$, and if this carbon data is overlaid with the updated 2014 land cover map then a value of 68 t dm $ha^{-1}$ is obtained (see **Appendix F**). Therefore, the value identified from the literature is within this range. The woodland/dense bush AGB values were adjusted from the previous inventory due to data from the NTCSA (Department of Environmental Affairs, 2015), but also due to changes in classification. This vegetation class is very large and covers savannas and woodlands so the variation and uncertainty on the average value is large. Intersecting the new land cover map (2014) with the woody and herbaceous carbon data from the DEA (2015) report provided a value of 14.86 t dm $ha^{-1}$. This is within the range of 3.4 – 57.8 t dm $ha^{-1}$ sourced from the literature (Scholes and Hall, 1996; Rutherford, 1982; Shackelton and Scholes, 2011;

Table 5.15: Sector 3 AFOLU – Land: Above ground biomass for the various land classes.

| Land class | Biomass carbon stock (t dm $ha^{-1}$) | Data source |
|---|---|---|
| Plantations<br>Eucalyptus grandis<br>Other Eucs<br>Softwood pulp<br>Acacia<br>Other sp. | <br>84<br>111<br>71<br>132<br>92 | Values for plantation species were calculated from FSA data and Dovey and Smith (2005) dry matter ratios. |
| Thicket | 60 | Previous inventory |
| Woodland/open bush | 18 | Scholes and Hall, 1996; Rutherford, 1982; Shackelton and Scholes, 2011; Colgaren et al., 2012. Also supported by the outputs of the intersection of DEA (2015) AGB data and the new 2014 land cover map |
| Grasslands | 6.1 | IPCC 2006 Guidelines |
| Cultivated annual | 10 | DEA (2015); IPCC 2006 Guidelines |
| Orchards | 59 | Overlay of DEA (2015) AGB data and the new 2014 land cover map |
| Vines | 22 | |

Colgan et al., 2012). The average AGB value of 18 t dm $ha^{-1}$ provided by Scholes and Hall (1996) was used in this inventory. The biomass data for other land classes before conversions are provided in **Table 5.15**. The IPCC default values for annual cropland and grassland AGB were used as in the previous inventory as the data from the NTCSA (Department of Environmental Affairs, 2015) are in the same range (see **Appendix F**).

An IPCC default carbon gain value of 5 t C $ha^{-1}$ was applied for annual croplands (IPCC 2006, Vol 4, chapter 5, page 28, Table 5.9). Gains and losses for phase 2 of the equation were determined as for cropland remaining cropland. The carbon fraction was the default of 0.5 t C/t $dm^{-1}$.

##### *5.4.8.3.2 Mineral soils*

Data are as described in **Section 5.4.7.3.3**.

#### *5.4.8.4 Uncertainty 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 5.4.4**. 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 one year of growth in crops planted after conversion also have an error of ±75% (IPCC, 2006, p. 5.28).

For default soil organic C stocks for mineral soils there is a nominal error estimate of ±90% (IPCC 2006 Guidelines, p 2.31). The error on the stock change factors is indicated in **Table 5.14**. The biomass and DOM activity data is highly variable and the standard deviation on these data sets are shown in **Appendix F**.

##### *5.4.8.4.2 Time-series consistency*

The same sources of data and land cover maps were used throughout the 12 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 was compared to other data sets. Land-use change and activity data was compared to the literature and other data sources, where possible. The land areas were checked and summed across all land-use categories to ensure that the total area in the inventory remained constant over the time series. All general QC procedures discussed in **Section 1.4.1** were carried out on this category to ensure consistency in the data. An independent reviewer provided comment on the crop land category and the inventory was improved accordingly.

#### *5.4.8.6 Source-specific Recalculations*

The updated land cover maps meant that recalculations had to be done for all years between 2000 and 2012. Updated activity and soil carbon data were also incorporated.

#### *5.4.8.7 Category-specific Planned Improvements and Recommendations*

Under the GHG Improvement Programme initiated by the DEA, a project was recently completed by the Agricultural Research Council (ARC) which provides more detailed cropland data. Due to the timing of the project the data could not be incorporated into this inventory but will be considered in the next one. The next inventory will make use of the ALU software which will enable a more detailed categorization of croplands, and also allow for the integration of the detailed crop management data (irrigation, fertilization, rotations). The improved management data will also assist in improving the soil carbon data. Detailed categorization of crops will also allow more crop specific biomass and growth data to be included which can aid in reducing uncertainty. It is important for South Africa to move towards a Tier 2 for croplands.

### 5.4.9 Grassland [3B3]

#### *5.4.9.1 Source Category Description*

The *Grassland remaining grassland* category includes all grasslands, managed pastures and rangelands. The IPCC does recommend separating out improved grassland; however, there was insufficient information at the national scale to enable this division so all grasslands were classified together. 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. $CO_2$ emissions from biomass burning were not reported since they are largely balanced by the $CO_2$ that is reincorporated back into the biomass via photosynthetic activity.

*Grasslands remaining grasslands* were assumed to be in balance so there were no emissions from this sub-category. *Land converted to grasslands* were estimated to be a source of $CO_2$ (7 904 Gg $CO_2$ per year) because of land use conversions. The sink remained constant, as a constant annual change was derived over the mapping period between 2000 and 2013-14. It is assumed that equilibrium is reached after a year of conversion, therefore, even though the land converted to grassland area increased every year, the change is only determined for the annual area converted. DOM was not estimated for grasslands.

### 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 5.25 above. The average carbon stock change is equal to the carbon stock change due to the removal of biomass from the initial land use plus carbon stocks for biomass growth. Tier 1 method assumes that biomass is cleared when preparing a site for grassland use, so the default for biomass immediately after conversion is zero. The other assumption is that grasslands achieve their steady state biomass during the first year following conversion so there are no stock changes associated with Phase 2. The carbon fraction was the default of 0.5 t C /t $dm^{-1}$.

#### 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, 2015). 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 (2015) and are discussed in detail in **section 5.4.4**. The $B_{BEFORE}$ AGB values are provided in **Table 5.15** and in the relevant biomass sections.

#### 5.4.9.3.2 Mineral soils

Data are as described in **Section 5.4.7.3.3**.

### 5.4.9.4 Uncertainties 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 5.4.4**). Grasslands achieved a user accuracy of 85% but a producer's accuracy of 70%, which resulted from the confusion between grasslands, woodland/open bush and low shrubland (GTI 2013). A full uncertainty assessment has not been conducted, but is this will be done in the next inventory. Uncertainty on the biomass carbon stocks for the various land classes is given in **Appendix F**. Default biomass carbon stocks for the various land categories have an error of ±75%. IPCC default values for carbon stocks after one year of growth in crops planted after conversion also have an error of ±75% (IPCC, 2006, p. 5.28).

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

#### 5.4.9.4.2 Time-series consistency

The same sources of data and land-cover maps were used throughout the 12-year period 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 was compared to other data sets. Land-use change and activity data were compared to the literature and other data sources where possible; otherwise no other source-specific QA/QC procedures were carried out on this subcategory. The land areas were checked and summed across all land-use categories to ensure that the total area in the inventory remained constant over the time series. All general QC procedures discussed in **Section 1.4.1** were carried out on this category to ensure consistency in the data. An independent reviewer provided comment on the forest land category and the inventory was improved accordingly.

### 5.4.9.6 Source-specific Recalculations

Due to the updated land-cover maps and improved soils data recalculations were done for all years between 2000 and 2012.

### 5.4.9.7 Category-specific Planned Improvements and Recommendations

No specific improvements are planned for this category, however it is recommended that in future a more detailed classification of grasslands be included so as to improve the soil carbon for this category and to reduce uncertainty.

## 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 5.4.5.5**. 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 429 Gg $CO_2$eq and this declined by 37.7% to 267 Gg $CO_2$eq in 2012 (**Figure 5.17**). This decline is related to the reduced area of flooded lands as the wetland area decreased by 9.2% between 2000 and 2012[5].

### 5.4.10.2 Methodological Issues

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

$$CH_4\ emissions_{WWFlood} = P * E(CH_4)_{diff} * A * 10^{-6} \quad \text{(Eq. 5.26)}$$

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 It should be noted that this decreased wetland area should be considered with some caution as 1990 was a wetter year than 2013-14 so this reduction may be overestimated.

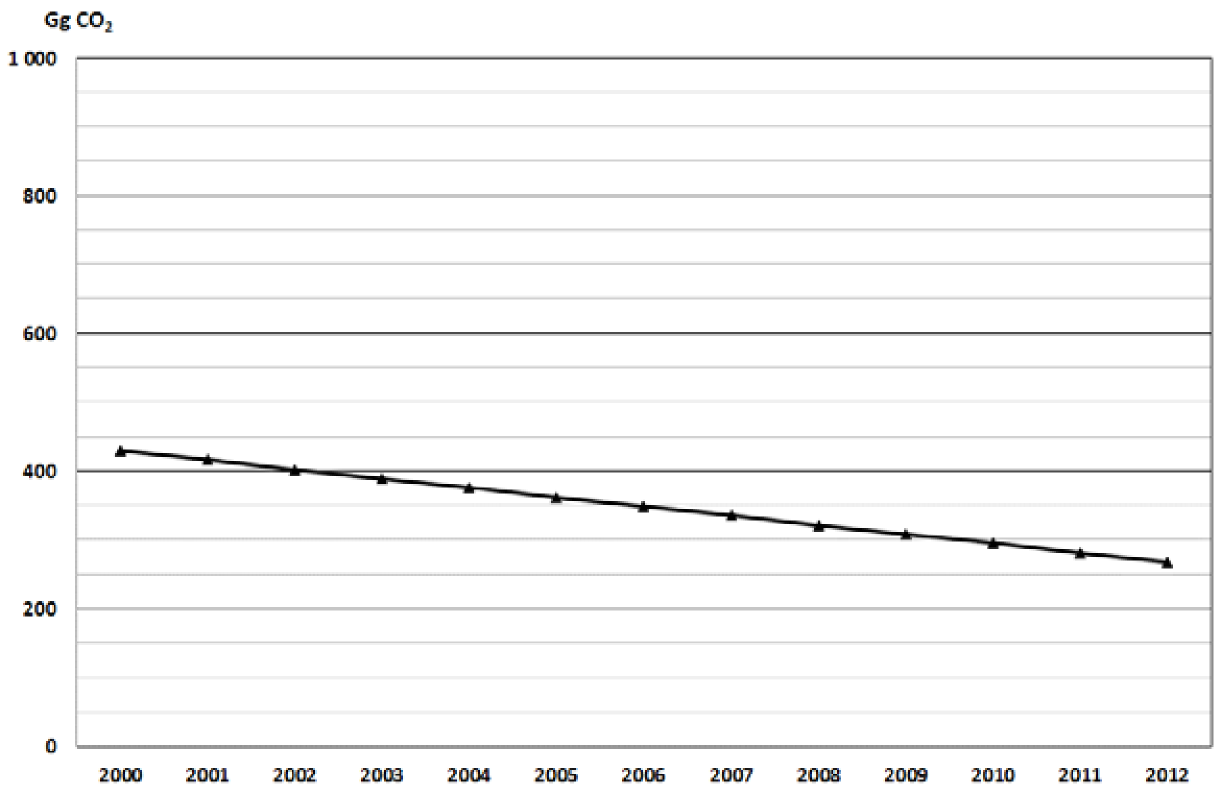



Figure 5.17: Sector 3 AFOLU – Land: Trend in $CH_4$ emissions (in Gg $CO_2$eq) in wetlands between 2000 and 2012.

### *5.4.10.3 Data Sources*

The area of waterbodies was taken from the GeoTerraImage (2014) 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, volume 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*

The main uncertainties were associated with the area estimates of the wetland categories (discussed in **Section 5.4.4**). The same sources of data and land-cover maps were used throughout the 12-year period to provide a consistent time series of data.

### *5.4.10.5 Source-specific Recalculations*

The 2000 to 2012 emissions were recalculated using the updated wetland area.

### *5.4.10.6 Source-specific Planned Improvements and Recommendations*

No improvements are planned for this category.

### 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 (Department of Environmental Affairs, 2011). The surface area of settlements provided by the land cover map developed for this inventory was 3 228 445 ha (2 901 090 ha of settlements and 327 354 ha under mines) in 2012. This area was higher than the area used in the 2010 inventory. Changes in the extent of urban areas between 1990 and 2013-14 (increase of 6.7%) may not be as locally significant as expected as the settlements category includes peripheral smallholding areas around the main built-up areas; and these tend to be the first land-use that is converted to formal urban areas, before further expansion into natural and cultivated lands.

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 $CO_2$ (1 195 Gg $CO_2$) due to land conversions. The soil source is approximately a third of the carbon, with the rest being from biomass.

#### *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 5.25 above. A 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. Above-ground biomass of the various land categories was taken from **Table 5.15.** as the biomass value before conversion. It is also assumed that there is no additional growth or loss of carbon on the land after it becomes a settlement. The carbon fraction was the default of 0.5 t C/t $dm^{-1}$.

##### *5.4.11.2.2Mineral soils*

**Land converted to settlements**

Soil carbon sources and sinks were calculated as described in **Section 5.4.7.2.3**.

#### *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 (2015) and are discussed in detail in **section 5.4.4**. Biomass carbon stocks before conversion for the various vegetation types are provided in **Table 5.15**. and the relevant biomass sections.

##### *5.4.11.3.2Mineral soils*

The land areas for the various categories were obtained from the land-use change maps (GeoTerraImage, 2015) and described in **Section 5.4.4**. For *land converted to settlements* the land area includes all converted land since 1990. All other data are described in **Section 5.4.7.3.3**. A stock change factor of 0.8 was applied to settlements.

#### 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 5.4.4**.

##### 5.4.11.4.2 Time-series consistency

The same sources of data and land-cover maps were used throughout the 12-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 was compared to other data sets. Land-use change and activity data were compared to the literature and other data sources, where possible, otherwise no other source-specific QA/QC procedures were carried out on this subcategory.

#### 5.4.11.6 Source-specific Recalculations

Due to new land areas from the updated land-cover maps, recalculations were done for all years between 2000 and 2012.

#### 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 low shrublands). This category includes emissions and sinks for *other land remaining other land* and *land converted to other lands*. There are assumed to be no changes in the *Other land remaining Other land* category, although this should be investigated further in future submissions as there can be a change in carbon if low shrubland is converted to bare ground for example. For the *land converted to other land* category both the biomass and soil carbon changes are included. This category was found to have an annual sink of 960 Gg $CO_2$. Soils were the largest contributors to this category although biomass has not been fully incorporated.

#### 5.4.12.2 Methodological Issues

##### 5.4.12.2.1 Biomass

**Land converted to other lands**

Annual change in biomass carbon stocks on land converted to other lands was estimated using equation 5.25 above. Carbon stocks before the conversion are provided in **Table 5.15.** and in the relevant biomass sections. Following the Tier 1 approach, it was assumed that other lands 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). The carbon fraction was the default of 0.5 t C/t dm$^{-1}$.

##### 5.4.12.2.2 Mineral soils

**Land converted to other lands**

Soil carbon sources and sinks were calculated as described in **Section 5.4.7.2.3**. According to IPCC Tier 1 method the reference C stock at the end of the 23 year transition period is assumed to be zero. This, however, only applies to areas that have no vegetation or have no possibility of having vegetation on them. South Africa's classification of *Other land* includes low shrublands, bare ground and degraded land all of which have some form of vegetation on them (see GTI report in **Appendix G**). Only a small portion of the bare ground category has no vegetation or does not have the potential to have vegetation on it. Based on this the assumption of zero carbon after 23 years was not assumed to be the case and the IPCC default SOC reference values were applied as in the other land categories.

### 5.4.12.3 Data Sources

##### 5.4.12.3.1 Biomass

The area of Land converted to settlements was obtained from the updated land use maps developed by GeoTerraImage (2015) and are discussed in detail in **section 5.4.4**. Biomass carbon stocks before conversion for the various vegetation types are shown in **Table 5.15**. and in the relevant biomass sections.

##### 5.4.12.3.2 Mineral soils

The land areas for the various categories was obtained from the land-use change maps (GeoTerraImage, 2015) and described in **Section 5.4.4**. For *land converted to other lands* the land area includes all converted land since 1990. All other data are described in **Section 5.4.7.3.2**.

### 5.4.12.4 Uncertainties and Time-series Consistency

##### 5.4.12.4.1 Uncertainties

The main uncertainties were associated with the area estimates of other lands and this is discussed in **Section 5.4.4**. Standard deviations on biomass activity data are provided in **Appendix F**.

##### 5.4.12.4.2 Time-series consistency

The same sources of data and land-cover maps were used throughout the 12-year period to provide a consistent time series of data.

### 5.4.12.5 Source-specific QA/QC and Verification

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

### 5.4.12.6 Source-specific Recalculations

Recalculations were completed for all years between 2000 and 2012 due to updated land areas.

### 5.4.12.7 Category-specific Planned Improvements and Recommendations

Changes in biomass for other land remaining other land will be included in the next inventory. Other than that no other improvements are planned for this category.

## 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 an accumulated total of 302 275 Gg $CO_2$eq between 2000 and 2012. The annual emissions fluctuated between a low of 22 529 Gg $CO_2$eq in 2012 and a high of 24 607 Gg $CO_2$eq 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 (**Figure 5.18**). Direct $N_2O$ emissions from managed soil was the biggest contributor to this category, producing between 65.3% (2012) and 67.6% (2000) of the total annual aggregated and non-$CO_2$ emissions. This was followed by indirect $N_2O$ emissions from managed soils (20.3% in 2000 to 20.2% in 2012) and biomass burning (8.1% to 7.5 %).

### 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 implications for regional and global atmospheric chemistry and biogeochemical cycles (Korontzi *et al.*, 2003). According to the National

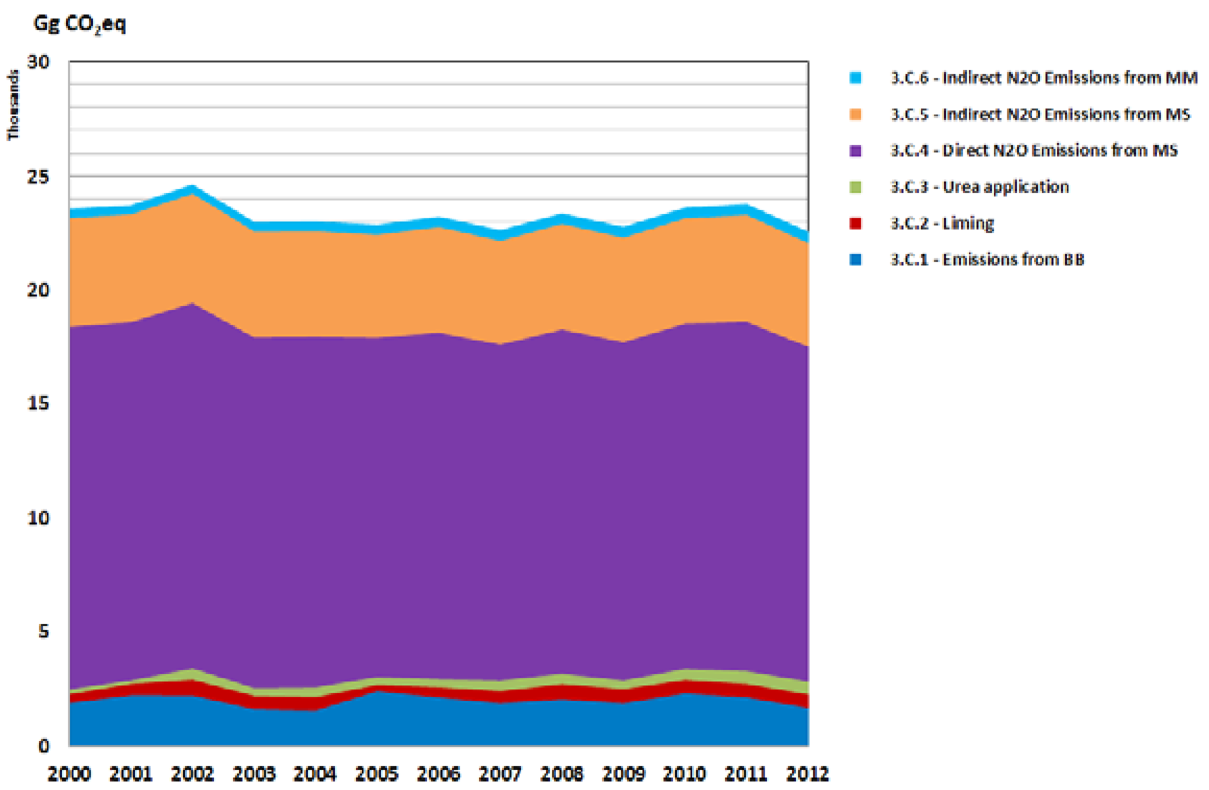



Figure 5.18: Sector 3 AFOLU – Aggregated and non-$CO_2$ sources: Trend and emission levels, 2000 – 2012. MM = Manure management; MS = Managed soils; BB = Biomass burning.

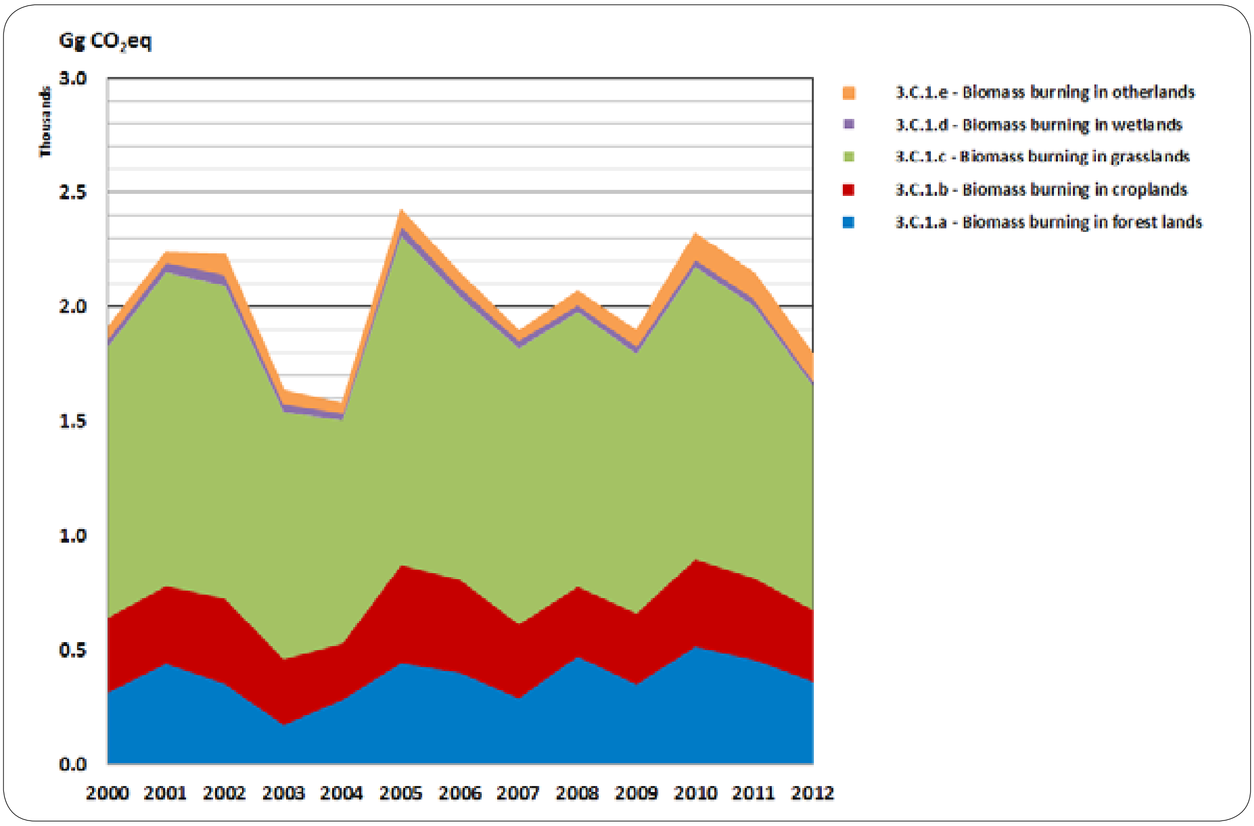



Figure 5.19: Sector 3 AFOLU – Aggregated and non-$CO_2$ sources: Contribution of the various land categories to the biomass burning emissions, 2000 – 2012.

Inventory Report (Department of Environmental Affairs and Tourism, 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 precursors of GHGs that originate from incomplete combustion of the fuel. The key GHGs are $CO_2$, $CH_4$, and $N_2O$; however, NOx, $NH_3$, 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 NOx) from all land categories, as explained in the 2000 inventory (Department of Environmental Affairs and Tourism, 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 woodlands and open bush have been classified as forest land, their emissions were dealt with under forest land.

Although the 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; there was also a sub-division for sugarcane as residue burning 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 1 576 Gg $CO_2$eq (2004) and 2 419 Gg $CO_2$eq (2005) to the overall emissions in the AFOLU sector. Of this, about 53% was $CH_4$ and 47% $N_2O$. Grasslands contributed the most to biomass-burning emissions (62.0% to 54.7 %), followed by forest lands (17.1% to 17.4 %) and croplands (16.6% to 20.33 %) (**Figure 5.19**). In the previous inventory (Department of Environmental Affairs, 2014), grasslands contributed about 52% and forest lands 28% in 2010, compared with the 55.1% and 16.3%, respectively, in 2010 in this inventory. This change was likely due to changes in land area that were brought about by the incorporation of the new land-cover maps, as well as the updated emission factors.

#### *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):

$$L_{fire} = A * M_B * Cf * G_{ef} * 10\text{-}3$$

(Eq. 5.27)

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 2012). 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 reprojected into the UTM 35S projection to remain consistent with the 2013-14 land-cover dataset project. All the monthly maps were then merged into an annual map by adding the valid burnt areas in each map. This was done for each year between 2000 and 2012. These burnt-area maps were then overlaid with the 2013-14 land-cover maps to determine the burnt area in each land class. The percentage of burnt area in each land class is shown in **Table 5.16**.

Some burnt area corrections were applied to the data. It was assumed that there was no burning in indigenous forests and thickets, so any burnt area under these categories was allocated to grasslands. The FSA reports burnt area for plantations so these figures were used and any difference between the FSA and MODIS burnt area was added or subtracted from grasslands. Any burning on bare ground was allocated to low shrublands, and any burning under water bodies was allocated to wetlands.

Table 5.16: Sector 3 AFOLU – Aggregated and non-$CO_2$ sources: Percentage area burnt within each land class between 2000 and 2012.

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Indigenous forest** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Thicket** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Woodland / Open bush** | 5.88 | 8.46 | 6.54 | 2.51 | 4.69 | 7.92 | 6.87 | 3.95 | 7.14 | 4.71 | 8.09 | 6.94 | 6.97 |
| **Plantations** | 1.08 | 0.92 | 0.89 | 1.55 | 1.51 | 1.20 | 1.54 | 3.77 | 3.78 | 1.06 | 0.84 | 0.82 | 0.51 |
| **Annual crops: pivot** | 3.91 | 3.05 | 3.96 | 3.67 | 4.62 | 5.08 | 3.81 | 3.82 | 2.70 | 2.80 | 4.18 | 3.19 | 2.32 |
| **Annual crops: non-pivot** | 3.88 | 3.59 | 4.40 | 3.28 | 2.77 | 4.69 | 4.78 | 2.70 | 3.13 | 3.09 | 3.90 | 4.31 | 2.70 |
| **Orchard** | 0.60 | 1.15 | 0.84 | 0.86 | 0.47 | 1.06 | 0.74 | 1.28 | 1.64 | 0.70 | 1.46 | 0.97 | 1.34 |
| **Viticulture** | 0.54 | 0.35 | 0.28 | 0.44 | 0.11 | 0.31 | 0.61 | 0.29 | 0.22 | 0.33 | 0.12 | 0.29 | 0.01 |
| **Subsistence crops** | 5.44 | 8.14 | 6.41 | 5.44 | 4.34 | 9.40 | 7.37 | 11.41 | 6.86 | 8.12 | 9.88 | 5.98 | 4.62 |
| **Settlements** | 1.94 | 2.15 | 1.90 | 1.64 | 1.28 | 2.90 | 2.54 | 2.81 | 1.73 | 2.08 | 2.76 | 1.52 | 1.83 |
| **Mines** | 3.30 | 2.97 | 4.26 | 2.90 | 3.31 | 4.85 | 4.71 | 2.31 | 2.42 | 1.96 | 3.09 | 2.71 | 2.01 |
| **Wetlands** | 7.37 | 8.90 | 10.07 | 8.24 | 7.06 | 10.45 | 9.28 | 8.17 | 7.45 | 8.37 | 8.41 | 8.32 | 5.72 |
| **Grasslands** | 10.89 | 12.70 | 12.69 | 9.84 | 8.49 | 13.44 | 11.62 | 11.34 | 10.73 | 10.65 | 12.12 | 11.32 | 9.14 |
| **Water bodies** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Low shrublands** | 0.36 | 0.30 | 0.73 | 0.46 | 0.28 | 0.48 | 0.37 | 0.32 | 0.38 | 0.51 | 0.88 | 0.86 | 0.44 |
| **Degraded** | 7.19 | 6.51 | 8.72 | 2.56 | 7.70 | 9.43 | 13.98 | 2.13 | 9.95 | 6.46 | 9.91 | 10.47 | 3.35 |

*5.5.2.4.2 Mass of fuel available for combustion (MB) and the combustion factor (Cf)*

The values for fuel density were sourced from various sources (**Table 5.17**). A weighted average for fuel density and the combustion factor (Cf) was determined for low shrublands. According to the 2013/2014 land cover map report (GTI, 2015) low shrublands are mainly Karoo type vegetation. Also included in this category is a portion of Fynbos (13% according to the 2013/2014 land cover map). The karoo vegetation classes have similar fuel densities and Cf values, but these are very different for Fynbos (**Table 5.17**). A weighted average fuel density and Cf value was calculated from these numbers for the low shrubland category in this inventory. Wetlands were assumed to have the same values as grasslands as done in the earlier inventories (Department of Environmental Affairs, 2009; 1994).

Comparing the data to IPCC values highlights a few discrepancies. The woodland/open bush and the grassland combustion factors are higher than the values provided by IPCC but this estimate is based on actual data for South Africa therefore assumed to be more appropriate. The low shrubland weighted average fuel density is lower than the general shrubland values provided in IPCC. The reason for this is that for South Africa this category includes arid shrublands which have much lower fuel density than the shrublands used to determine the IPCC default table (IPCC, 2006, Table 2.4, vol 4, chapter 2, page 2.46).

Table 5.17: Sector 3 AFOLU – Aggregated and non-$CO_2$ sources: Fuel density and combustion fractions for the various vegetation classes.

| Vegetation class | Fuel density (t/ha) | Source | IPCC default (Table 2.4, vol 4, chapt 2) | Combustion fraction | Source | IPCC value |
|---|---|---|---|---|---|---|
| Plantations | 30 | 2000 NIR (DEA, 2009) | | 0.4 | 2000 NIR (DEA, 2009) | |
| Woodlands/open bush | 4 | Hely et al. (2003) | 2.6 – 4.6 | 0.88 | Hely et al. (2003) | 0.4 – 0.74 |
| Croplands | 7 | DAFF (2010) | 4 – 10 (agricultural residue) | 1 | DAFF (2010) | 0.8 – 0.9 (agricultural residue) |
| Grasslands | 4 | Hely et al. (2003) | 2.1 - 10 | 0.88 | Hely et al. (2003) | 0.74 – 0.77 |
| Low shrublands in general | 2.42[a] | Weighted average | 5.7 – 26.7 | 0.91a | Weighted average | 0.61 – 0.95 |
| Fynbos | 12.9 | IPCC 2006 | | 0.61 | IPCC 2006 | |
| Nama karoo | 1 | 1994 NIR (??) | | 0.95 | 1994 NIR (??) | |
| Succulent karoo | 0.6 | 1994 NIR (??) | | 0.95 | 1994 NIR (??) | |
| Wetlands | 4 | 2000 NIR (DEA, 2009) | | 0.88 | 2000 NIR (DEA, 2009) | |

a See text for explanation.

#### 5.5.2.4.3 Emission factors

IPCC 2006 default emission factors (IPCC, 2006, vol 4, chapter 2, Table 2.5, page 2.47) were applied as shown in **Table 5.18**.

Table 5.18: Sector 3 AFOLU – Aggregated and non-$CO_2$ sources: Emission factors applied to the various vegetation classes.

| Vegetation class | EF | | ± SE |
|---|---|---|---|
| Plantations | $CO_2$ | 1569 | 131 |
| | CO | 107 | 37 |
| | $CH_4$ | 4.7 | 1.9 |
| | $N_2O$ | 0.26 | 0.07 |
| | NOx | 3.0 | 1.4 |
| Woodland/open bush; grasslands; low shrublands; wetlands | $CO_2$ | 1613 | 95 |
| | CO | 65 | 20 |
| | $CH_4$ | 2.3 | 0.9 |
| | $N_2O$ | 0.21 | 0.1 |
| | NOx | 3.9 | 2.4 |
| Croplands | $CO_2$ | 1515 | 177 |
| | CO | 92 | 84 |
| | $CH_4$ | 2.7 | |
| | $N_2O$ | 0.07 | |
| | NOx | 2.5 | 1.0 |

### 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, 2009). 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 5.4.4**) and some corrections for misclassified pixels were made. 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 (Department of Environmental Affairs and Tourism, 2009) still apply to this data set.

#### 5.5.2.5.2 Time-series consistency

The MODIS burnt area product was used for all 12 years to maintain consistency.

### 5.5.2.6 Source-specific QA/QC

The burnt area data derived in this inventory were compared to the data from the previous inventories (Department of Environmental Affairs and Tourism, 2009; Department of Environmental Affairs, 2014) using the data from the same years. Direct comparisons are difficult, however, due to the changes in the land-class definitions.

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.

All general QC procedures to check data, transcriptions and spreadsheets, as detailed in **Section 1.4.1**, were also conducted.

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

### 5.5.2.7 Source-specific Recalculations

Recalculations were done for all years between 2000 and 2012 due to the introduction of new land cover data and the incorporation of updated emission factors.

#### 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 5.20**). The variation was directly linked to limestone and dolomite consumption (**Figure 5.20**). The $CO_2$ emissions from urea application showed a similar annual variability (Figure

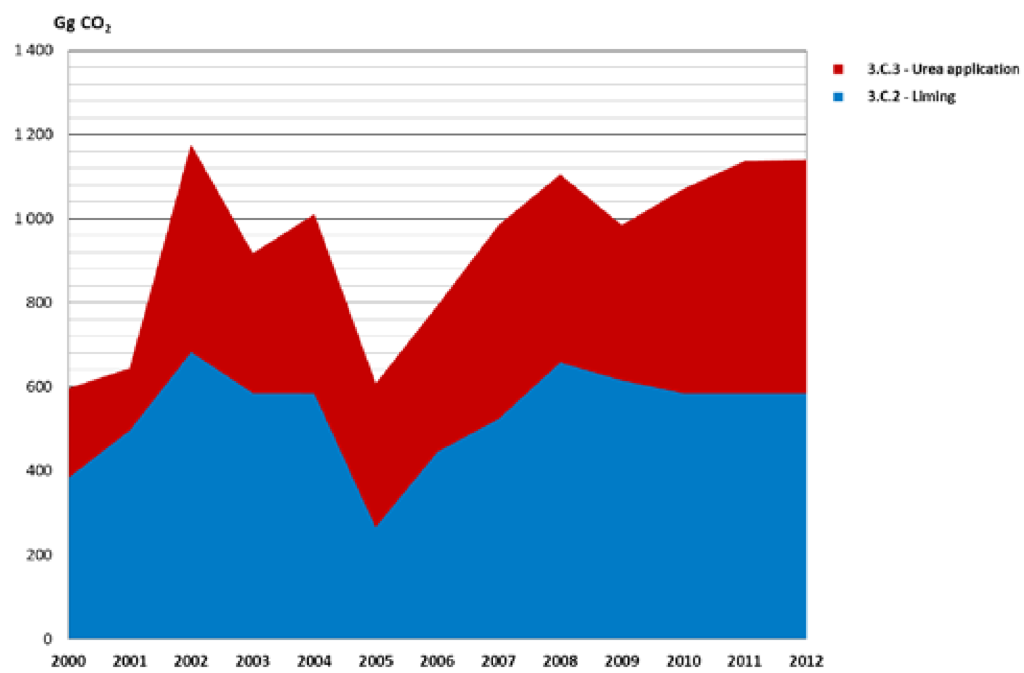



Figure 5.20: Sector 3 AFOLU – Aggregated and non-$CO_2$ sources: Trends and emission levels from liming and urea application, 2000 – 2012.

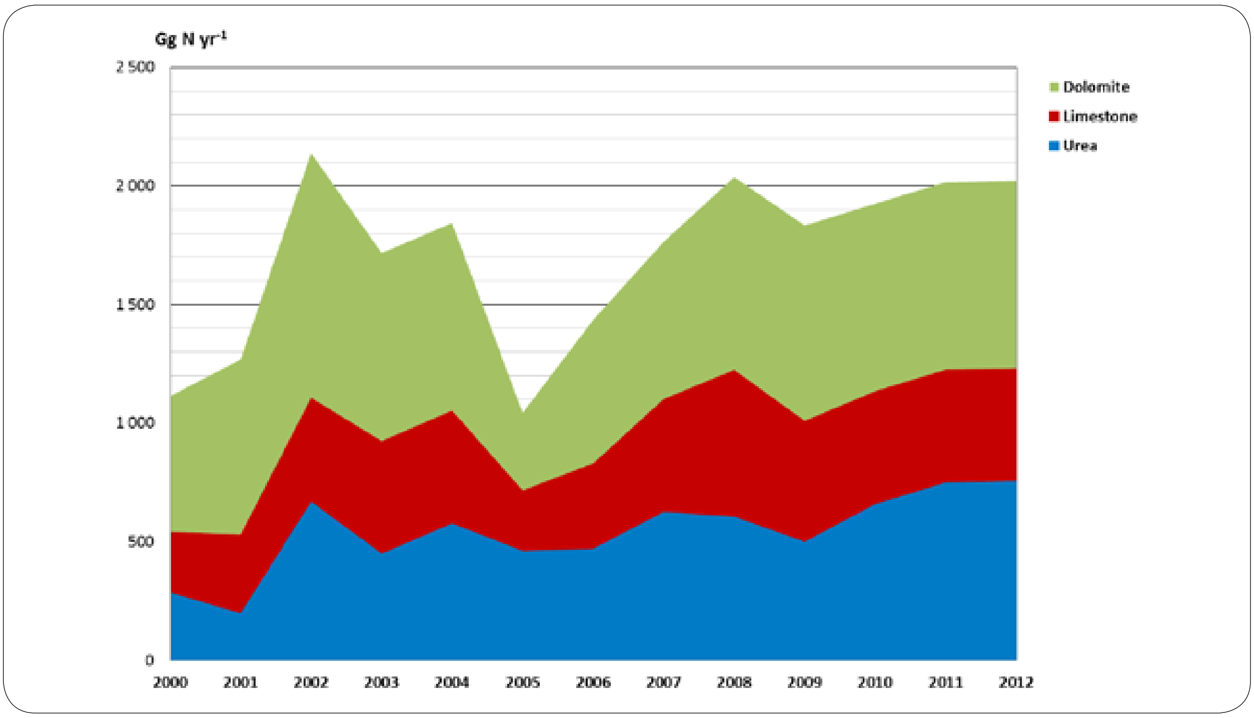



Figure 5.21: Sector 3 AFOLU – Aggregated and non-$CO_2$ sources: Annual amount of lime and urea applied to soils, 2000 – 2012.

5.21). Urea application produced an accumulated amount of 5 156 Gg $CO_2$ between 2000 and 2012, with the lowest emissions (147 Gg $CO_2$) occurring in 2001 and the highest (555 Gg $CO_2$) in 2012. There was a sharp decline in emissions from both liming and urea application in 2005.

#### 5.5.3.3 Methodologocal 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).

#### 5.5.3.4 Data Sources

The amount of limestone and dolomite applied was obtained from the Fertilizer Association of South Africa (http://www.fssa.org.za/Statistics.html) (**Table 5. 19**). Data for 2011 to 2012 were not available due to restrictions placed by the Competition Commission. Annual consumption is highly variable and does not appear to have any relationship with surrogate data, making extrapolation difficult. So in this inventory the value from 2010 was used for all three years, but this issue needs to be addressed in the next inventory. In the previous inventory the amount of urea used was assumed to be the amount imported into South Africa (FAOSTAT; http://faostat.fao.org/site/575/default.aspx#ancor; accessed on 02/2013). However, in this inventory the consumption was assumed to be the difference between urea imports and exports in the FAO database.

##### 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.

Table 3.19: Sector 1 Energy: Fugitive emissions from coal mining for the period 2000 to 2012.

| 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 | 670 700 |
| 2003 | 473 006 | 792 736 | 451 636 |
| 2004 | 474 215 | 790 673 | 578 942 |
| 2005 | 253 606 | 326 898 | 463 086 |
| 2006 | 357 970 | 605 148 | 472 523 |
| 2007 | 474 753 | 662 893 | 627 196 |
| 2008 | 616 844 | 812 959 | 607 729 |
| 2009 | 508 526 | 823 382 | 501 526 |
| 2010 | 487 816 | 667 564 | 660 707 |
| 2011 | 487 816 | 667 564 | 751 527 |
| 2012 | 487 816 | 667 564 | 756 827 |

#### 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 12 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. Data, calculations and spreadsheets were all checked to ensure data was carried through properly and that there were no transcription errors. An external reviewer provided the quality assurance.

#### 5.5.3.7 Source-specific Recalculations

Emission data for urea were recalculated for all years between 2000 and 2012 due to the adjustment made to the urea consumption data.

#### 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 GHGs 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, 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; and

- $N_2O$ 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); and
  - 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 198 528 Gg $CO_2$eq between 2000 and 2012. Emissions fluctuated annually with 2002 having the highest (15 909 Gg $CO_2$eq and 2012 the lowest emissions of 14 701 Gg $CO_2$eq (**Figure 5.22**). The variation was due mainly to the fluctuation in manure and synthetic fertilizer inputs, while emissions from compost, sewage sludge and crop residues did not change significantly over the 12-year period since 2000. The greatest contributor to the direct $N_2O$ emissions was emissions from urine and dung deposited in pasture, rangeland and paddocks, which contributed between 80.3% and 83.36% between 2000 and 2012.

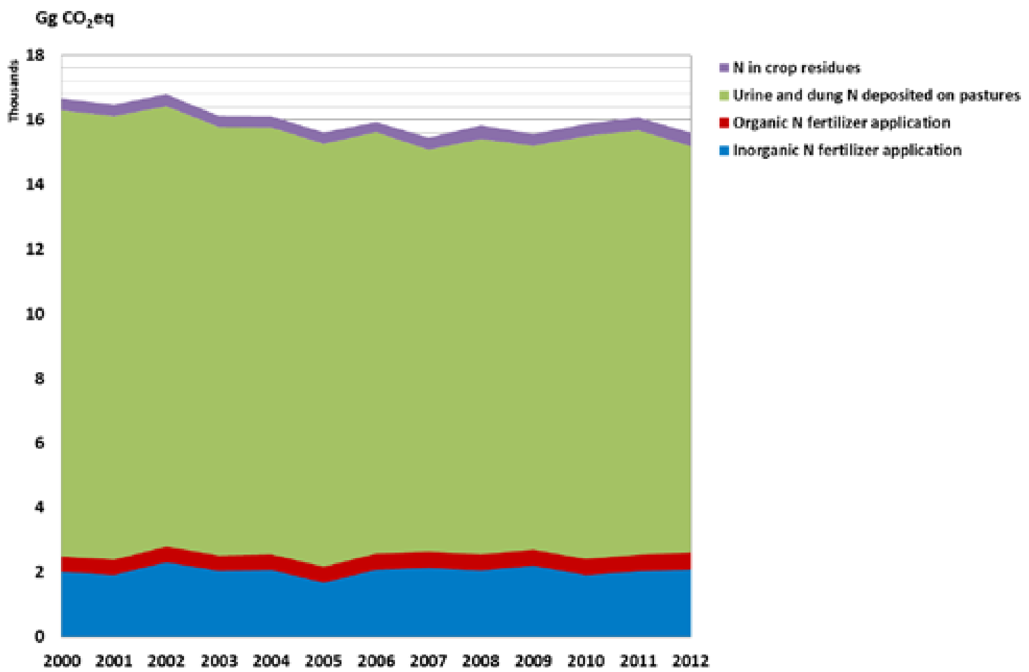



Figure 5.22: Sector 3 AFOLU – Aggregated and non-$CO_2$ sources: Trend and emission levels of direct $N_2O$ from managed soils, 2000 – 2012

### 5.5.4.3 Methodological Issue

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) was assumed to be minimal and was therefore excluded from the calculations. Furthermore, since there are no flooded rice fields in South Africa these emissions were also excluded. The simplified equation for direct $N_2O$ emissions from soils is therefore as follows:

$$N_2O_{Direct}\text{-}N = N_2O\text{-}N_{N\ inputs} + N_2O\text{-}N_{PRP} \quad \text{(Eq. 5.28)}$$

Where:

$$N_2O\text{-}N_{N\ inputs} = [(F_{SN} + F_{ON} + F_{CR}) * EF_1] \quad \text{(Eq. 5.29)}$$

$$N_2O\text{-}N_{PRP} = [(F_{PRP,CPP} * EF_{3PRP,CPP}) + (F_{PRP,SO} * EF_{3PRP,SO})] \quad \text{(Eq. 5.30)}$$

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 recorded by the Fertilizer Association 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 manage 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 12 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), however, indicated that this amount was probably an overestimate, as the use of sewage sludge for agricultural purposes had reduced significantly 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 2012 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 pastures, ranges or paddocks 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 5.3.3.4.1**);
- Nex data (**Section 5.3.4.3.2**);
- Manure management system usage data (**Section 5.3.4.4.1**);
- 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 were 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 were 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 $F_{SN}$ data were 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 (DAFF, 2010). All of this was taken into account when estimating N inputs from compost. Further details are provided in DAFF (2010) and Otter (2011).

**Sewage sludge**

Waste water treatment data was obtained from the 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 for 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 were no reported data between 2007 and 2012, so dry pea production was assumed to be zero for those years. The same applied to lentil production between 2006 and 2012. Rye production data were not recorded between 2003 and 2009, but the data for these years were 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 the 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 5.3.3.4.1**), $N_{ex}$ data (**Section 5.3.4.3.2**) and the fraction of total annual N excretion for each livestock species that is deposited on pastures, rangelands and paddocks (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).

For game the default factor for other animals (i.e. the SO EF) was used.

The IPCC 2006 default EFs for PRP were thought to be overestimated 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 the 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 to 0.03, 0.007 to 0.06, and 0.003 to 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 were available.

Sewage sludge use in agriculture is also uncertain due to a lack of actual data. In this inventory, data from 72 WWTPs were used as representative of all 1 697 WWTPs in South Africa. 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 and 80%. The N content for sludge, from the 72 WWTPs 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, 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 12 year period 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 followed for the compilation of this inventory and identify areas of improvement.

#### 5.5.4.7 Source-specific Recalculations

The livestock population data were updated for other cattle and poultry, therefore recalculations were done for 2000 to 2012 due to the associated change in manure production. An estimate for game manure emissions was included (which was not in previous inventories) and this amount was included in the emissions for each year since 2000.

#### 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 pastures, rangelands and paddocks. 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. Lastly it is recommended that FSOM (N mineralization associated with loss of SOM resulting from change of land use or management) and FOS (N from managed organic soils) be investigated further. These sources should be regarded as areas for potential improvement and attempts should be made to include these emissions in future.

## 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 2012 was estimated at 60 358 Gg $CO_2$eq and 4 558 Gg $CO_2$eq was produced in 2012. There was a decreasing trend over this period with losses due to atmospheric deposition of N volatilised from managed soils decreasing by 7.5% and losses due to leaching and run-off declining by 6.0% between 2000 and 2012 (**Figure 5.23**). Indirect $N_2O$ losses due to leaching and run-off accounted for 56.5% of the indirect emissions in 2012.

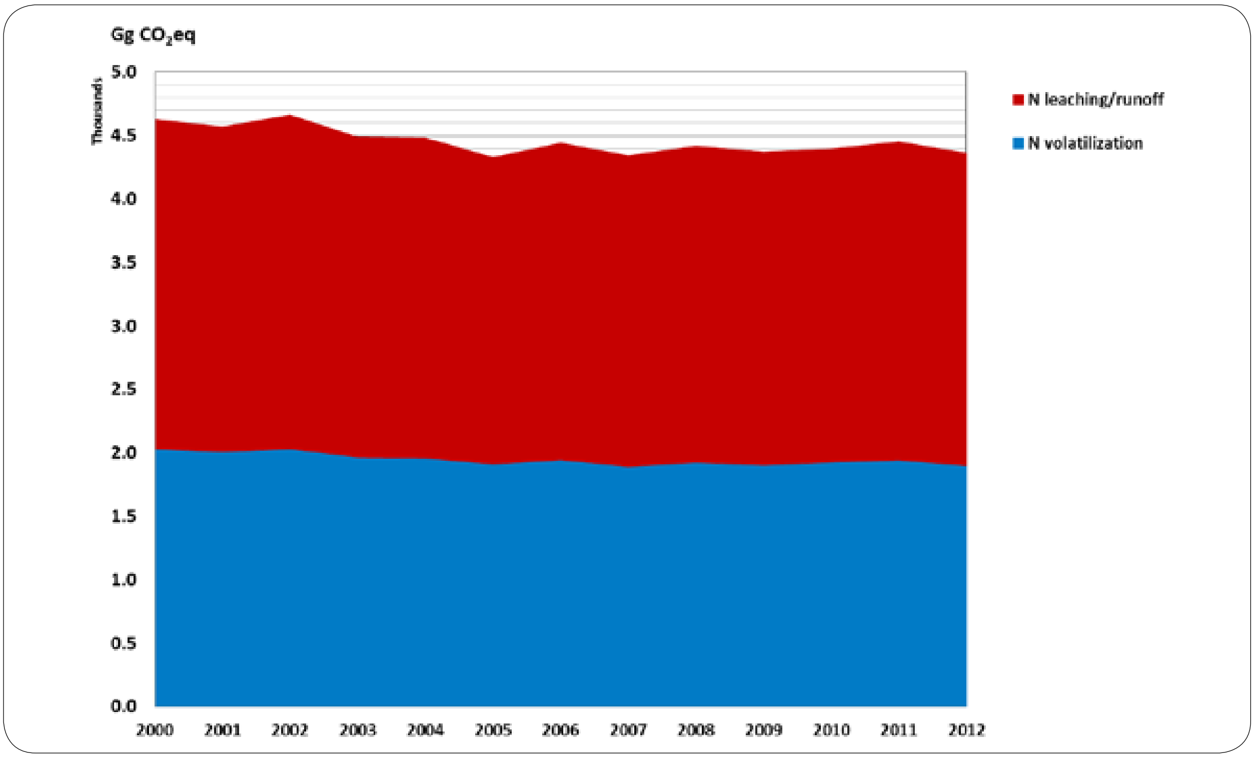



Figure 5.23: Sector 3 AFOLU – Aggregated and non-$CO_2$ sources: Trend and emission level estimates of indirect $N_2O$ losses from managed soils, 2000 – 2012.

#### *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 to 0.05, and 0.0005 to 0.025, respectively. For $Frac_{GASF}$, $Frac_{GASM}$ and $Frac_{LEACH-(H)}$, the uncertainty ranges are 0.03 to 0.3, 0.05 to 0.5 and 0.1 to 0.8, respectively (IPCC 2006 Guidelines, Table 11.3, p. 11.24).

##### *5.5.5.5.2 Time-series consistency*

The same data sources were used throughout the 12 year period 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*

Recalculations were completed for all years between 2000 and 2010 due to adjustments in the livestock population numbers (Other cattle, poultry and game) which led to changes in the FPRP inputs.

#### *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 run-off losses from various management systems is extremely limited, 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 run-off from manure management systems available, i.e. there is only a Tier 2 method. There was insufficient data for South Africa to do the Tier 2 calculation, so there is no estimate for manure management N losses due to leaching and run-off.

#### *5.5.6.2 Overview of Shares and Trends in Emissions*

The amount of manure N lost due to volatilized $NH_3$ and NOx 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 5 081 Gg $CO_2$eq between 2000 and 2012. The annual variation was low and there was an increasing trend from 349 Gg $CO_2$eq in 2000 to 436 Gg $CO_2$eq in 2012 (**Table 5. 20**).

#### 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 NOx was calculated using Equation 10.26 (IPCC, 2006). This requires Nex data (**Section 5.3.3.4.1**), manure management system data (**Section 5.3.4.4.1**), and default fractions of N losses from manure management systems due to volatilization ((IPCC 2006, Table 10.22) (**Table 5. 21**).

##### *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 the IPCC 2006 Guidelines as 0.01 kg $N_2O$-N (kg $NH_3$-N + NOx-N volatilized)$^{-1}$) was used to calculate indirect $N_2O$ emissions due to volatilization of N from manure management (Equation 10.27, IPCC 2006).

#### 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. 21**) and uncertainty on manure management system usage. The uncertainty range on EF4 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 12 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 followed for the compilation of this inventory and to identify areas of improvements.

#### 5.5.6.7 Source-specific Recalculations

No source-specific recalculations were necessary.

#### 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.

Table 5.20: Sector 3 AFOLU – Aggregated and non-$CO_2$ sources: Indirect emissions of $N_2O$ (Gg $CO_2$eq) due to volatilization from manure management between 2000 and 2012.

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Indirect $N_2O$ | 349 | 352 | 358 | 360 | 364 | 382 | 397 | 411 | 410 | 412 | 414 | 428 | 436 |

Table 5.21: Sector 3 AFOLU – Aggregated and non-$CO_2$ sources: Default values used for N loss due to volatilization of $NH_3$ and NOx 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.

## 5.5.7 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 (HWPs) to annual $CO_2$ emissions or removals. HWPs 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 $CO_2$ (except in 2011 when it was a weak source) which fluctuated annually between 2000 and 2012. The total accumulated sink over the 12 years was estimated at 7 376 Gg $CO_2$ with a sink of 512 Gg $CO_2$ in 2012. The sink increased from 312 Gg $CO_2$ in 2000 to 1 185 Gg $CO_2$ in 2004. After this the sink fluctuated between 98 Gg $CO_2$ and 882 Gg $CO_2$ with a source of 82 Gg $CO_2$ in 2011 (**Table 5. 22**).

### 5.5.7.3 *Methodological Issues*

The HWP contribution was determined by following the updated guidance provided in the 2013 IPCC KP Supplement (IPCC, 2014). One of the implications of Decision 2/CMP.7 is that accounting of HWP is confined to products in use where the wood was derived from domestic harvest. Carbon in imported HWP is excluded. The guidelines also suggest that it is good practice to allocate the carbon in HWP to the activities afforestation (A), reforestation (R) and deforestation (D) under Article 3 paragraph 3 and forest management (FM) under Article 3 paragraph 4. For South Africa, there is insufficient data

Table 5.22: Sector 3 AFOLU – Other: Trend in the HWP $CO_2$ sink (Gg) between 2000 and 2012.

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HWP | -312 | -675 | -817 | -927 | -1 185 | -197 | -882 | -581 | -781 | -98 | -490 | 82 | -512 |

to differentiate between the harvest from AR and FM, it is conservative and in line with good practice to assume that all HWPs entering the accounting framework originate from FM (KP Supplement, Chapter 2, p 2.118).

Equation 5.31 and 5.32 (Eq 2.8.1 and 2.8.2 in KP Supplement) were applied to estimate the annual fraction of feedstock for HWP production originating from domestic harvest and domestically produced wood pulp as feedstock for paper and paperboard production.

$$f_{IRW}(i) = (IRW_P(i) - IRW_{EX}(i)) / (IRW_P(i) + IRW_{IM}(i) - IRW_{EX}(i))$$

(Eq. 5.31)

Where:

$f_{IRW}(i)$ = share of industrial roundwood for the domestic production og HWP originating from domestic forests in year $i$;

$IRW_P(i)$ = production of industrial roundwood in year $i$ (Gg C $yr^{-1}$);

$IRW_{IM}(i)$ = import of industrial roundwood in year $i$ (Gg C $yr^{-1}$);

$IRW_{EX}(i)$ = export of industrial roundwood in year $i$ (Gg C $yr^{-1}$).

$$f_{PULP}(i) = (PULP_P(i) - PULP_{EX}(i)) / (PULP_P(i) + PULP_{IM}(i) - PULP_{EX}(i))$$

(Eq. 5.32)

where:

$f_{PULP}(i)$ = share of domestically produced pulp for the domestic production of paper and paperboard in year i;

$PULP_P(i)$ = production of wood pulp in year $i$ (Gg C $yr^{-1}$);

$PULP_{IM}(i)$ = import of wood pulp in year $i$ (Gg C $yr^{-1}$);

$PULP_{EX}(i)$ = export of wood pulp in year $i$ (Gg C $yr^{-1}$).

The resulting feedstock factors were applied to Equation 5.33 (Eq 2.8.4 KP Supplement) to estimate the HWP contribution of the aggregate commodities sawnwood, wood-based panels and paper and paperboard.

$$HWP_j(i) = HWP_P(i) * f_{DP}(i) * f_j(i)$$

(Eq. 5.33)

where:

$HWP_j(i)$ = HWP amounts produced from domestic harvest associated with activity $j$ in year $i$ ($m^3$ $yr^{-1}$ or Mt $yr^{-1}$);

$HWP_P(i)$ = production of the particular HWP commodities (i.e. sawnwood, wood-based panels and paper and paperboard) in year $i$ ($m^3$ $yr^{-1}$ or Mt $yr^{-1}$);

$f_{DP}(i)$ = share of domestic feedstock for the production of the particular HWP category originating from domestic forests in year $i$, with:

$f_{DP}(i) = f_{IRW}(i)$ for HWP categories 'sawnwood' and 'wood-based panels'; and

$f_{DP}(i) = f_{IRW}(i) * f_{PULP}(i)$ for HWP category 'paper and paperboard'; and

$f_{IRW}(i) = 0$ if $f_{IRW}(i) < 0$ and $f_{PULP}(i) = 0$ if $f_{PULP}(i) < 0$.

$f_j(i)$ = share of harvest originating from the particular activity $j$ (FM or AR or D) in year $i$. For SA this was assumed to be 1 as all the harvest was allocated to FM.

**First order decay**

Transparent and verifiable data were available for sawnwood, wood-based panels and paper and paperboard, but no country-specific information for Tier 3 was available so a Tier 2 first order decay approach (Eq 5.34 (Eq 12.1

in 2006 IPCC Guidelines)) was applied to estimate the HWP contribution:

$$C(i+1) = e^{-k} * C(i) + ((1 - e^{-k})/k) * Inflow(i)$$

(Eq. 5.34)

Where:

$C(i)$ = the carbon stock in the particular HWP category at the beginning of year $i$ (Gg C);

$k$ = decay constant of FOD for each HWP category (units $yr^{-1}$) ($k$ = ln(2)/HL where HL is the half life of the HWP pool in years;

$Inflow(i)$ = the inflow to the particular HWP category during year $i$ (Gg C $yr^{-1}$);

$\Delta C(i)$ = $C(i+1) - C(i)$ = carbon stock change of the HWP category during year $i$ (Gg C $yr^{-1}$).

As a proxy in the Tier 2 method it is assumed that the HWP pools are in steady state at the initial time (t0) from which the activity data start. This means that as a proxy ΔC(t0) is assumed to be equal to 0 and this steady state for each HWP commodity category is approximated using the following equation (Eq 2.8.6 KP Supplement):

$$C(t_0) = Inflow_{average}/k$$

(Eq. 5.35)

where:

$$Inflow_{average} = (\textstyle\sum_{i=t0}^{t4} Inflow(i))/5$$

(Eq. 5.36)

$C(t_0)$ was taken to be 1990 (S. Ruter, pers. comm.) and was substituted into Eq 5.34 so that $C(i)$ and $\Delta C(i)$ in the sequential time instants can be calculated.

#### 5.5.7.4 Data Sources

All the data on production, imports and exports of roundwood, sawnwood, wood-based panels, paper and paperboard, and wood pulp were obtained from the FAOSTAT database (http://faostat.fao.org/).

#### 5.5.7.5 Uncertainty and Time-series Consistency

The activity data was obtained from the FAO and the same data set, dating back to 1961, was applied throughout to maintain consistency. Uncertainties for activity data and parameters associated with HWP variables are provided in the IPCC Guidelines (IPCC 2006, Volume 4, p. 12.22). Production and trade data have an uncertainty of 50% since 1961, while the product volume to product weight factors and oven-dry product weight to carbon weight have uncertainties of ±25% and ±10%, respectively. There was also a ±50% uncertainty on the half-life values.

#### 5.5.7.6 Source-specific QA/QC and Verification

As part of the quality control the data was run through the WoodCarbonMonitor model and the IPCC HWP model and the outputs were compared. Although there were some slight differences the data were all within a similar range.

#### 5.5.7.7 Source-specific Recalculations

Recalculations were necessary as the recent KP Supplement guidelines were applied, so as to reduce uncertainty, and there were several changes to the methodology. Data was recalculated for all years between 2000 and 2012. Recalculations resulted in a significant reduction in the $CO_2$ sink of the HWP category.

#### 5.5.7.8 Source-specific Planned Improvements and Recommendations

Due to the recent improvements made to this subsector there are no further source-specific improvements planned.

# 6. WASTE SECTOR

## 6.1 Overview of Sector

Climate change caused by greenhouse gas (GHG) emissions, mainly from anthropogenic sources, is one of the most significant challenges defining human history over the past few decades. Among the sectors that contribute to the increasing quantities of GHGs into the atmosphere is the waste sector. This section highlights the GHG emissions into the atmosphere from managed landfills and wastewater treatment systems in South Africa, estimated using the IPCC 2006 Guidelines.

The waste sector in the national inventory of South Africa comprises two sources:

- 4A Solid waste disposal; and
- 4D Wastewater treatment and discharge.

The results were derived by either using available data or estimates based on 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 a 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 – 2010 GHG emissions from the waste sector (Department of Environmental Affairs and Tourism, 2014) were adopted for this 2000 – 2012 inventory. Therefore, 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 address completeness in this sector by quantifying emissions from the following sources:

- the open burning of waste, as these emissions also have potential impacts for air-quality management;
- the biological treatment of organic waste, where a clear and unambiguous link with agricultural practices can be made; and
- the 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 estimated to have increased by 78.5% from 12 288 Gg $CO_2$eq in 2000 to 21 928 Gg $CO_2$eq in 2012 (**Figure 6.1**). The annual increase declined from 7.5% to 3.7% 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 76.2% in 2000 to 84.0% in 2012. There are two likely reasons for the increase: firstly, the first order decay (FOD) methodology has an in-built lag-effect and, as a result, the reported emissions from solid waste in managed landfills 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 sanitation services, particularly with respect to collecting and managing solid waste streams in managed landfills, is likely to result in an increase in emissions of more than 5% annually. In addition, at present very little methane is captured at the country's landfills and the percentages of recycled organic waste are low. Intervention mechanisms designed to reduce GHG emissions from solid waste are likely to yield significant reductions in the waste sector.

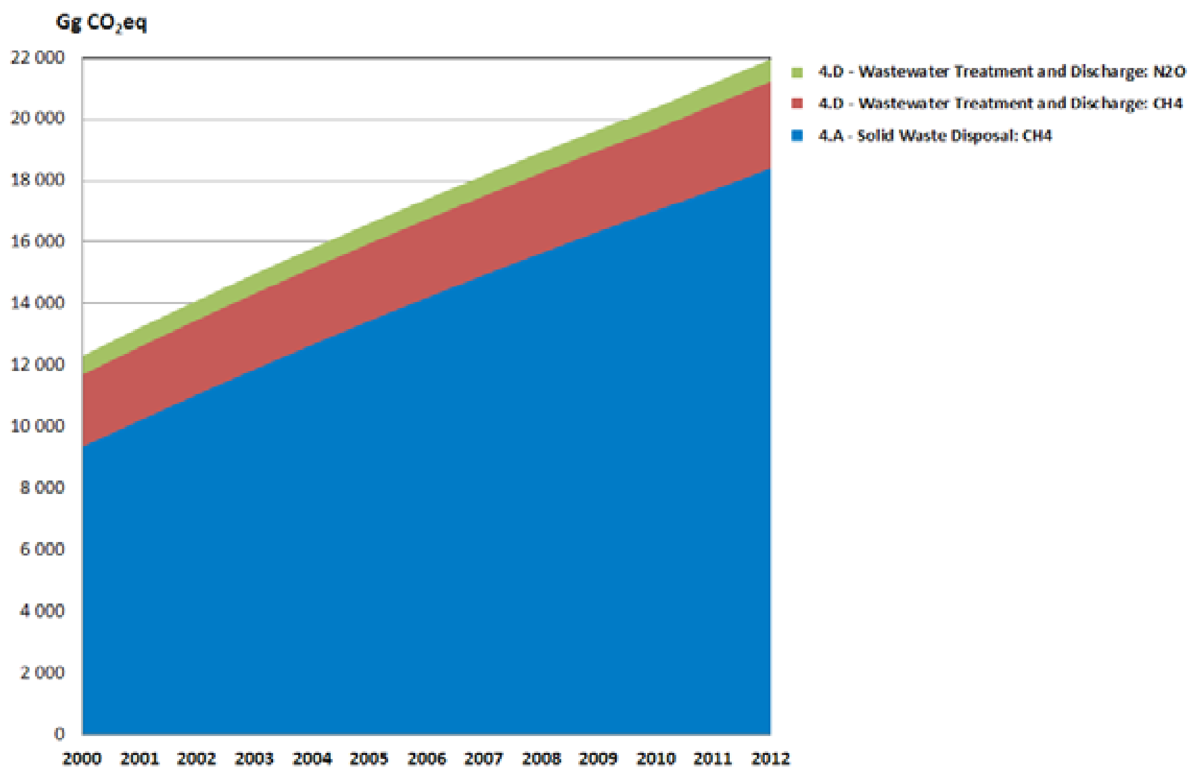



Figure 6.1: Sector 4 Waste: Trends and emission levels of source categories, 2000 – 2012.

## 6.3 Key categories

The key categories in the waste sector are shown to be *wastewater treatment and discharge* (domestic) (4.D.1) in terms of level (**Table 1.9**), and in terms of the trend *solid waste disposal* (4.A) is a key (**Table 1.11**).

## 6.4 Solid waste disposal on land [4A]

### 6.4.1 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 (Department of Environmental Affairs and Tourism 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 are not documented and the sites are generally shallow. A periodic survey is still needed to assess the percentage share of unmanaged sites and semi-managed sites. Generating this information is central to understanding methane generation rates for different solid waste disposal pathways.

### 6.4.2 Overview of shares and trends in emissions

The total accumulated GHG emissions from solid waste disposal between 2000 and 2010 was estimated at 183 048 Gg $CO_2$eq, increasing from 9 368 Gg $CO_2$eq in 2000 to 18 412 Gg $CO_2$eq in 2012 (**Figure 6.1**). This is an increase of 78.5% over the 12 year period.

### 6.4.3 Methodological issues

The FOD model was used to estimate GHG emissions from this source category for the period 1950 to 2012 using the following input activity data: population, 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), as well as other factors described in the IPPC Guidelines, Volume 5, Chapter (IPPC, 2006). Notably, due to a lack of published specific-activity data for many of these parameters in South Africa, the default values suggested in the IPCC Guidelines were applied. In addition, the inventory compilers noted that the information on national waste composition presented in the National Waste Baseline Information Report (NWIBR, 2012) was not compatible with the approach set out in the 2006 IPCC Guidelines, therefore, even though domestic information on waste composition was available, it could not be used for the purposes of this inventory. Instead, default IPCC waste composition values were used. The NWIBR, however, does provide information on the percentage of the waste generated that is disposed of in solid waste disposal sites. This value was estimated at 91% for 2011. It was assumed that this value was constant throughout the time series due to a lack of data for the previous years.

### 6.4.4 Data sources

For the FOD methodology, the model required historical data with at least three to five half-lives. Therefore, the activity data used comprised 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 for the period 1950- to 2001 was sourced from United Nations population statistics (UN, 2012). Statistics South Africa population data was used for the period 2002 to 2012 (StatsSA, 2013). Waste Generation rates for industrial waste were estimated using GDP values sourced from StatsSA (StatsSA, 2013) and tonnages of industrial waste reported in the NWIBR for 2011. A value of 8 tonnes/ per unit of GDP in US dollars was derived and assumed constant throughout the time series.

Among the chief limitations of the FOD methodology is that even if activity data improved considerably, the limitations of the data, or lack thereof, of previous years will still introduce a considerable degree of uncertainty. On the other hand, the estimated waste generations derived from previous years, back to 1950, will remain useful in future estimations of GHGs as they will aid in taking into account half-lives.

No detailed analysis of the methane recovery from landfills was accounted for between 2000 and 2010. As noted in the previous inventory (Department of Environmental Affairs, 2009), the recovery of methane from landfills commenced on a large-scale after 2000, with some sites having a lifespan of about 21 years (DME, 2008). To address these data limitations, the DEA has implemented the National Climate Change Response Database, which captures valuable data from mitigation and adaptation projects for future GHG estimates from landfills. This tool will be used in the future to identify and implement methane recovery projects. However, at present there are limited publicly accessible data on the quantities of methane recovered annually from managed landfills in South Africa.

### 6.4.5 Uncertainty and time-series consistency

#### *6.4.5.1 Uncertainty*

Uncertainty in this category is due mainly to the lack of data on the characterization of landfills, as well as of the quantities of waste disposed in them over the medium to long term. An uncertainty of 30% is typical for countries that collect waste-generation data on a regular basis (IPCC 2006 Guidelines, Table 3.5). Another source of uncertainty is that methane production is calculated using bulk waste because of a lack of data on waste composition, therefore, uncertainty is more than a factor of two (Department of Environmental Affairs and Tourism, 2009). For the purpose of the bulk waste estimates, the whole of South Africa is classified as a "warm 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).

#### *6.4.5.2 Time-series Consistency*

The FOD methodology for estimating methane emissions from solid waste requires a minimum of 48 years' worth of historical waste disposal data. However, in South Africa, 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.

### 6.4.6 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 ends in waste disposal sites, GDP values for estimating emissions from industrial waste, as well as waste generation rates were all reviewed and updated. Verification focused on waste generation rates, population statistics and GDP values using Statistics SA datasets and the DEA's waste baseline study.

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

### 6.4.7 Source-specific recalculations

Source-specific recalculations have been performed for the period 2000 to 2010 in this source category because of the following:

- Population statistics for the period 2002 to 2010 based on new information available in the 2011 national census conducted by Statistics South Africa.
- The percentage of waste generated that is disposed in solid waste disposal sites was reviewed and updated based on the NWIBR.
- A waste generation rate for municipal solid waste was reviewed based on new information sourced from the NWIBR. The new waste generation rate is based on provincial weighted average waste generation rates. This rate was assumed constant for the entire time period.

- A waste generation rate for industrial waste was reviewed based on GDP data reported by StatsSA as well as industrial waste tonnage rates available from the NWIBR for 2011. This rate was assumed constant for the entire time period.

### 6.4.8 Source-specific planned improvements and recommendations

The most challenging task in 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 solid waste and wastewater sources were largely computed using default values suggested in IPCC 2006 Guidelines and, as a consequence, margins of error were large. Therefore, several recommendations for improving the activity and emission factors data are suggested. These include:

(i) advance data capturing, particularly the quantities of waste disposed of into managed and unmanaged landfills. Other activities that merit improvement are the MCF and rate constants, owing to their impact on the computed methane emissions from landfills; and

(ii) improve the reporting of economic data (e.g. annual growth) to include different population groups. The assumption that GDP growth is evenly distributed (using a computed mean) across all the population groups is highly misleading and leads to exacerbated margins of error.

## 6.5 Wastewater treatment and discharge [4D]

### 6.5.1 Source category description

Wastewater treatment contributes to anthropogenic emissions, mainly $CH_4$ and $N_2O$. 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 Africa 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.

### 6.5.2 Overview of shares and trends in emissions

Domestic and commercial waste water treatment and discharge were estimated to produce a total accumulated emission of 41 362 Gg $CO_2$eq between 2000 and 2012. The $CH_4$ emissions accounted for approximately 80.4% of total emissions (**Table 6.1**). In 2012 $CH_4$ emissions totalled 2827 Gg $CO_2$eq, while $N_2O$ emissions contributed 689 Gg $CO_2$eq (**Table 6.1**).

Table 6.1: Sector 4 Waste: $CH_4$ and $N_2O$ emissions from domestic and industrial wastewater treatment, 2000 – 2012.

| | Wastewater Treatment and Discharge $CH_4$ emissions | Wastewater Treatment and Discharge $N_2O$ emissions | Total GHG emission |
|---|---|---|---|
| | (Gg $CO_2$eq) | | |
| 2000 | 2 348 | 572 | **2 921** |
| 2001 | 2 397 | 584 | **2 981** |
| 2002 | 2 430 | 592 | **3 022** |
| 2003 | 2 461 | 600 | **3 061** |
| 2004 | 2 491 | 607 | **3 097** |
| 2005 | 2 519 | 613 | **3 132** |
| 2006 | 2 548 | 621 | **3 168** |
| 2007 | 2 576 | 628 | **3 203** |
| 2008 | 2 604 | 635 | **3 239** |
| 2009 | 2 632 | 641 | **3 274** |
| 2010 | 2 661 | 649 | **3 310** |
| 2011 | 2 763 | 673 | **3 436** |
| 2012 | 2 828 | 689 | **3 516** |

The urban low-income population had the highest total contribution of methane emissions. Results suggest that for South Africa to reduce the methane emissions 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 sewer treatment systems are suitable for potential capturing of generated methane emissions – unlike the open latrines and sewer systems currently serving approximately 60% of the low-income urban population in South Africa.

### 6.5.3 Methodological issues

#### *6.5.3.1 Domestic Wastewater Treatment and Discharge*

The projected methane emissions from the wastewater follow the same methodology described in the 2014 National GHG Inventory Report (Department of Environmental Affairs and Tourism, 2014). The estimated methane emissions reported are from domestic and commercial sources of wastewater because the IPPC 2006 Guidelines do not stipulate a different set of equations or differentiated computational approaches for the two sources, as was 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 estimated values in this report are assumed to be due to domestic and industrial sources treated in municipal wastewater treatment systems.

### 6.5.4 Data sources

To be consistent, the specific-category data described in **Section 6.4.1** of the National GHG Inventory Report (Department of Environmental Affairs and Tourism, 2009) and its underlying assumptions were adopted. For example, in determining the total quantity of kg BOD $yr^{-1}$, population data was sourced from Statistics South Africa's mid-year population statistics published in 2013 (StatsSA, 2013). Default population distribution trends between rural and urban settlements as a function of income, as well as a default average South African BOD production value of 37 g $person^{-1}$ $day^{-1}$ were sourced from the 2006 IPCC Guidelines. Generally, it is good practice to express BOD product as a function of income, however, this information is not readily available in South Africa, therefore, it could not be included in the waste sector model. In this case, a default IPCC correction factor of 1.25 was applied in order to take into account the industrial wastewater treated in sewage treatment systems.

The emissions factors for different wastewater treatment and discharge systems were taken from the 2006 IPCC Guidelines (**Table 6.2**) as was the data on distribution and utilization of different treatment and discharge systems (**Table 6.3**).

#### *6.5.4.1 Domestic Wastewater $N_2O$ Emissions*

The default values provided by the IPCC Guidelines were used in estimating the potential growing trends of $N_2O$ 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.

### 6.5.5 Uncertainties and time-series consistency

#### *6.5.5.1 Uncertainties*

An analysis of the results for methane emissions suggest that the likely sources of uncertainties may be due to the input data. These include uncertainties associated with South African 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

Table 6.2: Sector 4 Waste: Emission factors for different wastewater treatment and discharge systems (Source: Department of Environmental Affairs and Toursim, 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: Department of Environmental Affairs and Tourism, 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 income | 0.24 |
| | Septic tank | 0.17 |
| | Sewer (open and warm) | 0.34 |
| | Sewer (flowing) | 0.20 |
| | Other | 0.05 |

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.

#### *6.5.5.2 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 12-year time series and default IPCC emission factors used.

### 6.5.6 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 to population statistics, the percentage split of wastewater pathways, total organics in wastewater and methane correction factors were all reviewed.

### 6.5.7 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.

### 6.5.8 Source-specific planned improvements and recommendations

The biggest challenge in estimating GHG emissions in South Africa is the lack of specific-activity and emissions factor data. As a result, estimations of GHGs from both solid waste and wastewater sources were largely computed using default values suggested in the IPCC 2006 Guidelines and, as a consequence, margins of error were high. Therefore, several recommendations are suggested to improve the activity and emission factors data:

- obtain data on the quantities of waste disposed of into managed and unmanaged landfills;
- improve the MCF and rate constants;
- improve the reporting of economic data (e.g. annual growth) to include different population groups. The assumption that GDP growth is evenly distributed (using a computed mean) across all the population groups is highly misleading, and leads to exacerbated margins of error;
- Obtain information on population distribution trends between rural and urban settlements as a function of income;
- Conduct a study to trace waste streams and obtain more information on the bucket system which is still widely used in South Africa.

# 7. REFERENCES

Abstracts of Agricultural Statistics, 2012. Department of Agriculture, Forestry and Fisheries, Pretoria, RSA. Can be downloaded from www.daff.gov.za.

Airports Company South Africa (ACSA), 2013. Passenger travel Statistics. http://www.acsa.co.za/home.asp?pid=137. [Accessed April 2013]

Alembong, OA., 2015. Carbon flow analysis in the South African Forest and the Forestry Sector, MSC thesis, University of KwaZulu-Natal.

Anaya, J.A. and Chuvieco, E., 2012. Accuracy Assessment of Burned Area Products in the Orinoco Basin, *Photogrammetric Engineering & Remote Sensing*, 78: 53 – 60.

Anglo American 2011: The South African Iron and Steel Value Chain. http://www.angloamericankumba.com/ [Accessed July 2012]

Anton Eberhard, 2009. *South African Coal: market, investment and policy challenges*. South African coal paper, University of Cape Town.

Archibald, S., Roy, D.P., Van Wilgen, B.W, Scholes, R.J., 2010. What limits fire? An examination of the drivers of burnt area in southern Africa. *Global Change Biology*.

Archibald, S., Scholes, R.J., Roy, D., Roberts, G. and Boscheti, L., 2009. Southern African fire regimes as revealed by remote sensing. African Journal of Ecology.

Association of Cementitious Material Producers, 2008. Sustainability Report. http://www.acmp.co.za/climate_change.htm [Accessed March 2013

Association of Cementitious Material Producers, 2009. *Cement Manufacturing Process*. http://www.acmp.co.za/cement_manufacturing_process.htm. [Accessed March 2013].

Aucamp, A.J. and Howe, L.G., 1979. The production potential of the Eastern Cape Valley Bushveld. *Proc. Grassl. Soc. S Afr.* 14: 115 – 117.

Australian National Inventory Report (ANIR), 2009. Australian national greenhouse accounts: National inventory report. Department of climate change and energy efficiency, Commonwealth of Australia, Canberra, ACT.

Baggott, S.L., Brown, L., Cardenas, L., Downes, M.K., Garnett, E., Hobson, M., Jackson, J., Milne, R., Mobbs, D.C., Passant, N., Thistlethwaite, G., Thomson, A. and Watterson, J., 2006. Greenhouse Gas Inventory, 1990 to 2004.

Bessinger, D., 2000. *Cooling Characteristics of High Titania Slags, MSc dissertation*, University of Pretoria, Pretoria. http://upetd.up.ac.za/thesis/available/etd-07212006-102324 [Accessed 30 January 2013].

Bexley, J., 2013. *A perspective on the Glass Manufacturing Industry*. (Personal communication, February, 2013).

Blaxter, K.L. and Clapperton, J.L., 1965. Prediction of the amount of methane produced by ruminants. Brit. J. Nutr. 19: 511 – 522.

Boschetti, L., Roy, D., Hoffman, A.A. and Humber, M., 2012. MODIS Collection 5.1 burned area product – MCD45: User's guide version 3.

Brouwer, 1965. Report of sub-committee on constants and factors. In: Proceedings of the 3rd symposium on energy metabolism, pp. 441 – 443. K.L Blaxter (Edt). London: Academic Press.

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

Burns, R., 2012. Poultry production and climate change. XXIV World's poultry Congress, Salvador, Brazil.

Cement and Concrete Institute, 2008. *Cement and Concrete Institute Review 2008*. http://www.cnci.org.za/Uploads/Overall_Review%202008.pdf. [Accessed October 2012].

CHAPOPSA, 2002. *Charcoal potential in southern Africa*. INCO_DEV: International cooperation with developing countries (1998 – 2002).

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

Chidumayo, E.N., 1993. *Response of miombo to harvesting: ecology and management*. Stockholm Environmental Institute, Stockholm.

Christie, S.I. and Scholes, R.J. 1995. Carbon storage in Eucalyptus and Pine plantations in South Africa. *Environmental Monitoring and Assessment*, 38: 231 – 241.

Clauss, M., Frey, R., Kiefer, B., Lechner-Doll, M., Loehlein, W. Polster, C., Rössner, G.E., Streich, W.J., 2003. The maximum attainable body size of herbivorous mammals: morphophysiological constraints on foregut, and adaptations of hindgut fermenters. Oecologia, 136, 14–27.

Colgan, M.S., Asner, G.P., Levick, S.R., Martin, R.E. and Chadwick, O.A., 2012. Topo-edaphic controls over woody plant biomass in South African savannas. *Biogeosciences*, 9: 1809-1821.

Cowling, R.M., Richardson, D.M. and Mustart, P.J., 1997. Fynbos. In: Cowling, R.M., Richardson, D.M. and Pierce, S.M. (eds), *Vegetation of Southern Africa*. Cambridge University Press, Cambridge, UK, pp 99 – 130.

Damm, O. and Triebel, R., 2008. A Synthesis Report on Biomass Energy Consumption and Availability in South Africa. A report prepared for ProBEC.

Department of Agriculture, Forestry and Fisheries, 2010. The South African Agricultural GHG Inventory for 2004. Department of Agriculture, Forestry and Fisheries, ISBN: 978-1-86871-321-9, DAFF, Pretoria, RSA.

Department of Environmental Affairs (DEA), 2011: *National Climate Change Response, White Paper*. Department of Environmental Affairs, Pretoria.

Department of Environmental Affairs (DEA), 2011. *South Africa's Second National Communication under the United Nations Framework Convention on Climate Change*. Department of Environmental Affairs, Republic of South Africa, Pretoria.

Department of Environmental Affairs (DEA), 2012. *Atmospheric Emissions Licenses*, Department of Environmental Affairs, Pretoria.

Department of Environmental Affairs (DEA), 2012. *National Waste Information Baseline Report*, 2012. Department of Environmental Affairs, Pretoria.

Department of Environmental Affairs (DEA), 2014. *South Africa's 1st Biennial Update Report*. Department of Environmental Affairs, Pretoria. Draft, published for public comment.

DEA, 2015. National Terrestrial Carbon Sinks Assessment, Department of Environmental Affairs, Pretoria.

Department of Environmental Affairs and Tourism (DEAT), 2006. South Africa Environment Outlook. A report on the state of the environment. Executive summary and key findings. Department of Environmental Affairs and Tourism, Pretoria. 42pp.

Department of Environment Affairs and Tourism (DEAT), 2009. *Greenhouse Gas Inventory South Africa, 1990 to 2000*. National Inventory Report, May 2009. Pretoria: Department of Environmental Affairs and Tourism (DEAT, 2009).

Department of Energy (DoE), 2000. *Digest of South African Energy Statistics*. Pretoria.

Department of Minerals and Resources, 2001a. *Department of Minerals and Resources Annual Report 2001/2002*. Pretoria

Department of Minerals and Resources, 2001b. *South Africa's mineral industry (SAMI) 2001/2002*. Pretoria

Department of Minerals and Resources, 2004. *South Africa's mineral industry (SAMI) 2004/2005*. Pretoria

Department of Minerals and Resources, 2005. *South Africa's mineral industry (SAMI) 2005/2006*. Pretoria

Department of Minerals and Resources, 2006. *South Africa's mineral industry (SAMI) 2006/2007*. Pretoria

Department of Minerals and Resources, 2006. *South African Ferroalloy Production Trends 1995-2004*. Directorate: Mineral Economics, Report 52/2006, Pretoria.

Department of Minerals and Resources, 2008. *South Africa's mineral industry (SAMI) 2007/2008*. Pretoria

Department of Minerals and Resources, 2009. *South Africa's mineral industry (SAMI) 2009/2010*. Pretoria

Department of Minerals and Resources, 2013. *South Africa's mineral industry (SAMI) 2012/2013*. Pretoria

Department of Minerals and Resources, 2010c. *Lime Industry SA 2010*. Directorate: Mineral Economics, Report 85, Pretoria.

Department of Minerals and Resources, 2010d. *Operating and Developing Coal Mines in the Republic of South Africa 2010*. Directorate: Mineral Economics, Directory D2/2010, Pretoria.

Department of Minerals and Resources, 2010e. *Producers of Industrial Mineral Commodities in South Africa*. Directorate: Mineral Economics, Directory D11/2010, Pretoria.

Department of Minerals and Resources, 2010f. *South Africa's mineral industry (SAMI) 2009/2010*. Pretoria

Department of Minerals and Resources, 2010g. *Statistical Tables*, 1988 -2009. Directorate: Mineral Economics, Bulletin B1/2010, Pretoria.

Department of Minerals and Resources, 2010h. *Dolomites and Limestone in South Africa: Supply and Demand*. Directorate: Mineral Economics, Report R49/2005, Pretoria.

Department of Minerals and Resources, 2011. *Operating Mines and Quarries and Mineral Processing Plants in the Republic of South Africa, 2011*. Directorate: Mineral Economics, Directory D1/2011, Pretoria

Department of Transport 2001: *Statistics*, Pretoria. http://www.dot.gov.za [Accessed October 2012].

Department of Transport, 2009. *Transport Statistics 2008*. Annual Transport Statistics Bulletin, Pretoria. http://www.dot.gov.za, [Accessed 11 July 2012].

Department of Water Affairs (DWA), 2009. Directorate: Resource Protection and Waste. Inventory of Waste Water Treatment Works, Department of Water Affairs, Pretoria, RSA.

Desjardins, R., Rochette, P., Pattey, E. and MacPherson, I., 1993. Measurements of Greenhouse Gas Fluxes using Aircraft and Tower-based Techniques. In: Harper, L.A., Mosier, A.R. and Duxbury, J.M. (eds), Agricultural ecosystems effects on trace gases and global climate change: proceedings of a symposium / sponsored by Divisions A-3 and S-3 of the American Society of Agronomy and Soil Science Society of America. ASA Special Publication Number 55, USA.

Dingaan, M.N.V and du Preez, P.J., 2013. Grassland communities of urban open spaces in Bloemfontein, Free State, South Africa. *Koedoe* 55: 1-8, http://www.koedoe.co.za, doi:10.4102/koedoe.v55i1.1075.

Department of Minerals and Energy (DME), 2000. *Hydrocarbons and Energy Planning Branch – Liquid Fuel*, Department of Minerals and Energy, Pretoria.

Department of Minerals and Energy (DME), 2001. *National Electrification Programme NEP*. Summary evaluation Report, Department of Minerals and Energy, Pretoria.

Department of Minerals and Energy (DME), 2002. *South African National Energy Database: Energy Prices*, Department of Minerals and Energy, Pretoria.

Department of Minerals and Energy (DME), 2008. *National Efficiency Strategy of the Republic of South Africa*, Report 32342, Department of Minerals and Energy, Pretoria.

Department of Minerals and Energy (DME), 2010a. *Department of Minerals and Energy annual reports 2009/2010*, Department of Minerals and Energy, Pretoria.

Department of Minerals and Energy (DME), 2010b. *Department of Minerals and Energy annual reports 2009/2010*, Department of Minerals and Energy, Pretoria.

Department of Mineral Resources (DMR), 2010. *Department of Mineral Resources Lime Industry in South Africa Report, R85/2010*. Department of Mineral Resources, Pretoria.

Department of Minerals and Energy (DME), Eskom, Energy Research Institute and University of Cape Town 2002: *Energy Outlook for South Africa 2002*. http://www.info.gov.za/view/DownloadFileAction [Accessed August 2012].

Department of Energy (DoE), 2005. *Digest of South African Energy Statistics*, Department of Energy, Pretoria.

Department of Energy (DoE), 2005. *Energy Price Report. Directorate: Energy Planning and Development*, Department of Energy, Pretoria.

Department of Energy (DoE), 2007. *Biofuels Industrial Strategy of the Republic of South Africa*, Department of Energy, Pretoria. http://www.energy.gov.za/files/esources/petroleum/biofuels_indus_strat.pdf(2).pdf [Accessed October 2012].

Department of Energy (DoE), 2008. *Energy Balances Statistics*. Department of Energy, http://www.energy.gov.za/files/energyStats_frame.html. [Accessed November 2012].

Department of Energy (DoE), 2009a. *Digest of South African Energy Statistics*, Department of Energy, Pretoria.

Department of Energy (DoE), 2009b. *Electrification Statistics*. Electrification Policy Development and Management Directorate, Department of Energy, Pretoria.

Department of Energy (DoE), 2010. South Africa National energy Balance (2000-2010). Department of Energy, Pretoria, DOE. http://www.energy.gov.za/files/energyStats_frame.html

Department of Energy (DoE), 2010. *South African Energy Synopsis 2010*. Department of Energy, http://www.energy.gov.za [Accessed June 2012].

Donaldson, R.A., 2009. Season effects on the potential biomass and sucrose accumulation of some commercial cultivars of sugarcane, PhD Thesis, University of KwaZulu-Natal, Pietermaritzburg, RSA.

Donaldson, R.A., Redshaw, K.A., Rhodes, R. and Van Antwerpen, R., 2008. Season effects on productivity of some commercial South African sugarcane cultivars, I: Biomass and radiation use efficiency. *Proc. S Afr. Sug. Technol. Ass.* 81: 517 – 527.

Dovey, S.B. and Smith, C.W., 2005. Simple ratios to estimate bark and branch biomass and nutrient contents of commercial plantations. ICFR Bulletin Series 13/2005, ICFR, Pietermaritzburg, RSA.

Du Toit, C.J.L., Meissner, H.H. and van Niekerk, W.A., 2013a. Direct methane and nitrous oxide emissions of South African dairy and beef cattle. *South African Journal of Animal Science*, 43 (3): 320 – 339.

Du Toit, C.J.L., Meissner, H.H. and van Niekerk, W.A., 2013d. Direct greenhouse gas emissions of the game industry in South Africa. *South African Journal of Animal Science*, 43 (3): 376 – 393.

Du Toit, C.J.L., van Niekerk, W.A. and Meissner, H.H., 2013b. Direct greenhouse gas emissions of the South African small stock sectors. *South African Journal of Animal Science*, 43 (3): 340 – 361.

Du Toit, C.J.L., van Niekerk, W.A. and Meissner, H.H., 2013c. Direct methane and nitrous oxide emissions of monogastric livestock in South Africa. *South African Journal of Animal Science*, 43 (3): 362 - 375.

Engelbrecht, A., Golding, A., Hietkamp, S. and Scholes, R.J., 2004. *The potential for sequestration of carbon dioxide in South Africa*. Council for Scientific and Industrial Research (CSIR), Pretoria, RSA.

Environment Canada, 2009. Municipal Waste Water sources and characteristics. http://www.atl.ec.gc.ca/epb/issues/wstewtr.html

Eskom 2005: *Eskom Annual Report*, 2005. http://www.eskom.co.za/c/article/289/publications/ [Accessed February 2012]

Eskom 2007: *Eskom Annual Report*, 2007. http://www.eskom.co.za/c/article/289/publications/ [Accessed February 2012]

Eskom 2008: *Eskom Annual Report*, 2008. http://www.eskom.co.za/c/article/289/publications/ [Accessed February 2012]

Eskom 2010: *Eskom Annual Report*, 2010. http://www.eskom.co.za/c/article/289/publications/ [Accessed February 2012]

Eskom 2011: *Eskom Annual Report*, 2011. http://www.eskom.co.za/c/article/289/publications/ [Accessed February 2012]

FAOSTAT, 2012. Food and Agriculture Organization of the United Nations: Statistics. 2012. http://faostat.fao.org/site/605/default.aspx#ancor; accessed on 11/2012.

Fertilizer Society of SA (FSSA), 2009. Fertilizer Society of South Africa, http://www.fssa.org.za.

Ford, Dave, 2013. Personal communication with Dave Ford, Executive Director, SA Feedlot Association. Telephone +27 12 667 1189, Pretoria.

Forestry South Africa, 2012. Forestry and FP Industry Facts, 1980 – 2011. Forestry South Africa.

Garcia-Apaza, E., Paz, O. and Arana, I., 2008. Greenhouse gas emissions from enteric fermentation of livestock in Bolivia: values for 1990–2000 and future projections. *Australian Journal of Experimental Agriculture*, 48: 255–259.

GCIS, 2008. *South African Year Book on Transport 2007/2008*. Government Communication and Information System, http://www.gcis.gov.za/content/resource-centre/sa-info/yearbook/2009-10. [Accessed November 2012]

GCIS, 2009. *South African Year Book on Economy 2008/2009*. Government Communication and Information System, http://www.gcis.gov.za/content/resource-centre/sa-info/yearbook/2009-10. [Accessed November 2012]

GCIS, 2010. *South African Year Book on Energy 2009/2010*. Government Communication and Information System, http://www.gcis.gov.za/content/resource-centre/sa-info/yearbook/2009-10http://www.gcis.gov.za. [Accessed November 2012]

GeoTerraImage (GTI) Pty Ltd., 2015. 1990 – 2013-14 South African National Land-cover change. Department of Environmental Affairs, Pretoria.

GeoTerraImage (GTI) Pty Ltd., 2015. 2013-2014 South African National Land-cover dataset. Department of Environmental Affairs, Pretoria.

Global Forest Resource Assessment SA (GFRASA), 2005. *Global Forest Resources Assessment: Country Reports – South Africa*. FAO, Rome, Italy.

Global Forest Resource Assessment SA (GFRASA), 2010. *Global Forest Resources Assessment: Country Reports – South Africa*. FAO, Rome, Italy.

Gonzalez-Avalos, E. and Ruiz-Suarez, L.G., 2001. Methane emission factors from cattle manure in Mexico. Biosecure Technology, 80(1): 63 – 71.

Government Communication and Information System (GCIS), 2009. *2009/10 Year South African Year Book*. http://www.gcis.gov.za/content/resource-centre/sa-info/yearbook/2009-10 [Accessed: February 2013].

Hély, C., Dowty, P.R., Alleane, S., Caylor, K.K., Korontzi, S., Swap, R.J., Shugart, H.H. and Justice, C.O., 2003. Regional fuel load for two climatically contrasting years in southern Africa. *Journal of Geophysical Research*, 108.

Howden, S.M., White, D.H., McKeon, G.M., Scanlan, J.C and Carter J.O., 1994. Methods for Exploring Management Options to Reduce Greenhouse Gas Emissions from Tropical Grazing Systems, *Climatic Change*, vol 27 pp 49–70.

Hurly, K.M., Lynsky, R.J. and Stranack, R.A., 2003. Protecting the Privilege of Burning Sugarcane at Harvest Ie International Farm Management Congress http://ageconsearch.umn.edu/bitstream/24381/1/ cp03hu02.pdf

International Energy Agency (IEA), 2012. $CO_2$ emissions from fuel combustion: Highlights. (http://www.iea.org/co2highlights/co2highlights.pdf)

IPCC, 1997. Greenhouse Gas Inventory Reporting Instructions. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. UNEP, WMO, OECD and IEA, Bracknell United Kingdom.

IPCC, 2001. *IPCC Third Assessment Report (TAR): Climate Change 2001*. Cambridge: Intergovernmental Panel on Climate Change. Cambridge University Press.

IPCC, 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry.

IPCC, 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. The National Greenhouse Gas Inventories Programme, Eggleston H S, Buenida L, Miwa K, Ngara T, and Tanabe K, eds; Institute for Global Environmental Strategies (IGES). Hayama, Kanagawa, Japan.

IPCC, 2014. 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol, Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. and Troxler, T.G. (eds), Published: IPCC, Switzerland.

Korontzi, S., Justice, C.O. and Scholes, R.J., 2003. Influence of timing and spatial extent of Savanna fires in Southern Africa on atmospheric emissions. *Journal of Arid Environments*, 54: 395 - 404.

Kurihara, M., Magner, T., Hunter, R.A. and McCrabb, G.J., 1999. Methane production and energy partition of cattle in the tropics. British J. Nutr. 81, 227 – 234.

LACTO data, 2010. Milk producers statistics, MPO, Pretoria. Vol 14 (1).

Lambers, H., Raven, J.A., Shaver, G.R. and Smith, S.E., 2008. Plant nutrient-acquisition strategies change with soil age. *Trends Ecol Evol* 23: 95–103.

Lechmere-Oertel, R.G., 2003. The effects of goat browsing on ecosystem patterns and processes in succulent thicket, South Africa. PhD thesis, Nelson Mandela Metropolitan University.

Lloyd P.J.D., 2001. The South African Petroleum Industry: A Review. Prepared for the Automobile Association of South Africa. Energy Research Institute: University of Cape Town.

Low, A.B. and Rebelo, A.G., 1996. Vegetation of South Africa, Lesotho and Swaziland, Department of Environmental Affairs and Tourism, Pretoria. 0-621-17316-9 ISBN.

Malimbwi, R.E. and Zahabu, E., 2009. The analysis of sustainable charcoal production systems in Tanzania. In: Simmone, S., Remedio, E. and Trossero, M.A. (eds), Criteria and Indicators for Sustainable Woodfuels: Case studies from Brazil, Guyana, Nepal, Philippines and Tanzania. FAO, Rome, Italy.

Madubansi, M., Shackleton C.M., 2007. Changes in fuelwood use and selection following electrification in the Bushbuckridge lowveld South Africa. Journal of Environmental Management.

Matsika R, Erasmus, B.F.N., Twine, W.C., 2013. A tale of two villages: assessing the dynamics of fuelwood supply in communal landscapes in South Africa. Environ. Conserv.

McGinn, S.M., Chen, D., Loh, Z., Hill, J., Beauchemin, K.A. and Denmead, O.T., 2008. Methane emissions from feedlot cattle in Australia and Canada. *Australian Journal of Experimental Agriculture*, 48: 183–185.

Midgley, J.J. and Seydack, A.H.W., 2006. No adverse signs of the effect of environmental change on tree biomass in the Knysna forest during the 1990s. *S A J Science* 102: 96-97.

Mills, A.J. and Cowling, R.M., 2006. Rate of carbon sequestration at two thicket restoration sites in the Eastern Cape, South Africa. *Restoration Ecology*, 14 (1):38 – 49.

Mills, A.J., Birch, S.C., Stephenson, J.D. and Bailey, R.V., 2012. Carbon stocks in Fynbos, pastures and vineyards on the Agulhas Plain, South Africa: a preliminary assessment. *S A J Plant. Soil*, iFirst: 1-3.

Mills, A.J., Cowling, R.M., Fey, M.V., Kerley, G.I.H., Donaldson, J.S., Lechmere-Oertel, R.G., Sigwela, A.M., Skowno, A.L. and Rundel, P., 2005. Effects of goat pastoralism on ecosystem carbon storage in semiarid thicket, Easern Cape, South Africa. *Austral Ecology* 30: 797 – 804.

Milton, S.J., 1990. Above-ground biomass and plant cover in a succulent shrubland in the southern Karoo, South Africa. *S A J Bot.* 56: 587-589.

Milton, S.J., Yeaton, R., Dean, W.R.J. and Vlok, J.H.J., 1997. Succulent Karoo. In: Cowling, R.M., Richardson, D.M. and Pierce, S.M. (Eds.), Vegetation of Southern Africa. Cambridge: Cambridge University Press, Cambridge, UK.

Minson, D.J. and McDonald, C.K., 1987. Estimating forage intake from growth of cattle. Tropical grasslands, 21(3): 116 – 121.

Moe, P.W. and Tyrell, H.F., 1979. Methane production in dairy cows. J. Dairy Sci. 62: 1583 – 1586.

Moeletsi, M., Paterson, G. Van Der Walt, M., Malherbe, J., Nape, M., Nkambule, V. and Malaka, S., 2013. ARC Contribution to ALU GHG Project, ARC-ISCW, unpublished report no. GW/A/2013/19, Pretoria, RSA.

Mucina, L. and Rutherford, M.C. (eds), 2006. The Vegetation of South Africa, Lesotho and Swaziland. Strelitzia 19. South African National Biodiversity Institute, Pretoria.

National Electricity Regulator, 2000. *Electricity Supply Statistics for South Africa*. http://www.ner.org.za. [Accessed July 2012].

National Electricity Regulator, 2004. *Electricity Supply Statistics for South Africa*. http://www.ner.org.za. [Accessed July 2012].

National Electricity Regulator, 2006. *Electricity Supply Statistics for South Africa*. http://www.ner.org.za. [Accessed July 2012].

NERSA, National Energy Regulator of South Africa (NERSA), 2006. *2006 Electricity statistics for South Africa*. National Energy Regulator of South Africa, http://www.nersa.org.za [Accessed February 2012]

NERSA, 2008. 2008 Electricity statistics for South Africa. National Energy Regulator of South Africa, http://www.nersa.org.za [Accessed February 2012]

NERSA, 2008. The national electricity supply shortage and load shedding. National Energy Regulator of South Africa, http://www.eepublishers.co.za/article/nersa-enquiry-into-the-national-electricity-supply-shortage-and-load-shedding.html [Accessed February 2012]

O'Connor, T.G. and Bredenkamp, G.J., 1997. Grassland. In: Cowling, R.M., Richardson, D.M. and Pierce, S.M. (eds), *Vegetation of Southern Africa*. Cambridge University Press, Cambridge, UK.

O'Connor, T.G., 2008. Influence of land use on phytomass accumulation in Highland Sourveld grassland in the southern Drakensberg, South Africa. *Afr. J. Range & Forage Sci*. 25: 17 – 27.

Otter, L. and Scholes, M., 2000. Methane sources and sinks in a periodically flooded South African savannah. *Glob. Biogeochem. Cycles*, vol 14: 97 – 111.

Otter, L. B., 2011. Agricultural GHG Inventory: 2000 to 2009 and forward projections to 2020. Unpublished report prepared for Department of Environmental Affairs, Pretoria.

Palmer, T. and Ainslie, A., 2002. South Africa: FAO Country Profile – Country Pasture/Forage Resource Profile, Rome: FAO. http://www.fao.org/ag/agp/agpc/doc/counprof/southafrica/southafrica.htm ; accessed on 15/03/2013.

PFG Glass, 2010. *Chemical composition of glass*. http://www.pfg.co.za/all-about-glass.aspx [Accessed February 2013]

Prinsloo, Magda, 2014. Statistician for the South African Poultry Association, personal communication via email. Email: Magda@sapoultry.co.za

Research Unit of Creamer Media (Pty) Ltd, 2009. *South Africa's Steel Industry 2009*. Creamer media, Johannesburg.

Roy, D.P. and Boschetti, L., 2009. Southern Africa validation of the MODIS, L3JRC and GlobCarbon Burned-Area Products, *IEEE Transactions on Geoscience and Remote Sensing*, 47(4):1–13.

Roy, D.P., Jin, Y., Lewis, P.E. and Justice, C.O., 2005. Prototyping a global algorithm for systematic fire-affected area mapping using MODIS time series data. *Remote Sensing of Environment* 97(2), pp.137-162

Rutherford, M.C., 1982. Aboveground biomass categories of woody plants in a Burkea africana - Ochna pulchra Savanna. *Bothalia*, 14: 131-138.

SA Feedlot Association, 2013. http://www.safeedlot.co.za/index.asp?Content=90 [Accessed 10 June 2013]

Scholes, R.J. and Walker, B.H., 1993. *An African Savanna: Synthesis of the Nylsvley study*. Cambridge University Press, Cambridge, UK.

Scholes R.J. and Hall D.O., 1996. The carbon budget of tropical savannas, woodlands and grasslands. In: Breymeyer A.I., Hall D.O., Melillo J.M. and Agren G.I. (Eds.) *Global Change: Effects on Coniferous Forests and Grasslands*, SCOPE Volume 56. Wiley, Chichester. pp. 69-100.

Shackleton, C.M. and Scholes, R.J., 2011. Above ground woody community attributes, biomass and carbon stocks along a rainfall gradient in the savannas of the central lowveld, South Africa. S A J Bot 77: 184 -192.

Shackleton, C.M. & Shackleton, S.E. 2004.The importance of non-timber forest products in rural livelihood security and as safety-nets: evidence from South Africa. South African Journal of Science, 100: 658-664.

Siebrits, F., 2012. Report to authors on pig diets in South Africa. Pretoria.

Simalenga, T.E., Joubert, A.B.D. and Hanekom, D., 2002. Agricultural Mechanization in South Africa: Status, Trend and Challenges, ARC-AII, Pretoria.

Singh, J.S. and Joshi, M.C., 1979. Primary Production. Chapter 17 in: Coupland, R.T. (ed), *Grassland ecosystems of the world: Analysis of grasslands and their uses*. Cambridge University Press, Cambridge, UK.

Snyman, H.A., 2005. Influence of fire on root distribution, seasonal root production and root/shoot ratios in grass species in a semi-arid grassland of South Africa. *S A J Bot*. 71: 133-144.

Snyman, H.A., 2011. Root studies in a semi-arid climate. In: Grassroots, The Grassland Society of Southern Africa, http://www.grassland.org.za.

Snyman, H.G., Herselman, J.E. and Kasselman, G., 2004. *A metal content survey of South African Sewage Sludge and an Evaluation of Analytical Methods for their Determination in Sludge*. WRC Report No 1283/1/04. Water Research Commission, Pretoria, RSA.

South Africa Iron and Steel Institute (SAISI), 2009. *Local Sales of Iron and Crude Steel Production in South Africa*. http://www.saisi.co.za/localsales.php. [Accessed September 2012].

South Africa Iron and Steel Institute (SAISI), 2009. *Local Sales of Iron and Crude Steel Production in South Africa*. http://www.saisi.co.za/localsales.php. [Accessed September 2012].

South Africa Iron and Steel Institute (SAISI), 2012. *Iron and Crude Steel Production in South Africa*. http://www.saisi.co.za/ironsteelproduction.php. [Accessed September 2012].

South Africa Iron and Steel Institute (SAISI), 2012. *Overview of Iron and Crude Steel Production in South Africa*. http://www.saisi.co.za/primover.php. [Accessed September 2012].

South African Iron and Steel Institute (SAISI), 2008. Steel Stats. http://www.saisi.co.za/index.php/steel-stats [Accessed May 2012]

South African Petroleum Industry Association (SAPIA), 2006. SAPIA Annual Report 2006. http://www.sapia.co.za. [Accessed September 2011].

South African Petroleum Industry Association (SAPIA), 2008. Petrol and Diesel in South Africa and the Impact on Air Quality. http://www.sapia.co.za. [Accessed September 2011].

South African Petroleum Industry Association (SAPIA), 2010. SAPIA Annual Report 2010. http://www.sapia.co.za. [Accessed September 2011].

South African Petroleum Industry Association (SAPIA), 2011. SAPIA Annual Report 2011. http://www.sapia.co.za. [Accessed September 2012].

South African Statistics Council, 2006. South African Statistics Council Annual Report 2005/2006, Report 174/2006. http://www.statssa.gov.za/publications/StatsCouncilAnnualReport0506.pdf. [Accessed February 2012].

South African Statistics Council, 2007. South African Statistics Council Annual Report 2006/2007, Report. http://www.statssa.gov.za/publications/statsdownload.asp?PPN=AnnualReport&SCH=4026 [Accessed February 2012].

South African Statistics Council, 2011. South African Statistics Council Annual Report 2011/11, Report 174/2011. http://www.statssa.gov.za/publications/StatsCouncilAnnualReport0506.pdf. [Accessed February 2012].

South African Wine Industry Statistics, 2012. www.sawis.co.za. Paarl, South Africa.

Standards South Africa (SSA), 2004. SANS 1877:2004 - A standard land-cover classification scheme for remote-sensing applications in South Africa. Edition 1. Pretoria, RSA.

Statistics South Africa (Statistics SA), 2006. *Statistics South Africa Annual Report 2005/2006*. http://www.statssa.gov.za/annual reports. [Accessed September 2012]

Statistics South Africa, 2010. Mid-year population estimates: 2010. Statistical release P0302.

Statistics South Africa, 2013. Mid-year population estimates: 2013. Statistical release P0302.

Thompson, M.W., 1999. South African National Land-cover database project. Data users manual, Final report. CSIR-ARC Contract Report. ENV/P/C 98136, Pretoria.

United Nations (UN), 2012. Population Division of the Department of Economic and Social Affairs of the Secretariat, World Population Prospects: http://esa.un.org/unpd/wpp/index.htm [Accessed April 2013]

Van den Berg, E.C., Plarre, C., Van den Berg, H.M. and Thompson, M.W., 2008. *The South African National Land-Cover 2000*. Agricultural Research Council-Institute for Soil, Climate and Water, Unpublished Report No. GW/A/2008/86.

Van der Merwe, M. and Scholes, R. J., 1998. *Greenhouse Gas Emissions Inventory of 1990 for South Africa, Phase 1*. Council for Scientific and Industrial Research (CSIR), Pretoria: National Research Foundation, RSA.

Van der Vyver, M.L., 2011. Restoring the biodiversity of canopy species within degraded Spekboom thicket. MSc thesis, Nelson Mandela Metropolitan University.

Van der Waal, C., 2008. *Guidelines for the Utilization and Disposal of Wastewater Sludge, Volume 1-5: Impact Assessment*. WRC Report No TT 370/08. Water Research Commission, Pretoria, RSA.

Van Dyk J.P., 2006. *An overview of the Zincor Process, Southern African Pyrometallurgy 2006*. South African Institute of Mining and Metallurgy, Johannesburg

Van Heerden, P.D.R., Donaldson, R.A., Watt, D.A. and Singels, A., 2010. Biomass accumulation in sugarcane: unravelling the factors underpinning reduced growth phenomena. *J Exp. Bot.*, June 13, 2010, p 1 – 11; doi:10.1093/jeb/erq144.

Wang, S. and Huang, D., 2005. Assessment of Greenhouse Gas Emissions from Poultry Enteric Fermentation. Asian-Australian *Journal of Animal Science* 18:873-878.

Wessels, K.J., Colgan, M.S., Erasmus, B.F.N., Asner, G.P., Twine, W.C., Mathieu, R., Aardt, J.A.N., Fisher, J.T. and Smit, I.P.J., 2013. Unsustainable fuelwood extraction from South African savannas. *Environ. Res. Lett.* 8: 1-10.

World Steel Association, 2010. Key Facts about World Steel Industry. http://www.worldsteel.org/media-centre/key-facts.html . [Accessed May 2012].

# APPENDICES

# 8. APPENDIX A: SUMMARY TABLES

| INVENTORY YEAR: 2000 | Emissions/removals (Gg $CO_2$eq) | | | | | |
|---|---|---|---|---|---|---|
| **Categories** | **Net $CO_2$** | **$CH_4$** | **$N_2O$** | **HFCs** | **PFCs** | **Total** |
| **Total including FOLU** | **357 791.87** | **48 367.06** | **27 162.82** | **0.00** | **982.24** | **434 303.98** |
| **Total excluding FOLU** | **367 050.44** | **47 937.81** | **27 162.82** | **0.00** | **982.24** | **443 133.31** |
| **1 - Energy** | **335 519.08** | **5 002.45** | **2 070.76** | | | **342 592.29** |
| 1.A - Fuel Combustion Activities | 306 596.79 | 572.96 | 2 070.76 | | | 309 240.52 |
| *1.A.1 - Energy Industries* | 219 524.69 | 58.12 | 963.57 | | | 220 546.38 |
| *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 | 234.66 | 435.38 | | | 19 036.34 |
| *1.A.5 - Non-Specified* | 985.58 | 0.98 | 2.53 | | | 989.09 |
| 1.B - Fugitive emissions from fuels | 28 922.29 | 4 429.49 | | | | 33 351.77 |
| *1.B.1 - Solid Fuels* | 23.67 | 1 978.88 | | | | 2 002.55 |
| *1.B.2 - Oil and Natural Gas* | 752.04 | | | | | 752.04 |
| *1.B.3 - Other emissions from Energy Production* | 28 146.58 | 2 450.60 | | | | 30 597.19 |
| **2 - Industrial Processes and Product Use** | **30 935.81** | **75.50** | **1 570.25** | | **982.24** | **33 563.79** |
| 2.A - Mineral Industry | 3 847.79 | | | | | 3 847.79 |
| *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* | 74.36 | | | | | 74.36 |
| 2.B - Chemical Industry | 1 063.45 | 71.88 | 1 570.25 | | | 2 705.58 |
| 2.C - Metal Industry | 25 828.66 | 3.62 | | | 982.24 | 26 814.51 |
| *2.C.1 - Iron and Steel Production* | 16 410.53 | | | | | 16 410.53 |
| *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 | | | | | | |
| **3 - Agriculture, Forestry, and Other Land Use** | **-7 702.83** | **31 573.24** | **22 949.57** | | | **46 819.97** |
| 3.A - Livestock | | 30 155.07 | 1 007.32 | | | 31 162.38 |
| *3.A.1 - Enteric Fermentation* | | 29 290.35 | | | | 29 290.35 |
| *3.A.2 - Manure Management* | | 864.71 | 1 007.32 | | | 1 872.03 |

| INVENTORY YEAR: 2000 | Emissions/removals (Gg $CO_2$eq) | | | | | |
|---|---|---|---|---|---|---|
| Categories | Net $CO_2$ | $CH_4$ | $N_2O$ | HFCs | PFCs | Total |
| 3.B - Land | -7 986.19 | 429.25 | | | | -7 556.94 |
| *3.B.1 - Forest land* | -21 565.09 | | | | | -21 565.09 |
| *3.B.2 - Cropland* | 4 480.05 | | | | | 4 480.05 |
| *3.B.3 - Grassland* | 7 904.13 | | | | | 7 904.13 |
| *3.B.4 - Wetlands* | | 429.25 | | | | 429.25 |
| *3.B.5 - Settlements* | 1 194.72 | | | | | 1 194.72 |
| *3.B.6 - Other lands* | -960.20 | | | | | -960.20 |
| 3.C - Aggregate sources and non-$CO_2$ emissions sources on land | 595.55 | 988.92 | 21 942.25 | | | 23 526.72 |
| *3.C.1 - Emissions from biomass burning* | | 988.92 | 914.31 | | | 1 903.24 |
| *3.C.2 - Liming* | 384.05 | | | | | 384.05 |
| *3.C.3 - Urea application* | 211.49 | | | | | 211.49 |
| *3.C.4 - Direct $N_2O$ Emissions from managed soils* | | | 15 909.52 | | | 15 909.52 |
| *3.C.5 - Indirect $N_2O$ Emissions from managed soils* | | | 4 768.44 | | | 4 768.44 |
| *3.C.6 - Indirect $N_2O$ Emissions from manure management* | | | 349.97 | | | 349.97 |
| 3.D - Other | -312.19 | | | | | -312.19 |
| *3.D.1 - Harvested Wood Products* | -312.19 | | | | | -312.19 |
| **4 - Waste** | | **11 715.88** | **572.24** | | | **12 288.12** |
| 4.A - Solid Waste Disposal | | 9 367.55 | | | | 9 367.55 |
| 4.D - Wastewater Treatment and Discharge | | 2 348.33 | 572.24 | | | 2 920.57 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Memo Items (5)** | | | | | | |
| **International Bunkers** | **2 972.40** | **2.87** | **6.73** | | | **2 981.99** |
| *1.A.3.a.i - International Aviation (International Bunkers)* | 2 972.40 | 2.87 | 6.73 | | | 2 981.99 |
| *1.A.3.d.i - International water-borne navigation (International bunkers)* | | | | | | |
| ***1.A.5.c - Multilateral Operations*** | | | | | | |

| INVENTORY YEAR: 2001 | Emissions/removals (Gg $CO_2$eq) | | | | | |
|---|---|---|---|---|---|---|
| **Categories** | **Net $CO_2$** | **$CH_4$** | **$N_2O$** | **HFCs** | **PFCs** | **Total** |
| **Total including FOLU** | **356 779.41** | **49 243.42** | **27 062.21** | **0.00** | **1 008.22** | **434 093.27** |
| **Total excluding FOLU** | **366 067.83** | **48 827.62** | **27 062.21** | **0.00** | **1 008.22** | **442 965.89** |
| **1 - Energy** | **334 283.28** | **4 991.41** | **2 062.81** | | | **341 337.50** |
| 1.A - Fuel Combustion Activities | 305 136.09 | 570.72 | 2 062.81 | | | 307 769.62 |
| *1.A.1 - Energy Industries* | 214 845.49 | 57.07 | 941.96 | | | 215 844.53 |
| *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 | 234.55 | 449.20 | | | 22 509.06 |
| *1.A.5 - Non-Specified* | 980.25 | 0.98 | 2.51 | | | 983.74 |
| 1.B - Fugitive emissions from fuels | 29 147.19 | 4 420.70 | | | | 33 567.89 |
| *1.B.1 - Solid Fuels* | 23.35 | 1 966.46 | | | | 1 989.81 |
| *1.B.2 - Oil and Natural Gas* | 752.90 | | | | | 752.90 |
| *1.B.3 - Other emissions from Energy Production* | 28 370.94 | 2 454.24 | | | | 30 825.18 |
| **2 - Industrial Processes and Product Use** | **31 140.73** | **75.72** | **1 512.39** | | **1 008.22** | **32 728.83** |
| 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 | 25 939.17 | 3.56 | | | 1 008.22 | 25 942.73 |
| *2.C.1 - Iron and Steel Production* | 16 410.54 | | | | | 16 410.54 |
| *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** | **-7 684.40** | **31 554.96** | **22 902.94** | | | **46 773.50** |
| 3.A - Livestock | | 29 992.39 | 1 010.84 | | | 31 003.23 |
| *3.A.1 - Enteric Fermentation* | | 29 117.18 | | | | 29 117.18 |
| *3.A.2 - Manure Management* | | 875.20 | 1 010.84 | | | 1 886.04 |

| INVENTORY YEAR: 2001 | Emissions/removals (Gg $CO_2$eq) | | | | | |
|---|---|---|---|---|---|---|
| **Categories** | **Net $CO_2$** | **$CH_4$** | **$N_2O$** | **HFCs** | **PFCs** | **Total** |
| 3.B - Land | -7 653.70 | 415.80 | | | | -7 237.90 |
| *3.B.1 - Forest land* | -21 326.32 | | | | | -21 326.32 |
| *3.B.2 - Cropland* | 4 573.77 | | | | | 4 573.77 |
| *3.B.3 - Grassland* | 7 904.13 | | | | | 7 904.13 |
| *3.B.4 - Wetlands* | | 415.80 | | | | 415.80 |
| *3.B.5 - Settlements* | 1 194.72 | | | | | 1 194.72 |
| *3.B.6 - Other lands* | -960.20 | | | | | -960.20 |
| 3.C - Aggregate sources and non-$CO_2$ emissions sources on land | 643.82 | 1 146.77 | 21 892.11 | | | 23 682.69 |
| *3.C.1 - Emissions from biomass burning* | | 1 146.77 | 1 089.52 | | | 2 236.29 |
| *3.C.2 - Liming* | 497.15 | | | | | 497.15 |
| *3.C.3 - Urea application* | 146.67 | | | | | 146.67 |
| *3.C.4 - Direct $N_2O$ Emissions from managed soils* | | | 15 734.91 | | | 15 734.91 |
| *3.C.5 - Indirect $N_2O$ Emissions from managed soils* | | | 4 714.91 | | | 4 714.91 |
| *3.C.6 - Indirect $N_2O$ Emissions from manure management* | | | 352.76 | | | 352.76 |
| 3.D - Other | -674.52 | | | | | -674.52 |
| *3.D.1 - Harvested Wood Products* | -674.52 | | | | | -674.52 |
| **4 - Waste** | | **12 621.33** | **584.07** | | | **13 205.41** |
| 4.A - Solid Waste Disposal | | 10 224.44 | | | | 10 224.44 |
| 4.D - Wastewater Treatment and Discharge | | 2 396.90 | 584.07 | | | 2 980.97 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **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 $CO_2$eq) | | | | | |
|---|---|---|---|---|---|---|
| **Categories** | **Net $CO_2$** | **$CH_4$** | **$N_2O$** | **HFCs** | **PFCs** | **Total** |
| **Total including FOLU** | **367 237.91** | **49 891.51** | **27 517.74** | **0.00** | **898.28** | **445 545.45** |
| **Total excluding FOLU** | **379 047.67** | **49 489.16** | **27 517.74** | **0.00** | **898.28** | **456 952.86** |
| **1 - Energy** | **345 080.78** | **5 022.89** | **2 112.26** | | | **352 215.93** |
| 1.A - Fuel Combustion Activities | 315 297.94 | 572.22 | 2 112.26 | | | 317 982.42 |
| *1.A.1 - Energy Industries* | 220 110.01 | 57.98 | 968.39 | | | 221 136.38 |
| *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 | 234.20 | 460.84 | | | 25 613.19 |
| *1.A.5 - Non-Specified* | 979.76 | 0.98 | 2.51 | | | 983.25 |
| 1.B - Fugitive emissions from fuels | 29 782.84 | 4 450.67 | | | | 34 233.51 |
| *1.B.1 - Solid Fuels* | 23.02 | 1 938.08 | | | | 1 961.10 |
| *1.B.2 - Oil and Natural Gas* | 955.13 | | | | | 955.13 |
| *1.B.3 - Other emissions from Energy Production* | 28 804.70 | 2 512.59 | | | | 31 317.29 |
| **2 - Industrial Processes and Product Use** | **32 791.35** | **72.97** | **1 508.05** | | **898.28** | **34 372.37** |
| 2.A - Mineral Industry | 3 901.64 | | | | | 3 901.64 |
| *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* | 88.35 | | | | | 88.35 |
| 2.B - Chemical Industry | 1 102.00 | 68.53 | 1 508.05 | | | 2 678.59 |
| 2.C - Metal Industry | 27 537.39 | 4.43 | | | 898.28 | 27 541.82 |
| *2.C.1 - Iron and Steel Production* | 17 176.10 | | | | | 17 176.10 |
| *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** | **-9 674.03** | **31 299.47** | **23 305.26** | | | **44 930.70** |
| 3.A - Livestock | | 29 743.58 | 1 027.60 | | | 30 771.18 |
| *3.A.1 - Enteric Fermentation* | | 28 873.92 | | | | 28 873.92 |
| *3.A.2 - Manure Management* | | 869.66 | 1 027.60 | | | 1 897.26 |

| INVENTORY YEAR: 2002 | Emissions/removals (Gg $CO_2$eq) | | | | | |
|---|---|---|---|---|---|---|
| Categories | Net $CO_2$ | $CH_4$ | $N_2O$ | HFCs | PFCs | Total |
| 3.B - Land | -10 032.41 | 402.35 | | | | -9 630.06 |
| *3.B.1 - Forest land* | -23 798.42 | | | | | -23 798.42 |
| *3.B.2 - Cropland* | 4 667.15 | | | | | 4 667.15 |
| *3.B.3 - Grassland* | 7 904.13 | | | | | 7 904.13 |
| *3.B.4 - Wetlands* | | 402.35 | | | | 402.35 |
| *3.B.5 - Settlements* | 1 194.72 | | | | | 1 194.72 |
| *3.B.6 - Other lands* | -960.20 | | | | | -960.20 |
| 3.C - Aggregate sources and non-$CO_2$ emissions sources on land | 1 175.54 | 1 153.54 | 22 277.66 | | | 24 606.73 |
| *3.C.1 - Emissions from biomass burning* | | 1 153.54 | 1 074.61 | | | 2 228.15 |
| *3.C.2 - Liming* | 683.69 | | | | | 683.69 |
| *3.C.3 - Urea application* | 491.85 | | | | | 491.85 |
| *3.C.4 - Direct $N_2O$ Emissions from managed soils* | | | 16 035.20 | | | 16 035.20 |
| *3.C.5 - Indirect $N_2O$ Emissions from managed soils* | | | 4 809.62 | | | 4 809.62 |
| *3.C.6 - Indirect $N_2O$ Emissions from manure management* | | | 358.22 | | | 358.22 |
| 3.D - Other | -817.15 | | | | | -817.15 |
| *3.D.1 - Harvested Wood Products* | -817.15 | | | | | -817.15 |
| **4 - Waste** | | **13 496.19** | **592.17** | | | **14 088.37** |
| 4.A - Solid Waste Disposal | | 11 066.05 | | | | 11 066.05 |
| 4.D - Wastewater Treatment and Discharge | | 2 430.15 | 592.17 | | | 3 022.32 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **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 $CO_2$eq) | | | | | |
|---|---|---|---|---|---|---|
| **Categories** | **Net $CO_2$** | **$CH_4$** | **$N_2O$** | **HFCs** | **PFCs** | **Total** |
| **Total including FOLU** | **390 889.84** | **49 992.50** | **25 986.77** | **0.00** | **896.23** | **467 765.34** |
| **Total excluding FOLU** | **402 059.98** | **49 603.60** | **25 986.77** | **0.00** | **896.23** | **478 546.57** |
| **1 - Energy** | **368 291.84** | **5 187.23** | **2 238.93** | | | **375 718.00** |
| 1.A - Fuel Combustion Activities | 339 500.15 | 591.41 | 2 238.93 | | | 342 330.49 |
| *1.A.1 - Energy Industries* | 237 730.31 | 63.04 | 1 052.05 | | | 238 845.40 |
| *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 | 238.28 | 475.71 | | | 27 908.37 |
| *1.A.5 - Non-Specified* | 1 011.23 | 1.01 | 2.59 | | | 1 014.82 |
| 1.B - Fugitive emissions from fuels | 28 791.69 | 4 595.82 | | | | 33 387.51 |
| *1.B.1 - Solid Fuels* | 24.85 | 2 092.96 | | | | 2 117.81 |
| *1.B.2 - Oil and Natural Gas* | 1 457.99 | | | | | 1 457.99 |
| *1.B.3 - Other emissions from Energy Production* | 27 308.85 | 2 502.86 | | | | 29 811.71 |
| **2 - Industrial Processes and Product Use** | **32 850.94** | **75.65** | **936.31** | | **896.23** | **33 862.90** |
| 2.A - Mineral Industry | 4 138.81 | | | | | 4 138.81 |
| *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* | 91.33 | | | | | 91.33 |
| 2.B - Chemical Industry | 1 123.51 | 71.20 | 936.31 | | | 2 131.02 |
| 2.C - Metal Industry | 27 340.02 | 4.45 | | | 896.23 | 27 344.47 |
| *2.C.1 - Iron and Steel Production* | 16 786.44 | | | | | 16 786.44 |
| *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** | **-9 292.75** | **30 382.86** | **22 211.77** | | | **43 301.88** |
| 3.A - Livestock | | 29 143.08 | 1 050.50 | | | 30 193.58 |
| *3.A.1 - Enteric Fermentation* | | 28 306.34 | | | | 28 306.34 |
| *3.A.2 - Manure Management* | | 836.74 | 1 050.50 | | | 1 887.24 |

| INVENTORY YEAR: 2003 | Emissions/removals (Gg $CO_2$eq) | | | | | |
|---|---|---|---|---|---|---|
| **Categories** | **Net $CO_2$** | **$CH_4$** | **$N_2O$** | **HFCs** | **PFCs** | **Total** |
| 3.B - Land | -9 282.59 | 388.90 | | | | -8 893.69 |
| *3.B.1 - Forest land* | -23 142.12 | | | | | -23 142.12 |
| *3.B.2 - Cropland* | 4 760.67 | | | | | 4 760.67 |
| *3.B.3 - Grassland* | 7 904.13 | | | | | 7 904.13 |
| *3.B.4 - Wetlands* | | 388.90 | | | | 388.90 |
| *3.B.5 - Settlements* | 1 194.72 | | | | | 1 194.72 |
| *3.B.6 - Other lands* | -960.20 | | | | | -960.20 |
| 3.C - Aggregate sources and non-$CO_2$ emissions sources on land | 917.19 | 850.88 | 21 161.27 | | | 22 929.34 |
| *3.C.1 - Emissions from biomass burning* | | 850.88 | 759.62 | | | 1 610.50 |
| *3.C.2 - Liming* | 585.99 | | | | | 585.99 |
| *3.C.3 - Urea application* | 331.20 | | | | | 331.20 |
| *3.C.4 - Direct $N_2O$ Emissions from managed soils* | | | 15 395.78 | | | 15 395.78 |
| *3.C.5 - Indirect $N_2O$ Emissions from managed soils* | | | 4 645.23 | | | 4 645.23 |
| *3.C.6 - Indirect $N_2O$ Emissions from manure management* | | | 360.63 | | | 360.63 |
| 3.D - Other | -927.35 | | | | | -927.35 |
| *3.D.1 - Harvested Wood Products* | -927.35 | | | | | -927.35 |
| **4 - Waste** | | **14 346.76** | **599.76** | | | **14 946.52** |
| 4.A - Solid Waste Disposal | | 11 885.50 | | | | 11 885.50 |
| 4.D - Wastewater Treatment and Discharge | | 2 461.26 | 599.76 | | | 3 061.02 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **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 $CO_2$eq) | | | | | |
|---|---|---|---|---|---|---|
| Categories | Net $CO_2$ | $CH_4$ | $N_2O$ | HFCs | PFCs | Total |
| **Total including FOLU** | **410 820.35** | **50 733.51** | **26 301.34** | **0.00** | **888.40** | **488 743.60** |
| **Total excluding FOLU** | **420 083.03** | **50 358.06** | **26 301.34** | **0.00** | **888.40** | **497 630.82** |
| **1 - Energy** | **385 957.52** | **5 336.79** | **2 312.84** | | | **393 607.16** |
| 1.A - Fuel Combustion Activities | 355 578.75 | 601.60 | 2 312.84 | | | 358 493.19 |
| *1.A.1 - Energy Industries* | 245 486.53 | 64.10 | 1 083.65 | | | 246 634.27 |
| *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 | 238.05 | 487.07 | | | 32 683.05 |
| *1.A.5 - Non-Specified* | 1 041.37 | 1.04 | 2.67 | | | 1 045.08 |
| 1.B - Fugitive emissions from fuels | 30 378.77 | 4 735.20 | | | | 35 113.96 |
| *1.B.1 - Solid Fuels* | 25.43 | 2 141.35 | | | | 2 166.78 |
| *1.B.2 - Oil and Natural Gas* | 1 378.91 | | | | | 1 378.91 |
| *1.B.3 - Other emissions from Energy Production* | 28 974.43 | 2 593.85 | | | | 31 568.28 |
| **2 - Industrial Processes and Product Use** | **33 115.41** | **79.51** | **1 207.03** | | **888.40** | **34 401.95** |
| 2.A - Mineral Industry | 4 433.51 | | | | | 4 433.51 |
| *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* | 95.89 | | | | | 95.89 |
| 2.B - Chemical Industry | 1 140.19 | 74.88 | 1 207.03 | | | 2 422.10 |
| 2.C - Metal Industry | 27 295.53 | 4.63 | | | 888.40 | 27 300.16 |
| *2.C.1 - Iron and Steel Production* | 16 425.25 | | | | | 16 425.25 |
| *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* | 180.60 | | | | | 180.60 |
| 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** | **-7 292.38** | **30 144.14** | **22 174.57** | | | **45 026.32** |
| 3.A - Livestock | | 28 972.91 | 1 066.06 | | | 30 038.97 |
| *3.A.1 - Enteric Fermentation* | | 28 141.07 | | | | 28 141.07 |
| *3.A.2 - Manure Management* | | 831.84 | 1 066.06 | | | 1 897.90 |

| INVENTORY YEAR: 2004 | Emissions/removals (Gg $CO_2$eq) | | | | | |
|---|---|---|---|---|---|---|
| Categories | Net $CO_2$ | $CH_4$ | $N_2O$ | HFCs | PFCs | Total |
| 3.B - Land | -7 117.31 | 375.46 | | | | -6 741.86 |
| *3.B.1 - Forest land* | -21 072.76 | | | | | -21 072.76 |
| *3.B.2 - Cropland* | 4 856.59 | | | | | 4 856.59 |
| *3.B.3 - Grassland* | 7 904.13 | | | | | 7 904.13 |
| *3.B.4 - Wetlands* | | 375.46 | | | | 375.46 |
| *3.B.5 - Settlements* | 1 194.72 | | | | | 1 194.72 |
| *3.B.6 - Other lands* | -960.20 | | | | | -960.20 |
| 3.C - Aggregate sources and non-$CO_2$ emissions sources on land | 1 010.10 | 795.78 | 21 108.50 | | | 22 914.38 |
| *3.C.1 - Emissions from biomass burning* | | 795.78 | 715.19 | | | 1 510.97 |
| *3.C.2 - Liming* | 585.54 | | | | | 585.54 |
| *3.C.3 - Urea application* | 424.56 | | | | | 424.56 |
| *3.C.4 - Direct $N_2O$ Emissions from managed soils* | | | 15 385.86 | | | 15 385.86 |
| *3.C.5 - Indirect $N_2O$ Emissions from managed soils* | | | 4 642.92 | | | 4 642.92 |
| *3.C.6 - Indirect $N_2O$ Emissions from manure management* | | | 364.54 | | | 364.54 |
| 3.D - Other | -1 185.17 | | | | | -1 185.17 |
| *3.D.1 - Harvested Wood Products* | -1 185.17 | | | | | -1 185.17 |
| **4 - Waste** | | **15 173.07** | **606.90** | | | **15 779.97** |
| 4.A - Solid Waste Disposal | | 12 682.51 | | | | 12 682.51 |
| 4.D - Wastewater Treatment and Discharge | | 2 490.56 | 606.90 | | | 3 097.46 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **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 $CO_2$eq) | | | | | |
|---|---|---|---|---|---|---|
| Categories | Net $CO_2$ | $CH_4$ | $N_2O$ | HFCs | PFCs | Total |
| **Total including FOLU** | **405 084.98** | **51 716.57** | **26 971.95** | **841.90** | **871.87** | **485 487.27** |
| **Total excluding FOLU** | **414 229.56** | **51 354.56** | **26 971.95** | **841.90** | **871.87** | **494 269.85** |
| **1 - Energy** | **379 149.49** | **5 139.90** | **2 297.55** | | | **386 586.94** |
| 1.A - Fuel Combustion Activities | 352 498.77 | 595.48 | 2 297.55 | | | 355 391.79 |
| *1.A.1 - Energy Industries* | 241 609.61 | 62.83 | 1 068.47 | | | 242 740.90 |
| *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 | 227.68 | 475.11 | | | 32 811.92 |
| *1.A.5 - Non-Specified* | 1 058.49 | 1.05 | 2.71 | | | 1 062.25 |
| 1.B - Fugitive emissions from fuels | 26 650.73 | 4 544.42 | | | | 31 195.15 |
| *1.B.1 - Solid Fuels* | 25.60 | 2 155.57 | | | | 2 181.17 |
| *1.B.2 - Oil and Natural Gas* | 1 160.14 | | | | | 1 160.14 |
| *1.B.3 - Other emissions from Energy Production* | 25 464.99 | 2 388.85 | | | | 27 853.84 |
| **2 - Industrial Processes and Product Use** | **34 473.06** | **103.56** | **1 971.93** | **841.90** | **871.87** | **38 262.32** |
| 2.A - Mineral Industry | 4 840.16 | | | | | 4 840.16 |
| *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* | 102.36 | | | | | 102.36 |
| 2.B - Chemical Industry | 818.00 | 99.16 | 1 971.93 | | | 2 889.09 |
| 2.C - Metal Industry | 28 347.05 | 4.40 | | | 871.87 | 29 223.32 |
| *2.C.1 - Iron and Steel Production* | 17 359.70 | | | | | 17 359.70 |
| *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* | 178.88 | | | | | 178.88 |
| 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 | | | | 841.90 | | 841.90 |
| **3 - Agriculture, Forestry, and Other Land Use** | **-7 577.38** | **30 496.13** | **22 088.65** | | | **45 007.40** |
| 3.A - Livestock | | 28 866.77 | 1 131.24 | | | 29 998.01 |
| *3.A.1 - Enteric Fermentation* | | 28 024.05 | | | | 28 024.05 |
| *3.A.2 - Manure Management* | | 842.72 | 1 131.24 | | | 1 973.96 |

| INVENTORY YEAR: 2005 | Emissions/removals (Gg $CO_2$eq) | | | | | |
|---|---|---|---|---|---|---|
| Categories | Net $CO_2$ | $CH_4$ | $N_2O$ | HFCs | PFCs | Total |
| 3.B - Land | -7 987.02 | 362.01 | | | | -7 625.01 |
| *3.B.1 - Forest land* | -22 034.70 | | | | | -22 034.70 |
| *3.B.2 - Cropland* | 4 948.84 | | | | | 4 948.84 |
| *3.B.3 - Grassland* | 7 904.13 | | | | | 7 904.13 |
| *3.B.4 - Wetlands* | | 362.01 | | | | 362.01 |
| *3.B.5 - Settlements* | 1 194.72 | | | | | 1 194.72 |
| *3.B.6 - Other lands* | -960.20 | | | | | -960.20 |
| 3.C - Aggregate sources and non-$CO_2$ emissions sources on land | 607.00 | 1 267.35 | 20 957.41 | | | 22 831.77 |
| *3.C.1 - Emissions from biomass burning* | | 1 267.35 | 1 151.93 | | | 2 419.27 |
| *3.C.2 - Liming* | 267.41 | | | | | 267.41 |
| *3.C.3 - Urea application* | 339.60 | | | | | 339.60 |
| *3.C.4 - Direct $N_2O$ Emissions from managed soils* | | | 14 907.37 | | | 14 907.37 |
| *3.C.5 - Indirect $N_2O$ Emissions from managed soils* | | | 4 515.81 | | | 4 515.81 |
| *3.C.6 - Indirect $N_2O$ Emissions from manure management* | | | 382.32 | | | 382.32 |
| 3.D - Other | -197.37 | | | | | -197.37 |
| *3.D.1 - Harvested Wood Products* | -197.37 | | | | | -197.37 |
| **4 - Waste** | | **15 976.98** | **613.83** | | | **16 590.81** |
| 4.A - Solid Waste Disposal | | 13 457.97 | | | | 13 457.97 |
| 4.D - Wastewater Treatment and Discharge | | 2 519.01 | 613.83 | | | 3 132.84 |

| **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 $CO_2$eq) | | | | | |
|---|---|---|---|---|---|---|
| **Categories** | **Net $CO_2$** | **$CH_4$** | **$N_2O$** | **HFCs** | **PFCs** | **Total** |
| **Total including FOLU** | **410 389.31** | **52 064.40** | **27 212.50** | **1 107.58** | **934.55** | **491 708.33** |
| **Total excluding FOLU** | **421 926.95** | **51 715.84** | **27 212.50** | **1 107.58** | **934.55** | **502 897.41** |
| **1 - Energy** | **386 029.62** | **4 943.90** | **2 102.83** | | | **393 076.35** |
| 1.A - Fuel Combustion Activities | 359 486.62 | 465.66 | 2 102.83 | | | 362 055.11 |
| *1.A.1 - Energy Industries* | 243 646.73 | 63.35 | 1 078.55 | | | 244 788.63 |
| *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 | 93.31 | 254.49 | | | 35 422.92 |
| *1.A.5 - Non-Specified* | 1 069.30 | 1.06 | 2.74 | | | 1 073.10 |
| 1.B - Fugitive emissions from fuels | 26 543.00 | 4 478.24 | | | | 31 021.24 |
| *1.B.1 - Solid Fuels* | 25.58 | 2 154.20 | | | | 2 179.78 |
| *1.B.2 - Oil and Natural Gas* | 1 133.24 | | | | | 1 133.24 |
| *1.B.3 - Other emissions from Energy Production* | 25 384.18 | 2 324.04 | | | | 27 708.22 |
| **2 - Industrial Processes and Product Use** | **35 104.85** | **113.30** | **2 038.21** | **1 107.58** | **934.55** | **39 298.49** |
| 2.A - Mineral Industry | 5 193.11 | | | | | 5 193.11 |
| *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* | 101.77 | | | | | 101.77 |
| 2.B - Chemical Industry | 513.21 | 108.40 | 2 038.21 | | | 2 659.82 |
| 2.C - Metal Industry | 28 889.38 | 4.90 | | | 934.55 | 29 828.82 |
| *2.C.1 - Iron and Steel Production* | 17 218.49 | | | | | 17 218.49 |
| *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* | 154.80 | | | | | 154.80 |
| 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 | | | | 1 107.58 | | 1 107.58 |
| **3 - Agriculture, Forestry, and Other Land Use** | **-9 784.97** | **30 246.83** | **22 450.70** | | | **42 912.56** |
| 3.A - Livestock | | 28 761.12 | 1 194.68 | | | 29 955.79 |
| *3.A.1 - Enteric Fermentation* | | 27 928.16 | | | | 27 928.16 |
| *3.A.2 - Manure Management* | | 832.96 | 1 194.68 | | | 2 027.63 |

| INVENTORY YEAR: 2006 | Emissions/removals (Gg $CO_2$eq) | | | | | |
|---|---|---|---|---|---|---|
| **Categories** | **Net $CO_2$** | **$CH_4$** | **$N_2O$** | **HFCs** | **PFCs** | **Total** |
| 3.B - Land | -9 695.62 | 348.56 | | | | -9 347.06 |
| *3.B.1 - Forest land* | -23 840.67 | | | | | -23 840.67 |
| *3.B.2 - Cropland* | 5 046.20 | | | | | 5 046.20 |
| *3.B.3 - Grassland* | 7 904.13 | | | | | 7 904.13 |
| *3.B.4 - Wetlands* | | 348.56 | | | | 348.56 |
| *3.B.5 - Settlements* | 1 194.72 | | | | | 1 194.72 |
| *3.B.6 - Other lands* | -960.20 | | | | | -960.20 |
| 3.C - Aggregate sources and non-$CO_2$ emissions sources on land | 792.48 | 1 137.15 | 21 256.02 | | | 23 185.65 |
| *3.C.1 - Emissions from biomass burning* | | 1 137.15 | 1 006.50 | | | 2 143.65 |
| *3.C.2 - Liming* | 445.96 | | | | | 445.96 |
| *3.C.3 - Urea application* | 346.52 | | | | | 346.52 |
| *3.C.4 - Direct $N_2O$ Emissions from managed soils* | | | 15 213.78 | | | 15 213.78 |
| *3.C.5 - Indirect $N_2O$ Emissions from managed soils* | | | 4 637.90 | | | 4 637.90 |
| *3.C.6 - Indirect $N_2O$ Emissions from manure management* | | | 397.84 | | | 397.84 |
| 3.D - Other | -881.82 | | | | | -881.82 |
| *3.D.1 - Harvested Wood Products* | -881.82 | | | | | -881.82 |
| **4 - Waste** | | **16 760.37** | **620.76** | | | **17 381.13** |
| 4.A - Solid Waste Disposal | | 14 212.91 | 0.00 | | | 14 212.91 |
| 4.D - Wastewater Treatment and Discharge | | 2 547.46 | 620.76 | | | 3 168.22 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **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 $CO_2$eq) | | | | | |
|---|---|---|---|---|---|---|
| **Categories** | **Net $CO_2$** | **$CH_4$** | **$N_2O$** | **HFCs** | **PFCs** | **Total** |
| **Total including FOLU** | **437 042.25** | **52 160.85** | **25 916.69** | **1 077.88** | **970.11** | **517 167.77** |
| **Total excluding FOLU** | **449 545.16** | **51 825.73** | **25 916.69** | **1 077.88** | **970.11** | **529 335.57** |
| **1 - Energy** | **414 451.61** | **5 047.57** | **2 253.89** | | | **421 753.06** |
| 1.A - Fuel Combustion Activities | 387 517.38 | 483.81 | 2 253.89 | | | 390 255.08 |
| *1.A.1 - Energy Industries* | 266 709.01 | 69.29 | 1 184.00 | | | 267 962.29 |
| *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 | 96.03 | 259.70 | | | 36 550.41 |
| *1.A.5 - Non-Specified* | 1 095.70 | 1.09 | 2.81 | | | 1 099.60 |
| 1.B - Fugitive emissions from fuels | 26 934.23 | 4 563.75 | | | | 31 497.98 |
| *1.B.1 - Solid Fuels* | 25.88 | 2 179.14 | | | | 2 205.01 |
| *1.B.2 - Oil and Natural Gas* | 1 132.69 | | | | | 1 132.69 |
| *1.B.3 - Other emissions from Energy Production* | 25 775.66 | 2 384.62 | | | | 28 160.28 |
| **2 - Industrial Processes and Product Use** | **34 108.74** | **152.84** | **1 195.78** | **1 077.88** | **970.11** | **37 505.35** |
| 2.A - Mineral Industry | 5 217.15 | | | | | 5 217.15 |
| *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* | 104.99 | | | | | 104.99 |
| 2.B - Chemical Industry | 581.39 | 148.25 | 1 195.78 | | | 1 925.41 |
| 2.C - Metal Industry | 28 076.12 | 4.60 | | | 970.11 | 29 050.83 |
| *2.C.1 - Iron and Steel Production* | 15 147.10 | | | | | 15 147.10 |
| *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* | 173.72 | | | | | 173.72 |
| 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 | | | | 1 077.88 | | 1 077.88 |
| **3 - Agriculture, Forestry, and Other Land Use** | **-10 557.90** | **29 436.27** | **21 839.42** | | | **40 717.79** |
| 3.A - Livestock | | 28 088.53 | 1 236.93 | | | 29 325.46 |
| *3.A.1 - Enteric Fermentation* | | 27 238.59 | | | | 27 238.59 |
| *3.A.2 - Manure Management* | | 849.94 | 1 236.93 | | | 2 086.87 |

| INVENTORY YEAR: 2007 | Emissions/removals (Gg $CO_2$eq) | | | | | |
|---|---|---|---|---|---|---|
| Categories | Net $CO_2$ | $CH_4$ | $N_2O$ | HFCs | PFCs | Total |
| 3.B - Land | -10 961.33 | 335.11 | | | | -10 626.22 |
| *3.B.1 - Forest land* | -25 206.57 | | | | | -25 206.57 |
| *3.B.2 - Cropland* | 5 146.39 | | | | | 5 146.39 |
| *3.B.3 - Grassland* | 7 904.13 | | | | | 7 904.13 |
| *3.B.4 - Wetlands* | | 335.11 | | | | 335.11 |
| *3.B.5 - Settlements* | 1 194.72 | | | | | 1 194.72 |
| *3.B.6 - Other lands* | -960.20 | | | | | -960.20 |
| 3.C - Aggregate sources and non-$CO_2$ emissions sources on land | 984.81 | 1 012.63 | 20 602.49 | | | 22 599.93 |
| *3.C.1 - Emissions from biomass burning* | | 1 012.63 | 880.03 | | | 1 892.66 |
| *3.C.2 - Liming* | 524.87 | | | | | 524.87 |
| *3.C.3 - Urea application* | 459.94 | | | | | 459.94 |
| *3.C.4 - Direct $N_2O$ Emissions from managed soils* | | | 14 752.90 | | | 14 752.90 |
| *3.C.5 - Indirect $N_2O$ Emissions from managed soils* | | | 4 558.33 | | | 4 558.33 |
| *3.C.6 - Indirect $N_2O$ Emissions from manure management* | | | 411.23 | | | 411.23 |
| 3.D - Other | -581.39 | | | | | -581.39 |
| *3.D.1 - Harvested Wood Products* | -581.39 | | | | | -581.39 |
| **4 - Waste** | | **17 524.16** | **627.60** | | | **18 151.76** |
| 4.A - Solid Waste Disposal | | 14 948.63 | | | | 14 948.63 |
| 4.D - Wastewater Treatment and Discharge | | 2 575.53 | 627.60 | | | 3 203.13 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **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 $CO_2$eq) | | | | | |
|---|---|---|---|---|---|---|
| **Categories** | **Net $CO_2$** | **$CH_4$** | **$N_2O$** | **HFCs** | **PFCs** | **Total** |
| **Total including FOLU** | **433 548.32** | **53 865.09** | **25 761.83** | **1 039.92** | **548.12** | **514 763.28** |
| **Total excluding FOLU** | **439 941.08** | **53 543.42** | **25 761.83** | **1 039.92** | **548.12** | **520 834.37** |
| **1 - Energy** | **406 097.55** | **5 353.88** | **2 246.75** | | | **413 698.19** |
| 1.A - Fuel Combustion Activities | 380 440.80 | 493.07 | 2 246.75 | | | 383 180.63 |
| *1.A.1 - Energy Industries* | 255 965.96 | 66.85 | 1 132.84 | | | 257 165.65 |
| *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 | 119.15 | 309.36 | | | 38 619.42 |
| *1.A.5 - Non-Specified* | 1 049.34 | 1.04 | 2.69 | | | 1 053.07 |
| 1.B - Fugitive emissions from fuels | 25 656.75 | 4 860.81 | | | | 30 517.56 |
| *1.B.1 - Solid Fuels* | 26.35 | 2 219.14 | | | | 2 245.50 |
| *1.B.2 - Oil and Natural Gas* | 1 138.17 | | | | | 1 138.17 |
| *1.B.3 - Other emissions from Energy Production* | 24 492.23 | 2 641.67 | | | | 27 133.90 |
| **2 - Industrial Processes and Product Use** | **32 738.93** | **78.38** | **529.63** | **1 039.92** | **548.12** | **34 934.98** |
| 2.A - Mineral Industry | 5 110.84 | | | | | 5 110.84 |
| *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* | 117.37 | | | | | 117.37 |
| 2.B - Chemical Industry | 574.34 | 73.85 | 529.63 | | | 1 177.83 |
| 2.C - Metal Industry | 26 832.68 | 4.52 | | | 548.12 | 27 385.32 |
| *2.C.1 - Iron and Steel Production* | 14 152.03 | | | | | 14 152.03 |
| *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* | 141.04 | | | | | 141.04 |
| 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 | | | | 1 039.92 | | 1 039.92 |
| **3 - Agriculture, Forestry, and Other Land Use** | **-4 327.97** | **30 162.73** | **22 350.87** | | | **48 185.63** |
| 3.A - Livestock | | 28 742.71 | 1 226.33 | | | 29 969.04 |
| *3.A.1 - Enteric Fermentation* | | 27 878.12 | | | | 27 878.12 |
| *3.A.2 - Manure Management* | | 864.59 | 1 226.33 | | | 2 090.92 |

| **INVENTORY YEAR: 2008** | **Emissions/removals** (Gg $CO_2$eq) | | | | | |
|---|---|---|---|---|---|---|
| **Categories** | **Net $CO_2$** | **$CH_4$** | **$N_2O$** | **HFCs** | **PFCs** | **Total** |
| 3.B - Land | -4 651.82 | 321.66 | | | | -4 330.15 |
| *3.B.1 - Forest land* | -18 988.89 | | | | | -18 988.89 |
| *3.B.2 - Cropland* | 5 238.22 | | | | | 5 238.22 |
| *3.B.3 - Grassland* | 7 904.13 | | | | | 7 904.13 |
| *3.B.4 - Wetlands* | | 321.66 | | | | 321.66 |
| *3.B.5 - Settlements* | 1 194.72 | | | | | 1 194.72 |
| *3.B.6 - Other lands* | -960.20 | | | | | -960.20 |
| 3.C - Aggregate sources and non-$CO_2$ emissions sources on land | 1 104.59 | 1 098.35 | 21 124.55 | | | 23 327.49 |
| *3.C.1 - Emissions from biomass burning* | | 1 098.35 | 966.71 | | | 2 065.06 |
| *3.C.2 - Liming* | 658.92 | | | | | 658.92 |
| *3.C.3 - Urea application* | 445.67 | | | | | 445.67 |
| *3.C.4 - Direct $N_2O$ Emissions from managed soils* | | | 15 119.24 | | | 15 119.24 |
| *3.C.5 - Indirect $N_2O$ Emissions from managed soils* | | | 4 628.28 | | | 4 628.28 |
| *3.C.6 - Indirect $N_2O$ Emissions from manure management* | | | 410.32 | | | 410.32 |
| 3.D - Other | -780.75 | | | | | -780.75 |
| *3.D.1 - Harvested Wood Products* | -780.75 | | | | | -780.75 |
| **4 - Waste** | | **18 270.10** | **634.57** | | | **18 904.67** |
| 4.A - Solid Waste Disposal | | 15 665.97 | | | | 15 665.97 |
| 4.D - Wastewater Treatment and Discharge | | 2 604.14 | 634.57 | | | 3 238.71 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **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 $CO_2$eq) | | | | | |
|---|---|---|---|---|---|---|
| **Categories** | **Net $CO_2$** | **$CH_4$** | **$N_2O$** | **HFCs** | **PFCs** | **Total** |
| **Total including FOLU** | **433 118.33** | **53 880.13** | **25 406.94** | **995.54** | **108.25** | **513 509.19** |
| **Total excluding FOLU** | **446 550.77** | **53 571.92** | **25 406.94** | **995.54** | **108.25** | **526 633.42** |
| **1 - Energy** | **414 213.63** | **5 333.58** | **2 286.63** | | | **421 833.84** |
| 1.A - Fuel Combustion Activities | 388 137.62 | 500.51 | 2 286.63 | | | 390 924.76 |
| *1.A.1 - Energy Industries* | 262 391.52 | 68.57 | 1 163.21 | | | 263 623.30 |
| *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 | 119.23 | 320.12 | | | 41 395.66 |
| *1.A.5 - Non-Specified* | 1 072.49 | 1.07 | 2.75 | | | 1 076.30 |
| 1.B - Fugitive emissions from fuels | 26 076.01 | 4 833.07 | | | | 30 909.08 |
| *1.B.1 - Solid Fuels* | 26.18 | 2 204.26 | | | | 2 230.44 |
| *1.B.2 - Oil and Natural Gas* | 1 243.38 | | | | | 1 243.38 |
| *1.B.3 - Other emissions from Energy Production* | 24 806.46 | 2 628.81 | | | | 27 435.26 |
| **2 - Industrial Processes and Product Use** | **31 353.12** | **56.58** | **512.02** | **995.54** | **108.25** | **33 025.51** |
| 2.A - Mineral Industry | 5 161.29 | | | | | 5 161.29 |
| *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* | 109.77 | | | | | 109.77 |
| 2.B - Chemical Industry | 483.76 | 52.97 | 512.02 | | | 1 048.75 |
| 2.C - Metal Industry | 25 474.31 | 3.60 | | | 108.25 | 25 586.17 |
| *2.C.1 - Iron and Steel Production* | 12 794.45 | | | | | 12 794.45 |
| *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* | 147.92 | | | | | 147.92 |
| 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 | | | | 995.54 | | 995.54 |
| **3 - Agriculture, Forestry, and Other Land Use** | **-11 488.23** | **29 492.44** | **21 966.87** | | | **39 971.08** |
| 3.A - Livestock | | 28 174.26 | 1 237.97 | | | 29 412.23 |
| *3.A.1 - Enteric Fermentation* | | 27 304.98 | | | | 27 304.98 |
| *3.A.2 - Manure Management* | | 869.28 | 1 237.97 | | | 2 107.25 |

| INVENTORY YEAR: 2009 | Emissions/removals (Gg $CO_2$eq) | | | | | |
|---|---|---|---|---|---|---|
| **Categories** | **Net $CO_2$** | **$CH_4$** | **$N_2O$** | **HFCs** | **PFCs** | **Total** |
| 3.B - Land | -12 373.92 | 308.22 | | | | -12 065.71 |
| *3.B.1 - Forest land* | -26 788.44 | | | | | -26 788.44 |
| *3.B.2 - Cropland* | 5 315.67 | | | | | 5 315.67 |
| *3.B.3 - Grassland* | 7 904.13 | | | | | 7 904.13 |
| *3.B.4 - Wetlands* | | 308.22 | | | | 308.22 |
| *3.B.5 - Settlements* | 1 194.72 | | | | | 1 194.72 |
| *3.B.6 - Other lands* | -960.20 | | | | | -960.20 |
| 3.C - Aggregate sources and non-$CO_2$ emissions sources on land | 984.02 | 1 009.96 | 20 728.90 | | | 22 722.87 |
| *3.C.1 - Emissions from biomass burning* | | 1 009.96 | 868.73 | | | 1 878.69 |
| *3.C.2 - Liming* | 616.23 | | | | | 616.23 |
| *3.C.3 - Urea application* | 367.79 | | | | | 367.79 |
| *3.C.4 - Direct $N_2O$ Emissions from managed soils* | | | 14 860.12 | | | 14 860.12 |
| *3.C.5 - Indirect $N_2O$ Emissions from managed soils* | | | 4 587.21 | | | 4 587.21 |
| *3.C.6 - Indirect $N_2O$ Emissions from manure management* | | | 412.83 | | | 412.83 |
| 3.D - Other | -98.32 | | | | | -98.32 |
| *3.D.1 - Harvested Wood Products* | -98.32 | | | | | -98.32 |
| **4 - Waste** | | **18 997.54** | **641.43** | | | **19 638.96** |
| 4.A - Solid Waste Disposal | | 16 365.27 | | | | 16 365.27 |
| 4.D - Wastewater Treatment and Discharge | | 2 632.26 | 641.43 | | | 3 273.69 |

| **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 $CO_2$eq) | | | | | |
|---|---|---|---|---|---|---|
| **Categories** | **Net $CO_2$** | **$CH_4$** | **$N_2O$** | **HFCs** | **PFCs** | **Total** |
| **Total including FOLU** | **445 646.53** | **55 651.24** | **25 858.89** | **2 096.25** | **138.26** | **529 391.16** |
| **Total excluding FOLU** | **461 307.91** | **55 356.47** | **25 858.89** | **2 096.25** | **138.26** | **544 757.78** |
| **1 - Energy** | **427 401.95** | **5 354.59** | **2 360.68** | | | **435 117.22** |
| 1.A - Fuel Combustion Activities | 401 990.65 | 516.32 | 2 360.68 | | | 404 867.65 |
| *1.A.1 - Energy Industries* | 268 617.11 | 69.83 | 1 193.45 | | | 269 880.40 |
| *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 | 115.51 | 325.07 | | | 45 124.41 |
| *1.A.5 - Non-Specified* | 1 134.86 | 1.13 | 2.91 | | | 1 138.90 |
| 1.B - Fugitive emissions from fuels | 25 411.29 | 4 838.27 | | | | 30 249.57 |
| *1.B.1 - Solid Fuels* | 26.59 | 2 239.46 | | | | 2 266.05 |
| *1.B.2 - Oil and Natural Gas* | 964.25 | | | | | 964.25 |
| *1.B.3 - Other emissions from Energy Production* | 24 420.45 | 2 598.82 | | | | 27 019.27 |
| **2 - Industrial Processes and Product Use** | **32 835.90** | **67.13** | **325.54** | **2 096.25** | **138.26** | **35 463.07** |
| 2.A - Mineral Industry | 4 792.86 | | | | | 4 792.86 |
| *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* | 103.88 | | | | | 103.88 |
| 2.B - Chemical Industry | 622.89 | 62.88 | 325.54 | | | 1 011.31 |
| 2.C - Metal Industry | 27 186.27 | 4.24 | | | 138.26 | 27 328.78 |
| *2.C.1 - Iron and Steel Production* | 13 861.71 | | | | | 13 861.71 |
| *2.C.2 - Ferroalloys Production* | 11 822.05 | 4.24 | | | | 11 826.29 |
| *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* | 146.20 | | | | | 146.20 |
| 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 | | | | 2 096.25 | | 2 096.25 |
| **3 - Agriculture, Forestry, and Other Land Use** | **-13 631.13** | **30 523.72** | **22 524.09** | | | **39 416.68** |
| 3.A - Livestock | | 28 996.25 | 1 249.22 | | | 30 245.47 |
| *3.A.1 - Enteric Fermentation* | | 28 132.82 | | | | 28 132.82 |
| *3.A.2 - Manure Management* | | 863.44 | 1 249.22 | | | 2 112.65 |

| INVENTORY YEAR: 2010 | Emissions/removals (Gg $CO_2$eq) | | | | | |
|---|---|---|---|---|---|---|
| **Categories** | **Net $CO_2$** | **$CH_4$** | **$N_2O$** | **HFCs** | **PFCs** | **Total** |
| 3.B - Land | -14 210.93 | 294.77 | | | | -13 916.16 |
| *3.B.1 - Forest land* | -28 732.32 | | | | | -28 732.32 |
| *3.B.2 - Cropland* | 5 422.53 | | | | | 5 422.53 |
| *3.B.3 - Grassland* | 7 904.13 | | | | | 7 904.13 |
| *3.B.4 - Wetlands* | | 294.77 | | | | 294.77 |
| *3.B.5 - Settlements* | 1 194.72 | | | | | 1 194.72 |
| *3.B.6 - Other lands* | -960.20 | | | | | -960.20 |
| 3.C - Aggregate sources and non-$CO_2$ emissions sources on land | 1 070.06 | 1 232.70 | 21 274.88 | | | 23 577.63 |
| *3.C.1 - Emissions from biomass burning* | | 1 232.70 | 1 085.11 | | | 2 317.81 |
| *3.C.2 - Liming* | 585.54 | | | | | 585.54 |
| *3.C.3 - Urea application* | 484.52 | | | | | 484.52 |
| *3.C.4 - Direct $N_2O$ Emissions from managed soils* | | | 15 162.46 | | | 15 162.46 |
| *3.C.5 - Indirect $N_2O$ Emissions from managed soils* | | | 4 612.45 | | | 4 612.45 |
| *3.C.6 - Indirect $N_2O$ Emissions from manure management* | | | 414.85 | | | 414.85 |
| 3.D - Other | -490.26 | | | | | -490.26 |
| *3.D.1 - Harvested Wood Products* | -490.26 | | | | | -490.26 |
| **4 - Waste** | | **19 705.80** | **648.58** | | | **20 354.38** |
| 4.A - Solid Waste Disposal | | 17 044.19 | | | | 17 044.19 |
| 4.D - Wastewater Treatment and Discharge | | 2 661.62 | 648.58 | | | 3 310.20 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **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*** | | | | | | |

| INVENTORY YEAR: 2011 | Emissions/removals (Gg $CO_2$eq) | | | | | |
|---|---|---|---|---|---|---|
| **Categories** | **Net $CO_2$** | **$CH_4$** | **$N_2O$** | **HFCs** | **PFCs** | **Total** |
| **Total including FOLU** | **426 660.77** | **57 071.31** | **26 364.51** | **1 749.86** | **2 410.85** | **514 257.30** |
| **Total excluding FOLU** | **442 653.44** | **56 789.99** | **26 364.51** | **1 749.86** | **2 410.85** | **529 968.65** |
| **1 - Energy** | **407 525.47** | **6 053.19** | **2 263.95** | | | **415 842.61** |
| 1.A - Fuel Combustion Activities | 382 461.72 | 508.85 | 2 263.95 | | | 385 234.52 |
| *1.A.1 - Energy Industries* | 266 586.27 | 69.36 | 1 184.67 | | | 267 840.30 |
| *1.A.2 - Manufacturing Industries and Construction* | 28 289.72 | 8.54 | 114.31 | | | 28 412.56 |
| *1.A.3 - Transport* | 47 293.87 | 318.80 | 669.94 | | | 48 282.61 |
| *1.A.4 - Other Sectors* | 39 157.78 | 111.02 | 292.12 | | | 39 560.92 |
| *1.A.5 - Non-Specified* | 1 134.09 | 1.13 | 2.91 | | | 1 138.13 |
| 1.B - Fugitive emissions from fuels | 25 063.75 | 5 544.34 | | | | 30 608.09 |
| *1.B.1 - Solid Fuels* | 35.05 | 2 951.32 | | | | 2 986.37 |
| *1.B.2 - Oil and Natural Gas* | 785.76 | | | | | 785.76 |
| *1.B.3 - Other emissions from Energy Production* | 24 242.94 | 2 593.02 | | | | 26 835.96 |
| **2 - Industrial Processes and Product Use** | **33 991.31** | **92.45** | **643.36** | **1 749.86** | **2 410.85** | **38 887.83** |
| 2.A - Mineral Industry | 4 512.70 | | | | | 4 512.70 |
| *2.A.1 - Cement production* | 3 849.20 | | | | | 3 849.20 |
| *2.A.2 - Lime production* | 557.45 | | | | | 557.45 |
| *2.A.3 - Glass Production* | 106.05 | | | | | 106.05 |
| 2.B - Chemical Industry | 671.58 | 87.93 | 643.36 | | | 1 402.87 |
| 2.C - Metal Industry | 28 610.64 | 4.52 | | | 2 410.85 | 31 026.01 |
| *2.C.1 - Iron and Steel Production* | 14 922.65 | | | | | 14 922.65 |
| *2.C.2 - Ferroalloys Production* | 12 236.33 | 4.52 | | | | 12 240.85 |
| *2.C.3 - Aluminium production* | 1 299.50 | | | | 2 410.85 | 3 710.35 |
| *2.C.4 - Magnesium production* | | | | | | 0.00 |
| *2.C.5 - Lead Production* | 28.32 | | | | | 28.32 |
| *2.C.6 - Zinc Production* | 123.84 | | | | | 123.84 |
| 2.D - Non-Energy Products from Fuels and Solvent Use | 196.39 | | | | | 268.00 |
| *2.D.1 - Lubricant Use* | 192.57 | | | | | 250.58 |
| *2.D.2 - Paraffin Wax Use* | 3.81 | | | | | 17.42 |
| 2.F - Product Uses as Substitutes for ODS | | | | 1 749.86 | | 1 749.86 |
| **3 - Agriculture, Forestry, and Other Land Use** | **-14 856.01** | **30 447.92** | **22 783.90** | | | **38 375.81** |
| 3.A - Livestock | | 29 024.32 | 1 324.46 | | | 30 348.78 |
| *3.A.1 - Enteric Fermentation* | | 28 168.96 | | | | 28 168.96 |
| *3.A.2 - Manure Management* | | 855.35 | 1 324.46 | | | 2 179.82 |

| INVENTORY YEAR: 2011 | Emissions/removals (Gg $CO_2$eq) | | | | | |
|---|---|---|---|---|---|---|
| Categories | Net $CO_2$ | $CH_4$ | $N_2O$ | HFCs | PFCs | Total |
| 3.B - Land | -16 074.59 | 281.32 | | | | -15 793.26 |
| *3.B.1 - Forest land* | -29 731.24 | | | | | -29 731.24 |
| *3.B.2 - Cropland* | 5 518.00 | | | | | 5 518.00 |
| *3.B.3 - Grassland* | 7 904.13 | | | | | 7 904.13 |
| *3.B.4 - Wetlands* | | 281.32 | | | | 281.32 |
| *3.B.5 - Settlements* | 1 194.72 | | | | | 1 194.72 |
| *3.B.6 - Other lands* | -960.20 | | | | | -960.20 |
| 3.C - Aggregate sources and non-$CO_2$ emissions sources on land | 1 136.66 | 1 142.29 | 21 459.44 | | | 23 738.38 |
| *3.C.1 - Emissions from biomass burning* | | 1 142.29 | 1 003.12 | | | 2 145.41 |
| *3.C.2 - Liming* | 585.54 | | | | | 585.54 |
| *3.C.3 - Urea application* | 551.12 | | | | | 551.12 |
| *3.C.4 - Direct $N_2O$ Emissions from managed soils* | | | 15 349.19 | | | 15 349.19 |
| *3.C.5 - Indirect $N_2O$ Emissions from managed soils* | | | 4 678.35 | | | 4 678.35 |
| *3.C.6 - Indirect $N_2O$ Emissions from manure management* | | | 428.77 | | | 428.77 |
| 3.D - Other | 81.91 | | | | | 81.91 |
| *3.D.1 - Harvested Wood Products* | 81.91 | | | | | 81.91 |
| **4 - Waste** | | **20 477.74** | **673.30** | | | **21 151.04** |
| 4.A - Solid Waste Disposal | | 17 714.67 | | | | 17 714.67 |
| 4.D - Wastewater Treatment and Discharge | | 2 763.07 | 673.30 | | | 3 436.38 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Memo Items (5)** | | | | | | |
| **International Bunkers** | **2 481.84** | **2.40** | **6.16** | | | **2 490.40** |
| *1.A.3.a.i - International Aviation (International Bunkers)* | 2 481.84 | 2.40 | 6.16 | | | 2 490.40 |
| *1.A.3.d.i - International water-borne navigation (International bunkers)* | | | | | | |
| ***1.A.5.c - Multilateral Operations*** | | | | | | |

| INVENTORY YEAR: 2012 | Emissions/removals (Gg $CO_2$eq) | | | | | |
|---|---|---|---|---|---|---|
| Categories | Net $CO_2$ | $CH_4$ | $N_2O$ | HFCs | PFCs | Total |
| **Total including FOLU** | **433 839.25** | **55 436.76** | **25 645.87** | **1 396.12** | **1 979.19** | **518 297.18** |
| **Total excluding FOLU** | **454 921.51** | **55 168.88** | **25 645.87** | **1 396.12** | **1 979.19** | **539 111.58** |
| **1 - Energy** | **420 846.23** | **4 923.31** | **2 342.21** | | | **428 111.75** |
| 1.A - Fuel Combustion Activities | 395 047.32 | 499.97 | 2 342.21 | | | 397 889.49 |
| *1.A.1 - Energy Industries* | 277 964.06 | 70.39 | 1 267.98 | | | 279 302.43 |
| *1.A.2 - Manufacturing Industries and Construction* | 29 084.19 | 8.78 | 119.11 | | | 29 212.08 |
| *1.A.3 - Transport* | 46 713.90 | 312.66 | 663.06 | | | 47 689.62 |
| *1.A.4 - Other Sectors* | 40 174.62 | 107.05 | 289.22 | | | 40 570.89 |
| *1.A.5 - Non-Specified* | 1 110.53 | 1.11 | 2.85 | | | 1 114.48 |
| 1.B - Fugitive emissions from fuels | 25 798.91 | 4 423.34 | | | | 30 222.25 |
| *1.B.1 - Solid Fuels* | 20.65 | 1 739.17 | | | | 1 759.83 |
| *1.B.2 - Oil and Natural Gas* | 641.83 | | | | | 641.83 |
| *1.B.3 - Other emissions from Energy Production* | 25 136.44 | 2 684.17 | | | | 27 820.60 |
| **2 - Industrial Processes and Product Use** | **32 934.73** | **73.55** | **745.00** | **1 396.12** | **1 979.19** | **37 128.59** |
| 2.A - Mineral Industry | 4 411.50 | | | | | 4 411.50 |
| *2.A.1 - Cement production* | 3 844.50 | | | | | 3 844.50 |
| *2.A.2 - Lime production* | 453.09 | | | | | 453.09 |
| *2.A.3 - Glass Production* | 113.91 | | | | | 113.91 |
| 2.B - Chemical Industry | 516.54 | 70.18 | 745.00 | 0.00 | 0.00 | 1 331.71 |
| 2.C - Metal Industry | 27 738.70 | 3.37 | | | 1 979.19 | 29 721.26 |
| *2.C.1 - Iron and Steel Production* | 15 020.70 | | | | | 15 020.70 |
| *2.C.2 - Ferroalloys Production* | 11 623.80 | 3.37 | 0.00 | 0.00 | 0.00 | 11 627.18 |
| *2.C.3 - Aluminium production* | 1 066.90 | | | | 1 979.19 | 3 046.09 |
| *2.C.4 - Magnesium production* | | | | | | |
| *2.C.5 - Lead Production* | 27.29 | | | | | 27.29 |
| *2.C.6 - Zinc Production* | | | | | | |
| 2.D - Non-Energy Products from Fuels and Solvent Use | 268.00 | | | | | 268.00 |
| *2.D.1 - Lubricant Use* | 250.58 | | | | | 250.58 |
| *2.D.2 - Paraffin Wax Use* | 17.42 | | | | | 17.42 |
| 2.F - Product Uses as Substitutes for ODS | | | | 1 396.12 | | 1 396.12 |
| **3 - Agriculture, Forestry, and Other Land Use** | **-19 941.72** | **29 200.23** | **21 869.61** | | | **31 128.13** |
| 3.A - Livestock | | 28 050.11 | 1 362.80 | | | 29 412.91 |
| *3.A.1 - Enteric Fermentation* | | 27 198.21 | | | | 27 198.21 |
| *3.A.2 - Manure Management* | | 851.91 | 1 362.80 | | | 2 214.70 |

| INVENTORY YEAR: 2012 | Emissions/removals (Gg $CO_2$eq) | | | | | |
|---|---|---|---|---|---|---|
| Categories | Net $CO_2$ | $CH_4$ | $N_2O$ | HFCs | PFCs | Total |
| 3.B - Land | -20 570.44 | 267.87 | | | | -20 302.57 |
| *3.B.1 - Forest land* | -34 325.17 | | | | | -34 325.17 |
| *3.B.2 - Cropland* | 5 616.07 | | | | | 5 616.07 |
| *3.B.3 - Grassland* | 7 904.13 | | | | | 7 904.13 |
| *3.B.4 - Wetlands* | | 267.87 | | | | 267.87 |
| *3.B.5 - Settlements* | 1 194.72 | | | | | 1 194.72 |
| *3.B.6 - Other lands* | -960.20 | | | | | -960.20 |
| 3.C - Aggregate sources and non-$CO_2$ emissions sources on land | 1 140.55 | 882.25 | 20 506.82 | | | 22 529.61 |
| *3.C.1 - Emissions from biomass burning* | | 882.25 | 809.56 | | | 1 691.81 |
| *3.C.2 - Liming* | 585.54 | | | | | 585.54 |
| *3.C.3 - Urea application* | 555.01 | | | | | 555.01 |
| *3.C.4 - Direct $N_2O$ Emissions from managed soils* | | | 14 701.80 | | | 14 701.80 |
| *3.C.5 - Indirect $N_2O$ Emissions from managed soils* | | | 4 558.59 | | | 4 558.59 |
| *3.C.6 - Indirect $N_2O$ Emissions from manure management* | | | 436.87 | | | 436.87 |
| 3.D - Other | -511.83 | | | | | -511.83 |
| *3.D.1 - Harvested Wood Products* | -511.83 | | | | | -511.83 |
| **4 - Waste** | | **21 239.67** | **689.05** | | | **21 928.72** |
| 4.A - Solid Waste Disposal | | 18 411.96 | | | | 18 411.96 |
| 4.D - Wastewater Treatment and Discharge | | 2 827.71 | 689.05 | | | 3 516.76 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Memo Items (5)** | | | | | | |
| **International Bunkers** | **2 413.48** | **2.33** | **5.99** | | | **2 421.81** |
| *1.A.3.a.i - International Aviation (International Bunkers)* | 2 413.48 | 2.33 | 5.99 | | | 2 421.81 |
| *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 Assess-ment (%) | Cumula-tive total (%) |
|---|---|---|---|---|---|
| 1.A.1,a | Energy Industries - Solid Fuels - Main activity electricity and heat production | $CO_2$ | 185027.4 | 41.3 | 41.3 |
| 1.A.3.b | Transport - Liquid Fuels - Road Transportation | $CO_2$ | 32623.3 | 7.3 | 48.6 |
| 1.A.1.c | Energy Industries - Liquid Fuels - Manufacture of solid fuels and other energy industries | $CO_2$ | 30454.7 | 6.8 | 55.4 |
| 1.A.2 | Manufacturing Industries and Construction - Solid Fuels | $CO_2$ | 29101.6 | 6.5 | 61.9 |
| 3.A.1.a | Enteric Fermentation - Cattle | $CH_4$ | 22819.4 | 5.1 | 67.0 |
| 2.C.1 | Metal industry - Iron and Steel Production | $CO_2$ | 16410.5 | 3.7 | 70.7 |
| 3.B.1.b | Forest land - Land Converted to Forest land | $CO_2$ | -15339.9 | 3.4 | 74.1 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - Urine and dung N deposits in PRP | $N_2O$ | 13180.8 | 2.9 | 77.0 |
| 4.A | Solid Waste Disposal | $CH_4$ | 9367.6 | 2.1 | 79.1 |
| 2.C.2 | Metal industry - Ferroalloys Production | $CO_2$ | 8079.1 | 1.8 | 80.9 |
| 3.B.3.b | Grassland - Land Converted to Grassland | $CO_2$ | 7904.1 | 1.8 | 82.7 |
| 1.A.4.a | Other Sectors - Liquid Fuels - Commercial/Institutional | $CO_2$ | 7690.4 | 1.7 | 84.4 |
| 3.B.1.a | Forest land - Forest land Remaining Forest land | $CO_2$ | -6225.2 | 1.4 | 85.8 |
| 3.B.2.b | Cropland - Land Converted to Cropland | $CO_2$ | 5721.7 | 1.3 | 87.1 |
| 3.A.1.c | Enteric Fermentation - Sheep | $CH_4$ | 4169.0 | 0.9 | 88.0 |
| 1.A.4.b | Other Sectors - Solid Fuels - Residential | $CO_2$ | 3604.2 | 0.8 | 88.8 |
| 2.A.1 | Mineral industry - Cement production | $CO_2$ | 3347.1 | 0.7 | 89.5 |
| 1.A.1.b | Energy Industries - Liquid Fuels - Petroleum refining | $CO_2$ | 3164.8 | 0.7 | 90.3 |
| 1.A.4.b | Other Sectors - Liquid Fuels - Residential | $CO_2$ | 2868.9 | 0.6 | 90.9 |
| 3.C.5 | Indirect $N_2O$ Emissions from managed soils - N leaching/runoff | $N_2O$ | 2479.0 | 0.6 | 91.4 |
| 4.D.1 | Wastewater Treatment and Discharge - Domestic | $CH_4$ | 2348.3 | 0.5 | 92.0 |
| 1.A.2 | Manufacturing Industries and Construction - Gaseous Fuels | $CO_2$ | 2217.7 | 0.5 | 92.5 |
| 1.A.4.c | Other Sectors - Liquid Fuels - Agriculture/Forestry/ Fishing/Fish farms | $CO_2$ | 2207.2 | 0.5 | 93.0 |

| IPCC Category code | IPCC Category | GHG | 2000 (Gg $CO_2$ eq) | Level Assessment (%) | Cumulative total (%) |
|---|---|---|---|---|---|
| 1.A.3.a | Transport - Liquid Fuels - Civil Aviation | $CO_2$ | 2040.0 | 0.5 | 93.4 |
| 3.C.5 | Indirect $N_2O$ Emissions from managed soils - N volatilization | $N_2O$ | 1939.5 | 0.4 | 93.8 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - Inorganic N application | $N_2O$ | 1934.7 | 0.4 | 94.3 |
| 1.A.4.a | Other Sectors - Solid Fuels - Commercial/Institutional | $CO_2$ | 1811.2 | 0.4 | 94.7 |
| 2.B | Chemical industry - Industry F | $N_2O$ | C[a] | 0.4 | 95.0 |
| 3.B.2.a | Cropland - Cropland Remaining Cropland | $CO_2$ | -1241.6 | 0.3 | 95.3 |
| 3.B.5.b | Settlements - Land Converted to Settlements | $CO_2$ | 1191.0 | 0.3 | 95.6 |
| 1.A.2 | Manufacturing Industries and Construction - Liquid Fuels | $CO_2$ | 1186.1 | 0.3 | 95.8 |
| 3.A.1.j | Enteric Fermentation - Other | $CH_4$ | 1106.7 | 0.2 | 96.1 |
| 2.C.3 | Metal industry - Aluminium production | $CO_2$ | 1105.5 | 0.2 | 96.3 |
| 3.A.1.d | Enteric Fermentation - Goats | $CH_4$ | 993.6 | 0.2 | 96.6 |
| 1.A.5.a | Non-Specified - Liquid Fuels - Stationary | $CO_2$ | 985.6 | 0.2 | 96.8 |
| 2.C.3 | Metal industry - Aluminium production | PFCs | 982.2 | 0.2 | 97.0 |
| 3.B.6.b | Other land - Land Converted to Other land | $CO_2$ | -960.2 | 0.2 | 97.2 |
| 1.A.1,a | Energy Industries - Solid Fuels - Main activity electricity and heat production | $N_2O$ | 853.5 | 0.2 | 97.4 |
| 3.A.2.i | Manure management - Poultry | $N_2O$ | 642.6 | 0.1 | 97.5 |
| 3.C.1.c | Emissions from biomass burning - Grasslands | $N_2O$ | 637.5 | 0.1 | 97.7 |
| 3.A.2.h | Manure management - Swine | $CH_4$ | 612.1 | 0.1 | 97.8 |
| 4.D.1 | Wastewater Treatment and Discharge - Domestic | $N_2O$ | 572.2 | 0.1 | 98.0 |
| 1.A.3.c | Transport - Liquid Fuels - Railways | $CO_2$ | 551.5 | 0.1 | 98.1 |
| 3.C.1.c | Emissions from biomass burning - Grasslands | $CH_4$ | 542.5 | 0.1 | 98.2 |
| 2.B | Chemical industry - Industry X | $CO_2$ | C[a] | 0.1 | 98.3 |
| 1.A.3.b | Transport - Liquid Fuels - Road Transportation | $N_2O$ | 463.0 | 0.1 | 98.4 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - Organic N application | $N_2O$ | 441.3 | 0.1 | 98.5 |
| 2.B | Chemical industry - Industry K | $CO_2$ | C[a] | 0.1 | 98.6 |

| IPCC Category code | IPCC Category | GHG | 2000 (Gg $CO_2$ eq) | Level Assess-ment (%) | Cumula-tive total (%) |
|---|---|---|---|---|---|
| 3.B.4.a. | Wetlands - Flooded land remaining flooded land | $CH_4$ | 429.2 | 0.1 | 98.7 |
| 2.A.2 | Mineral industry - Lime production | $CO_2$ | 426.4 | 0.1 | 98.8 |
| 3.C.2 | Liming | $CO_2$ | 384.1 | 0.1 | 98.9 |
| 1.A.4.b | Other Sectors - Biomass - Residential | $N_2O$ | 380.9 | 0.1 | 99.0 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - N in crop residues | $N_2O$ | 352.8 | 0.1 | 99.0 |
| 3.C.6 | Indirect $N_2O$ Emissions from manure management | $N_2O$ | 350.0 | 0.1 | 99.1 |
| 3.D.1 | Harvested Wood Products | $CO_2$ | -312.2 | 0.1 | 99.2 |
| 3.A.2.a | Manure management - Cattle | $N_2O$ | 301.0 | 0.1 | 99.3 |
| 1.A.3.b | Transport - Liquid Fuels - Road Transportation | $CH_4$ | 267.6 | 0.1 | 99.3 |
| 3.C.1.b | Emissions from biomass burning - Croplands | $CH_4$ | 244.2 | 0.1 | 99.4 |
| 1.A.4.b | Other Sectors - Biomass - Residential | $CH_4$ | 222.0 | 0.0 | 99.4 |
| 3.C.3 | Urea application | $CO_2$ | 211.5 | 0.0 | 99.5 |
| 2.C.6 | Metal industry - Zinc Production | $CO_2$ | 194.4 | 0.0 | 99.5 |
| 2.D.1 | Non-Energy Products from Fuels and Solvent Use - Lubricant use | $CO_2$ | 188.5 | 0.0 | 99.6 |
| 3.A.2.a | Manure management - Cattle | $CH_4$ | 182.6 | 0.0 | 99.6 |
| 1.A.4.c | Other Sectors - Solid Fuels - Agriculture/Forestry/ Fishing/Fish farms | $CO_2$ | 171.5 | 0.0 | 99.6 |
| 3.C.1.a | Emissions from biomass burning - Forest lands | $CH_4$ | 164.6 | 0.0 | 99.7 |
| 3.C.1.a | Emissions from biomass burning - Forest lands | $N_2O$ | 151.1 | 0.0 | 99.7 |
| 2.B | Chemical industry - Industry Q | $CO_2$ | C[a] | 0.0 | 99.7 |
| 1.A.2 | Manufacturing Industries and Construction - Solid Fuels | $N_2O$ | 134.2 | 0.0 | 99.8 |
| 3.A.1.f | Enteric Fermentation - Horses | $CH_4$ | 111.8 | 0.0 | 99.8 |
| 1.A.1.c | Energy Industries - Liquid Fuels - Manufacture of solid fuels and other energy industries | $N_2O$ | 105.4 | 0.0 | 99.8 |
| 3.C.1.b | Emissions from biomass burning - Croplands | $N_2O$ | 81.5 | 0.0 | 99.8 |
| 2.A.3 | Mineral industry - Glass Production | $CO_2$ | 74.4 | 0.0 | 99.9 |
| 2.B | Chemical industry - Industry X | $CH_4$ | C[a] | 0.0 | 99.9 |
| 3.A.2.h | Manure management - Swine | $N_2O$ | 63.7 | 0.0 | 99.9 |
| 1.A.3.c | Transport - Liquid Fuels - Railways | $N_2O$ | 63.0 | 0.0 | 99.9 |
| 3.A.2.i | Manure management - Poultry | $CH_4$ | 54.2 | 0.0 | 99.9 |

| IPCC Category code | IPCC Category | GHG | 2000 (Gg $CO_2$ eq) | Level Assess-ment (%) | Cumula-tive total (%) |
|---|---|---|---|---|---|
| 3.A.1.h | Enteric Fermentation - Swine | $CH_4$ | 52.1 | 0.0 | 99.9 |
| 1.A.1,a | Energy Industries - Solid Fuels - Main activity electricity and heat production | $CH_4$ | 44.2 | 0.0 | 99.9 |
| 2.C.5 | Metal industry - Lead Production | $CO_2$ | 39.2 | 0.0 | 99.9 |
| 3.A.1.g | Enteric Fermentation - Mules and assess | $CH_4$ | 37.7 | 0.0 | 99.9 |
| 3.C.1.e | Emissions from biomass burning - Other lands | $N_2O$ | 23.1 | 0.0 | 100.0 |
| 3.C.1.d | Emissions from biomass burning - Wetlands | $N_2O$ | 21.1 | 0.0 | 100.0 |
| 3.C.1.e | Emissions from biomass burning - Other lands | $CH_4$ | 19.7 | 0.0 | 100.0 |
| 1.A.4.a | Other Sectors - Liquid Fuels - Commercial/Institutional | $N_2O$ | 18.3 | 0.0 | 100.0 |
| 3.C.1.d | Emissions from biomass burning - Wetlands | $CH_4$ | 18.0 | 0.0 | 100.0 |
| 1.A.4.b | Other Sectors - Solid Fuels - Residential | $N_2O$ | 16.6 | 0.0 | 100.0 |
| 1.A.4.a | Other Sectors - Gaseous Fuels - Commercial/ Institutional | $CO_2$ | 13.0 | 0.0 | 100.0 |
| 1.A.1.c | Energy Industries - Liquid Fuels - Manufacture of spolid fuels and other energy industries | $CH_4$ | 11.6 | 0.0 | 100.0 |
| 3.A.2.f | Manure management - Horses | $CH_4$ | 10.2 | 0.0 | 100.0 |
| 1.A.4.a | Other Sectors - Solid Fuels - Commercial/Institutional | $N_2O$ | 8.3 | 0.0 | 100.0 |
| 2.D.1 | Non-Energy Products from Fuels and Solvent Use - Paraffin wax use | $CO_2$ | 7.4 | 0.0 | 100.0 |
| 1.A.4.a | Other Sectors - Liquid Fuels - Commercial/Institutional | $CH_4$ | 7.1 | 0.0 | 100.0 |
| 1.A.2 | Manufacturing Industries and Construction - Solid Fuels | $CH_4$ | 7.0 | 0.0 | 100.0 |
| 1.A.4.c | Other Sectors - Liquid Fuels - Agriculture/Forestry/ Fishing/Fish farms | $N_2O$ | 5.3 | 0.0 | 100.0 |
| 1.A.4.b | Other Sectors - Liquid Fuels - Residential | $N_2O$ | 5.2 | 0.0 | 100.0 |
| 1.A.3.a | Transport - Liquid Fuels - Civil Aviation | $N_2O$ | 5.1 | 0.0 | 100.0 |
| 2.C.2 | Metal industry - Ferroalloys Production | $CH_4$ | 3.6 | 0.0 | 100.0 |
| 3.A.2.g | Manure management - Mules and asses | $CH_4$ | 3.4 | 0.0 | 100.0 |
| 1.A.1.b | Energy Industries - Liquid Fuels - Petroleum refining | $N_2O$ | 3.2 | 0.0 | 100.0 |
| 1.A.2 | Manufacturing Industries and Construction - Liquid Fuels | $N_2O$ | 2.8 | 0.0 | 100.0 |

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 Assess-ment (%) | Cumula-tive total (%) |
|---|---|---|---|---|---|
| 1.A.1,a | Energy Industries - Solid Fuels - Main activity electricity and heat production | $CO_2$ | 185027.4 | 45.3 | 45.3 |
| 1.A.3.b | Transport - Liquid Fuels - Road Transportation | $CO_2$ | 32623.3 | 8.0 | 53.3 |
| 1.A.1.c | Energy Industries - Liquid Fuels - Manufacture of solid fuels and other energy industries | $CO_2$ | 30454.7 | 7.5 | 60.7 |
| 1.A.2 | Manufacturing Industries and Construction - Solid Fuels | $CO_2$ | 29101.6 | 7.1 | 67.9 |
| 3.A.1.a | Enteric Fermentation - Cattle | $CH_4$ | 22819.4 | 5.6 | 73.4 |
| 2.C.1 | Metal industry - Iron and Steel Production | $CO_2$ | 16410.5 | 4.0 | 77.5 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - Urine and dung N deposits in PRP | $N_2O$ | 13180.8 | 3.2 | 80.7 |
| 4.A | Solid Waste Disposal | $CH_4$ | 9367.6 | 2.3 | 83.0 |
| 2.C.2 | Metal industry - Ferroalloys Production | $CO_2$ | 8079.1 | 2.0 | 84.9 |
| 1.A.4.a | Other Sectors - Liquid Fuels - Commercial/Institutional | $CO_2$ | 7690.4 | 1.9 | 86.8 |
| 3.A.1.c | Enteric Fermentation - Sheep | $CH_4$ | 4169.0 | 1.0 | 87.9 |
| 1.A.4.b | Other Sectors - Solid Fuels - Residential | $CO_2$ | 3604.2 | 0.9 | 88.7 |
| 2.A.1 | Mineral industry - Cement production | $CO_2$ | 3347.1 | 0.8 | 89.6 |
| 1.A.1.b | Energy Industries - Liquid Fuels - Petroleum refining | $CO_2$ | 3164.8 | 0.8 | 90.3 |
| 1.A.4.b | Other Sectors - Liquid Fuels - Residential | $CO_2$ | 2868.9 | 0.7 | 91.0 |
| 3.C.5 | Indirect $N_2O$ Emissions from managed soils - N leaching/runoff | $N_2O$ | 2479.0 | 0.6 | 91.6 |
| 4.D.1 | Wastewater Treatment and Discharge - Domestic | $CH_4$ | 2348.3 | 0.6 | 92.2 |
| 1.A.2 | Manufacturing Industries and Construction - Gaseous Fuels | $CO_2$ | 2217.7 | 0.5 | 92.8 |
| 1.A.4.c | Other Sectors - Liquid Fuels - Agriculture/Forestry/ Fishing/Fish farms | $CO_2$ | 2207.2 | 0.5 | 93.3 |
| 1.A.3.a | Transport - Liquid Fuels - Civil Aviation | $CO_2$ | 2040.0 | 0.5 | 93.8 |
| 3.C.5 | Indirect $N_2O$ Emissions from managed soils - N volatilization | $N_2O$ | 1939.5 | 0.5 | 94.3 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - Inorganic N application | $N_2O$ | 1934.7 | 0.5 | 94.7 |
| 1.A.4.a | Other Sectors - Solid Fuels - Commercial/Institutional | $CO_2$ | 1811.2 | 0.4 | 95.2 |

| IPCC Category code | IPCC Category | GHG | 2000 (Gg $CO_2$ eq) | Level Assess-ment (%) | Cumula-tive total (%) |
|---|---|---|---|---|---|
| 2.B | Chemical industry - Industry F | $N_2O$ | C[a] | 0.4 | 95.6 |
| 1.A.2 | Manufacturing Industries and Construction - Liquid Fuels | $CO_2$ | 1186.1 | 0.3 | 95.9 |
| 3.A.1.j | Enteric Fermentation - Other | $CH_4$ | 1106.7 | 0.3 | 96.1 |
| 2.C.3 | Metal industry - Aluminium production | $CO_2$ | 1105.5 | 0.3 | 96.4 |
| 3.A.1.d | Enteric Fermentation - Goats | $CH_4$ | 993.6 | 0.2 | 96.6 |
| 1.A.5.a | Non-Specified - Liquid Fuels - Stationary | $CO_2$ | 985.6 | 0.2 | 96.9 |
| 2.C.3 | Metal industry - Aluminium production | PFCs | 982.2 | 0.2 | 97.1 |
| 1.A.1,a | Energy Industries - Solid Fuels - Main activity electricity and heat production | $N_2O$ | 853.5 | 0.2 | 97.3 |
| 3.A.2.i | Manure management - Poultry | $N_2O$ | 642.6 | 0.2 | 97.5 |
| 3.C.1.c | Emissions from biomass burning - Grasslands | $N_2O$ | 637.5 | 0.2 | 97.6 |
| 3.A.2.h | Manure management - Swine | $CH_4$ | 612.1 | 0.1 | 97.8 |
| 4.D.1 | Wastewater Treatment and Discharge - Domestic | $N_2O$ | 572.2 | 0.1 | 97.9 |
| 1.A.3.c | Transport - Liquid Fuels - Railways | $CO_2$ | 551.5 | 0.1 | 98.1 |
| 3.C.1.c | Emissions from biomass burning - Grasslands | $CH_4$ | 542.5 | 0.1 | 98.2 |
| 2.B | Chemical industry - Industry X | $CO_2$ | C[a] | 0.1 | 98.3 |
| 1.A.3.b | Transport - Liquid Fuels - Road Transportation | $N_2O$ | 463.0 | 0.1 | 98.4 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - Organic N application | $N_2O$ | 441.3 | 0.1 | 98.5 |
| 2.B | Chemical industry - Industry K | $CO_2$ | C[a] | 0.1 | 98.7 |
| 2.A.2 | Mineral industry - Lime production | $CO_2$ | 426.4 | 0.1 | 98.8 |
| 3.C.2 | Liming | $CO_2$ | 384.1 | 0.1 | 98.9 |
| 1.A.4.b | Other Sectors - Biomass - Residential | $N_2O$ | 380.9 | 0.1 | 98.9 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - N in crop residues | $N_2O$ | 352.8 | 0.1 | 99.0 |
| 3.C.6 | Indirect $N_2O$ Emissions from manure management | $N_2O$ | 350.0 | 0.1 | 99.1 |
| 3.A.2.a | Manure management - Cattle | $N_2O$ | 301.0 | 0.1 | 99.2 |
| 1.A.3.b | Transport - Liquid Fuels - Road Transportation | $CH_4$ | 267.6 | 0.1 | 99.3 |
| 3.C.1.b | Emissions from biomass burning - Croplands | $CH_4$ | 244.2 | 0.1 | 99.3 |
| 1.A.4.b | Other Sectors - Biomass - Residential | $CH_4$ | 222.0 | 0.1 | 99.4 |
| 3.C.3 | Urea application | $CO_2$ | 211.5 | 0.1 | 99.4 |

| IPCC Category code | IPCC Category | GHG | 2000 (Gg $CO_2$ eq) | Level Assess-ment (%) | Cumula-tive total (%) |
|---|---|---|---|---|---|
| 2.C.6 | Metal industry - Zinc Production | $CO_2$ | 194.4 | 0.0 | 99.5 |
| 2.D.1 | Non-Energy Products from Fuels and Solvent Use - Lubricant use | $CO_2$ | 188.5 | 0.0 | 99.5 |
| 3.A.2.a | Manure management - Cattle | $CH_4$ | 182.6 | 0.0 | 99.6 |
| 1.A.4.c | Other Sectors - Solid Fuels - Agriculture/Forestry/ Fishing/Fish farms | $CO_2$ | 171.5 | 0.0 | 99.6 |
| 3.C.1.a | Emissions from biomass burning - Forest lands | $CH_4$ | 164.6 | 0.0 | 99.6 |
| 3.C.1.a | Emissions from biomass burning - Forest lands | $N_2O$ | 151.1 | 0.0 | 99.7 |
| 2.B | Chemical industry - Industry Q | $CO_2$ | C[a] | 0.0 | 99.7 |
| 1.A.2 | Manufacturing Industries and Construction - Solid Fuels | $N_2O$ | 134.2 | 0.0 | 99.7 |
| 3.A.1.f | Enteric Fermentation - Horses | $CH_4$ | 111.8 | 0.0 | 99.8 |
| 1.A.1.c | Energy Industries - Liquid Fuels - Manufacture of spolid fuels and other energy industries | $N_2O$ | 105.4 | 0.0 | 99.8 |
| 3.C.1.b | Emissions from biomass burning - Croplands | $N_2O$ | 81.5 | 0.0 | 99.8 |
| 2.A.3 | Mineral industry - Glass Production | $CO_2$ | 74.4 | 0.0 | 99.8 |
| 2.B | Chemical industry - Industry X | $CH_4$ | C[a] | 0.0 | 99.9 |
| 3.A.2.h | Manure management - Swine | $N_2O$ | 63.7 | 0.0 | 99.9 |
| 1.A.3.c | Transport - Liquid Fuels - Railways | $N_2O$ | 63.0 | 0.0 | 99.9 |
| 3.A.2.i | Manure management - Poultry | $CH_4$ | 54.2 | 0.0 | 99.9 |
| 3.A.1.h | Enteric Fermentation - Swine | $CH_4$ | 52.1 | 0.0 | 99.9 |
| 1.A.1,a | Energy Industries - Solid Fuels - Main activity electricity and heat production | $CH_4$ | 44.2 | 0.0 | 99.9 |
| 2.C.5 | Metal industry - Lead Production | $CO_2$ | 39.2 | 0.0 | 99.9 |
| 3.A.1.g | Enteric Fermentation - Mules and assess | $CH_4$ | 37.7 | 0.0 | 99.9 |
| 3.C.1.e | Emissions from biomass burning - Other lands | $N_2O$ | 23.1 | 0.0 | 99.9 |
| 3.C.1.d | Emissions from biomass burning - Wetlands | $N_2O$ | 21.1 | 0.0 | 100.0 |
| 3.C.1.e | Emissions from biomass burning - Other lands | $CH_4$ | 19.7 | 0.0 | 100.0 |
| 1.A.4.a | Other Sectors - Liquid Fuels - Commercial/Institutional | $N_2O$ | 18.3 | 0.0 | 100.0 |
| 3.C.1.d | Emissions from biomass burning - Wetlands | $CH_4$ | 18.0 | 0.0 | 100.0 |
| 1.A.4.b | Other Sectors - Solid Fuels - Residential | $N_2O$ | 16.6 | 0.0 | 100.0 |
| 1.A.4.a | Other Sectors - Gaseous Fuels - Commercial/ Institutional | $CO_2$ | 13.0 | 0.0 | 100.0 |

| IPCC Category code | IPCC Category | GHG | 2000 (Gg $CO_2$ eq) | Level Assess-ment (%) | Cumula-tive total (%) |
|---|---|---|---|---|---|
| 1.A.1.c | Energy Industries - Liquid Fuels - Manufacture of solid fuels and other energy industries | $CH_4$ | 11.6 | 0.0 | 100.0 |
| 3.A.2.f | Manure management – Horses | $CH_4$ | 10.2 | 0.0 | 100.0 |
| 1.A.4.a | Other Sectors - Solid Fuels - Commercial/Institutional | $N_2O$ | 8.3 | 0.0 | 100.0 |
| 2.D.1 | Non-Energy Products from Fuels and Solvent Use - Paraffin wax use | $CO_2$ | 7.4 | 0.0 | 100.0 |
| 1.A.4.a | Other Sectors - Liquid Fuels - Commercial/Institutional | $CH_4$ | 7.1 | 0.0 | 100.0 |
| 1.A.2 | Manufacturing Industries and Construction - Solid Fuels | $CH_4$ | 7.0 | 0.0 | 100.0 |
| 1.A.4.c | Other Sectors - Liquid Fuels - Agriculture/Forestry/ Fishing/Fish farms | $N_2O$ | 5.3 | 0.0 | 100.0 |
| 1.A.4.b | Other Sectors - Liquid Fuels – Residential | $N_2O$ | 5.2 | 0.0 | 100.0 |
| 1.A.3.a | Transport - Liquid Fuels - Civil Aviation | $N_2O$ | 5.1 | 0.0 | 100.0 |
| 2.C.2 | Metal industry - Ferroalloys Production | $CH_4$ | 3.6 | 0.0 | 100.0 |
| 3.A.2.g | Manure management - Mules and asses | $CH_4$ | 3.4 | 0.0 | 100.0 |
| 1.A.1.b | Energy Industries - Liquid Fuels - Petroleum refining | $N_2O$ | 3.2 | 0.0 | 100.0 |

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

## 9.3 Level assessment: 2012 (including FOLU)

| IPCC Category code | IPCC Category | GHG | 2000 (Gg $CO_2$ eq) | Level Assess-ment (%) | Cumula-tive total (%) |
|---|---|---|---|---|---|
| 1.A.1,a | Energy Industries - Solid Fuels - Main activity electricity and heat production | $CO_2$ | 242 154.0 | 43.5 | 43.5 |
| 1.A.3.b | Transport - Liquid Fuels - Road Transportation | $CO_2$ | 42 929.6 | 7.7 | 51.2 |
| 1.A.1.c | Energy Industries - Liquid Fuels - Manufacture of solid fuels and other energy industries | $CO_2$ | 29 903.3 | 5.4 | 56.6 |
| 3.B.1.b | Forest land - Land Converted to Forest land | $CO_2$ | -29 490.8 | 5.3 | 61.9 |
| 1.A.2 | Manufacturing Industries and Construction - Solid Fuels | $CO_2$ | 24 472.7 | 4.4 | 66.3 |
| 3.A.1.a | Enteric Fermentation - Cattle | $CH_4$ | 21 236.5 | 3.8 | 70.1 |
| 1.A.4.b | Other Sectors - Solid Fuels - Residential | $CO_2$ | 18 461.9 | 3.3 | 73.4 |
| 4.A | Solid Waste Disposal | $CH_4$ | 18 412.0 | 3.3 | 76.8 |
| 2.C.1 | Metal industry - Iron and Steel Production | $CO_2$ | 15 020.7 | 2.7 | 79.5 |
| 1.A.4.a | Other Sectors - Liquid Fuels - Commercial/Institutional | $CO_2$ | 12 685.4 | 2.3 | 81.7 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - Urine and dung N deposits in PRP | $N_2O$ | 11 815.0 | 2.1 | 83.9 |
| 2.C.2 | Metal industry - Ferroalloys Production | $CO_2$ | 11 623.8 | 2.1 | 85.9 |
| 3.B.3.b | Grassland - Land Converted to Grassland | $CO_2$ | 7 871.8 | 1.4 | 87.4 |
| 3.B.2.b | Cropland - Land Converted to Cropland | $CO_2$ | 5 721.0 | 1.0 | 88.4 |
| 3.B.1.a | Forest land - Forest land Remaining Forest land | $CO_2$ | -4 834.4 | 0.9 | 89.3 |
| 2.A.1 | Mineral industry - Cement production | $CO_2$ | 3 844.5 | 0.7 | 90.0 |
| 3.A.1.c | Enteric Fermentation - Sheep | $CH_4$ | 3 783.5 | 0.7 | 90.6 |
| 1.A.3.a | Transport - Liquid Fuels - Civil Aviation | $CO_2$ | 3 466.4 | 0.6 | 91.3 |
| 1.A.4.a | Other Sectors - Solid Fuels - Commercial/Institutional | $CO_2$ | 3 434.8 | 0.6 | 91.9 |
| 1.A.4.c | Other Sectors - Liquid Fuels - Agriculture/Forestry/ Fishing/Fish farms | $CO_2$ | 3 420.3 | 0.6 | 92.5 |
| 4.D.1 | Wastewater Treatment and Discharge - Domestic | $CH_4$ | 2 827.7 | 0.5 | 93.0 |
| 1.A.1.b | Energy Industries - Liquid Fuels - Petroleum refining | $CO_2$ | 2 802.4 | 0.5 | 93.5 |
| 1.A.2 | Manufacturing Industries and Construction - Gaseous Fuels | $CO_2$ | 2 497.5 | 0.4 | 93.9 |
| 3.C.5 | Indirect $N_2O$ Emissions from managed soils - N leaching/runoff | $N_2O$ | 2 330.0 | 0.4 | 94.4 |
| 1.A.4.b | Other Sectors - Liquid Fuels - Residential | $CO_2$ | 2 154.6 | 0.4 | 94.8 |

| IPCC Category code | IPCC Category | GHG | 2000 (Gg $CO_2$ eq) | Level Assess-ment (%) | Cumula-tive total (%) |
|---|---|---|---|---|---|
| 1.A.2 | Manufacturing Industries and Construction - Liquid Fuels | $CO_2$ | 2 114.0 | 0.4 | 95.1 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - Inorganic N application | $N_2O$ | 2000.1 | 0.4 | 95.5 |
| 2.C.3 | Metal industry - Aluminium production | PFCs | 1979.2 | 0.4 | 95.8 |
| 3.C.5 | Indirect $N_2O$ Emissions from managed soils - N volatilization | $N_2O$ | 1791.7 | 0.3 | 96.2 |
| 2.F.1 | Product uses as substitutes for ODS - Refrigeration and Air Conditioning | HFCs | 1396.1 | 0.3 | 96.4 |
| 3.B.5.b | Settlements - Land Converted to Settlements | $CO_2$ | 1183.2 | 0.2 | 96.6 |
| 1.A.1,a | Energy Industries - Solid Fuels - Main activity electricity and heat production | $N_2O$ | 1117.1 | 0.2 | 96.8 |
| 1.A.5.a | Non-Specified - Liquid Fuels - Stationary | $CO_2$ | 1110.5 | 0.2 | 97.0 |
| 3.A.1.j | Enteric Fermentation - Other | $CH_4$ | 1106.7 | 0.2 | 97.2 |
| 2.C.3 | Metal industry - Aluminium production | $CO_2$ | 1066.9 | 0.2 | 97.4 |
| 3.B.6.b | Other land - Land Converted to Other land | $CO_2$ | -960.3 | 0.2 | 97.6 |
| 3.A.2.i | Manure management - Poultry | $N_2O$ | 954.6 | 0.2 | 97.8 |
| 3.A.1.d | Enteric Fermentation - Goats | $CH_4$ | 855.6 | 0.2 | 97.9 |
| 2.B | Chemical industry - Industry F | $N_2O$ | C[a] | 0.1 | 98.1 |
| 4.D.1 | Wastewater Treatment and Discharge - Domestic | $N_2O$ | 689.1 | 0.1 | 98.2 |
| 1.A.3.b | Transport - Liquid Fuels - Road Transportation | $N_2O$ | 618.1 | 0.1 | 98.3 |
| 3.A.2.h | Manure management - Swine | $CH_4$ | 586.8 | 0.1 | 98.4 |
| 3.C.2 | Liming | $CO_2$ | 585.5 | 0.1 | 98.5 |
| 3.C.3 | Urea application | $CO_2$ | 555.0 | 0.1 | 98.6 |
| 3.C.1.c | Emissions from biomass burning - Grasslands | $CH_4$ | 542.3 | 0.1 | 98.7 |
| 3.D.1 | Harvested Wood Products | $CO_2$ | -511.8 | 0.1 | 98.8 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - Organic N application | $N_2O$ | 489.8 | 0.1 | 98.9 |
| 2.A.2 | Mineral industry - Lime production | $CO_2$ | 453.1 | 0.1 | 99.0 |
| 3.C.6 | Indirect $N_2O$ Emissions from manure management | $N_2O$ | 436.9 | 0.1 | 99.0 |
| 3.C.1.c | Emissions from biomass burning - Grasslands | $N_2O$ | 436.2 | 0.1 | 99.1 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - N in crop residues | $N_2O$ | 396.9 | 0.1 | 99.2 |

| IPCC Category code | IPCC Category | GHG | 2000 (Gg $CO_2$ eq) | Level Assess-ment (%) | Cumula-tive total (%) |
|---|---|---|---|---|---|
| 3.A.2.a | Manure management - Cattle | $N_2O$ | 347.0 | 0.1 | 99.3 |
| 1.A.3.c | Transport - Liquid Fuels - Railways | $CO_2$ | 318.0 | 0.1 | 99.3 |
| 1.A.3.b | Transport - Liquid Fuels - Road Transportation | $CH_4$ | 308.9 | 0.1 | 99.4 |
| 3.B.4.a. | Wetlands - Flooded land remaining flooded land | $CH_4$ | 267.9 | 0.0 | 99.4 |
| 2.D.1 | Non-Energy Products from Fuels and Solvent Use - Lubricant use | $CO_2$ | 250.6 | 0.0 | 99.5 |
| 3.C.1.b | Emissions from biomass burning - Croplands | $CH_4$ | 233.6 | 0.0 | 99.5 |
| 3.C.1.a | Emissions from biomass burning - Forest lands | $CH_4$ | 230.8 | 0.0 | 99.5 |
| 2.B | Chemical industry - Industry X | $CO_2$ | C[a] | 0.0 | 99.6 |
| 3.A.2.a | Manure management - Cattle | $CH_4$ | 167.5 | 0.0 | 99.6 |
| 2.B | Chemical industry - Industry K | $CO_2$ | Ca | 0.0 | 99.6 |
| 1.A.4.b | Other Sectors - Biomass - Residential | $N_2O$ | 146.6 | 0.0 | 99.7 |
| 1.A.1.c | Energy Industries - Liquid Fuels - Manufacture of solid fuels and other energy industries | $N_2O$ | 141.5 | 0.0 | 99.7 |
| 2.B | Chemical industry - Industry Q | $CO_2$ | C[a] | 0.0 | 99.7 |
| 3.C.1.a | Emissions from biomass burning - Forest lands | $N_2O$ | 133.1 | 0.0 | 99.7 |
| 3.A.1.f | Enteric Fermentation - Horses | $CH_4$ | 127.5 | 0.0 | 99.8 |
| 2.A.3 | Mineral industry - Glass Production | $CO_2$ | 113.9 | 0.0 | 99.8 |
| 1.A.2 | Manufacturing Industries and Construction - Solid Fuels | $N_2O$ | 112.9 | 0.0 | 99.8 |
| 3.B.2.a | Cropland - Cropland Remaining Cropland | $CO_2$ | -104.9 | 0.0 | 99.8 |
| 1.A.4.b | Other Sectors - Biomass - Residential | $CH_4$ | 85.5 | 0.0 | 99.8 |
| 1.A.4.b | Other Sectors - Solid Fuels - Residential | $N_2O$ | 85.2 | 0.0 | 99.9 |
| 3.A.2.i | Manure management - Poultry | $CH_4$ | 80.5 | 0.0 | 99.9 |
| 3.C.1.b | Emissions from biomass burning - Croplands | $N_2O$ | 77.9 | 0.0 | 99.9 |
| 2.B | Chemical industry - Industry X | $CH_4$ | C[a] | 0.0 | 99.9 |
| 3.A.2.h | Manure management - Swine | $N_2O$ | 61.1 | 0.0 | 99.9 |
| 3.C.1.e | Emissions from biomass burning - Other lands | $CH_4$ | 59.9 | 0.0 | 99.9 |
| 1.A.1,a | Energy Industries - Solid Fuels - Main activity electricity and heat production | $CH_4$ | 57.9 | 0.0 | 99.9 |
| 3.A.1.h | Enteric Fermentation – Swine | $CH_4$ | 50.0 | 0.0 | 99.9 |
| 3.C.1.e | Emissions from biomass burning - Other lands | $N_2O$ | 48.1 | 0.0 | 99.9 |
| 3.A.1.g | Enteric Fermentation - Mules and assess | $CH_4$ | 38.4 | 0.0 | 100.0 |

| IPCC Category code | IPCC Category | GHG | 2000 (Gg $CO_2$ eq) | Level Assess-ment (%) | Cumula-tive total (%) |
|---|---|---|---|---|---|
| 1.A.3.c | Transport - Liquid Fuels – Railways | $N_2O$ | 36.3 | 0.0 | 100.0 |
| 1.A.4.a | Other Sectors - Liquid Fuels - Commercial/Institutional | $N_2O$ | 30.2 | 0.0 | 100.0 |
| 2.C.5 | Metal industry - Lead Production | $CO_2$ | 27.3 | 0.0 | 100.0 |
| 1.A.4.a | Other Sectors - Gaseous Fuels - Commercial/ Institutional | $CO_2$ | 17.6 | 0.0 | 100.0 |
| 2.D.1 | Non-Energy Products from Fuels and Solvent Use - Paraffin wax use | $CO_2$ | 17.4 | 0.0 | 100.0 |
| 1.A.4.a | Other Sectors - Solid Fuels - Commercial/Institutional | $N_2O$ | 15.8 | 0.0 | 100.0 |
| 3.C.1.d | Emissions from biomass burning – Wetlands | $CH_4$ | 15.6 | 0.0 | 100.0 |
| 3.C.1.d | Emissions from biomass burning – Wetlands | $N_2O$ | 12.5 | 0.0 | 100.0 |
| 1.A.4.a | Other Sectors - Liquid Fuels - Commercial/Institutional | $CH_4$ | 11.7 | 0.0 | 100.0 |
| 3.A.2.f | Manure management – Horses | $CH_4$ | 11.6 | 0.0 | 100.0 |
| 1.A.3.a | Transport - Liquid Fuels - Civil Aviation | $N_2O$ | 8.6 | 0.0 | 100.0 |
| 1.A.1.c | Energy Industries - Liquid Fuels - Manufacture of solid fuels and other energy industries | $CH_4$ | 8.4 | 0.0 | 100.0 |
| 1.A.4.c | Other Sectors - Liquid Fuels - Agriculture/Forestry/ Fishing/Fish farms | $N_2O$ | 8.2 | 0.0 | 100.0 |
| 1.A.2 | Manufacturing Industries and Construction - Solid Fuels | $CH_4$ | 5.8 | 0.0 | 100.0 |
| 2.B | Chemical industry - Industry S | $CO_2$ | C[a] | 0.0 | 100.0 |
| 1.A.2 | Manufacturing Industries and Construction - Liquid Fuels | $N_2O$ | 4.9 | 0.0 | 100.0 |
| 1.A.4.b | Other Sectors - Solid Fuels – Residential | $CH_4$ | 4.4 | 0.0 | 100.0 |
| 3.A.2.g | Manure management - Mules and asses | $CH_4$ | 3.5 | 0.0 | 100.0 |
| 2.C.2 | Metal industry - Ferroalloys Production | $CH_4$ | 3.4 | 0.0 | 100.0 |

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

## 9.4 Level assessment: 2012 (excluding FOLU)

| IPCC Category code | IPCC Category | GHG | 2000 (Gg $CO_2$ eq) | Level Assess-ment (%) | Cumula-tive total (%) |
|---|---|---|---|---|---|
| 1.A.1,a | Energy Industries - Solid Fuels - Main activity electricity and heat production | $CO_2$ | 242 154.0 | 47.9 | 47.9 |
| 1.A.3.b | Transport - Liquid Fuels - Road Transportation | $CO_2$ | 42 929.6 | 8.5 | 56.4 |
| 1.A.1.c | Energy Industries - Liquid Fuels - Manufacture of spolid fuels and other energy industries | $CO_2$ | 29 903.3 | 5.9 | 62.3 |
| 1.A.2 | Manufacturing Industries and Construction - Solid Fuels | $CO_2$ | 24 472.7 | 4.8 | 67.2 |
| 3.A.1.a | Enteric Fermentation - Cattle | $CH_4$ | 21 236.5 | 4.2 | 71.4 |
| 1.A.4.b | Other Sectors - Solid Fuels - Residential | $CO_2$ | 18 461.9 | 3.7 | 75.0 |
| 4.A | Solid Waste Disposal | $CH_4$ | 18 412.0 | 3.6 | 78.7 |
| 2.C.1 | Metal industry - Iron and Steel Production | $CO_2$ | 15 020.7 | 3.0 | 81.6 |
| 1.A.4.a | Other Sectors - Liquid Fuels - Commercial/Institutional | $CO_2$ | 12 685.4 | 2.5 | 84.1 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - Urine and dung N deposits in PRP | $N_2O$ | 11 815.0 | 2.3 | 86.5 |
| 2.C.2 | Metal industry - Ferroalloys Production | $CO_2$ | 11 623.8 | 2.3 | 88.8 |
| 2.A.1 | Mineral industry - Cement production | $CO_2$ | 3 844.5 | 0.8 | 89.5 |
| 3.A.1.c | Enteric Fermentation - Sheep | $CH_4$ | 3 783.5 | 0.7 | 90.3 |
| 1.A.3.a | Transport - Liquid Fuels - Civil Aviation | $CO_2$ | 3 466.4 | 0.7 | 91.0 |
| 1.A.4.a | Other Sectors - Solid Fuels - Commercial/Institutional | $CO_2$ | 3 434.8 | 0.7 | 91.7 |
| 1.A.4.c | Other Sectors - Liquid Fuels - Agriculture/Forestry/ Fishing/Fish farms | $CO_2$ | 3 420.3 | 0.7 | 92.3 |
| 4.D.1 | Wastewater Treatment and Discharge - Domestic | $CH_4$ | 2 827.7 | 0.6 | 92.9 |
| 1.A.1.b | Energy Industries - Liquid Fuels - Petroleum refining | $CO_2$ | 2 802.4 | 0.6 | 93.4 |
| 1.A.2 | Manufacturing Industries and Construction - Gaseous Fuels | $CO_2$ | 2 497.5 | 0.5 | 93.9 |
| 3.C.5 | Indirect $N_2O$ Emissions from managed soils - N leaching/runoff | $N_2O$ | 2 330.0 | 0.5 | 94.4 |
| 1.A.4.b | Other Sectors - Liquid Fuels - Residential | $CO_2$ | 2 154.6 | 0.4 | 94.8 |
| 1.A.2 | Manufacturing Industries and Construction - Liquid Fuels | $CO_2$ | 2 114.0 | 0.4 | 95.2 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - Inorganic N application | $N_2O$ | 2000.1 | 0.4 | 95.6 |

| IPCC Category code | IPCC Category | GHG | 2000 (Gg $CO_2$ eq) | Level Assess-ment (%) | Cumula-tive total (%) |
|---|---|---|---|---|---|
| 2.C.3 | Metal industry - Aluminium production | PFCs | 1979.2 | 0.4 | 96.0 |
| 3.C.5 | Indirect $N_2O$ Emissions from managed soils - N volatilization | $N_2O$ | 1791.7 | 0.4 | 96.4 |
| 2.F.1 | Product uses as substitutes for ODS - Refrigeration and Air Conditioning | HFCs | 1396.1 | 0.3 | 96.7 |
| 1.A.1,a | Energy Industries - Solid Fuels - Main activity electricity and heat production | $N_2O$ | 1117.1 | 0.2 | 96.9 |
| 1.A.5.a | Non-Specified - Liquid Fuels - Stationary | $CO_2$ | 1110.5 | 0.2 | 97.1 |
| 3.A.1.j | Enteric Fermentation - Other | $CH_4$ | 1106.7 | 0.2 | 97.3 |
| 2.C.3 | Metal industry - Aluminium production | $CO_2$ | 1066.9 | 0.2 | 97.5 |
| 3.A.2.i | Manure management - Poultry | $N_2O$ | 954.6 | 0.2 | 97.7 |
| 3.A.1.d | Enteric Fermentation - Goats | $CH_4$ | 855.6 | 0.2 | 97.9 |
| 2.B | Chemical industry - Industry F | $N_2O$ | C[a] | 0.1 | 98.0 |
| 4.D.1 | Wastewater Treatment and Discharge - Domestic | $N_2O$ | 689.1 | 0.1 | 98.2 |
| 1.A.3.b | Transport - Liquid Fuels - Road Transportation | $N_2O$ | 618.1 | 0.1 | 98.3 |
| 3.A.2.h | Manure management - Swine | $CH_4$ | 586.8 | 0.1 | 98.4 |
| 3.C.2 | Liming | $CO_2$ | 585.5 | 0.1 | 98.5 |
| 3.C.3 | Urea application | $CO_2$ | 555.0 | 0.1 | 98.6 |
| 3.C.1.c | Emissions from biomass burning - Grasslands | $CH_4$ | 542.3 | 0.1 | 98.7 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - Organic N application | $N_2O$ | 489.8 | 0.1 | 98.8 |
| 2.A.2 | Mineral industry - Lime production | $CO_2$ | 453.1 | 0.1 | 98.9 |
| 3.C.6 | Indirect $N_2O$ Emissions from manure management | $N_2O$ | 436.9 | 0.1 | 99.0 |
| 3.C.1.c | Emissions from biomass burning - Grasslands | $N_2O$ | 436.2 | 0.1 | 99.1 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - N in crop residues | $N_2O$ | 396.9 | 0.1 | 99.2 |
| 3.A.2.a | Manure management - Cattle | $N_2O$ | 347.0 | 0.1 | 99.3 |
| 1.A.3.c | Transport - Liquid Fuels - Railways | $CO_2$ | 318.0 | 0.1 | 99.3 |
| 1.A.3.b | Transport - Liquid Fuels - Road Transportation | $CH_4$ | 308.9 | 0.1 | 99.4 |
| 2.D.1 | Non-Energy Products from Fuels and Solvent Use - Lubricant use | $CO_2$ | 250.6 | 0.0 | 99.4 |

| IPCC Category code | IPCC Category | GHG | 2000 (Gg $CO_2$ eq) | Level Assess-ment (%) | Cumula-tive total (%) |
|---|---|---|---|---|---|
| 3.C.1.b | Emissions from biomass burning - Croplands | $CH_4$ | 233.6 | 0.0 | 99.5 |
| 3.C.1.a | Emissions from biomass burning - Forest lands | $CH_4$ | 230.8 | 0.0 | 99.5 |
| 2.B | Chemical industry - Industry X | $CO_2$ | C[a] | 0.0 | 99.6 |
| 3.A.2.a | Manure management - Cattle | $CH_4$ | 167.5 | 0.0 | 99.6 |
| 2.B | Chemical industry - Industry K | $CO_2$ | Ca | 0.0 | 99.6 |
| 1.A.4.b | Other Sectors - Biomass - Residential | $N_2O$ | 146.6 | 0.0 | 99.7 |
| 1.A.1.c | Energy Industries - Liquid Fuels - Manufacture of solid fuels and other energy industries | $N_2O$ | 141.5 | 0.0 | 99.7 |
| 2.B | Chemical industry - Industry Q | $CO_2$ | C[a] | 0.0 | 99.7 |
| 3.C.1.a | Emissions from biomass burning - Forest lands | $N_2O$ | 133.1 | 0.0 | 99.7 |
| 3.A.1.f | Enteric Fermentation - Horses | $CH_4$ | 127.5 | 0.0 | 99.8 |
| 2.A.3 | Mineral industry - Glass Production | $CO_2$ | 113.9 | 0.0 | 99.8 |
| 1.A.2 | Manufacturing Industries and Construction - Solid Fuels | $N_2O$ | 112.9 | 0.0 | 99.8 |
| 1.A.4.b | Other Sectors - Biomass - Residential | $CH_4$ | 85.5 | 0.0 | 99.8 |
| 1.A.4.b | Other Sectors - Solid Fuels - Residential | $N_2O$ | 85.2 | 0.0 | 99.8 |
| 3.A.2.i | Manure management - Poultry | $CH_4$ | 80.5 | 0.0 | 99.9 |
| 3.C.1.b | Emissions from biomass burning - Croplands | $N_2O$ | 77.9 | 0.0 | 99.9 |
| 2.B | Chemical industry - Industry X | $CH_4$ | C[a] | 0.0 | 99.9 |
| 3.A.2.h | Manure management - Swine | $N_2O$ | 61.1 | 0.0 | 99.9 |
| 3.C.1.e | Emissions from biomass burning - Other lands | $CH_4$ | 59.9 | 0.0 | 99.9 |
| 1.A.1,a | Energy Industries - Solid Fuels - Main activity electricity and heat production | $CH_4$ | 57.9 | 0.0 | 99.9 |
| 3.A.1.h | Enteric Fermentation - Swine | $CH_4$ | 50.0 | 0.0 | 99.9 |
| 3.C.1.e | Emissions from biomass burning - Other lands | $N_2O$ | 48.1 | 0.0 | 99.9 |
| 3.A.1.g | Enteric Fermentation - Mules and assess | $CH_4$ | 38.4 | 0.0 | 99.9 |
| 1.A.3.c | Transport - Liquid Fuels - Railways | $N_2O$ | 36.3 | 0.0 | 100.0 |
| 1.A.4.a | Other Sectors - Liquid Fuels - Commercial/Institutional | $N_2O$ | 30.2 | 0.0 | 100.0 |
| 2.C.5 | Metal industry - Lead Production | $CO_2$ | 27.3 | 0.0 | 100.0 |
| 1.A.4.a | Other Sectors - Gaseous Fuels - Commercial/ Institutional | $CO_2$ | 17.6 | 0.0 | 100.0 |
| 2.D.1 | Non-Energy Products from Fuels and Solvent Use - Paraffin wax use | $CO_2$ | 17.4 | 0.0 | 100.0 |

| IPCC Category code | IPCC Category | GHG | 2000 (Gg $CO_2$ eq) | Level Assess-ment (%) | Cumula-tive total (%) |
|---|---|---|---|---|---|
| 1.A.4.a | Other Sectors - Solid Fuels - Commercial/Institutional | $N_2O$ | 15.8 | 0.0 | 100.0 |
| 3.C.1.d | Emissions from biomass burning - Wetlands | $CH_4$ | 15.6 | 0.0 | 100.0 |
| 3.C.1.d | Emissions from biomass burning - Wetlands | $N_2O$ | 12.5 | 0.0 | 100.0 |
| 1.A.4.a | Other Sectors - Liquid Fuels - Commercial/Institutional | $CH_4$ | 11.7 | 0.0 | 100.0 |
| 3.A.2.f | Manure management - Horses | $CH_4$ | 11.6 | 0.0 | 100.0 |
| 1.A.3.a | Transport - Liquid Fuels - Civil Aviation | $N_2O$ | 8.6 | 0.0 | 100.0 |
| 1.A.1.c | Energy Industries - Liquid Fuels - Manufacture of solid fuels and other energy industries | $CH_4$ | 8.4 | 0.0 | 100.0 |
| 1.A.4.c | Other Sectors - Liquid Fuels - Agriculture/Forestry/Fishing/Fish farms | $N_2O$ | 8.2 | 0.0 | 100.0 |
| 1.A.2 | Manufacturing Industries and Construction - Solid Fuels | $CH_4$ | 5.8 | 0.0 | 100.0 |
| 2.B | Chemical industry - Industry S | $CO_2$ | C[a] | 0.0 | 100.0 |
| 1.A.2 | Manufacturing Industries and Construction - Liquid Fuels | $N_2O$ | 4.9 | 0.0 | 100.0 |
| 1.A.4.b | Other Sectors - Solid Fuels - Residential | $CH_4$ | 4.4 | 0.0 | 100.0 |
| 3.A.2.g | Manure management - Mules and asses | $CH_4$ | 3.5 | 0.0 | 100.0 |
| 2.C.2 | Metal industry - Ferroalloys Production | $CH_4$ | 3.4 | 0.0 | 100.0 |
| 1.A.3.a | Transport - Liquid Fuels - Civil Aviation | $CH_4$ | 3.3 | 0.0 | 100.0 |

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

## 9.5 Trend assessment: 2000 – 2012 (including FOLU)

| IPCC Category code | IPCC Category | GHG | 2000 | 2012 | Trend Assessment (%) | Contribution to trend (%) | Cumulative total (%) |
|---|---|---|---|---|---|---|---|
| | | | (Gg $CO_2$ eq) | | | | |
| 3.B.1.b | Forest land - Land Converted to Forest land | $CO_2$ | -15339.9 | -29490.8 | 3.9 | 14.6 | 14.6 |
| 1.A.1,a | Energy Industries - Solid Fuels - Main activity electricity and heat production | $CO_2$ | 185027.4 | 242154.0 | 3.8 | 14.1 | 28.6 |
| 1.A.4.b | Other Sectors - Solid Fuels - Residential | $CO_2$ | 3604.2 | 18461.9 | 3.2 | 11.7 | 40.3 |
| 1.A.2 | Manufacturing Industries and Construction - Solid Fuels | $CO_2$ | 29101.6 | 24472.7 | 2.5 | 9.1 | 49.5 |
| 1.A.1.c | Energy Industries - Liquid Fuels - Manufacture of solid fuels and other energy industries | $CO_2$ | 30454.7 | 29903.3 | 1.6 | 6.0 | 55.4 |
| 4.A | Solid Waste Disposal | $CH_4$ | 9367.6 | 18412.0 | 1.6 | 5.8 | 61.3 |
| 3.A.1.a | Enteric Fermentation - Cattle | $CH_4$ | 22819.4 | 21236.5 | 1.5 | 5.4 | 66.7 |
| 2.C.1 | Metal industry - Iron and Steel Production | $CO_2$ | 16410.5 | 15020.7 | 1.1 | 4.1 | 70.8 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - Urine and dung N deposits in PRP | $N_2O$ | 13180.8 | 11815.0 | 0.9 | 3.5 | 74.3 |
| 1.A.4.a | Other Sectors - Liquid Fuels - Commercial/Institutional | $CO_2$ | 7690.4 | 12685.4 | 0.7 | 2.8 | 77.1 |
| 1.A.3.b | Transport - Liquid Fuels - Road Transportation | $CO_2$ | 32623.3 | 42929.6 | 0.7 | 2.7 | 79.8 |
| 2.C.2 | Metal industry - Ferroalloys Production | $CO_2$ | 8079.1 | 11623.8 | 0.4 | 1.5 | 81.3 |
| 3.B.3.b | Grassland - Land Converted to Grassland | $CO_2$ | 7904.1 | 7871.8 | 0.4 | 1.5 | 82.7 |
| 2.F.1 | Product uses as substitutes for ODS - Refrigeration and Air Conditioning | HFCs | 0.0 | 1396.1 | 0.3 | 1.2 | 83.9 |
| 1.A.4.b | Other Sectors - Liquid Fuels - Residential | $CO_2$ | 2868.9 | 2154.6 | 0.3 | 1.1 | 85.0 |
| 3.A.1.c | Enteric Fermentation - Sheep | $CH_4$ | 4169.0 | 3783.5 | 0.3 | 1.1 | 86.1 |
| 3.B.2.b | Cropland - Land Converted to Cropland | $CO_2$ | 5721.7 | 5721.0 | 0.3 | 1.0 | 87.1 |
| 1.A.4.a | Other Sectors - Solid Fuels - Commercial/Institutional | $CO_2$ | 1811.2 | 3434.8 | 0.3 | 1.0 | 88.1 |

| IPCC Cate-gory code | IPCC Category | GHG | 2000 | 2012 | Trend Assess-ment (%) | Contri-bution to trend (%) | Cumu-lative total (%) |
|---|---|---|---|---|---|---|---|
| | | | (Gg $CO_2$ eq) | | | | |
| 1.A.1.b | Energy Industries - Liquid Fuels - Petroleum refining | $CO_2$ | 3164.8 | 2802.4 | 0.2 | 0.9 | 89.0 |
| 1.A.3.a | Transport - Liquid Fuels - Civil Aviation | $CO_2$ | 2040.0 | 3466.4 | 0.2 | 0.8 | 89.8 |
| 3.B.2.a | Cropland - Cropland Remaining Cropland | $CO_2$ | -1241.6 | -104.9 | 0.2 | 0.7 | 90.6 |
| 2.C.3 | Metal industry - Aluminium production | PFCs | 982.2 | 1979.2 | 0.2 | 0.7 | 91.2 |
| 2.B | Chemical industry - Industry F | $N_2O$ | C[a] | C[a] | 0.2 | 0.6 | 91.8 |
| 1.A.4.c | Other Sectors - Liquid Fuels - Agriculture/Forestry/Fishing/Fish farms | $CO_2$ | 2207.2 | 3420.3 | 0.2 | 0.6 | 92.4 |
| 3.C.5 | Indirect $N_2O$ Emissions from managed soils - N leaching/runoff | $N_2O$ | 2479.0 | 2330.0 | 0.2 | 0.6 | 93.0 |
| 1.A.2 | Manufacturing Industries and Construction - Liquid Fuels | $CO_2$ | 1186.1 | 2114.0 | 0.2 | 0.6 | 93.6 |
| 3.C.5 | Indirect $N_2O$ Emissions from managed soils - N volatilization | $N_2O$ | 1939.5 | 1791.7 | 0.1 | 0.5 | 94.0 |
| 2.B | Chemical industry - Industry K | $CO_2$ | C[a] | C[a] | 0.1 | 0.3 | 94.4 |
| 2.B | Chemical industry - Industry X | $CO_2$ | C[a] | C[a] | 0.1 | 0.3 | 94.7 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - Inorganic N application | $N_2O$ | 1934.7 | 2000.1 | 0.1 | 0.3 | 95.0 |
| 3.A.1.d | Enteric Fermentation - Goats | $CH_4$ | 993.6 | 855.6 | 0.1 | 0.3 | 95.3 |
| 1.A.3.c | Transport - Liquid Fuels - Railways | $CO_2$ | 551.5 | 318.0 | 0.1 | 0.3 | 95.5 |
| 3.C.1.c | Emissions from biomass burning - Grasslands | $N_2O$ | 637.5 | 436.2 | 0.1 | 0.3 | 95.8 |
| 1.A.4.b | Other Sectors - Biomass - Residential | $N_2O$ | 380.9 | 146.6 | 0.1 | 0.3 | 96.1 |
| 3.C.3 | Urea application | $CO_2$ | 211.5 | 555.0 | 0.1 | 0.2 | 96.3 |
| 2.C.3 | Metal industry - Aluminium production | $CO_2$ | 1105.5 | 1066.9 | 0.1 | 0.2 | 96.6 |
| 3.D.1 | Harvested Wood Products | $CO_2$ | -312.2 | -511.8 | 0.1 | 0.2 | 96.8 |
| 3.B.5.b | Settlements - Land Converted to Settlements | $CO_2$ | 1191.0 | 1183.2 | 0.1 | 0.2 | 97.0 |
| 3.B.4.a. | Wetlands - Flooded land remaining flooded land | $CH_4$ | 429.2 | 267.9 | 0.1 | 0.2 | 97.2 |
| 3.A.1.j | Enteric Fermentation - Other | $CH_4$ | 1106.7 | 1106.7 | 0.1 | 0.2 | 97.4 |
| 2.C.6 | Metal industry - Zinc Production | $CO_2$ | 194.4 | 0.0 | 0.1 | 0.2 | 97.6 |

| IPCC Category code | IPCC Category | GHG | 2000 | 2012 | Trend Assessment (%) | Contribution to trend (%) | Cumulative total (%) |
|---|---|---|---|---|---|---|---|
| | | | (Gg $CO_2$ eq) | | | | |
| 2.A.1 | Mineral industry - Cement production | $CO_2$ | 3347.1 | 3844.5 | 0.1 | 0.2 | 97.8 |
| 1.A.4.c | Other Sectors - Solid Fuels - Agriculture/ Forestry/Fishing/Fish farms | $CO_2$ | 171.5 | 0.0 | 0.0 | 0.2 | 98.0 |
| 3.B.6.b | Other land - Land Converted to Other land | $CO_2$ | -960.2 | -960.3 | 0.0 | 0.2 | 98.2 |
| 1.A.2 | Manufacturing Industries and Construction - Gaseous Fuels | $CO_2$ | 2217.7 | 2497.5 | 0.0 | 0.2 | 98.3 |
| 1.A.4.b | Other Sectors - Biomass - Residential | $CH_4$ | 222.0 | 85.5 | 0.0 | 0.2 | 98.5 |
| 3.A.2.i | Manure management - Poultry | $N_2O$ | 642.6 | 954.6 | 0.0 | 0.1 | 98.6 |
| 3.A.2.h | Manure management - Swine | $CH_4$ | 612.1 | 586.8 | 0.0 | 0.1 | 98.8 |
| 3.C.1.c | Emissions from biomass burning - Grasslands | $CH_4$ | 542.5 | 542.3 | 0.0 | 0.1 | 98.9 |
| 3.C.2 | Liming | $CO_2$ | 384.1 | 585.5 | 0.0 | 0.1 | 99.0 |
| 1.A.5.a | Non-Specified - Liquid Fuels - Stationary | $CO_2$ | 985.6 | 1110.5 | 0.0 | 0.1 | 99.0 |
| 1.A.1,a | Energy Industries - Solid Fuels - Main activity electricity and heat production | N2O | 853.5 | 1117.1 | 0.0 | 0.1 | 99.1 |
| 2.B | Chemical industry - Industry X | $CH_4$ | C[a] | C[a] | 0.0 | 0.1 | 99.2 |
| 2.A.2 | Mineral industry - Lime production | $CO_2$ | 426.4 | 453.1 | 0.0 | 0.1 | 99.2 |
| 1.A.4.b | Other Sectors - Solid Fuels - Residential | $N_2O$ | 16.6 | 85.2 | 0.0 | 0.1 | 99.3 |
| 3.C.1.b | Emissions from biomass burning - Croplands | $CH_4$ | 244.2 | 233.6 | 0.0 | 0.1 | 99.3 |
| 3.A.2.a | Manure management - Cattle | $CH_4$ | 182.6 | 167.5 | 0.0 | 0.0 | 99.4 |
| 1.A.3.b | Transport - Liquid Fuels - Road Transportation | $N_2O$ | 463.0 | 618.1 | 0.0 | 0.0 | 99.4 |
| 3.C.1.a | Emissions from biomass burning - Forest lands | $N_2O$ | 151.1 | 133.1 | 0.0 | 0.0 | 99.4 |
| 1.A.2 | Manufacturing Industries and Construction - Solid Fuels | $N_2O$ | 134.2 | 112.9 | 0.0 | 0.0 | 99.5 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - Organic N application | $N_2O$ | 441.3 | 489.8 | 0.0 | 0.0 | 99.5 |
| 1.A.3.c | Transport - Liquid Fuels - Railways | $N_2O$ | 63.0 | 36.3 | 0.0 | 0.0 | 99.6 |
| 3.B.1.a | Forest land - Forest land Remaining Forest land | $CO_2$ | -6225.2 | -4834.4 | 0.0 | 0.0 | 99.6 |

| IPCC Category code | IPCC Category | GHG | 2000 | 2012 | Trend Assessment (%) | Contribution to trend (%) | Cumulative total (%) |
|---|---|---|---|---|---|---|---|
| | | | (Gg $CO_2$ eq) | | | | |
| 3.C.1.e | Emissions from biomass burning - Other lands | $CH_4$ | 19.7 | 59.9 | 0.0 | 0.0 | 99.6 |
| 2.B | Chemical industry - Industry Q | $CO_2$ | C[a] | C[a] | 0.0 | 0.0 | 99.7 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - N in crop residues | $N_2O$ | 352.8 | 396.9 | 0.0 | 0.0 | 99.7 |
| 4.D.1 | Wastewater Treatment and Discharge - Domestic | $CH_4$ | 2348.3 | 2827.7 | 0.0 | 0.0 | 99.7 |
| 3.C.1.a | Emissions from biomass burning - Forest lands | $CH_4$ | 164.6 | 230.8 | 0.0 | 0.0 | 99.7 |
| 2.A.3 | Mineral industry - Glass Production | $CO_2$ | 74.4 | 113.9 | 0.0 | 0.0 | 99.8 |
| 3.C.1.b | Emissions from biomass burning - Croplands | $N_2O$ | 81.5 | 77.9 | 0.0 | 0.0 | 99.8 |
| 2.D.1 | Non-Energy Products from Fuels and Solvent Use - Lubricant use | $CO_2$ | 188.5 | 250.6 | 0.0 | 0.0 | 99.8 |
| 2.C.5 | Metal industry - Lead Production | $CO_2$ | 39.2 | 27.3 | 0.0 | 0.0 | 99.8 |
| 3.C.1.e | Emissions from biomass burning - Other lands | $N_2O$ | 23.1 | 48.1 | 0.0 | 0.0 | 99.8 |
| 3.A.2.a | Manure management - Cattle | $N_2O$ | 301.0 | 347.0 | 0.0 | 0.0 | 99.8 |
| 1.A.3.b | Transport - Liquid Fuels - Road Transportation | $CH_4$ | 267.6 | 308.9 | 0.0 | 0.0 | 99.9 |
| 3.A.2.h | Manure management - Swine | $N_2O$ | 63.7 | 61.1 | 0.0 | 0.0 | 99.9 |
| 3.A.2.i | Manure management - Poultry | $CH_4$ | 54.2 | 80.5 | 0.0 | 0.0 | 99.9 |
| 3.A.1.h | Enteric Fermentation - Swine | $CH_4$ | 52.1 | 50.0 | 0.0 | 0.0 | 99.9 |
| 1.A.1.c | Energy Industries - Liquid Fuels - Manufacture of solid fuels and other energy industries | N2O | 105.4 | 141.5 | 0.0 | 0.0 | 99.9 |
| 3.C.1.d | Emissions from biomass burning - Wetlands | $N_2O$ | 21.1 | 12.5 | 0.0 | 0.0 | 99.9 |
| 3.C.6 | Indirect $N_2O$ Emissions from manure management | $N_2O$ | 350.0 | 436.9 | 0.0 | 0.0 | 99.9 |
| 3.A.1.f | Enteric Fermentation - Horses | $CH_4$ | 111.8 | 127.5 | 0.0 | 0.0 | 99.9 |
| 2.D.1 | Non-Energy Products from Fuels and Solvent Use - Paraffin wax use | $CO_2$ | 7.4 | 17.4 | 0.0 | 0.0 | 99.9 |

| IPCC Category code | IPCC Category | GHG | 2000 | 2012 | Trend Assessment (%) | Contribution to trend (%) | Cumulative total (%) |
|---|---|---|---|---|---|---|---|
| | | | (Gg $CO_2$ eq) | | | | |
| 1.A.4.a | Other Sectors - Liquid Fuels - Commercial/Institutional | $N_2O$ | 18.3 | 30.2 | 0.0 | 0.0 | 99.9 |
| 4.D.1 | Wastewater Treatment and Discharge - Domestic | $N_2O$ | 572.2 | 689.1 | 0.0 | 0.0 | 99.9 |
| 3.A.1.g | Enteric Fermentation - Mules and assess | $CH_4$ | 37.7 | 38.4 | 0.0 | 0.0 | 100.0 |

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

## 9.6 Trend assessment: 2000 – 2012 (including FOLU)

| IPCC Category code | IPCC Category | GHG | 2000 (Gg $CO_2$ eq) | 2012 (Gg $CO_2$ eq) | Trend Assessment (%) | Contribution to trend (%) | Cumulative total (%) |
|---|---|---|---|---|---|---|---|
| 1.A.4.b | Other Sectors - Solid Fuels - Residential | $CO_2$ | 3 604.2 | 18 461.9 | 3.4 | 14.7 | 14.7 |
| 1.A.1,a | Energy Industries - Solid Fuels - Main activity electricity and heat production | $CO_2$ | 185 027.4 | 242 154.0 | 3.0 | 13.0 | 27.7 |
| 1.A.2 | Manufacturing Industries and Construction - Solid Fuels | $CO_2$ | 29 101.6 | 24 472.7 | 2.9 | 12.3 | 40.0 |
| 1.A.1.c | Energy Industries - Liquid Fuels - Manufacture of solid fuels and other energy industries | $CO_2$ | 30 454.7 | 29 903.3 | 1.9 | 8.3 | 48.3 |
| 3.A.1.a | Enteric Fermentation - Cattle | $CH_4$ | 22 819.4 | 21 236.5 | 1.7 | 7.5 | 55.8 |
| 4.A | Solid Waste Disposal | $CH_4$ | 9 367.6 | 18 412.0 | 1.7 | 7.1 | 62.9 |
| 2.C.1 | Metal industry - Iron and Steel Production | $CO_2$ | 16 410.5 | 15 020.7 | 1.3 | 5.6 | 68.5 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - Urine and dung N deposits in PRP | $N_2O$ | 13 180.8 | 11 815.0 | 1.1 | 4.8 | 73.3 |
| 1.A.4.a | Other Sectors - Liquid Fuels - Commercial/Institutional | $CO_2$ | 7 690.4 | 12 685.4 | 0.8 | 3.3 | 76.6 |
| 1.A.3.b | Transport - Liquid Fuels - Road Transportation | $CO_2$ | 32 623.3 | 42 929.6 | 0.6 | 2.5 | 79.2 |
| 2.C.2 | Metal industry - Ferroalloys Production | $CO_2$ | 8 079.1 | 11 623.8 | 0.4 | 1.7 | 80.8 |
| 1.A.4.b | Other Sectors - Liquid Fuels - Residential | $CO_2$ | 2 868.9 | 2 154.6 | 0.3 | 1.5 | 82.3 |
| 2.F.1 | Product uses as substitutes for ODS - Refrigeration and Air Conditioning | HFCs | 0.0 | 1 396.1 | 0.3 | 1.5 | 83.8 |
| 3.A.1.c | Enteric Fermentation – Sheep | $CH_4$ | 4 169.0 | 3 783.5 | 0.3 | 1.5 | 85.3 |
| 1.A.4.a | Other Sectors - Solid Fuels - Commercial/Institutional | $CO_2$ | 1 811.2 | 3 434.8 | 0.3 | 1.2 | 86.5 |
| 1.A.1.b | Energy Industries - Liquid Fuels - Petroleum refining | $CO_2$ | 3 164.8 | 2 802.4 | 0.3 | 1.2 | 87.7 |
| 1.A.3.a | Transport - Liquid Fuels - Civil Aviation | $CO_2$ | 2 040.0 | 3 466.4 | 0.2 | 1.0 | 88.7 |
| 2.C.3 | Metal industry - Aluminium production | PFCs | 982.2 | 1 979.2 | 0.2 | 0.8 | 89.5 |

| IPCC Category code | IPCC Category | GHG | 2000 | 2012 | Trend Assessment (%) | Contribution to trend (%) | Cumulative total (%) |
|---|---|---|---|---|---|---|---|
| | | | (Gg $CO_2$ eq) | | | | |
| 3.C.5 | Indirect $N_2O$ Emissions from managed soils - N leaching/runoff | $N_2O$ | 2 479.0 | 2 330.0 | 0.2 | 0.8 | 90.3 |
| 2.B | Chemical industry - Industry F | $N_2O$ | C[a] | C[a] | 0.2 | 0.8 | 91.0 |
| 1.A.4.c | Other Sectors - Liquid Fuels - Agriculture/Forestry/Fishing/Fish farms | $CO_2$ | 2 207.2 | 3 420.3 | 0.2 | 0.7 | 91.8 |
| 1.A.2 | Manufacturing Industries and Construction - Liquid Fuels | $CO_2$ | 1 186.1 | 2 114.0 | 0.2 | 0.7 | 92.4 |
| 3.C.5 | Indirect $N_2O$ Emissions from managed soils - N volatilization | $N_2O$ | 1 939.5 | 1 791.7 | 0.2 | 0.6 | 93.1 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - Inorganic N application | $N_2O$ | 1 934.7 | 2 000.1 | 0.1 | 0.4 | 93.5 |
| 2.B | Chemical industry - Industry X | $CO_2$ | C[a] | C[a] | 0.1 | 0.4 | 93.9 |
| 2.B | Chemical industry - Industry K | $CO_2$ | C[a] | C[a] | 0.1 | 0.4 | 94.3 |
| 3.A.1.d | Enteric Fermentation - Goats | $CH_4$ | 993.6 | 855.6 | 0.1 | 0.4 | 94.7 |
| 1.A.3.c | Transport - Liquid Fuels - Railways | $CO_2$ | 551.5 | 318.0 | 0.1 | 0.4 | 95.1 |
| 3.C.1.c | Emissions from biomass burning - Grasslands | $N_2O$ | 637.5 | 436.2 | 0.1 | 0.4 | 95.5 |
| 1.A.4.b | Other Sectors - Biomass - Residential | $N_2O$ | 380.9 | 146.6 | 0.1 | 0.3 | 95.8 |
| 2.A.1 | Mineral industry - Cement production | $CO_2$ | 3347.1 | 3844.5 | 0.1 | 0.3 | 96.1 |
| 2.C.3 | Metal industry - Aluminium production | $CO_2$ | 1105.5 | 1066.9 | 0.1 | 0.3 | 96.5 |
| 3.C.3 | Urea application | $CO_2$ | 211.5 | 555.0 | 0.1 | 0.3 | 96.8 |
| 3.A.1.j | Enteric Fermentation - Other | $CH_4$ | 1106.7 | 1106.7 | 0.1 | 0.3 | 97.1 |
| 1.A.2 | Manufacturing Industries and Construction - Gaseous Fuels | $CO_2$ | 2217.7 | 2497.5 | 0.1 | 0.3 | 97.3 |
| 2.C.6 | Metal industry - Zinc Production | $CO_2$ | 194.4 | 0.0 | 0.1 | 0.3 | 97.6 |
| 1.A.4.c | Other Sectors - Solid Fuels - Agriculture/ Forestry/Fishing/Fish farms | $CO_2$ | 171.5 | 0.0 | 0.1 | 0.2 | 97.8 |
| 1.A.4.b | Other Sectors - Biomass - Residential | $CH_4$ | 222.0 | 85.5 | 0.0 | 0.2 | 98.0 |
| 3.A.2.h | Manure management - Swine | $CH_4$ | 612.1 | 586.8 | 0.0 | 0.2 | 98.2 |
| 3.A.2.i | Manure management - Poultry | $N_2O$ | 642.6 | 954.6 | 0.0 | 0.2 | 98.3 |
| 3.C.1.c | Emissions from biomass burning - Grasslands | $CH_4$ | 542.5 | 542.3 | 0.0 | 0.1 | 98.5 |

| IPCC Category code | IPCC Category | GHG | 2000 | 2012 | Trend Assessment (%) | Contribution to trend (%) | Cumulative total (%) |
|---|---|---|---|---|---|---|---|
| | | | (Gg $CO_2$ eq) | | | | |
| 1.A.5.a | Non-Specified - Liquid Fuels - Stationary | $CO_2$ | 985.6 | 1110.5 | 0.0 | 0.1 | 98.6 |
| 3.C.2 | Liming | $CO_2$ | 384.1 | 585.5 | 0.0 | 0.1 | 98.7 |
| 4.D.1 | Wastewater Treatment and Discharge - Domestic | $CH_4$ | 2348.3 | 2827.7 | 0.0 | 0.1 | 98.8 |
| 2.A.2 | Mineral industry - Lime production | $CO_2$ | 426.4 | 453.1 | 0.0 | 0.1 | 98.9 |
| 2.B | Chemical industry - Industry X | $CH_4$ | C[a] | C[a] | 0.0 | 0.1 | 99.0 |
| 3.C.1.b | Emissions from biomass burning - Croplands | $CH_4$ | 244.2 | 233.6 | 0.0 | 0.1 | 99.0 |
| 1.A.4.b | Other Sectors - Solid Fuels - Residential | $N_2O$ | 16.6 | 85.2 | 0.0 | 0.1 | 99.1 |
| 3.A.2.a | Manure management - Cattle | $CH_4$ | 182.6 | 167.5 | 0.0 | 0.1 | 99.2 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - Organic N application | $N_2O$ | 441.3 | 489.8 | 0.0 | 0.1 | 99.2 |
| 1.A.1,a | Energy Industries - Solid Fuels - Main activity electricity and heat production | $N_2O$ | 853.5 | 1117.1 | 0.0 | 0.1 | 99.3 |
| 3.C.1.a | Emissions from biomass burning - Forest lands | $N_2O$ | 151.1 | 133.1 | 0.0 | 0.1 | 99.3 |
| 1.A.2 | Manufacturing Industries and Construction - Solid Fuels | $N_2O$ | 134.2 | 112.9 | 0.0 | 0.1 | 99.4 |
| 1.A.3.b | Transport - Liquid Fuels - Road Transportation | $N_2O$ | 463.0 | 618.1 | 0.0 | 0.0 | 99.5 |
| 1.A.3.c | Transport - Liquid Fuels - Railways | $N_2O$ | 63.0 | 36.3 | 0.0 | 0.0 | 99.5 |
| 3.C.4 | Direct $N_2O$ Emissions from managed soils - N in crop residues | $N_2O$ | 352.8 | 396.9 | 0.0 | 0.0 | 99.5 |
| 2.B | Chemical industry - Industry Q | $CO_2$ | C[a] | C[a] | 0.0 | 0.0 | 99.6 |
| 3.C.1.e | Emissions from biomass burning - Other lands | $CH_4$ | 19.7 | 59.9 | 0.0 | 0.0 | 99.6 |
| 3.A.2.a | Manure management - Cattle | $N_2O$ | 301.0 | 347.0 | 0.0 | 0.0 | 99.6 |
| 3.C.1.a | Emissions from biomass burning - Forest lands | $CH_4$ | 164.6 | 230.8 | 0.0 | 0.0 | 99.7 |
| 1.A.3.b | Transport - Liquid Fuels - Road Transportation | $CH_4$ | 267.6 | 308.9 | 0.0 | 0.0 | 99.7 |
| 3.C.1.b | Emissions from biomass burning - Croplands | $N_2O$ | 81.5 | 77.9 | 0.0 | 0.0 | 99.7 |

| IPCC Category code | IPCC Category | GHG | 2000 | 2012 | Trend Assessment (%) | Contribution to trend (%) | Cumulative total (%) |
|---|---|---|---|---|---|---|---|
| | | | (Gg $CO_2$ eq) | | | | |
| 4.D.1 | Wastewater Treatment and Discharge - Domestic | $N_2O$ | 572.2 | 689.1 | 0.0 | 0.0 | 99.7 |
| 2.A.3 | Mineral industry - Glass Production | $CO_2$ | 74.4 | 113.9 | 0.0 | 0.0 | 99.8 |
| 2.C.5 | Metal industry - Lead Production | $CO_2$ | 39.2 | 27.3 | 0.0 | 0.0 | 99.8 |
| 3.C.1.e | Emissions from biomass burning - Other lands | $N_2O$ | 23.1 | 48.1 | 0.0 | 0.0 | 99.8 |
| 3.A.2.h | Manure management - Swine | $N_2O$ | 63.7 | 61.1 | 0.0 | 0.0 | 99.8 |
| 2.D.1 | Non-Energy Products from Fuels and Solvent Use - Lubricant use | $CO_2$ | 188.5 | 250.6 | 0.0 | 0.0 | 99.8 |
| 3.A.1.h | Enteric Fermentation - Swine | $CH_4$ | 52.1 | 50.0 | 0.0 | 0.0 | 99.9 |
| 3.C.1.d | Emissions from biomass burning - Wetlands | $N_2O$ | 21.1 | 12.5 | 0.0 | 0.0 | 99.9 |
| 3.A.2.i | Manure management - Poultry | $CH_4$ | 54.2 | 80.5 | 0.0 | 0.0 | 99.9 |
| 3.A.1.f | Enteric Fermentation - Horses | $CH_4$ | 111.8 | 127.5 | 0.0 | 0.0 | 99.9 |
| 1.A.1.c | Energy Industries - Liquid Fuels - Manufacture of solid fuels and other energy industries | $N_2O$ | 105.4 | 141.5 | 0.0 | 0.0 | 99.9 |
| 3.A.1.g | Enteric Fermentation - Mules and assess | $CH_4$ | 37.7 | 38.4 | 0.0 | 0.0 | 99.9 |
| 2.D.1 | Non-Energy Products from Fuels and Solvent Use - Paraffin wax use | $CO_2$ | 7.4 | 17.4 | 0.0 | 0.0 | 99.9 |
| 1.A.4.a | Other Sectors - Liquid Fuels - Commercial/Institutional | $N_2O$ | 18.3 | 30.2 | 0.0 | 0.0 | 99.9 |
| 3.C.1.d | Emissions from biomass burning - Wetlands | $CH_4$ | 18.0 | 15.6 | 0.0 | 0.0 | 99.9 |
| 1.A.1.c | Energy Industries - Liquid Fuels - Manufacture of solid fuels and other energy industries | $CH_4$ | 11.6 | 8.4 | 0.0 | 0.0 | 100.0 |
| 1.A.4.a | Other Sectors - Solid Fuels - Commercial/Institutional | $N_2O$ | 8.3 | 15.8 | 0.0 | 0.0 | 100.0 |
| 2.C.2 | Metal industry - Ferroalloys Production | $CH_4$ | 0.0 | 3.4 | 0.0 | 0.0 | 100.0 |
| 1.A.4.b | Other Sectors - Solid Fuels - Residential | $CH_4$ | 0.9 | 4.4 | 0.0 | 0.0 | 100.0 |
| 1.A.4.b | Other Sectors - Liquid Fuels - Residential | $N_2O$ | 5.2 | 3.1 | 0.0 | 0.0 | 100.0 |

| IPCC Category code | IPCC Category | GHG | 2000 | 2012 | Trend Assessment (%) | Contribution to trend (%) | Cumulative total (%) |
|---|---|---|---|---|---|---|---|
| | | | (Gg $CO_2$ eq) | | | | |
| 1.A.1,a | Energy Industries - Solid Fuels - Main activity electricity and heat production | $CH_4$ | 44.2 | 57.9 | 0.0 | 0.0 | 100.0 |
| 1.A.4.a | Other Sectors - Liquid Fuels - Commercial/Institutional | $CH_4$ | 7.1 | 11.7 | 0.0 | 0.0 | 100.0 |
| 1.A.2 | Manufacturing Industries and Construction - Solid Fuels | $CH_4$ | 7.0 | 5.8 | 0.0 | 0.0 | 100.0 |
| 2.B | Chemical industry - Industry S | $CO_2$ | C[a] | C[a] | 0.0 | 0.0 | 100.0 |
| 1.A.3.a | Transport - Liquid Fuels - Civil Aviation | $N_2O$ | 5.1 | 8.6 | 0.0 | 0.0 | 100.0 |
| 3.C.6 | Indirect $N_2O$ Emissions from manure management | $N_2O$ | 350.0 | 436.9 | 0.0 | 0.0 | 100.0 |
| 1.A.4.c | Other Sectors - Liquid Fuels - Agriculture/Forestry/Fishing/Fish farms | $N_2O$ | 5.3 | 8.2 | 0.0 | 0.0 | 100.0 |
| 1.A.1.b | Energy Industries - Liquid Fuels - Petroleum refining | $N_2O$ | 3.2 | 2.3 | 0.0 | 0.0 | 100.0 |
| 1.A.4.a | Other Sectors - Gaseous Fuels - Commercial/Institutional | $CO_2$ | 13.0 | 17.6 | 0.0 | 0.0 | 100.0 |
| 1.A.2 | Manufacturing Industries and Construction - Liquid Fuels | $N_2O$ | 2.8 | 4.9 | 0.0 | 0.0 | 100.0 |
| 1.A.4.b | Other Sectors - Liquid Fuels - Residential | $CH_4$ | 2.2 | 1.4 | 0.0 | 0.0 | 100.0 |
| 3.A.2.f | Manure management - Horses | $CH_4$ | 10.2 | 11.6 | 0.0 | 0.0 | 100.0 |
| 1.A.4.c | Other Sectors - Solid Fuels - Agriculture/Forestry/Fishing/Fish farms | $N_2O$ | 0.8 | 0.0 | 0.0 | 0.0 | 100.0 |
| 1.A.3.a | Transport - Liquid Fuels - Civil Aviation | $CH_4$ | 2.0 | 3.3 | 0.0 | 0.0 | 100.0 |
| 3.A.2.g | Manure management - Mules and asses | $CH_4$ | 3.4 | 3.5 | 0.0 | 0.0 | 100.0 |

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

# 10. APPENDIX C: UNCERTAINTY ANALYSIS

## 10.1 Energy sector uncertainty

| IPCC Category | Gas | Base year emissions / removals | Year t emissions/ removals | Activity data uncertainty | EF uncertainty | Combined uncertainty |
|---|---|---|---|---|---|---|
| | | Gg $CO_2e$ | Gg $CO_2e$ | (+)% | (+)% | (+)% |
| **1.A - Fuel Combustion Activities** | | | | | | |
| 1.A.1.a.i - Electricity Generation - Liquid Fuels | $CO_2$ | 0.00 | 2 527.71 | 5 | 7 | 8.6023 |
| 1.A.1.a.i - Electricity Generation - Liquid Fuels | $CH_4$ | 0.00 | 2.33 | 5 | 75 | 75.1665 |
| 1.A.1.a.i - Electricity Generation - Liquid Fuels | $N_2O$ | 0.00 | 6.00 | 5 | 75 | 75.1665 |
| 1.A.1.a.i - Electricity Generation - Solid Fuels | $CO_2$ | 185 027.44 | 242 154.03 | 5 | 7 | 8.6023 |
| 1.A.1.a.i - Electricity Generation - Solid Fuels | $CH_4$ | 44.21 | 57.87 | 5 | 75 | 75.1665 |
| 1.A.1.a.i - Electricity Generation - Solid Fuels | $N_2O$ | 853.53 | 1 117.05 | 5 | 75 | 75.1665 |
| 1.A.1.b - Petroleum Refining - Liquid Fuels | $CO_2$ | 3 164.79 | 2 802.41 | 5 | 7 | 8.6023 |
| 1.A.1.b - Petroleum Refining - Liquid Fuels | $CH_4$ | 1.67 | 1.35 | 5 | 75 | 75.1665 |
| 1.A.1.b - Petroleum Refining - Liquid Fuels | $N_2O$ | 3.15 | 2.32 | 5 | 75 | 75.1665 |
| 1.A.1.c.i - Manufacture of Solid Fuels - Liquid Fuels | $CO_2$ | 30 454.73 | 29 903.32 | 5 | 7 | 8.6023 |
| 1.A.1.c.i - Manufacture of Solid Fuels - Liquid Fuels | $CH_4$ | 11.64 | 8.42 | 5 | 75 | 75.1665 |
| 1.A.1.c.i - Manufacture of Solid Fuels - Liquid Fuels | $N_2O$ | 105.38 | 141.49 | 5 | 75 | 75.1665 |
| 1.A.1.c.i - Manufacture of Solid Fuels - Solid Fuels | $CO_2$ | 0.00 | 0.00 | 5 | 7 | 8.6023 |
| 1.A.1.c.i - Manufacture of Solid Fuels - Solid Fuels | $CH_4$ | 0.00 | 0.00 | 5 | 75 | 75.1665 |

| Contribution to variance in Year t | Type A sensitivity | Type B sensitivity | Uncertainty in trend in national emissions introduced by EF/ estimation parameter uncertainty | Uncertainty in trend in national emissions introduced by activity data uncertainty | Uncertainty introduced into the trend in total national emissions |
|---|---|---|---|---|---|
| (fraction) | % | % | % | % | % |
| | | | | | |
| 0.0026 | 0.0073 | 0.0073 | 0.0513 | 0.0519 | 0.0053 |
| 0.0000 | 0.0000 | 0.0000 | 0.0005 | 0.0000 | 0.0000 |
| 0.0000 | 0.0000 | 0.0000 | 0.0013 | 0.0001 | 0.0000 |
| 23.4730 | 0.0328 | 0.7025 | 0.2295 | 4.9675 | 24.7291 |
| 0.0001 | 0.0000 | 0.0002 | 0.0006 | 0.0012 | 0.0000 |
| 0.0381 | 0.0002 | 0.0032 | 0.0114 | 0.0229 | 0.0007 |
| 0.0031 | 0.0033 | 0.0081 | 0.0233 | 0.0575 | 0.0038 |
| 0.0000 | 0.0000 | 0.0000 | 0.0002 | 0.0000 | 0.0000 |
| 0.0000 | 0.0000 | 0.0000 | 0.0004 | 0.0000 | 0.0000 |
| 0.3580 | 0.0234 | 0.0868 | 0.1640 | 0.6134 | 0.4032 |
| 0.0000 | 0.0000 | 0.0000 | 0.0013 | 0.0002 | 0.0000 |
| 0.0006 | 0.0000 | 0.0004 | 0.0022 | 0.0029 | 0.0000 |
| 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

| IPCC Category | Gas | Base year emissions / removals | Year t emissions/ removals | Activity data uncertainty | EF uncertainty | Combined uncertainty |
|---|---|---|---|---|---|---|
| | | Gg $CO_2$e | Gg $CO_2$e | (+)% | (+)% | (+)% |
| 1.A.1.c.i - Manufacture of Solid Fuels - Solid Fuels | $N_2O$ | 0.00 | 0.00 | 5 | 75 | 75.1665 |
| 1.A.1.c.ii - Other Energy Industries - Liquid Fuels | $CO_2$ | 0.00 | 0.00 | 10 | 7 | 12.2066 |
| 1.A.1.c.ii - Other Energy Industries - Liquid Fuels | $CH_4$ | 0.00 | 0.00 | 10 | 75 | 75.6637 |
| 1.A.1.c.ii - Other Energy Industries - Liquid Fuels | $N_2O$ | 0.00 | 0.00 | 10 | 75 | 75.6637 |
| 1.A.2 - Manufacturing Industries and Construction - Liquid Fuels | $CO_2$ | 1 186.10 | 2 114.02 | 10 | 7 | 12.2066 |
| 1.A.2 - Manufacturing Industries and Construction - Liquid Fuels | $CH_4$ | 1.07 | 1.90 | 10 | 75 | 75.6637 |
| 1.A.2 - Manufacturing Industries and Construction - Liquid Fuels | $N_2O$ | 2.75 | 4.90 | 10 | 75 | 75.6637 |
| 1.A.2 - Manufacturing Industries and Construction - Solid Fuels | $CO_2$ | 29 101.57 | 24 472.72 | 10 | 7 | 12.2066 |
| 1.A.2 - Manufacturing Industries and Construction - Solid Fuels | $CH_4$ | 6.95 | 5.85 | 10 | 75 | 75.6637 |
| 1.A.2 - Manufacturing Industries and Construction - Solid Fuels | $N_2O$ | 134.25 | 112.89 | 10 | 75 | 75.6637 |
| 1.A.2 - Manufacturing Industries and Construction - Gaseous Fuels | $CO_2$ | 2 217.75 | 2 497.46 | 10 | 7 | 12.2066 |
| 1.A.2 - Manufacturing Industries and Construction - Gaseous Fuels | $CH_4$ | 0.91 | 1.02 | 10 | 75 | 75.6637 |
| 1.A.2 - Manufacturing Industries and Construction - Gaseous Fuels | $N_2O$ | 1.17 | 1.32 | 10 | 75 | 75.6637 |
| 1.A.3.a.i - International Aviation (International Bunkers) - Liquid Fuels | $CO_2$ | 2 972.40 | 2 413.48 | 5 | 1.5 | 5.2202 |

| | Contri-bution to variance in Year t | Type A sensitivity | Type B sensitivity | Uncertainty in trend in national emissions introduced by EF/ estimation parameter uncertainty | Uncertainty in trend in national emissions introduced by activity data uncertainty | Uncertainty introduced into the trend in total national emissions |
|---|---|---|---|---|---|---|
| | (fraction) | % | % | % | % | % |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0036 | 0.0018 | 0.0061 | 0.0129 | 0.0867 | 0.0077 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0001 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0003 | 0.0002 | 0.0000 |
| | 0.4827 | 0.0343 | 0.0710 | 0.2400 | 1.0041 | 1.0657 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0006 | 0.0002 | 0.0000 |
| | 0.0004 | 0.0002 | 0.0003 | 0.0119 | 0.0046 | 0.0002 |
| | 0.0050 | 0.0008 | 0.0072 | 0.0055 | 0.1025 | 0.0105 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0000 |
| | 0.0009 | 0.0038 | 0.0070 | 0.0056 | 0.0495 | 0.0025 |

| IPCC Category | Gas | Base year emissions / removals | Year t emissions/ removals | Activity data uncertainty | EF uncertainty | Combined uncertainty | |
|---|---|---|---|---|---|---|---|
| | | Gg $CO_2$e | Gg $CO_2$e | (+)% | (+)% | (+)% | |
| 1.A.3.a.i - International Aviation (International Bunkers) - Liquid Fuels | $CH_4$ | 2.87 | 2.33 | 5 | 50 | 50.2494 | |
| 1.A.3.a.i - International Aviation (International Bunkers) - Liquid Fuels | $N_2O$ | 7.38 | 5.99 | 5 | 50 | 50.2494 | |
| 1.A.3.a.ii - Domestic Aviation - Liquid Fuels | $CO_2$ | 2 040.00 | 3 466.36 | 5 | 1.5 | 5.2202 | |
| 1.A.3.a.ii - Domestic Aviation - Liquid Fuels | $CH_4$ | 1.97 | 3.35 | 5 | 50 | 50.2494 | |
| 1.A.3.a.ii - Domestic Aviation - Liquid Fuels | $N_2O$ | 5.07 | 8.61 | 5 | 50 | 50.2494 | |
| 1.A.3.b - Road Transportation - Liquid Fuels | $CO_2$ | 32 623.34 | 42 929.58 | 5 | 2 | 5.3852 | |
| 1.A.3.b - Road Transportation - Liquid Fuels | $CH_4$ | 267.59 | 308.90 | 5 | 9 | 10.2956 | |
| 1.A.3.b - Road Transportation - Liquid Fuels | $N_2O$ | 463.05 | 618.12 | 5 | 72 | 72.1734 | |
| 1.A.3.c - Railways - Liquid Fuels | $CO_2$ | 551.45 | 317.96 | 5 | 2 | 5.3852 | |
| 1.A.3.c - Railways - Liquid Fuels | $CH_4$ | 0.71 | 0.41 | 5 | 9 | 10.2956 | |
| 1.A.3.c - Railways - Liquid Fuels | $N_2O$ | 63.00 | 36.33 | 5 | 72 | 72.1734 | |
| 1.A.4.a - Commercial/ Institutional - Liquid Fuels | $CO_2$ | 7 690.43 | 12 685.42 | 10 | 7 | 12.2066 | |
| 1.A.4.a - Commercial/ Institutional - Liquid Fuels | $CH_4$ | 7.10 | 11.74 | 10 | 75 | 75.6637 | |
| 1.A.4.a - Commercial/ Institutional - Liquid Fuels | $N_2O$ | 18.27 | 30.22 | 10 | 75 | 75.6637 | |
| 1.A.4.a - Commercial/ Institutional - Solid Fuels | $CO_2$ | 1 811.19 | 3 434.78 | 10 | 7 | 12.2066 | |
| 1.A.4.a - Commercial/ Institutional - Solid Fuels | $CH_4$ | 0.44 | 0.82 | 10 | 75 | 75.6637 | |
| 1.A.4.a - Commercial/ Institutional - Solid Fuels | $N_2O$ | 8.31 | 15.84 | 10 | 75 | 75.6637 | |

| | Contri-bution to variance in Year t | Type A sensitivity | Type B sensitivity | Uncertainty in trend in national emissions introduced by EF/ estimation parameter uncertainty | Uncertainty in trend in national emissions introduced by activity data uncertainty | Uncertainty introduced into the trend in total national emissions |
|---|---|---|---|---|---|---|
| | (fraction) | % | % | % | % | % |
| | 0.0000 | 0.0000 | 0.0000 | 0.0002 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0005 | 0.0001 | 0.0000 |
| | 0.0018 | 0.0027 | 0.0101 | 0.0040 | 0.0711 | 0.0051 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0001 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0003 | 0.0002 | 0.0000 |
| | 0.2891 | 0.0065 | 0.1245 | 0.0130 | 0.8807 | 0.7757 |
| | 0.0001 | 0.0001 | 0.0009 | 0.0006 | 0.0063 | 0.0000 |
| | 0.0108 | 0.0001 | 0.0018 | 0.0085 | 0.0127 | 0.0002 |
| | 0.0000 | 0.0011 | 0.0009 | 0.0021 | 0.0065 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0001 | 0.0001 | 0.0088 | 0.0007 | 0.0001 |
| | 0.1297 | 0.0090 | 0.0368 | 0.0628 | 0.5205 | 0.2748 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0006 | 0.0005 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0001 | 0.0016 | 0.0012 | 0.0000 |
| | 0.0095 | 0.0034 | 0.0100 | 0.0239 | 0.1409 | 0.0204 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0012 | 0.0007 | 0.0000 |

| IPCC Category | Gas | Base year emissions / removals | Year t emissions/ removals | Activity data uncertainty | EF uncertainty | Combined uncertainty | |
|---|---|---|---|---|---|---|---|
| | | Gg $CO_2e$ | Gg $CO_2e$ | (+)% | (+)% | (+)% | |
| 1.A.4.a - Commercial/ Institutional - Gaseous Fuels | $CO_2$ | 12.96 | 17.62 | 10 | 7 | 12.2066 | |
| 1.A.4.a - Commercial/ Institutional - Gaseous Fuels | $CH_4$ | 0.01 | 0.01 | 10 | 75 | 75.6637 | |
| 1.A.4.a - Commercial/ Institutional - Gaseous Fuels | $N_2O$ | 0.01 | 0.01 | 10 | 75 | 75.6637 | |
| 1.A.4.b - Residential - Liquid Fuels | $CO_2$ | 2 868.85 | 2 154.59 | 10 | 7 | 12.2066 | |
| 1.A.4.b - Residential - Liquid Fuels | $CH_4$ | 2.19 | 1.41 | 10 | 75 | 75.6637 | |
| 1.A.4.b - Residential - Liquid Fuels | $N_2O$ | 5.18 | 3.11 | 10 | 75 | 75.6637 | |
| 1.A.4.b - Residential - Solid Fuels | $CO_2$ | 3 604.18 | 18 461.91 | 10 | 7 | 12.2066 | |
| 1.A.4.b - Residential - Solid Fuels | $CH_4$ | 0.86 | 4.41 | 10 | 75 | 75.6637 | |
| 1.A.4.b - Residential - Solid Fuels | $N_2O$ | 16.63 | 85.16 | 10 | 75 | 75.6637 | |
| 1.A.4.b - Residential - Biomass | $CO_2$ | 0.00 | 0.00 | 40 | 7 | 40.6079 | |
| 1.A.4.b - Residential - Biomass | $CH_4$ | 221.96 | 85.46 | 40 | 75 | 85.0000 | |
| 1.A.4.b - Residential - Biomass | $N_2O$ | 380.87 | 146.64 | 40 | 75 | 85.0000 | |
| 1.A.4.c.i - Stationary - Liquid Fuels | $CO_2$ | 2 207.17 | 3 420.32 | 10 | 7 | 12.2066 | |
| 1.A.4.c.i - Stationary - Liquid Fuels | $CH_4$ | 2.07 | 3.20 | 10 | 75 | 75.6637 | |
| 1.A.4.c.i - Stationary - Liquid Fuels | $N_2O$ | 5.32 | 8.23 | 10 | 75 | 75.6637 | |
| 1.A.4.c.i - Stationary - Solid Fuels | $CO_2$ | 171.52 | 0.00 | 10 | 7 | 12.2066 | |
| 1.A.4.c.i - Stationary - Solid Fuels | $CH_4$ | 0.04 | 0.00 | 10 | 75 | 75.6637 | |
| 1.A.4.c.i - Stationary - Solid Fuels | $N_2O$ | 0.79 | 0.00 | 10 | 75 | 75.6637 | |
| 1.A.4.c.ii - Off-road Vehicles and Other Machinery - Liquid Fuels | $CO_2$ | 0.00 | 0.00 | 2 | 2 | 2.8284 | |
| 1.A.4.c.ii - Off-road Vehicles and Other Machinery - Liquid Fuels | $CH_4$ | 0.00 | 0.00 | 2 | 9 | 9.2195 | |

| | Contri-bution to variance in Year t | Type A sensitivity | Type B sensitivity | Uncertainty in trend in national emissions introduced by EF/ estimation parameter uncertainty | Uncertainty in trend in national emissions introduced by activity data uncertainty | Uncertainty introduced into the trend in total national emissions |
|---|---|---|---|---|---|---|
| | (fraction) | % | % | % | % | % |
| | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0007 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0037 | 0.0041 | 0.0063 | 0.0289 | 0.0884 | 0.0087 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0003 | 0.0001 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0007 | 0.0001 | 0.0000 |
| | 0.2747 | 0.0405 | 0.0536 | 0.2836 | 0.7575 | 0.6542 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0007 | 0.0002 | 0.0000 |
| | 0.0002 | 0.0002 | 0.0002 | 0.0140 | 0.0035 | 0.0002 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0003 | 0.0006 | 0.0002 | 0.0416 | 0.0140 | 0.0019 |
| | 0.0008 | 0.0010 | 0.0004 | 0.0715 | 0.0241 | 0.0057 |
| | 0.0094 | 0.0019 | 0.0099 | 0.0135 | 0.1403 | 0.0199 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0001 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0003 | 0.0003 | 0.0000 |
| | 0.0000 | 0.0006 | 0.0000 | 0.0043 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0002 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

| IPCC Category | Gas | Base year emissions / removals | Year t emissions/ removals | Activity data uncertainty | EF uncertainty | Combined uncertainty | |
|---|---|---|---|---|---|---|---|
| | | Gg $CO_2$e | Gg $CO_2$e | (+)% | (+)% | (+)% | |
| 1.A.4.c.ii - Off-road Vehicles and Other Machinery - Liquid Fuels | $N_2O$ | 0.00 | 0.00 | 2 | 72 | 72.0278 | |
| 1.A.4.c.iii - Fishing (mobile combustion) - Liquid Fuels | $CO_2$ | 0.00 | 0.00 | 2 | 2 | 2.8284 | |
| 1.A.4.c.iii - Fishing (mobile combustion) - Liquid Fuels | $CH_4$ | 0.00 | 0.00 | 2 | 9 | 9.2195 | |
| 1.A.4.c.iii - Fishing (mobile combustion) - Liquid Fuels | $N_2O$ | 0.00 | 0.00 | 2 | 72 | 72.0278 | |
| 1.A.5.a - Stationary - Liquid Fuels | $CO_2$ | 985.58 | 1 110.53 | 5 | 7 | 8.6023 | |
| 1.A.5.a - Stationary - Liquid Fuels | $CH_4$ | 0.98 | 1.11 | 5 | 75 | 75.1665 | |
| 1.A.5.a - Stationary - Liquid Fuels | $N_2O$ | 2.53 | 2.85 | 5 | 75 | 75.1665 | |
| 1.A.3.b.vi - Urea-based catalysts | $CO_2$ | 0.00 | 0.00 | 30 | 7 | 30.8058 | |
| **1.B.1 - Fugitive Emissions from Fuels - Solid Fuels** | | | | | | | |
| 1.B.1.a.i.1 - Mining | $CO_2$ | 19.18 | 16.74 | 10 | 63 | 63.7887 | |
| 1.B.1.a.i.1 - Mining | $CH_4$ | 1 603.94 | 1 409.65 | 10 | 63 | 63.7887 | |
| 1.B.1.a.i.2 - Post-mining seam gas emissions | $CO_2$ | 4.48 | 3.91 | 10 | 50 | 50.9902 | |
| 1.B.1.a.i.2 - Post-mining seam gas emissions | $CH_4$ | 374.95 | 329.53 | 10 | 50 | 50.9902 | |
| 1.B.1.a.i.3 - Abandoned underground mines | $CH_4$ | 0.00 | 0.00 | 10 | 50 | 50.9902 | |
| 1.B.1.a.i.4 - Flaring of drained methane or conversion of methane to $CO_2$ | $CH_4$ | 0.00 | 0.00 | 10 | 50 | 50.9902 | |
| 1.B.1.a.ii.1 - Mining | $CO_2$ | 0.00 | 0.00 | 10 | 63 | 63.7887 | |
| 1.B.1.a.ii.1 - Mining | $CH_4$ | 0.00 | 0.00 | 10 | 63 | 63.7887 | |
| 1.B.1.a.ii.2 - Post-mining seam gas emissions | $CO_2$ | 0.00 | 0.00 | 10 | 50 | 50.9902 | |
| 1.B.1.a.ii.2 - Post-mining seam gas emissions | $CH_4$ | 0.00 | 0.00 | 10 | 50 | 50.9902 | |

| | Contri-bution to variance in Year t | Type A sensitivity | Type B sensitivity | Uncertainty in trend in national emissions introduced by EF/ estimation parameter uncertainty | Uncertainty in trend in national emissions introduced by activity data uncertainty | Uncertainty introduced into the trend in total national emissions |
|---|---|---|---|---|---|---|
| | (fraction) | % | % | % | % | % |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0005 | 0.0003 | 0.0032 | 0.0024 | 0.0228 | 0.0005 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0001 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | | | | | | |
| | 0.0000 | 0.0000 | 0.0000 | 0.0013 | 0.0007 | 0.0000 |
| | 0.0437 | 0.0017 | 0.0041 | 0.1080 | 0.0578 | 0.0150 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0002 | 0.0002 | 0.0000 |
| | 0.0015 | 0.0004 | 0.0010 | 0.0200 | 0.0135 | 0.0006 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

| IPCC Category | Gas | Base year emissions / removals | Year t emissions/ removals | Activity data uncertainty | EF uncertainty | Combined uncertainty |
|---|---|---|---|---|---|---|
| | | Gg $CO_2e$ | Gg $CO_2e$ | (+)% | (+)% | (+)% |
| **1.B.2 - Fugitive Emissions from Fuels - Oil and Natural Gas** | | | | | | |
| 1.B.2.a.i - Venting | $CO_2$ | 0.00 | 0.00 | 25 | 75 | 79.0569 |
| 1.B.2.a.i - Venting | $CH_4$ | 0.00 | 0.00 | 25 | 75 | 79.0569 |
| 1.B.2.a.i - Venting | $N_2O$ | 0.00 | 0.00 | 25 | 75 | 79.0569 |
| 1.B.2.a.ii - Flaring | $CO_2$ | 752.04 | 641.83 | 25 | 75 | 79.0569 |
| 1.B.2.a.ii - Flaring | $CH_4$ | 0.00 | 0.00 | 25 | 75 | 79.0569 |
| 1.B.3 - Other emissions from Energy Production | $CO_2$ | 28 146.58 | 25 136.44 | 25 | 75 | 79.0569 |
| 1.B.3 - Other emissions from Energy Production | $CH_4$ | 2 450.60 | 2 684.17 | 25 | 75 | 79.0569 |
| **1.C - $CO_2$ Transport Injection and Storage** | | | | | | |
| **TOTAL** | | | | | | |
| **Sum** | | 344 695.0945 | 429 955.4182 | | | |
| | | | | | | **Uncertainty in total inventory** |

| | Contri-bution to variance in Year t | Type A sensitivity | Type B sensitivity | Uncertainty in trend in national emissions introduced by EF/ estimation parameter uncertainty | Uncertainty in trend in national emissions introduced by activity data uncertainty | Uncertainty introduced into the trend in total national emissions |
|---|---|---|---|---|---|---|
| | (fraction) | % | % | % | % | % |
| | | | | | | |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0139 | 0.0009 | 0.0019 | 0.0645 | 0.0658 | 0.0085 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 21.3619 | 0.0289 | 0.0729 | 2.1680 | 2.5782 | 11.3476 |
| | 0.2436 | 0.0011 | 0.0078 | 0.0811 | 0.2753 | 0.0824 |
| | | | | | | |
| | | | | | | |
| | 46.76 | | | | | 39.45 |
| | 6.84 | | | | **Trend uncertainty** | 6.28 |

## 10.2 IPPU sector uncertainty

| IPCC Category | Gas | Base year emissions / removals | Year t emissions/ removals | Activity data uncertainty | EF uncertainty | Combined uncertainty |
|---|---|---|---|---|---|---|
| | | Gg $CO_2$e | Gg $CO_2$e | (+)% | (+)% | (+)% |
| **2.A - Mineral Industry** | | | | | | |
| 2.A.1 - Cement production | $CO_2$ | 3 347.05 | 3 844.50 | 1 | 4.5 | 4.6098 |
| 2.A.2 - Lime production | $CO_2$ | 426.37 | 453.09 | 1 | 6 | 6.0828 |
| 2.A.3 - Glass Production | $CO_2$ | 74.36 | 113.91 | 5 | 60 | 60.2080 |
| 2.A.4.a - Ceramics | $CO_2$ | 0.00 | 0.00 | 43 | 2.5 | 43.0726 |
| 2.A.4.b - Other Uses of Soda Ash | $CO_2$ | 0.00 | 0.00 | 43 | 2.5 | 43.0726 |
| 2.A.4.c - Non Metallurgical Magnesia Production | $CO_2$ | 0.00 | 0.00 | 43 | 2.5 | 43.0726 |
| 2.A.4.d - Other (please specify) | $CO_2$ | 0.00 | 0.00 | 43 | 2.5 | 43.0726 |
| **2.B - Chemical Industry** | | | | | | |
| 2.B.1 - Ammonia Production | $CO_2$ | 485.28 | 217.80 | 5 | 6 | 7.8102 |
| 2.B.1 - Ammonia Production | $CH_4$ | 71.81 | 70.10 | 5 | 6 | 7.8102 |
| 2.B.2 - Nitric Acid Production | $N_2O$ | 1 570.25 | 745.00 | 2 | 10 | 10.1980 |
| 2.B.3 - Adipic Acid Production | $N_2O$ | 0.00 | 0.00 | 2 | 10 | 10.1980 |
| 2.B.4 - Caprolactam, Glyoxal and Glyoxylic Acid Production | $N_2O$ | 0.00 | 0.00 | 2 | 40 | 40.0500 |
| 2.B.5 - Carbide Production | $CO_2$ | 1.98 | 5.20 | 5 | 10 | 11.1803 |
| 2.B.5 - Carbide Production | $CH_4$ | 0.00 | 0.00 | 5 | 10 | 11.1803 |
| 2.B.6 - Titanium Dioxide Production | $CO_2$ | 437.62 | 158.66 | 5 | 10 | 11.1803 |
| 2.B.7 - Soda Ash Production | $CO_2$ | 0.00 | 0.00 | 5 | 10 | 11.1803 |
| 2.B.8.a - Methanol | $CO_2$ | 0.00 | 0.00 | 30 | 30 | 42.4264 |
| 2.B.8.a - Methanol | $CH_4$ | 0.00 | 0.00 | 30 | 30 | 42.4264 |
| 2.B.8.b - Ethylene | $CO_2$ | 0.00 | 0.00 | 30 | 30 | 42.4264 |
| 2.B.8.b - Ethylene | $CH_4$ | 0.00 | 0.00 | 30 | 30 | 42.4264 |
| 2.B.8.c - Ethylene Dichloride and Vinyl Chloride Monomer | $CO_2$ | 0.00 | 0.00 | 2 | 20 | 20.0998 |
| 2.B.8.c - Ethylene Dichloride and Vinyl Chloride Monomer | $CH_4$ | 0.00 | 0.00 | 2 | 10 | 10.1980 |
| 2.B.8.d - Ethylene Oxide | $CO_2$ | 0.00 | 0.00 | 10 | 10 | 14.1421 |

| | Contri-bution to variance in Year t | Type A sensitivity | Type B sensitivity | Uncertainty in trend in national emissions introduced by EF/ estimation parameter uncertainty | Uncertainty in trend in national emissions introduced by activity data uncertainty | Uncertainty introduced into the trend in total national emissions |
|---|---|---|---|---|---|---|
| | (fraction) | % | % | % | % | % |
| | | | | | | |
| | 0.0001 | 4.4815 | 0.1140 | 20.1670 | 0.1612 | 406.7328 |
| | 0.0000 | 0.5725 | 0.0134 | 3.4349 | 0.0190 | 11.7986 |
| | 0.0000 | 0.0988 | 0.0034 | 5.9289 | 0.0239 | 35.1527 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | | | | | | |
| | 0.0000 | 0.6604 | 0.0065 | 3.9623 | 0.0457 | 15.7020 |
| | 0.0000 | 0.0966 | 0.0021 | 0.5796 | 0.0147 | 0.3362 |
| | 0.0000 | 2.1350 | 0.0221 | 21.3498 | 0.0625 | 455.8180 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0026 | 0.0002 | 0.0257 | 0.0011 | 0.0007 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.5967 | 0.0047 | 5.9665 | 0.0333 | 35.6007 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

| IPCC Category | Gas | Base year emissions / removals | Year t emissions/ removals | Activity data uncertainty | EF uncertainty | Combined uncertainty | |
|---|---|---|---|---|---|---|---|
| | | Gg $CO_2$e | Gg $CO_2$e | (+)% | (+)% | (+)% | |
| 2.B.8.d - Ethylene Oxide | $CH_4$ | 0.00 | 0.00 | 10 | 60 | 60.8276 | |
| 2.B.8.e - Acrylonitrile | $CO_2$ | 0.00 | 0.00 | 10 | 10 | 14.1421 | |
| 2.B.8.e - Acrylonitrile | $CH_4$ | 0.00 | 0.00 | 10 | 60 | 60.8276 | |
| 2.B.8.f - Carbon Black | $CO_2$ | 138.57 | 134.88 | 10 | 15 | 18.0278 | |
| 2.B.8.f - Carbon Black | $CH_4$ | 0.07 | 0.07 | 10 | 85 | 85.5862 | |
| **2.D - Non-Energy Products from Fuels and Solvent Use** | | | | | | | |
| 2.C.1 - Iron and Steel Production | $CO_2$ | 16 410.53 | 15 020.70 | 5 | 25 | 25.4951 | |
| 2.C.1 - Iron and Steel Production | $CH_4$ | 0.00 | 0.00 | 5 | 25 | 25.4951 | |
| 2.C.2 - Ferroalloys Production | $CO_2$ | 8 079.14 | 11 623.80 | 5 | 25 | 25.4951 | |
| 2.C.2 - Ferroalloys Production | $CH_4$ | 3.62 | 3.37 | 5 | 25 | 25.4951 | |
| 2.C.3 - Aluminium production | $CO_2$ | 1 105.47 | 1 066.90 | 5 | 10 | 11.1803 | |
| 2.C.3 - Aluminium production | $CF_4$ | 982.17 | 1 970.91 | 5 | 190 | 190.0658 | |
| 2.C.3 - Aluminium production | $C_2F_6$ | 156.94 | 325.74 | 5 | 190 | 190.0658 | |
| 2.C.4 - Magnesium production | $CO_2$ | 0.00 | 0.00 | | | 0.0000 | |
| 2.C.4 - Magnesium production | $SF_6$ | 0.00 | 0.00 | | | 0.0000 | |
| 2.C.5 - Lead Production | $CO_2$ | 39.16 | 27.29 | 5 | 15 | 15.8114 | |
| 2.C.6 - Zinc Production | $CO_2$ | 194.36 | 0.00 | 10 | 50 | 50.9902 | |
| **2.C - Metal Industry** | | | | | | | |
| 2.D.1 - Lubricant Use | $CO_2$ | 188.48 | 250.58 | 10 | 50 | 50.9902 | |
| 2.D.2 - Paraffin Wax Use | $CO_2$ | 7.44 | 17.42 | 10 | 100 | 100.4988 | |
| **2.E - Electronics Industry** | | | | | | | |
| **2.F - Product Uses as Substitutes for Ozone Depleting Substances** | | | | | | | |
| 2.F.1. - Refrigeration and Stationary Air Conditioning | HFC-23 | 0.00 | 7 400.00 | 25 | 25 | 35.3553 | |
| 2.F.1. - Refrigeration and Stationary Air Conditioning | HFC-32 | 0.00 | 0.00 | 25 | 25 | 35.3553 | |
| 2.F.1. - Refrigeration and Stationary Air Conditioning | HFC-41 | 0.00 | 0.00 | 25 | 25 | 35.3553 | |
| 2.F.1. - Refrigeration and Stationary Air Conditioning | HFC-43-10mee | 0.00 | 0.00 | 25 | 25 | 35.3553 | |

| | Contri-bution to variance in Year t | Type A sensitivity | Type B sensitivity | Uncertainty in trend in national emissions introduced by EF/ estimation parameter uncertainty | Uncertainty in trend in national emissions introduced by activity data uncertainty | Uncertainty introduced into the trend in total national emissions |
|---|---|---|---|---|---|---|
| | (fraction) | % | % | % | % | % |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.1864 | 0.0040 | 2.7966 | 0.0566 | 7.8243 |
| | 0.0000 | 0.0001 | 0.0000 | 0.0083 | 0.0000 | 0.0001 |
| | | | | | | |
| | 0.0601 | 22.0012 | 0.4454 | 550.0305 | 3.1498 | 302 543.4944 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0360 | 10.7331 | 0.3447 | 268.3278 | 2.4375 | 72 005.7599 |
| | 0.0000 | 0.0049 | 0.0001 | 0.1217 | 0.0007 | 0.0148 |
| | 0.0001 | 1.4872 | 0.0316 | 14.8717 | 0.2237 | 221.2178 |
| | 0.0575 | 1.2910 | 0.0584 | 245.2944 | 0.4133 | 60 169.5366 |
| | 0.0016 | 0.2060 | 0.0097 | 39.1434 | 0.0683 | 1 532.2117 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0530 | 0.0008 | 0.7951 | 0.0057 | 0.6321 |
| | 0.0000 | 0.2671 | 0.0000 | 13.3551 | 0.0000 | 178.3593 |
| | | | | | | |
| | 0.0001 | 0.2516 | 0.0074 | 12.5797 | 0.1051 | 158.2591 |
| | 0.0000 | 0.0097 | 0.0005 | 0.9703 | 0.0073 | 0.9415 |
| | | | | | | |
| | | | | | | |
| | 0.0280 | 0.2194 | 0.2194 | 5.4862 | 7.7587 | 90.2968 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

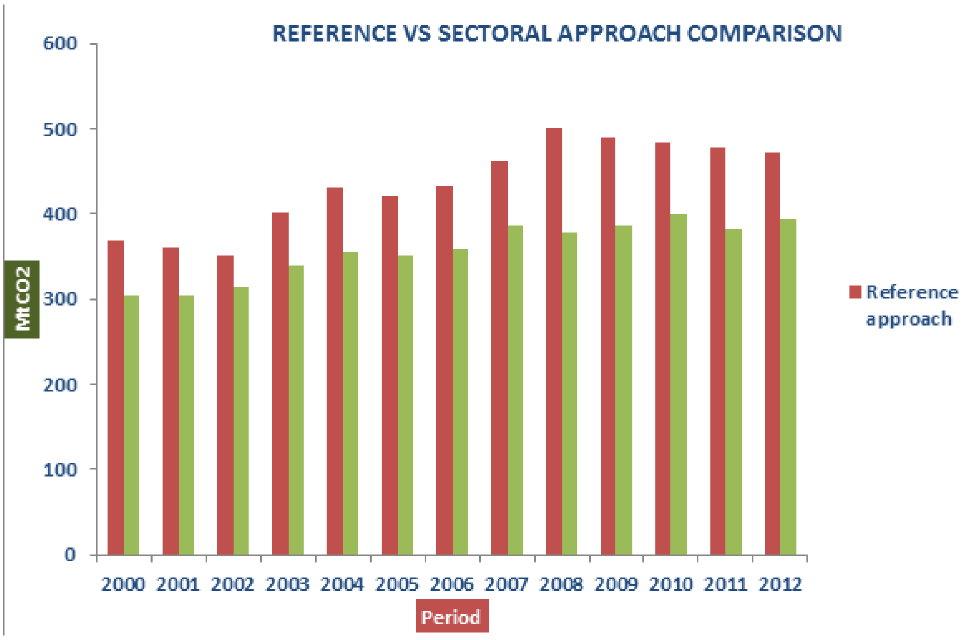
| IPCC Category | Gas | Base year emissions / removals | Year t emissions/ removals | Activity data uncertainty | EF uncertainty | Combined uncertainty | |
|---|---|---|---|---|---|---|---|
| | | Gg $CO_2$e | Gg $CO_2$e | (+)% | (+)% | (+)% | |
| 2.F.1. - Refrigeration and Stationary Air Conditioning | HFC-125 | 0.00 | 30 450.00 | 25 | 25 | 35.3553 | |
| 2.F.1. - Refrigeration and Stationary Air Conditioning | HFC-134 | 0.00 | 0.00 | 25 | 25 | 35.3553 | |
| 2.F.1. - Refrigeration and Stationary Air Conditioning | HFC-134a | 0.00 | 1 355 640.00 | 25 | 25 | 35.3553 | |
| 2.F.1. - Refrigeration and Stationary Air Conditioning | HFC-152a | 0.00 | 0.00 | 25 | 25 | 35.3553 | |
| 2.F.1. - Refrigeration and Stationary Air Conditioning | HFC-143 | 0.00 | 0.00 | 25 | 25 | 35.3553 | |
| 2.F.1. - Refrigeration and Stationary Air Conditioning | HFC-143a | 0.00 | 133 206.00 | 25 | 25 | 35.3553 | |
| 2.F.1. - Refrigeration and Stationary Air Conditioning | HFC-227ea | 0.00 | 0.00 | 25 | 25 | 35.3553 | |
| 2.F.1. - Refrigeration and Stationary Air Conditioning | HFC-236fa | 0.00 | 0.00 | 25 | 25 | 35.3553 | |
| 2.F.1. - Refrigeration and Stationary Air Conditioning | HFC-245ca | 0.00 | 0.00 | 25 | 25 | 35.3553 | |
| 2.F.1. - Refrigeration and Stationary Air Conditioning | HFC-152 | 0.00 | 0.00 | 25 | 25 | 35.3553 | |
| 2.F.1. - Refrigeration and Stationary Air Conditioning | HFC-161 | 0.00 | 0.00 | 25 | 25 | 35.3553 | |
| 2.F.1. - Refrigeration and Stationary Air Conditioning | HFC-236cb | 0.00 | 0.00 | 25 | 25 | 35.3553 | |
| 2.F.1. - Refrigeration and Stationary Air Conditioning | HFC-236ea | 0.00 | 0.00 | 25 | 25 | 35.3553 | |
| 2.F.1. - Refrigeration and Stationary Air Conditioning | HFC-245fa | 0.00 | 0.00 | 25 | 25 | 35.3553 | |
| 2.F.1. - Refrigeration and Stationary Air Conditioning | HFC-365mfc | 0.00 | 0.00 | 25 | 25 | 35.3553 | |
| 2.F.1. - Refrigeration and Stationary Air Conditioning | CF4 | 0.00 | 0.00 | 25 | 25 | 35.3553 | |

| | Contri-bution to variance in Year t | Type A sensitivity | Type B sensitivity | Uncertainty in trend in national emissions introduced by EF/ estimation parameter uncertainty | Uncertainty in trend in national emissions introduced by activity data uncertainty | Uncertainty introduced into the trend in total national emissions |
|---|---|---|---|---|---|---|
| | (fraction) | % | % | % | % | % |
| | 0.4746 | 0.9030 | 0.9030 | 22.5752 | 31.9261 | 1 528.9155 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 940.6369 | 40.2020 | 40.2020 | 1 005.0512 | 1 421.3570 | 3 030 383.7487 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 9.0820 | 3.9503 | 3.9503 | 98.7569 | 139.6634 | 29 258.7961 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

| IPCC Category | Gas | Base year emissions / removals | Year t emissions/ removals | Activity data uncertainty | EF uncertainty | Combined uncertainty | |
|---|---|---|---|---|---|---|---|
| | | Gg $CO_2$e | Gg $CO_2$e | (+)% | (+)% | (+)% | |
| 2.F.1. - Refrigeration and Stationary Air Conditioning | C2F6 | 0.00 | 0.00 | 25 | 25 | 35.3553 | |
| 2.F.1. - Refrigeration and Stationary Air Conditioning | C3F8 | 0.00 | 0.00 | 25 | 25 | 35.3553 | |
| 2.F.1. - Refrigeration and Stationary Air Conditioning | C4F10 | 0.00 | 0.00 | 25 | 25 | 35.3553 | |
| 2.F.1. - Refrigeration and Stationary Air Conditioning | c-C4F8 | 0.00 | 0.00 | 25 | 25 | 35.3553 | |
| 2.F.1. - Refrigeration and Stationary Air Conditioning | C5F12 | 0.00 | 0.00 | 25 | 25 | 35.3553 | |
| 2.F.1. - Refrigeration and Stationary Air Conditioning | C6F14 | 0.00 | 0.00 | 25 | 25 | 35.3553 | |
| **2.G - Electrical Equipment** | | | | | | | |
| **2.H - Other** | | | | | | | |
| **TOTAL** | | | | | | | |
| **Sum** | | 33 720.6701 | 1 562 745.9346 | | | | |
| | | | | | | **Uncertainty in total inventory** | |
| **Excluding 2.F - Product Uses as Substitutes for Ozone Depleting Substances** | | | | | | **Uncertainty in total inventory** | |

| | Contri-bution to variance in Year t | Type A sensitivity | Type B sensitivity | Uncertainty in trend in national emissions introduced by EF/ estimation parameter uncertainty | Uncertainty in trend in national emissions introduced by activity data uncertainty | Uncertainty introduced into the trend in total national emissions |
|---|---|---|---|---|---|---|
| | (fraction) | % | % | % | % | % |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | 950.38 | | | | | 3 499 041.15 |
| | 30.83 | | | | **Trend uncertainty** | 1 870.57 |
| | 8.83 | | | | **Trend uncertainty** | 4.74 |

# 11. APPENDIX D: ENERGY SECTOR – COMPARISON OF THE REFERENCE VS SECTORAL APPROACH




| REFERENCE VS SECTORAL APPROACH | | | | |
|---|---|---|---|---|
| Period | Reference approach | Sectoral Approach | Difference | Difference |
| | MtCO² | | Mt | % |
| 2000 | 368 | 305 | 62.87 | 21% |
| 2001 | 361 | 304 | 57.23 | 19% |
| 2002 | 351 | 315 | 35.68 | 11% |
| 2003 | 402 | 339 | 63.14 | 19% |
| 2004 | 430 | 355 | 75.76 | 21% |
| 2005 | 422 | 351 | 70.66 | 20% |
| 2006 | 433 | 358 | 74.36 | 21% |
| 2007 | 463 | 386 | 76.43 | 20% |
| 2008 | 500 | 379 | 121.54 | 32% |
| 2009 | 490 | 387 | 103.34 | 27% |
| 2010 | 483 | 401 | 82.59 | 21% |
| 2011 | 477 | 382 | 95.69 | 25% |
| 2012 | 471 | 394 | 77.72 | 20% |
| **Average** | | | **76.69** | **21%** |

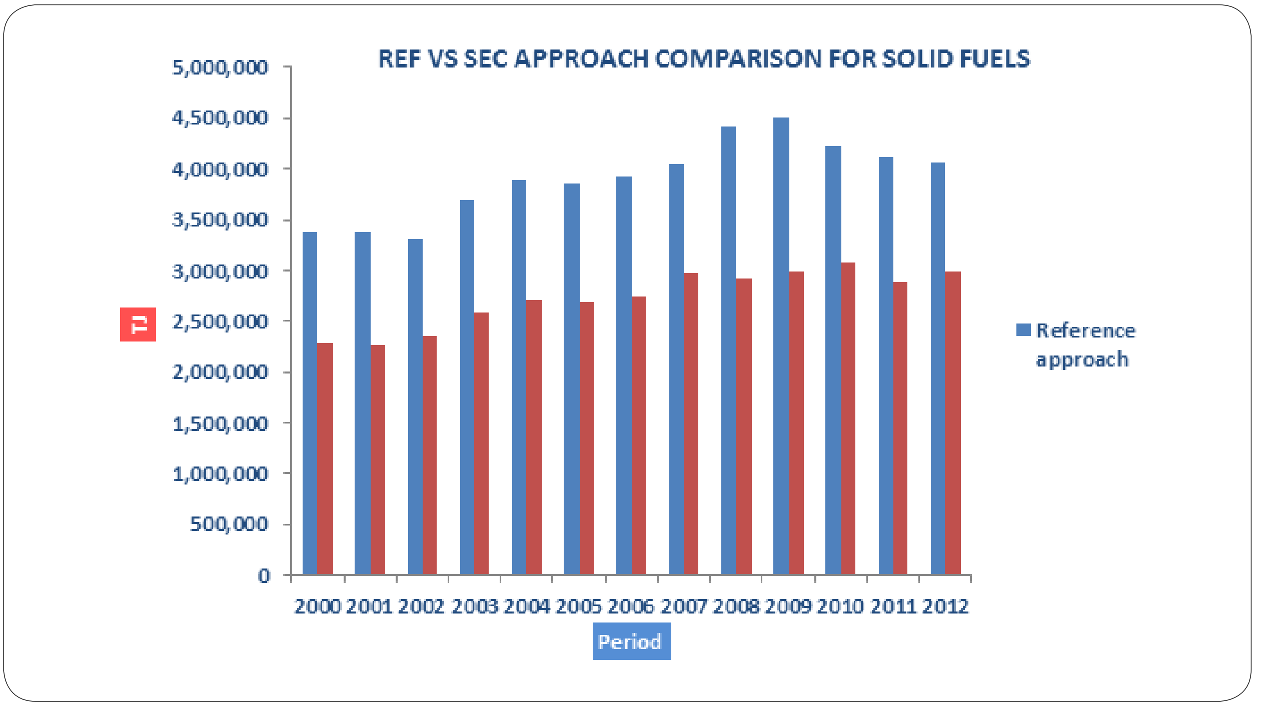
The Reference Approach is a top-down approach, using a country's energy supply data to calculate the emissions of $CO^2$ from combustion of mainly fossil fuels. The Reference Approach was applied on the basis of relatively easily available energy supply statistics. It is good practice to apply both a sectoral approach and the reference approach to estimate a country's $CO^2$ emissions from fuel combustion and to compare the results of these two independent estimates. Significant differences may indicate possible problems with the activity data, net calorific values, carbon content, excluded carbon calculation etc.

The Reference Approach and the Sectoral Approach often have different results because the Reference Approach is a top-down approach using a country's energy supply data and has no detailed information on how the individual fuels are used in each sector. The average difference in the reference and sectoral approach is approximately 21% which is quite significant. The main reasons for the differences were mainly from the gaseous fuels and solid fuels which had an average difference of 124% and 43% respectively. The generic reasons for the difference in reference and sectoral approach are as follows:

- Missing information on stock changes that may occur at the final consumer level. The relevance of consumer stocks depends on the method used for the Sectoral Approach.
- High distribution losses for gas will cause the Reference Approach to be higher than the Sectoral Approach,
- Unrecorded consumption of gas or other fuels may lead to an underestimation of the Sectoral Approach.
- The treatment of transfers and reclassifications of energy products may cause a difference in the Sectoral Approach estimation since different net calorific values and emission factors may be used depending on how the fuel is classified.
- 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.
- Inconsistencies on the sources of activity data within the time series and in some cases the application of extrapolation
- The misallocation of the quantities of fuels used for conversion into derived products (other than power or heat) or quantities combusted in the energy sector.
- Simplifications in the Reference Approach. There are small quantities of carbon which should be included in the Reference Approach because their emissions fall under fuel combustion. These quantities have been excluded where the flows are small or not represented by a major statistic available within energy data.
- Examples of quantities not accounted for in the Reference Approach include lubricants used in two-stroke e.g. natural gas leakage from pipelines, emissions from energy transformation, etc. Likely to be <5% of the reference approach.

## Solid Fuels

| SOLID FUELS | | | | |
|---|---|---|---|---|
| Period | Reference approach | Sectoral Approach | Difference | Difference |
| | TJ | | TJ | % |
| 2000 | 3 386 284 | 2 282 887 | 1 103 396.84 | 48% |
| 2001 | 3 380 674 | 2 258 656 | 1 122 017.53 | 50% |
| 2002 | 3 314 815 | 2 363 553 | 951 262.16 | 40% |
| 2003 | 3 687 775 | 2 576 732 | 1 111 043.31 | 43% |
| 2004 | 3 886 355 | 2 702 932 | 1 183 423.23 | 44% |
| 2005 | 3 849 218 | 2 689 024 | 1 160 194.32 | 43% |
| 2006 | 3 918 677 | 2 744 792 | 1 173 885.33 | 43% |
| 2007 | 4 039 592 | 2 978 118 | 1 061 474.11 | 36% |
| 2008 | 4 417 995 | 2 918 928 | 1 499 067.10 | 51% |
| 2009 | 4 503 950 | 2 984 812 | 1 519 138.10 | 51% |
| 2010 | 4 227 203 | 3 085 055 | 1 142 147.62 | 37% |
| 2011 | 4 122 114 | 2 878 821 | 1 243 292.94 | 43% |
| 2012 | 4 063 666 | 2 997 646 | 1 066 020.21 | 36% |
| **Average** | | | **1 179 720.22** | **43%** |



The source of discrepancies on solid fuels between the reference and sectoral approach can mainly be attributed to three categories namely; electricity generation, manufacturing industries, construction and residential sector.

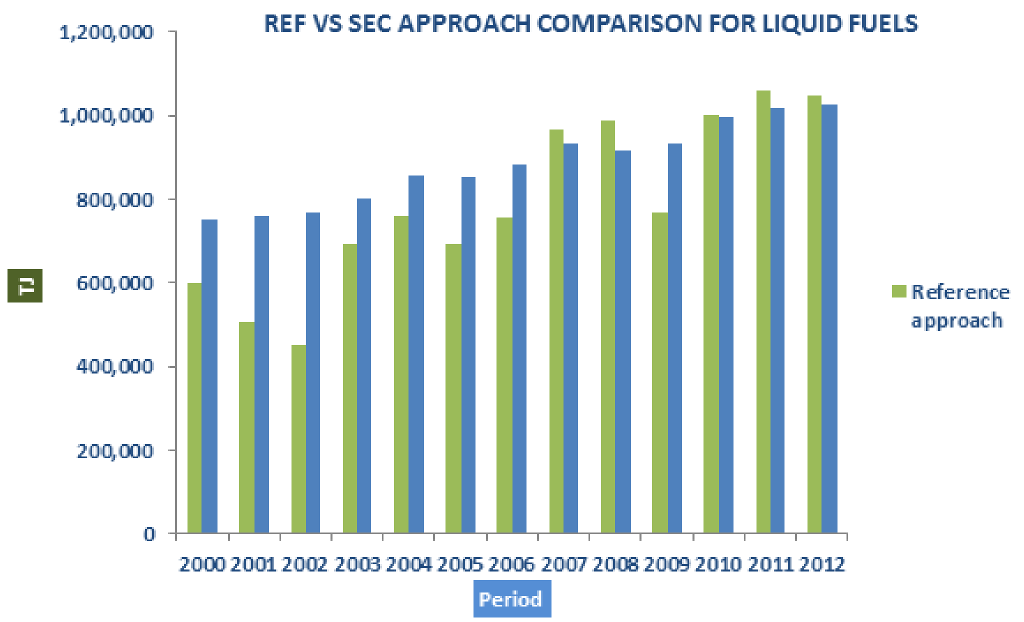
a. *Main electricity and heat production:* Data on fuel consumption for public electricity generation was obtained directly from the national power utility for the period 2000 to 2012 for the sectoral approach. Within this sector is the inclusion of auto electricity producers which was sourced from the energy balance for the period 2000-2006 and extrapolated for the period 2007-2012. Discrepancies in solid fuels can be as a result of the extrapolation for auto-electricity producers.

b. *Manufacturing industries and construction:* Sources of activity 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 remaining period of 2007-2010 the SAMI report was used to extrapolate the fuel consumption from this category. The difference in the two approaches may have been caused by the use of difference sources of activity data within the time series.

c. *Residential sector:* solid fuel consumption data from the residential sector was sourced from a variety of sources such as 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 the remaining period (20007-2010) the SAMI report was used to extrapolate the consumption of solid fuels for this category. Discrepancies in the solid fuels consumed in the residential sector might have been caused by the inconsistencies in the data sources within the time series.

## Solid Fuels

| LIQUID FUELS | | | | |
|---|---|---|---|---|
| Period | Reference approach | Sectoral Approach | Difference | Difference |
| | TJ | | TJ | % |
| 2000 | 601 099 | 752 782 | 151 682.97 | 20% |
| 2001 | 505 640 | 760 331 | 254 690.98 | 33% |
| 2002 | 451 170 | 766 941 | 315 771.88 | 41% |
| 2003 | 690 236 | 801 598 | 111 362.42 | 14% |
| 2004 | 759 904 | 855 739 | 95 834.86 | 11% |
| 2005 | 692 790 | 855 010 | 162 220.33 | 19% |
| 2006 | 755 250 | 881 793 | 126 543.33 | 14% |
| 2007 | 967 528 | 934 230 | 33 297.61 | 3.6% |
| 2008 | 989 048 | 917 143 | 71 904.76 | 7.8% |
| 2009 | 767 022 | 933 975 | 166 952.95 | 18% |
| 2010 | 1 001 273 | 995 940 | 5 332.86 | 0.5% |
| 2011 | 1 059 595 | 1 019 469 | 40 125.98 | 3.9% |
| 2012 | 1 048 417 | 1 028 408 | 20 008.23 | 1.9% |
| Average | | | 119 671.48 | 15% |



The source of discrepancies on liquid fuels between the reference and sectoral approach can mainly be attributed to three categories namely; road transportation, commercial sector and Agriculture/Forestry/Fishing/ Fish Farms.

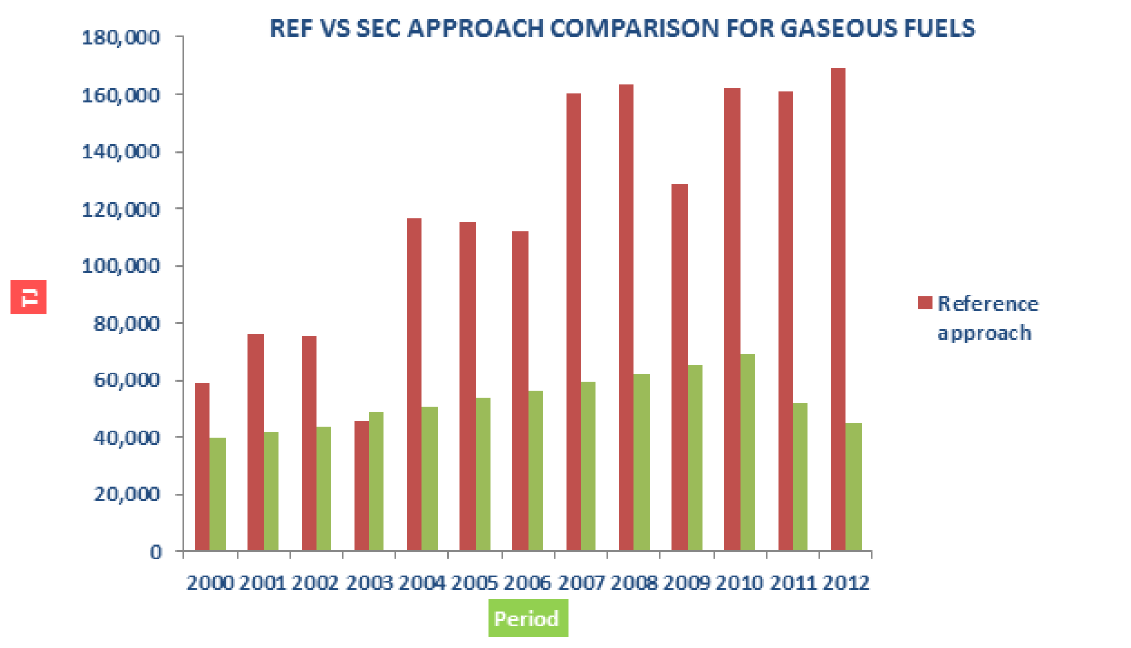
a. *The main consuming sector of liquid fuels is the road transportation.* The main source of activity data for liquid fuel consumption in the transportation sector, was the SAPIA annual reports. The discrepancies between the sectoral and reference approach might be attributed to the fact that SAPIA reports liquid fuel consumption at a disaggregated level various users.

b. *Commercial sector:* The commercial sector refers to institutional or commercial building. The main source of activity data for liquid fuels for this category was the SAPIA for the period 2000-2006. An extrapolation method was applied to estimate activity data for the period 2007-2012, this might have also contributed to the differences in the reference and sectoral approach.

c. *Agriculture/Forestry/Fishing/Fish Farms:* 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. Discrepancies might have been attributed by the application of different sources of activity data for the time series.

## Gaseous Fuels

| LIQUID FUELS | | | | |
|---|---|---|---|---|
| Period | Reference approach | Sectoral Approach | Difference | Difference |
| | TJ | | TJ | % |
| 2000 | 58 490 | 39 763 | 18 726.60 | 47% |
| 2001 | 75 990 | 41 482 | 34 508.42 | 83% |
| 2002 | 75 362 | 43 299 | 32 063.40 | 74% |
| 2003 | 45 176 | 48 844 | -3 668.43 | 7.5% |
| 2004 | 116 393 | 50 671 | 65 722.04 | 130% |
| 2005 | 115 472 | 53 541 | 61 930.94 | 116% |
| 2006 | 112 039 | 56 433 | 55 605.77 | 99% |
| 2007 | 160 103 | 59 323 | 100 780.23 | 170% |
| 2008 | 163 578 | 62 213 | 101 365.28 | 163% |
| 2009 | 128 702 | 65 101 | 63 601.23 | 98% |
| 2010 | 162 155 | 68 888 | 93 266.76 | 135% |
| 2011 | 160 982 | 51 744 | 109 238.46 | 211% |
| 2012 | 168 979 | 44 832 | 124 147.25 | 277% |
| Average | | | **65 945.23** | **124%** |



The source of discrepancies on gaseous fuels between the reference and sectoral approach can mainly be attributed to the manufacturing industries and construction mainly in the production of synfuels.

# 12. APPENDIX E: AGRICULTURAL ACTIVITY DATA

## 12.1 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 | |
| Goats | Breeding buck | Buck |
| | Young buck | |
| | Breeding doe | Doe |
| | Young doe | |

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

## 12.2 Livestock population data

| Category | Sub-category | Population | | | |
|---|---|---|---|---|---|
| | | 2000 | 2001 | 2002 | 2003 |
| Dairy (Commercial - TMR) | Lactating cow | 437 637 | 437 637 | 375 749 | 349 226 |
| | Dry cow | 106 452 | 106 452 | 91 398 | 84 947 |
| | Lactating heifer | 42 092 | 40 985 | 39 877 | 31 015 |
| | Pregnant heifer | 56 663 | 55 172 | 53 680 | 41 751 |
| | Heifer >1yr | 19 427 | 18 916 | 18 405 | 14 315 |
| | Heifer 6-12mths | 38 854 | 37 832 | 36 809 | 28 630 |
| | Heifer 2-6mths | 25 903 | 25 221 | 24 540 | 19 086 |
| | Calves <6mths | 25 903 | 25 221 | 24 540 | 19 086 |
| | **Total TMR** | **752 932** | **747 436** | **664 998** | **588 056** |
| Dairy (Commercial - Pasture) | Lactating cow | 358 667 | 358 667 | 307 946 | 286 209 |
| | Dry cow | 87 243 | 87 243 | 74 906 | 69 618 |
| | Lactating heifer | 34 497 | 33 589 | 32 681 | 25 419 |
| | Pregnant heifer | 46 438 | 45 216 | 43 994 | 34 218 |
| | Heifer >1yr | 15 922 | 15 503 | 15 084 | 11 732 |
| | Heifer 6-12mths | 31 843 | 31 005 | 30 167 | 23 463 |
| | Heifer 2-6mths | 21 229 | 20 670 | 20 112 | 15 642 |
| | Calves <6mths | 21 229 | 20 670 | 20 112 | 15 642 |
| | **Total Pasture** | **617 068** | **612 564** | **545 002** | **481 944** |
| ***Total Dairy*** | | ***1 370 000*** | ***1 360 000*** | ***1 210 000*** | ***1 070 000*** |

| | | | | | |
|---|---|---|---|---|---|
| Other cattle (Commercial) | Feedlot | 420 000 | 420 000 | 420 000 | 420 000 |
| | Bulls | 200 000 | 190 000 | 190 000 | 190 000 |
| | Cows | 3 540 000 | 3 600 000 | 3 430 000 | 3 080 000 |
| | Heifers | 1 050 000 | 1 040 000 | 1 020 000 | 950 000 |
| | Ox | 230 000 | 240 000 | 200 000 | 260 000 |
| | Young ox | 660 000 | 660 000 | 540 000 | 570 000 |
| | Calves | 1 630 000 | 1 610 000 | 1 470 000 | 1 910 000 |
| | **Total commercial** | **7 730 000** | **7 760 000** | **7 270 000** | **7 380 000** |

| 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|
| 340 385 | 362 487 | 353 646 | 349 226 | 433 217 | 442 058 | 442 058 |
| 82 796 | 88 173 | 86 022 | 84 947 | 105 377 | 107 528 | 107 528 |
| 27 692 | 31 015 | 31 015 | 32 123 | 35 446 | 37 662 | 37 662 |
| 37 278 | 41 751 | 41 751 | 43 243 | 47 716 | 50 698 | 50 698 |
| 12 781 | 14 315 | 14 315 | 14 826 | 16 360 | 17 382 | 17 382 |
| 25 562 | 28 630 | 28 630 | 29 652 | 32 720 | 34 764 | 34 764 |
| 17 041 | 19 086 | 19 086 | 19 768 | 21 813 | 23 176 | 23 176 |
| 17 041 | 19 086 | 19 086 | 19 768 | 21 813 | 23 176 | 23 176 |
| **560 577** | **604 544** | **593 552** | **593 552** | **714 461** | **736 445** | **736 445** |
| 278 963 | 297 078 | 289 832 | 286 209 | 355 044 | 362 290 | 362 290 |
| 67 856 | 72 262 | 70 500 | 69 618 | 86 362 | 88 125 | 88 125 |
| 22 695 | 25 419 | 25 419 | 26 327 | 29 050 | 30 866 | 30 866 |
| 30 551 | 34 218 | 34 218 | 35 440 | 39 106 | 41 550 | 41 550 |
| 10 475 | 11 732 | 11 732 | 12 151 | 13 408 | 14 246 | 14 246 |
| 20 950 | 23 463 | 23 463 | 24 301 | 26 815 | 28 491 | 28 491 |
| 13 966 | 15 642 | 15 642 | 16 201 | 17 877 | 18 994 | 18 994 |
| 13 966 | 15 642 | 15 642 | 16 201 | 17 877 | 18 994 | 18 994 |
| **459 423** | **495 456** | **486 448** | **486 448** | **585 539** | **603 555** | **603 555** |
| ***1 020 000*** | ***1 100 000*** | ***1 080 000*** | ***1 080 000*** | ***1 300 000*** | ***1 340 000*** | ***1 340 000*** |

| | | | | | | |
|---|---|---|---|---|---|---|
| 420 000 | 420 000 | 391 148 | 400 819 | 399 822 | 461 800 | 484 274 |
| 200 000 | 190 000 | 180 000 | 150 000 | 160 000 | 180 000 | 200 000 |
| 2 840 000 | 3 140 000 | 3 080 000 | 2 460 000 | 2 710 000 | 2 390 000 | 2 980 000 |
| 1 390 000 | 920 000 | 900 000 | 850 000 | 770 000 | 700 000 | 910 000 |
| 280 000 | 210 000 | 200 000 | 170 000 | 240 000 | 280 000 | 170 000 |
| 520 000 | 510 000 | 500 000 | 1 080 000 | 1 140 000 | 860 000 | 630 000 |
| 1 770 000 | 2 110 000 | 2 070 000 | 2 400 000 | 1 960 000 | 2 490 000 | 1 990 000 |
| **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 |
| Other cattle (Communal) | Bulls | 137 359 | 130 491 | 130 491 | 130 491 |
| | Cows | 2 431 256 | 2 472 464 | 2 355 709 | 2 115 330 |
| | Heifers | 721 135 | 714 267 | 700 531 | 652 456 |
| | Ox | 157 963 | 164 831 | 137 359 | 178 567 |
| | Young ox | 453 285 | 453 285 | 370 870 | 391 473 |
| | Calves | 1 119 477 | 1 105 741 | 1 009 589 | 1 311 779 |
| | **Total communal** | **5 020 475** | **5 041 079** | **4 704 549** | **4 780 097** |
| ***Total Other cattle*** | | ***12 750 475*** | ***12 801 079*** | ***11 974 549*** | ***12 160 096*** |
| | | | | | |
| Sheep (Commercial) | Wool lamb | 6 610 800 | 6 446 000 | 6 427 600 | 6 476 000 |
| | Wool ewe | 9 420 390 | 9 185 550 | 9 159 330 | 9 228 300 |
| | Wool ram | 495 810 | 483 450 | 482 070 | 485 700 |
| | Non-wool lamb | 2 823 600 | 2 753 200 | 2 618 000 | 2 601 200 |
| | Non-wool ewe | 4 023 630 | 3 923 310 | 3 730 650 | 3 706 710 |
| | Non-wool ram | 211 770 | 206 490 | 196 350 | 195 090 |
| | **Total commercial** | **23 586 000** | **22 998 000** | **22 614 000** | **22 693 000** |
| Sheep (Communal) | Wool lamb | 922 602 | 899 602 | 897 034 | 903 789 |
| | Wool ewe | 1 314 708 | 1 281 933 | 1 278 274 | 1 287 900 |
| | Wool ram | 69 195 | 67 470 | 67 278 | 67 784 |
| | Non-wool lamb | 394 061 | 384 236 | 365 368 | 363 023 |
| | Non-wool ewe | 561 537 | 547 536 | 520 649 | 517 308 |
| | Non-wool ram | 29 555 | 28 818 | 27 403 | 27 227 |
| | **Total communal** | **3 291 657** | **3 209 596** | **3 156 005** | **3 167 030** |
| ***Total sheep*** | | ***26 877 657*** | ***26 207 596*** | ***25 770 005*** | ***25 860 030*** |
| | | | | | |
| Goats (Commercial) | Buck | 207 086 | 213 417 | 194 863 | 189 939 |
| | Doe | 654 760 | 674 778 | 616 114 | 600 544 |
| | Kids | 618 749 | 637 667 | 582 229 | 567 515 |
| | Angora | 856 557 | 882 745 | 806 001 | 785 632 |
| | Milk goats | 17 847 | 18 392 | 16 793 | 16 369 |
| | **Total commercial** | **2 355 000** | **2 427 000** | **2 216 000** | **2 160 000** |

| 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|
| 137 359 | 130 491 | 123 623 | 103 019 | 109 887 | 123 623 | 137 359 |
| 1 950 499 | 2 156 538 | 2 115 330 | 1 689 517 | 1 861 216 | 1 641 441 | 2 046 651 |
| 954 646 | 631 852 | 618 116 | 583 776 | 528 833 | 480 757 | 624 984 |
| 192 303 | 144 227 | 137 359 | 116 755 | 164 831 | 192 303 | 116 755 |
| 357 134 | 350 266 | 343 398 | 741 739 | 782 947 | 590 644 | 432 681 |
| 1 215 628 | 1 449 138 | 1 421 667 | 1 648 309 | 1 346 119 | 1 710 121 | 1 366 723 |
| **4 807 568** | **4 862 512** | **4 759 493** | **4 883 116** | **4 793 833** | **4 738 889** | **4 725 153** |
| ***12 227 569*** | ***12 362 512*** | ***12 109 493*** | ***12 413 115*** | ***12 164 981*** | ***12 039 708*** | ***12 004 975*** |
| | | | | | | |
| 6 395 200 | 6 407 600 | 6 219 600 | 6 299 200 | 6 389 200 | 6 296 000 | 6 174 400 |
| 9 113 160 | 9 130 830 | 8 862 930 | 8 976 360 | 9 104 610 | 8 971 800 | 8 798 520 |
| 479 640 | 480 570 | 466 470 | 472 440 | 479 190 | 472 200 | 463 080 |
| 2 520 400 | 2 486 800 | 2 558 400 | 2 470 400 | 2 408 800 | 2 470 800 | 2 422 800 |
| 3 591 570 | 3 543 690 | 3 645 720 | 3 520 320 | 3 432 540 | 3 520 890 | 3 452 490 |
| 189 030 | 186 510 | 191 880 | 185 280 | 180 660 | 185 310 | 181 710 |
| **22 289 000** | **22 236 000** | **21 945 000** | **21 924 000** | **21 995 000** | **21 917 000** | **21 493 000** |
| 892 513 | 894 243 | 868 006 | 879 115 | 891 675 | 878 668 | 861 698 |
| 1 271 831 | 1 274 297 | 1 236 909 | 1 252 739 | 1 270 637 | 1 252 102 | 1 227 920 |
| 66 938 | 67 068 | 65 100 | 65 934 | 66 876 | 65 900 | 64 627 |
| 351 746 | 347 057 | 357 050 | 344 768 | 336 172 | 344 824 | 338 125 |
| 501 239 | 494 557 | 508 796 | 491 295 | 479 045 | 491 375 | 481 829 |
| 26 381 | 26 029 | 26 779 | 25 858 | 25 213 | 25 862 | 25 359 |
| **3 110 648** | **3 103 251** | **3 062 639** | **3 059 709** | **3 069 617** | **3 058 732** | **2 999 558** |
| ***25 399 648*** | ***25 339 251*** | ***25 007 639*** | ***24 983 709*** | ***25 064 617*** | ***24 975 732*** | ***24 492 558*** |
| | | | | | | |
| 190 291 | 187 828 | 191 786 | 186 070 | 185 894 | 182 640 | 180 442 |
| 601 657 | 593 872 | 606 383 | 588 311 | 587 755 | 577 468 | 570 517 |
| 568 566 | 561 210 | 573 033 | 555 955 | 555 429 | 545 708 | 539 140 |
| 787 087 | 776 903 | 793 270 | 769 629 | 768 901 | 755 444 | 746 351 |
| 16 399 | 16 187 | 16 528 | 16 035 | 16 020 | 15 740 | 15 550 |
| **2 164 000** | **2 136 000** | **2 181 000** | **2 116 000** | **2 114 000** | **2 077 000** | **2 052 000** |

| Category | Sub-category | Population | | | |
|---|---|---|---|---|---|
| | | 2000 | 2001 | 2002 | 2003 |
| Goats (Communal) | Buck | 147 130 | 151 628 | 138 445 | 134 947 |
| | Doe | 2 795 507 | 2 880 974 | 2 630 507 | 2 564 032 |
| | Kids | 1 709 028 | 1 761 278 | 1 608 155 | 1 567 516 |
| | **Total communal** | **4 651 664** | **4 793 880** | **4 377 107** | **4 266 494** |
| ***Total goats*** | | ***7 006 664*** | ***7 220 880*** | ***6 593 107*** | ***6 426 494*** |
| | | | | | |
| Swine (commercial) | Boars | 30 563 | 31 138 | 31 732 | 30 860 |
| | Sows | 529 757 | 539 728 | 550 021 | 534 903 |
| | Piglets | 543 340 | 553 567 | 564 124 | 548 619 |
| | Porkers | 81 501 | 83 035 | 84 619 | 82 293 |
| | Baconers | 461 839 | 470 532 | 479 505 | 466 326 |
| | **Total commercial** | **1 647 000** | **1 678 000** | **1 710 000** | **1 663 000** |
| Swine (communal) | Boars | 7 868 | 8 017 | 8 169 | 7 945 |
| | Sows | 102 290 | 104 216 | 106 203 | 103 284 |
| | Piglets | 52 457 | 53 444 | 54 463 | 52 966 |
| | Porkers | 7 868 | 8 017 | 8 169 | 7 945 |
| | Baconers | 44 588 | 45 427 | 46 294 | 45 021 |
| | **Total communal** | **215 072** | **219 120** | **223 299** | **217 161** |
| ***Total swine*** | | ***1 862 072*** | ***1 897 120*** | ***1 933 299*** | ***1 880 161*** |
| | | | | | |
| Horses | ***Total*** | ***270 000*** | ***270 000*** | ***270 000*** | ***270 000*** |
| | | | | | |
| Mules and asses | Asses | 150 000 | 150 000 | 150 000 | 150 000 |
| | Mules | 14 000 | 14 000 | 14 000 | 14 000 |
| ***Total mules/asses*** | | ***164 000*** | ***164 000*** | ***164 000*** | ***164 000*** |
| | | | | | |
| Poultry (Commercial) | Annual avg broilers | 65 716 784 | 65 716 888 | 67 671 233 | 71 163 068 |
| | Layers | 17 400 000 | 17 800 000 | 17 700 000 | 17 000 000 |
| | **Total commercial** | **83 116 784** | **83 516 888** | **85 371 233** | **88 163 068** |
| Poultry (Communal) | Annual avg broilers | 2 760 105 | 2 760 109 | 2 842 192 | 2 988 849 |
| ***Total poultry*** | | ***85 876 889*** | ***86 276 997*** | ***88 213 425*** | ***91 151 917*** |
| | | | | | |
| **Total livestock** | | **136 177 756** | **136 197 670** | **136 128 386** | **138 982 699** |

| | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|
| | 135 197 | 133 447 | 136 259 | 132 198 | 132 073 | 129 761 | 128 200 |
| | 2 568 780 | 2 535 542 | 2 588 960 | 2 511 801 | 2 509 427 | 2 465 506 | 2 435 830 |
| | 1 570 419 | 1 550 099 | 1 582 756 | 1 535 585 | 1 534 134 | 1 507 283 | 1 489 140 |
| | **4 274 395** | **4 219 089** | **4 307 974** | **4 179 584** | **4 175 634** | **4 102 550** | **4 053 170** |
| | ***6 438 395*** | ***6 355 089*** | ***6 488 974*** | ***6 295 584*** | ***6 289 634*** | ***6 179 550*** | ***6 105 170*** |
| | | | | | | | |
| | 30 860 | 30 637 | 30 099 | 30 637 | 29 969 | 29 932 | 29 579 |
| | 534 903 | 531 043 | 521 715 | 531 043 | 519 464 | 518 821 | 512 709 |
| | 548 619 | 544 660 | 535 093 | 544 660 | 532 784 | 532 124 | 525 856 |
| | 82 293 | 81 699 | 80 264 | 81 699 | 79 918 | 79 819 | 78 878 |
| | 466 326 | 462 961 | 454 829 | 462 961 | 452 866 | 452 305 | 446 977 |
| | **1 663 000** | **1 651 000** | **1 622 000** | **1 651 000** | **1 615 000** | **1 613 000** | **1 594 000** |
| | 7 945 | 7 888 | 7 749 | 7 888 | 7 716 | 7 706 | 7 615 |
| | 103 284 | 102 539 | 100 738 | 102 539 | 100 303 | 100 179 | 98 999 |
| | 52 966 | 52 584 | 51 660 | 52 584 | 51 437 | 51 374 | 50 769 |
| | 7 945 | 7 888 | 7 749 | 7 888 | 7 716 | 7 706 | 7 615 |
| | 45 021 | 44 696 | 43 911 | 44 696 | 43 722 | 43 668 | 43 153 |
| | **217 161** | **215 594** | **211 807** | **215 594** | **210 893** | **210 632** | **208 151** |
| | ***1 880 161*** | ***1 866 594*** | ***1 833 807*** | ***1 866 594*** | ***1 825 893*** | ***1 823 632*** | ***1 802 151*** |
| | | | | | | | |
| | ***270 000*** | ***270 000*** | ***280 000*** | ***290 000*** | ***298 000*** | ***300 000*** | ***300 000*** |
| | | | | | | | |
| | 150 000 | 150 000 | 150 000 | 150 500 | 150 500 | 150 500 | 152 000 |
| | 14 000 | 14 000 | 14 050 | 14 100 | 14 200 | 14 300 | 14 300 |
| | ***164 000*** | ***164 000*** | ***164 050*** | ***164 600*** | ***164 700*** | ***164 800*** | ***166 300*** |
| | | | | | | | |
| | 72 846 641 | 79 846 641 | 86 769 951 | 89 769 951 | 90 950 137 | 92 129 907 | 93 057 627 |
| | 17 590 000 | 18 660 000 | 20 590 000 | 22 780 000 | 23 080 000 | 22 230 000 | 23 100 000 |
| | **90 225 595** | **98 506 641** | **106 911 425** | **112 549 951** | **114 030 137** | **114 359 907** | **116 157 627** |
| | 3 050 695 | 3 353 559 | 3 625 500 | 3 770 338 | 3 819 906 | 3 869 456 | 3 908 420 |
| | ***93 276 290*** | ***101 860 200*** | ***110 536 925*** | ***116 320 289*** | ***117 850 043*** | ***118 229 363*** | ***120 066047*** |
| | | | | | | | |
| | **140 676 063** | **149 317 645** | **157 500 889** | **163 413 893** | **164 957 871** | **165 052 786** | **166 277 200** |

# 13. APPENDIX F: LAND SECTOR ACTIVITY DATA

## 13.1 Land cover by climate

The 2013-14 land cover map (GeoTerraImage, 2015) was intersected with the long term climate map provided by the ARC.

| Description | Climate Type Area (ha) | | | | |
|---|---|---|---|---|---|
| | WTD | WTM | CTD | CTM | Total (ha) |
| Indigenous Forest | 365 000 | 11 100 | 100 | 0 | 376 200 |
| Thicket /Dense bush | 7 460 300 | 24 800 | 1 800 | 400 | 7 487 300 |
| Woodland/Open bush | 11 422 900 | 14 600 | 3 400 | 200 | 11 441 100 |
| Low shrubland | 38 197 100 | 60 300 | 6 500 | 7 300 | 38 271 200 |
| Plantations / Woodlots | 1 707 500 | 26 900 | 0 | 0 | 1 734 400 |
| Cultivated commercial annual crops pivot | 720 900 | 0 | 0 | 0 | 720 900 |
| Cultivated commercial annual crops non-pivot | 9 811 600 | 500 | 0 | 0 | 9 812 100 |
| Cultivated commercial permanent orchards | 312 200 | 2 200 | 0 | 0 | 314 400 |
| Cultivated commercial permanent vines | 174 800 | 400 | 0 | 0 | 175 200 |
| Cultivated subsistence crops | 1 875 600 | 700 | 0 | 0 | 1 876 300 |
| Settlements | 2 663 400 | 1 000 | 0 | 0 | 2 664 400 |
| Wetlands | 936 700 | 2 100 | 1 100 | 300 | 940 200 |
| Grasslands | 23 610 500 | 63 400 | 68 100 | 19 500 | 23 761 500 |
| Mines | 302 000 | 100 | 0 | 0 | 302 100 |
| Waterbodies (incl coastal sea extent) | 447 900 | 700 | 0 | 0 | 448 600 |
| Bare Ground | 11 753 000 | 3 300 | 1 800 | 2 600 | 11 760 700 |
| Degraded | 868 400 | 100 | 0 | 0 | 868 500 |

## 13.2 Land cover by soil type

The 2013-14 land cover map (GeoTerraImage, 2015) was intersected with the soil type (using the IPCC default classification) map provided by the ARC.

| Description | Area on each IPCC soil type (ha) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Sandy mineral soils | Wetland mineral soils | Spodic mineral soils | Rocky areas | Low activity clay mineral soils | High activity clay mineral soils | Water body |
| Indigenous Forest | 96 696 | 226 | 0 | 30 403 | 91 295 | 203 150 | 1 863 |
| Thicket /Dense bush | 658 937 | 924 | 2 200 | 1 185 382 | 562 013 | 5 817 654 | 9 370 |
| Woodland/Open bush | 2 135 567 | 161 | 518 | 1 424 284 | 576 444 | 8 243 359 | 4 073 |
| Low shrubland | 15 748 119 | 124 | 2 063 | 4 634 043 | 24 304 | 20 955 223 | 7 588 |
| Plantations / Woodlots | 164 824 | 36 | 52 | 23 253 | 1 121 099 | 561 068 | 568 |
| Cultivated commercial annual crops pivot | 162 477 | 540 | 0 | 1 117 | 50 719 | 565 961 | 71 |
| Cultivated commercial annual crops non-pivot | 1 167 966 | 1 252 | 1 501 | 57 126 | 712 547 | 8 669 075 | 658 |
| Cultivated commercial permanent orchards | 75 632 | 0 | 22 | 6 955 | 57 575 | 206 523 | 242 |
| Cultivated commercial permanent vines | 55 978 | 0 | 0 | 4 672 | 0 | 128 053 | 8 |
| Cultivated subsistence crops | 110 808 | 720 | 0 | 11 934 | 175 470 | 1 737 450 | 169 |
| Settlements | 349 109 | 539 | 0 | 55 124 | 300 620 | 2 201 493 | 394 |
| Wetlands | 62 972 | 1 861 | 118 | 28 006 | 149 993 | 766 409 | 9 770 |
| Grasslands | 1 644 147 | 3 601 | 50 | 1 724 952 | 2 210 455 | 20 142 593 | 15 568 |
| Mines | 78 653 | 265 | 0 | 8 713 | 43 353 | 195 486 | 7 |
| Waterbodies (incl coastal sea extent) | 29 812 | 983 | 1 | 9 446 | 23 205 | 192 189 | 199 991 |
| Bare Ground | 2 038 559 | 11 754 | 12 | 1 198 308 | 15 371 | 9 485 819 | 3 235 |
| Degraded | 166 972 | 10 | 0 | 23 355 | 15 931 | 737 663 | 9 |

## 13.3 Biomass and soil data

Total above ground biomass data from the NTCSA (Department of Environmental Affairs, 2015) for the various land classes.

| Description | Mean biomass carbon [gC/m^2] | Std. Dev. [gC/m^2] | tC/ha | tdm/ha |
|---|---|---|---|---|
| Indigenous Forest | 7186 | 3 423 | 71.9 | 152.9 |
| Thicket | 2 370 | 3 159 | 23.7 | 50.4 |
| Savanna | 418 | 756 | 4.2 | 8.9 |
| Plantations | 4 603 | 969 | 46.0 | 97.9 |
| Cultivated land | 186 | 50 | 1.9 | 3.9 |
| Grasslands | 532 | 748 | 5.3 | 11.3 |

Above ground woody biomass data for the more detailed vegetation classes determined by intersecting the NTCSA (Department of Environmental Affairs, 2015) carbon layers with the 2013-14 land-cover data set.

| Description | Woody biomass | | | |
|---|---|---|---|---|
| | Mean Woody Biomass [gC/m^2] | Std. Dev. [gC/m^2] | tC/ha | tdm/ha |
| Indigenous Forest | 828 | 2 697 | 8.28 | 17.62 |
| Thicket /Dense bush | 3 175 | 4 697 | 31.75 | 67.55 |
| Woodland/Open bush | 686 | 1 852 | 6.86 | 14.59 |
| Low shrubland | 248 | 1 054 | 2.48 | 5.29 |
| Plantations / Woodlots | 8 962 | 8 826 | 89.62 | 190.68 |
| Cultivated commercial annual crops pivot | 450 | 1 122 | 4.50 | 9.58 |
| Cultivated commercial annual crops non-pivot | 461 | 1 450 | 4.61 | 9.81 |
| Cultivated commercial permanent orchards | 2 729 | 4 591 | 27.29 | 58.06 |
| Cultivated commercial permanent vines | 1 012 | 1 354 | 10.12 | 21.53 |
| Cultivated subsistence crops | 853 | 2 139 | 8.53 | 18.15 |
| Settlements | 1 177 | 2 763 | 11.77 | 25.04 |
| Wetlands | 981 | 2 488 | 9.81 | 20.87 |
| Grasslands | 709 | 1 873 | 7.09 | 15.09 |
| Mines | 241 | 934 | 2.41 | 5.13 |
| Waterbodies (incl coastal sea extent) | 854 | 2 555 | 8.54 | 18.18 |
| Bare Ground | 50 | 560 | 0.50 | 1.07 |
| Degraded | 211 | 565 | 2.11 | 4.48 |

Herbaceous biomass data for the more detailed vegetation classes determined by intersection the NTCSA (Department of Environmental Affairs, 2015) layers with the 2013-14 land-cover data set.

| Description | Herbaceous biomass | | | |
|---|---|---|---|---|
| | Mean Herbaceous Biomass C [gC/m^2] | Std. Dev. [gC/m^2] | tC/ha | tdm/ha |
| Indigenous Forest | 87 | 82 | 0.87 | 1.86 |
| Thicket /Dense bush | 39 | 44 | 0.39 | 0.82 |
| Woodland/Open bush | 13 | 19 | 0.13 | 0.27 |
| Low shrubland | 3 | 10 | 0.03 | 0.06 |
| Plantations / Woodlots | 81 | 76 | 0.81 | 1.73 |
| Cultivated commercial annual crops pivot | 10 | 15 | 0.10 | 0.21 |
| Cultivated commercial annual crops non-pivot | 9 | 17 | 0.09 | 0.20 |
| Cultivated commercial permanent orchards | 37 | 46 | 0.37 | 0.78 |
| Cultivated commercial permanent vines | 12 | 17 | 0.12 | 0.26 |
| Cultivated subsistence crops | 15 | 23 | 0.15 | 0.33 |
| Settlements | 22 | 30 | 0.22 | 0.46 |
| Wetlands | 17 | 28 | 0.17 | 0.37 |
| Grasslands | 12 | 21 | 0.12 | 0.27 |
| Mines | 8 | 13 | 0.08 | 0.17 |
| Waterbodies (incl coastal sea extent) | 18 | 30 | 0.18 | 0.38 |
| Bare Ground | 1 | 6 | 0.01 | 0.02 |
| Degraded | 6 | 8 | 0.06 | 0.13 |

Soil carbon data for the various vegetation classes determined by intersection the NTCSA (Department of Environmental Affairs, 2015) layers with the 2013-14 land-cover data set.

| Description | Soil carbon (0 – 30cm) | | |
|---|---|---|---|
| | Mean Soil Carbon Content [gC/m^2] | Std. Dev. [gC/m^2] | tC/ha |
| Indigenous Forest | 3 184 | 4 169 | 31.84 |
| Thicket /Dense bush | 2 589 | 3 700 | 25.89 |
| Woodland/Open bush | 1 723 | 2 874 | 17.23 |
| Low shrubland | 826 | 2 542 | 8.26 |
| Plantations / Woodlots | 3 795 | 3 543 | 37.95 |
| Cultivated commercial annual crops pivot | 1 923 | 3 409 | 19.23 |
| Cultivated commercial annual crops non-pivot | 2 038 | 3 363 | 20.38 |
| Cultivated commercial permanent orchards | 2 222 | 3 322 | 22.22 |
| Cultivated commercial permanent vines | 1 117 | 1 575 | 11.17 |
| Cultivated subsistence crops | 2 614 | 3 696 | 26.14 |
| Settlements | 2 594 | 3 680 | 25.94 |
| Wetlands | 2 556 | 4 300 | 25.56 |
| Grasslands | 2 514 | 4 326 | 25.14 |
| Mines | 1 543 | 3 346 | 15.43 |
| Waterbodies (incl coastal sea extent) | 1 296 | 4 241 | 12.96 |
| Bare Ground | 380 | 1 574 | 3.80 |
| Degraded | 1 488 | 2 250 | 14.88 |

# 14. APPENDIX G: METHODOLOGY FOR LAND COVER AND LAND USE CHANGE MATRIX

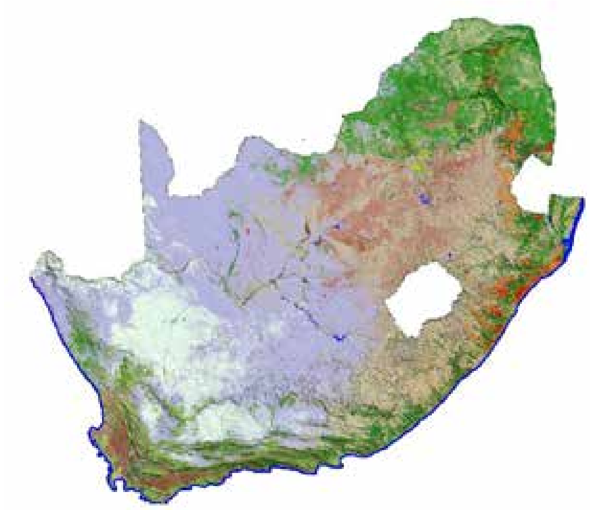
## 14.1 South African 2013-14 National Land-cover dataset

GEOTERRA IMAGE

**2013 - 2014 South African National Land-Cover Dataset**

DEA/CARDNO SCPF002: Implementation of Land-Use Maps for South Africa

**Project Specific Data User Report and Metadata**



DATA PRODUCT CREATED BY
**GEOTERRAIMAGE (South Africa),**
www.geoterraimage.com
July 2015, version 05b (pivot code corrected data)

**OPEN ACCESS LICENCE**

## LICENSE AND COPYRIGHT

The data supplied are licensed by GEOTERRAIMAGE to the Client, but remains the property of GEOTERRAIMAGE as is protected by copyright laws. The data can be used by the client as per the conditions set forth in the offer. The client does not obtain any ownership or intellectual property rights in the data. "Client" refers to the South African Department of Environmental Affairs.

The following shall always be clearly mentioned: (© GEOTERRAIMAGE - 2014).

## OPEN DATA LICENSING (PERMITTED & INTENDED DATA USE)

The Department is granted an Open Data User license, which allows the Department unrestricted access to and use the supplied data. The data is defined as the 72 Class GTI South African National Land Cover Dataset (2013/2014). The Open Data License allows the Department to distribute the data unrestricted to third parties with the full understanding that the Department and third parties may not use the data to develop new products that will compete directly with GEOTERRAIMAGE existing or "in-progress" commercial data products; and that the Department and third parties accept and understand the stated Data Copyright, Licensing and Liability conditions.

## LIABILITY

The Client has to verify prior to his commitment, the adequacy of GEOTERRAIMAGE datasets and products to the specific data and analyses needs as set out by the client. GEOTERRAIMAGE will in no event be liable for any direct, indirect, incidental or consequential damages including lost savings or profit, legal fees, lost data, lost sales, loss of commitments, business interruption, including loss of or other damage, resulting from its datasets and products, whether or not GEOTERRAIMAGE has been advised of the possibility of such damage. This includes damages incurred by the client or any third party.

GEOTERRAIMAGE datasets and products are processed from sources like topographic maps and satellite images. The quality of these sources is not the responsibility of GEOTERRAIMAGE. The data and data products are provided "as is", without warranty of any kind, either express or implied, including, but not limited to, the implied warranties of merchantability and fitness for a particular purpose.

Whilst all possible care and attention has been taken in the production of the data, neither GEOTERRAIMAGE or any of its respective sub-organisations or employees, accept any liability whatsoever for any perceived or actual inaccuracies or misrepresentations in the supplied data or accompanying report(s), as a result of the nature of mapping from coarse and medium scale satellite imagery. Any mapped boundaries either implied or inferred within the data do not have any legal status whatsoever.

All rights not specifically granted or specified in this agreement, pertaining to this data are reserved to GEOTERRAIMAGE Pty Ltd.

## CONTENTS

**PLEASE NOTE**

This report provides information on the specific version of the 2013-14 GEOTERRAIMAGE South African National Land-Cover Dataset supplied to the South African Department of Environmental Affairs under the DEA / CARDNO Project: SCPF002:"Implementation of Land Use Maps for South Africa".

The supplied dataset referred to in this report represents a subset of the full 2013-14 GEOTERRAIMAGE South African National Land-Cover Dataset, in terms of supplied land-cover / land-use categories and associated class legend.

Use of this DEA / CARDNO data version is governed by the LICENCE AGREEMENT shown previously.

## 1. INTRODUCTION

Land-cover is a key information requirement for a wide range of landscape planning, inventory and management activities, ranging from environmental resource management to telecommunication planning. The recent global availability of Landsat 8 satellite imagery offered the opportunity to create a new, national land-cover dataset[1] for South Africa, circa 2013-14, replacing and updating the previous 1994 and 2000 South African National Landcover datasets. The 2013-14 national land-cover dataset is based on 30x30m raster cells, and is ideally suited for ± 1:75,000 - 1:250,000 scale GIS-based mapping and modelling applications.

The dataset has been derived from multi-seasonal Landsat 8 imagery, using operationally proven, semi-automated modelling procedures developed specifically for the generation of this dataset, based on repeatable and standardised modelling routines. The dataset has been created by GEOTERRAIMAGE (GTI) and is available as a commercial data product.

The production of a comparable 1990 land-cover product is also in progress that will provide, for the very first time, a standardised and directly comparable set of national land-cover datasets that can be used to determine landscape change in South Africa over a 20+ year period[2].

## 2. BACKGROUND

The recent global availability of Landsat 8 imagery (April 2013), was the primary catalyst behind the development of new, innovative automated land-cover modelling procedures, which allowed the creation of the 2013-14 South African National Land-Cover dataset. Primarily because Landsat 8 offered a free, and regular supply of radiometrically and geometrically standardised, medium resolution, multi-spectral imagery, suitable for medium to large area mapping. Collectively, this offered an ideal opportunity for GTI to re-look at using automated land-cover mapping techniques as a more efficient alternative to conventional, analyst-assisted per-pixel classifiers, allowing rapid production of Standardised, yet informative land-cover information.

## 3. OBJECTIVE

The primary objective was to generate a new, national land-cover dataset for the whole of South Africa, and to be able to release this as a commercial data product within ±1 year of image data acquisition to ensure that the dataset is up-to-date and current. In support of this primary objective was the requirement to develop operational procedures based on semi- automated (spectral) modelling techniques that would facilitate the rapid production of consistent, standardised land-cover information from multi-seasonal Landsat 8 imagery.

1 Note that the term "land-cover" is used loosely to incorporate both land-cover and land-use information in the context of the GTI 2013-14 South African National Land-Cover dataset.

2 The existing 1994 and 2000 South African National Land-cover datasets were generated independently, using very different source image formats (i.e. paper versus digital), and end-product formats (i.e. 1:250,000 scale digital vector versus 1:50,000 digital raster), despite being derived from equivalent Landsat imagery. See Thompson MW, 1991. South African National Land-Cover Database Project. Data User's Manual. Final Report (Phases 1, 2, & 3). CSIR Project Report ENV/P/C 98136, February 1999; and Thompson MW et al, 2001. Guideline Procedures for National Land-Cover Mapping and Change Monitoring. CSIR Client Project Report ENV/P/C 2001-006, March 2001.

## 4. PRODUCT DESCRIPTION

The 2013-14 South African National Land-cover dataset produced by GEOTERRAIMAGE as a commercial data product has been generated from digital, multi-seasonal Landsat 8 multispectral imagery, acquired between April 2013 and March 2014. In excess of 600

Landsat images were used to generate the land-cover information, based on an average of 8 different seasonal image acquisition dates, within each of the 76 x image frames required to cover South Africa. The land-cover dataset, which covers the whole of South Africa, is presented in a map-corrected, raster format, based on 30x30m cells equivalent to the image resolution of the source Landsat 8 multi-spectral imagery. The full dataset contains 72 x land-cover / use information classes, covering a wide range of natural and man-made landscape characteristics. *The DEA / CARDNO dataset contains a summarised 35 x class legend.* Each data cell contains a single code representing the dominant land-cover class (by area) within that 30x30m unit, as determined from analysis of the multi-date imagery acquired over that image frame. The original land-cover dataset was processed in UTM (north) / WGS84 map projection format based on the Landsat 8 standard map projection format as provided by the USGS[3]. The final product is available in UTM35 (north) and (south), WGS84 map projections and Geographic Coordinates, WGS84.

### 4.1 Land-Cover Legend

The 2013-14 SA National Land-cover legend is aligned with SANS 1877[4] South African National Land-cover Classification Standard in terms of class definitions and hierarchical format. The complete list of information classes that have been mapped and supplied as part of the DEA / CARDNO land-cover dataset, and the associated class definitions are supplied in **Appendix A**.

Note that in recent CD:NGI[5] national land-cover mapping projects, the FAO LCCS2[6] land- cover classification system has been adopted as an alternative to SANS 1877, although this is not a national standard. However in September 2014 the SA GEO[7] Group's Land-Cover Community of Practice (CoP) task team, which includes CD:NGI representation, proposed that the class detail and content of SANS 1877 be retained / re-included within a proposed new SA national land-cover standard, which will be based on the latest, internationally accepted Land-Cover MetaData Language (LCML) classification system (ISO1944-2).

## 5. OVERVIEW OF THE AUTOMATED MODELLING APPROACH

Automated modelling procedures offer significant advantages in terms of ensuring data standards, minimising processing time, allowing easy repeatability and facilitating accurate change detection; when compared to more conventional image mapping approaches where there is a greater reliance on individual image analyst knowledge and inputs. To this end, a series of automated image-based modelling steps were developed that utilise the seasonal dynamics associated with the broad landscape characteristics across South Africa. These were then used

3 United States Geological Survey.

4 SANS 1877: SA Bureau of Standards designated national land-cover classification standard for South Africa.

5 Chief Directorate: National Geospatial Information

6 Food and Agriculture Organisation: Land Cover Classification vs 2

7 SA Group Earth Observation

to rapidly produce a set of "foundation" cover classes that could be easily converted into more meaningful land-cover information categories, using pre-defined geographic masks in the GEOTERRAIMAGE data libraries.

The "foundation" cover classes represent the basic building blocks associated with all landscape characteristics, namely water, bare ground, grass and tree-bush-shrub cover types, with each being defined in terms of seasonal occurrence or permanence. These basic foundation cover classes represented the initial output from the automated modelling approach. The foundation cover classes are then converted into more conventional land- cover *information* classes, i.e. urban, forest plantation etc, as part of the post-automated modelling data processing steps.

The foundation cover classes are essentially "*spectrally dependent*" classes, since they are generated from automated modelling procedures that are based directly on the spectral characteristics associated with each image pixel over time (i.e. seasonal) and space (i.e. within an image frame). The final land-cover information classes are referred to as "*spectrally independent*" classes since different cover classes can share similar foundation class spectral characteristics in a one-to-many type relationship. For example, the "bare ground" spectrally dependent cover classes could represent non-vegetated built-up urban areas, natural rock exposures, beach sand or a mine pit and tailings dump. Similarly the tree-bush classes could represent a natural vegetation cover, a timber plantation or a fruit orchard. The advantage of this approach is that the conversion of the initial, spectrally dependent foundation cover classes into the final, spectrally independent land-cover information classes can be tailored to suit a variety of end-user information requirements; simply by using a different set of pre-determined masks and foundation class sub-divisions and amalgamations.

### 5.1 Model Portability to other Geographical Areas and Sensors

Although model development was focussed on using Landsat 8 imagery within South Africa, the same models have also been proven to work with equivalent success on Landsat 8 imagery over sites in Sudan, Zimbabwe, Botswana, Namibia and Mozambique; as well as using comparable Landsat 5 archive imagery over South Africa; all of which indicate a high level of model portability. This should allow and support the production of directly comparable historical land-cover datasets for change detection, assuming of course that the required level of seasonal image coverage is available in the data archives.

### 5.2 Use of Object Based Modelling

No attempt was made to include or use object-based modelling in the automated mapping process, primarily because the medium resolution format of multi-spectral Landsat 8 imagery does not lend itself to this type of modelling; since pixel resolution typically precludes the identification of true landscape "objects" in comparison to high and ultra-high resolution image formats. The 30 metre Landat resolution pixels typically represent a mix of land-cover characteristics rather than a pure cover surface, i.e. an urban pixel is typically a composite of building roofs, garden vegetation and / or road surfaces etc. However, object-based modelling may be useful approach for helping to generate 2nd level information classes from the primary level "foundation" class dataset, such as for example, separating water in rivers (i.e. natural) from water in dams (i.e. artificial), based on size, shape and context etc.

## 6. LANDSAT IMAGERY

The primary imagery source used in the generation of the 2013-14 SA National Land-cover dataset was 30m resolution Landsat 8 imagery, acquired between April 2013 and March 2014. Within each image frame, a range of seasonal image acquisition dates were used (within the automated modelling procedures), to characterise the seasonal dynamics across the landscape in terms of the basic tree, bush, grass, water and bare foundation cover classes. Nine image acquisition dates per image frame, per complete seasonal cycle was taken as the optimal number of dates, based on Landsat's 16-day overpass schedule[8]. Unfortunately due to localised, prolonged cloud cover problems in some regions during this April 2013 - March 2014 period, this was not possible to achieve. In such cases, archival Landsat 5 imagery was used as a substitute, but only if it was from a suitable seasonal period to compliment the Landsat 8 data, and was ± 100% cloud free. **Figure 1** illustrates the total number of image acquisition dates per image frame, whilst **Figure 2** illustrates the location and number of Landsat 5 images that were also used.

In summary, 76 x Landsat image frames were required to provide complete coverage of South Africa, Swaziland and Lesotho. 616 x individual Landsat images were used to model and produce the land-cover data, representing and average of 8 x acquisitions per image frame per year. Of the 616 x images, 592 x images were from Landsat 8 (i.e. 96 %) and 24 x images (i.e. 4 %) were from Landsat 5. The Landsat 5 images were however only used in 10 of the 76 image frames defining the geographic extent of the land-cover dataset.

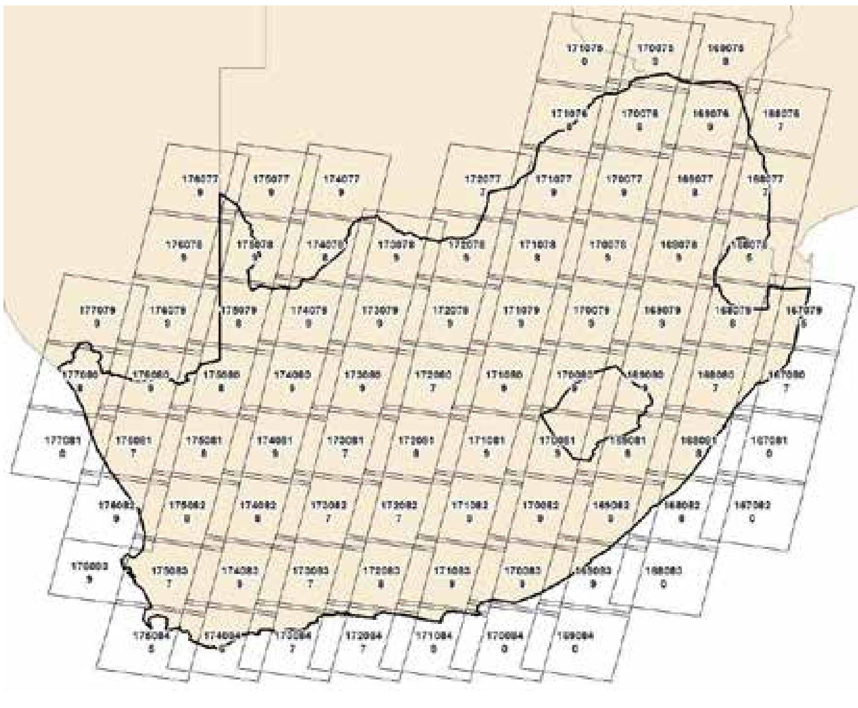


Figure 1: Total number of image acquisition dates used in the land-cover modelling per image frame.

8 This seasonal window requirement, whilst improving the overall accuracy of interpretation and land-cover modelling, means that in practice that between 12 - 16 months are actually required to acquire sufficient cloud free seasonal imagery for input into the modelling processes. This means that a new land-cover dataset could only be generated approximately every 2 - 3 years (minimum), since a shorter period may not provide sufficient separation between the seasonal input image dates.

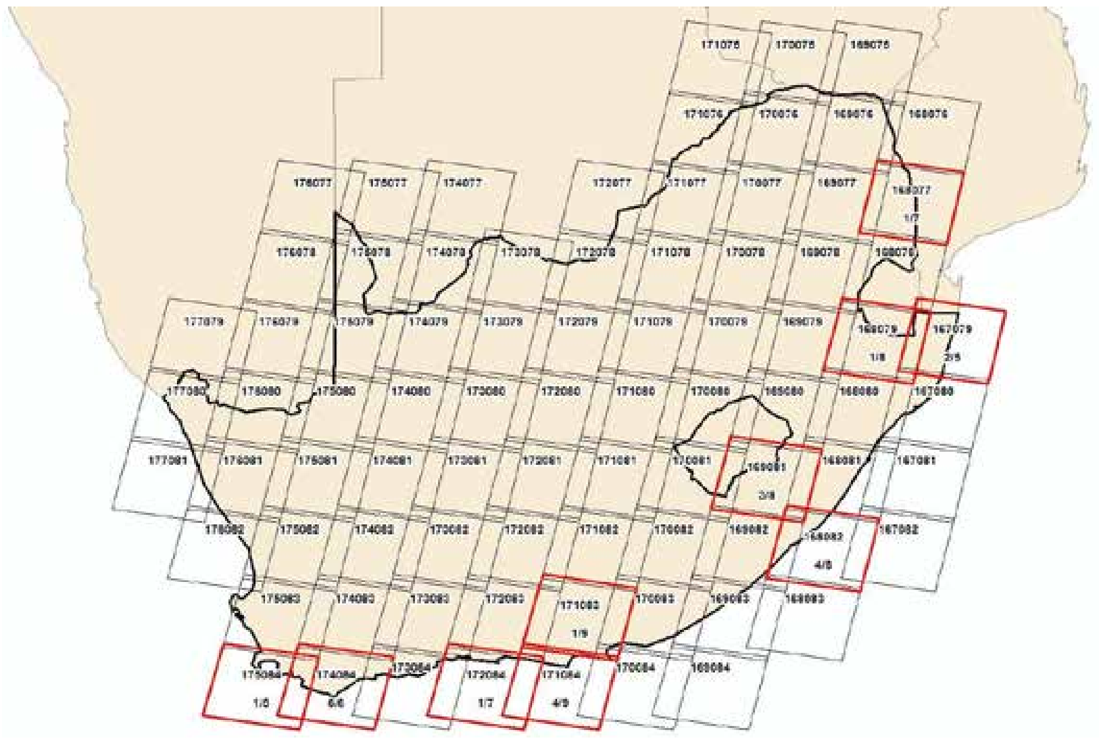


Figure 2: Location of the 10 x image frames that required the use of archival Landsat 5 imagery due to the limited availability of Landsat 8 data during the period April 2013 to March 2014.

## 6.1 Landsat Image Sourcing

All Landsat 8 and 5 imagery used in the 2013-14 land-cover data modelling was sourced from the on-line data archives of the United States Geological Survey (USGS, http://glovis.usgs.gov/). The data are provided in a precise geo-corrected UTM (north) / WGS84 map projection format, and was used "as-is" without any further geo-correction. A complete list of the image acquisition dates used in the modelling of the 2013-14 South African Land-cover dataset (for both Landsat 8 and 5) is contained in the accompanying spreadsheet (see **Appendix B**).

## 6.2 Landsat Data Preparation

All Landsat 8 and 5 imagery was standardised to 16-bit, Top-of-Atmosphere (ToA) reflectance values prior to land-cover modelling using a generic modelling approach. The original USGS generated UTM (north), WGS84 map projection format was retained without change or modification throughout all image-frame based modelling procedures. As far as possible only cloud free or image dates with limited cloud cover were used in the land-cover modelling (i.e. maximum ± 20% terrestrial cloud cover in any one date). Any cloud affected regions were corrected by merging cloud affected ToA corrected imagery with cloud free ToA corrected data from preferably the preceding or following overpass date; so that as far as possible, the final cloud-free merged imagery composite only represented a maximum difference of ± 16 days. Cloud masks were created using either using conventional pixel classification procedures (within analyst defined sub-image areas), or spectral based modelling using generic thermal and blue light reflectance thresholds[9]; depending on cloud characteristics. This was deemed acceptable in terms of minimising any changes in local vegetation cover growth changes. Approximately 35% of the 616 x images used in the land- cover modelling were cloud-masked composites. No external atmospheric correction was applied to the image data.

## 7. LAND-COVER MODELLING

### 7.1 Spectral Modelling

Derived spectral indices, generated from the ToA corrected imagery were used as the only inputs into the land-cover models. No original spectral (i.e. ToA reflectance) data was used as an input, although collectively, 5 out of the 8 available non-thermal spectral bands were used in the various spectral indices[10]. A standardised set of spectral indices were identified from which the required foundation cover classes, namely (1) tree dominated, (2) bush dominated, (3) grass dominated, (4) water and (5) bare ground could be modelled, using pre-determined, generic spectral threshold values. The generic threshold values associated with each indices and cover type were tested over several landscapes and seasons before being confirmed and accepted as such.

The spectral indices included both existing algorithms such as the Normalised Difference Vegetation Index (NDVI) and Normalised Difference Water Index (NDWI), as well as algorithms developed in-house specifically for the GTI land-cover modelling requirements. All models were developed in ERDAS Imagine © image processing software using the Model Maker function.

The modelling and generation of each foundation cover class was undertaken as a separate modelling exercise, i.e. water was modelled separately from bare ground, which was modelled separately from tree and bush cover etc. This approach simplified the modelling steps and facilitated easier desk-top quality control of outputs; compared to attempting to model all foundation cover types simultaneously within a single model workflow. In most cases the final geographic extent of a particular foundation cover class was generated from the combined use of several different spectral indices, since no single index was found to work well in all landscapes and all seasons.

All modelling was undertaken on an individual image frame-by-frame basis, where the original USGS supplied UTM (north) map projection format was retained as-is. This allowed the models to be adapted according to the number of acquisition dates and associated seasonal ranges available for each particular image frame. The model modifications reflected the need to standardise the outputs according to pre-defined definitions of seasonal permanence, for example, whether a foundation cover class occurred, i.e. in only one image date, in several, but not all image dates, or in all image dates. Obviously the more image acquisition dates available per frame, and the wider the seasonal range, the more accurate the modelled interpretation of a particular cover class's seasonal characteristics.

Examples of the *separate* model outputs for bare ground and tree/bush foundation cover classes are shown in **Figure 3**. The examples show eastern Pretoria, from within Landsat 8 frame 170-078.

9 The spectral modelling approach could only be applied to Landsat 8 imagery (if applicable) due to its enhanced spectral band range, compared to Landsat 5.

10 (2) Green, (3) Red, (4) Red, (5) NIR, (6) SWIR-1 and (7) SWIR-2 Landsat 8 spectral bands.

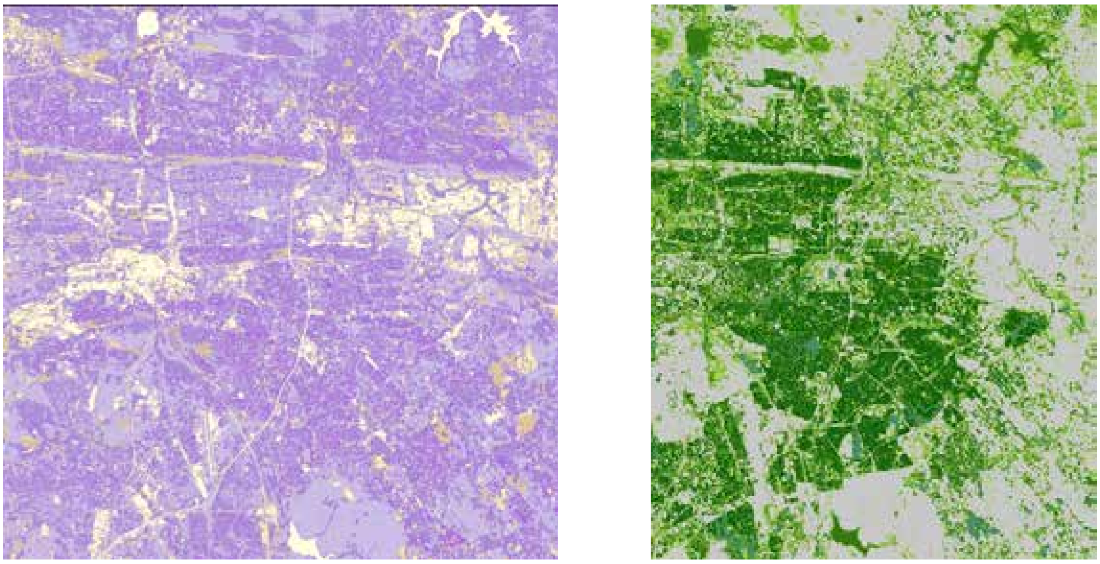


Figure 3: Spectral indices derived model outputs for bare ground and tree bush dominated foundation cover classes, over eastern Pretoria (frame 170-078).

In some circumstances, modifications or additional modelling steps were used to account for regional landscape characteristics that could not be accurately modelled using the only generic models. For example, in some of the far western arid areas, additional tree-bush modelling steps were taken using a slightly modified modelling approach in order to better detect and separate between the sparse, low bush and shrub covers in these landscapes.

## 7.2 Terrain Modifications

Terrain based modifications were included within some of the foundation cover class modelling procedures (i.e. water, bare and tree-bush classes), in order to minimise seasonally induced terrain shadowing effects, using a combination of solar illumination and slope parameters. These parameters were modelled independently using the 90m resolution SRTM dataset[11], with outputs being re-sampled to a Landsat comparable 30m resolution format, prior to being incorporated into the foundation cover class models. For example, solar illumination and DEM slope masks were used to minimise any spectral confusion between dark terrain shadow areas and comparable water body reflectance levels. Note that when creating the DEM derived parameters, such as shadow extents, modelling was based on the full range of seasonal solar azimuth and zenith angles and not a specific date or season, in order to better align with seasonal differences evident across the any given range of image acquisition dates.

## 7.3 Individual Frame Spectral Models

The basic modelling parameters used to create each of

11 Although the 30m SRTM terrain dataset would have been more preferable it did not become publically accessible until after the completion of the bulk of the 2013-14 land-cover modelling had been completed.

the "foundation" cover classes are described below. In each case the modelled output would typically represent a (qualitative) gradient of spatial densities and as well as temporal, i.e. seasonal occurrence. For example the bare ground model output consisted of a set of classes that represented a range of conditions from "pure bare" to "mixed bare / sparsely vegetated", with each described in terms of seasonal permanent or temporary occurrence. The foundation water class modelling was the only exception to this, with the model output describing water extent in terms of only permanent or seasonal occurrence.

### 7.3.1 *Spectral Modelling of Water*

Water was modelled using a combination of 5 spectral indices, including a burn index, and DEM derived solar illumination and slope masks. The burn index was used to minimise any spectral confusion between dark burnt areas and comparable water body reflectance. The solar illumination and slope masks were used to minimise any spectral confusion between dark terrain shadow areas and comparable water body reflectance. Generic spectral water models were developed for both flat (standard) and hilly terrain, and for shallow water (pan) dominated landscapes.

### 7.3.2 *Spectral Modelling of Bare Ground*

Bare ground was modelled using a combination of 2 spectral indices, and DEM derived solar illumination and slope masks. The solar illumination and slope masks were used to minimise any spectral confusion between dark terrain shadow areas and comparable bare ground reflectance. The output represented a gradient of bare ground from pure bare to sparsely vegetated cover.

### 7.3.3 *Spectral Modelling of Tree / Bush Cover*

Tree and bush cover was generated within the same spectral model. Both woody covers were modelled using a combination of 4 spectral indices, and DEM derived slope mask. The slope mask was used to minimise any spectral confusion between dark terrain shadow areas and comparable woody cover in two of the 4 spectral indices. "Trees" refers to dense, typically tall woody cover, such as natural and planted forests, dense woodland and thickets, etc; whereas "bush" refers to more open, often lower mixed tree / bush communities such as typical bushveld or open woodland. The spectral modelling procedure also separated woody cover spectral classes that showed similar characteristics to other vegetated covers such as crops, sports fields, golf fields (especially if irrigated), from those that didn't. An additional "desert" tree / bush model was developed as an extra model to be run in addition to the standard model in more arid areas, in increase the representation of bush cover in these regions where the modelling thresholds used in the standard model were not sensitive enough.

### 7.3.4 *Spectral Modelling of Grass*

Grass cover was modelled using only a single spectral indices. No DEM derived solar illumination and slope mask modifiers were used.

### 7.3.5 *Spectral Modelling of Burnt Areas*

Burnt cover was modelled using only a single spectral indices. No DEM derived solar illumination and slope mask modifiers were used.

## 7.4 Seasonally Defined Spectral Land-Cover per Image Frame

The modelled outputs for each foundation cover class were combined into a single composite dataset for each frame, in a pre-determined hierarchical order, in order that the final output cover class combinations reflected the dominant and sub-dominant cover types in terms of seasonal occurrence. For example:

- water in all dates (permanent),
- water in many dates (seasonal),

- tree-dominated in all dates,
- tree-dominated in many but not all dates plus bare ground in one date, etc

**Figure 4** shows the output after all the separate foundation land-cover classes have been combined into a composite set of seasonally defined foundation land-cover classes. The illustrated area is the same eastern Pretoria area as shown in **Figure 3** previously. This interim land-cover product consists of 51 x seasonally defined foundation cover classes, as listed in **Appendix C**. These seasonally combined foundation cover classes are still essentially *"spectrally dependent"* classes, since they have been generated using automated modelling procedures, on only the spectral characteristics associated with each image pixel over time (i.e. seasonal) and space (i.e. within an image frame).

Note that in addition to the basic tree, bush, grass, water and bare ground foundation classes already described, fire scar extent and occurrence was also modelled and incorporated into the final combined foundation cover composite classes, in order to provide an indication of whether or not fire was a factor in the modelled seasonal cover profiles, i.e. a single date, bare ground area could be the result of a wildfire event that then re-vegetated later in the season.

The spectrally dependent and seasonally defined foundation cover classes in this base dataset represent the ***"building blocks"***, from which more information focused land-cover classes can be derived, especially if combined with ancillary datasets such as vegetation or land-use maps to facilitate further class sub-divisions or area-based class modifications. The entire spectral modelling procedure is summarised graphically in **Figure 5**.

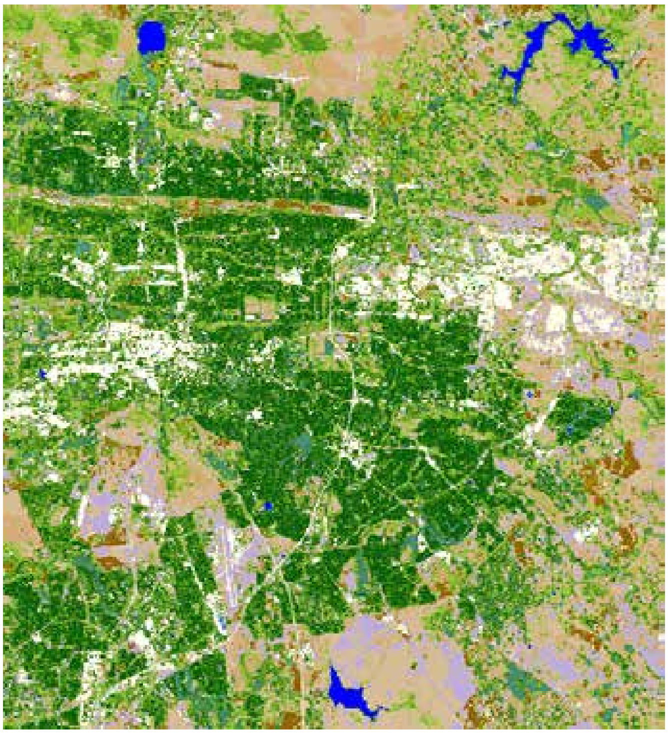


Figure 4: Interim spectral land-cover product after combining all the seasonal defined foundation cover classes, (eastern Pretoria, frame 170-078)

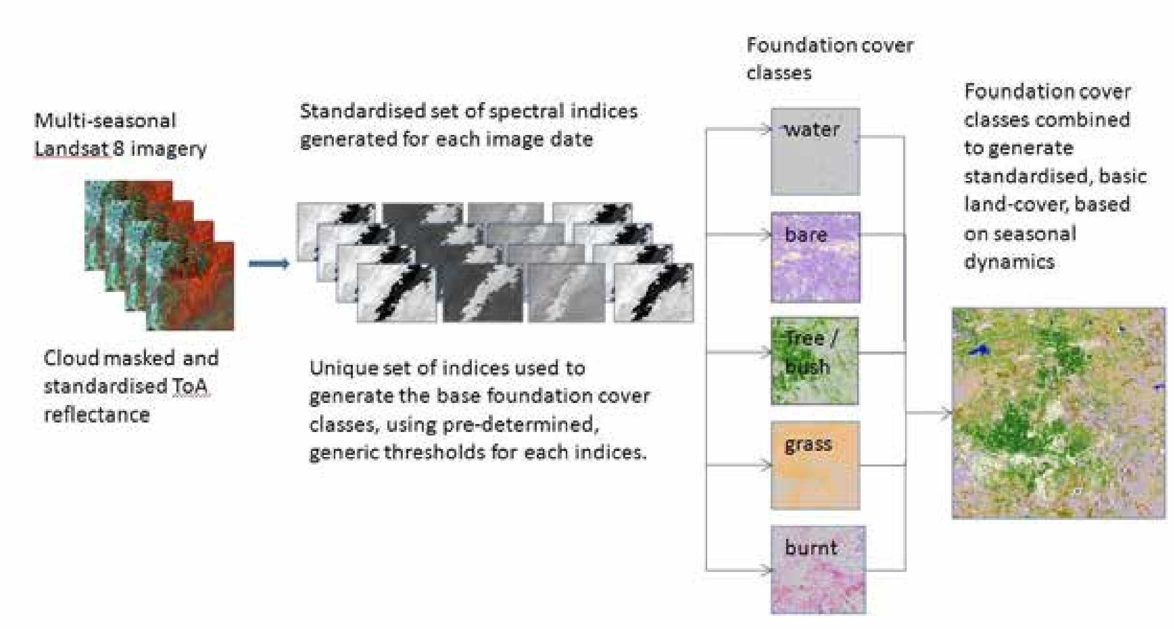



Figure 5: Summary of the full spectral land-cover modelling process

## 7.5 Generation of Full South African Spectral Class Mosaic

Once the spectral modelling for the individual frames had been completed, the next step was to merge these into a single, seamless coverage for the whole of South Africa. Achieving this involved several processing steps. Individual image frame datasets were first edge-cleaned

to ensure that no frame-edge pixel anomalies would be carried over into the final country-wide mosaic. Cleaned image frames were then re-projected, were necessary, to a standardised UTM35 (north), WGS84 map projection; since the majority of image datasets covering South Africa were sourced from the USGS data archives were in this UTM zone.

Individual image frames were merged into a single, country-wide spectral foundation class composite, based on an analyst determined sequence of image border overlap rules in order to ensure the best possible seamless integration of the individual frames. This approach was necessary since some image-to-image edge differences do occur between image frames where spectral foundation classes have been generated from significantly different input acquisition dates, simply as a result of image data availability.

Although the standardised modelling approach used to generate the es supported generation of spatial and content comparable land-cover data in adjacent image frames (*if both frames utilised comparable input image acquisition dates*), if there was a significant difference in the number or seasonal range of input images, then adjacent images often showed edge matching differences. In such cases, the adjacent images were often spatially comparable, but not necessarily content comparable. In these cases, the edge matching process was set-up, as far as possible so that the most prominent and spatially extensive landscape pattern was maintained across the image borders, in order to provide a more visually seamless image frame overlap.

Note that for water ("seasonal" and "permanent") and bare ground ("pure bare, all dates") country-wide coverages, the maximum extent of each class, from all images, was transferred across to the final country-wide spectral class composite; regardless of any frame overlap edge matching applied to other spectral classes.

### 7.5.1 Grassland Corrections: Inland

Persistent cloud cover problems on several image acquisition dates during the 2013-14 wet season period over the Highveld region resulted in the unavailability of usable, early wet season imagery for modelling inputs. This resulted in the standard spectral models under-estimating the grassland extent. In order to correct this, an alternative grassland model was developed, based on a single, rather than multiple, image acquisition date. The optimal single date representing the best, dry season image for visually separating green woody vegetation from senescent grassland vegetation, with minimal burn scars. For image frames covering areas of significant topographical relief, such as over the escarpment, the single- date grass corrective model included use of solar illumination and slope parameters to improve modelling outputs. For standardisation purposes, the inland grassland corrective model was applied to all image frames overlapping or contained within the SANBI grassland Biome boundary. The resultant grassland extents for each image frame where then merged into a composite geographical mask and integrated back into the original county-wide spectral class dataset to improve the overall grassland delineation.

### 7.5.2 Grassland Corrections: Coastal

In some high rainfall coastal regions, the standard spectral models were unable to accurately distinguish between grassland and woody cover, where the grass biomass was exceptionally high as a result of high local rainfall during the 2013-14 wet season, even if suitable image acquisition dates were available. This was especially the case around Pondoland (E Cape) and Zululand and Maputoland (KZN). To correct this another grassland correction model was developed with alternate spectral thresholds to better delineate the correct grassland extent in these areas. The resultant frame specific outputs were then merged into a composite geographical mask and integrated back into the original county-wide spectral class dataset to improve the overall grassland delineation.

# 8. LAND-COVER INFORMATION GENERATION

Multi-seasonal Landsat imagery has been used to generate a comprehensive set of spectrally-based outputs that describe the seasonal characteristics of tree, bush, grass, bare and water cover characteristics within each image pixel, as represented by the 51 x spectral foundation classes. These were converted into more meaningful and informative land-cover and land-use information classes, aligned with the SANS 1877 South African National Land-cover Classification Standard (see **Section 4.1**). For example a pixel may be described as having a detectable tree cover on more than one image acquisition date, but not all dates; and grass covered for several but not all dates. This would then be interpreted as an open, deciduous tree covered woody community, (i.e. woodland), where the grass cover became evident when the tree canopy showed less than maximum foliage cover.

## 8.1 Conversion from Spectral to Information Classes

The creation of both land-cover and land-use information classes involves the recoding and re-grouping of selected spectral foundation classes either in a controlled or uncontrolled geographic area. In a controlled re-coding, independently sourced and / or generated geographical masks are used to define the location and extent of the recode process. This is required because in many situations different landscape features can be represented by similar spectral characteristics. For example a spectrally modelled area of permanent bare ground (i.e. spectral characteristics are representative of a non-vegetated surface in all image acquisition dates), could be representative of a beach, a mine, or a large building. By using an appropriate geographic mask (essentially an independently defined or sourced polygon coverage), it is then possible to code all bare ground pixels within the mask to, for example, mining, whilst allowing all other bare areas outside the mask to represent other bare ground surfaces, which can then be further re-coded as and where required.

The key to this process is that the spectral modelling defines the exact footprint of the spectral cover class (in a user independent manner), whereas the geographic mask defines the information content (based on user expertise and knowledge). This approach overcomes problems where spectral characteristics are shared between two or more separate land-cover/use classes, which is self-evident in many image-based mapping applications. **Figure 6** illustrates the various procedural pathways that can be used to convert the spectral foundation classes into land-cover / land-use information classes.

## 8.2 Creating Base Vegetation Land-Cover Classes

The natural vegetation base classes, namely thicket / dense bush, woodland / open bush, grassland, low shrubland and bare, non-vegetated were created by merging selected groups of spectral classes. Generally, selected spectral classes were merged into the required vegetation cover classes without geographical control, using the original spectral class extent and distribution 'as-is'. However in some regions, and for some spectral classes it was necessary for the re-coding and merging process to be geographically controlled, and only allow the recode

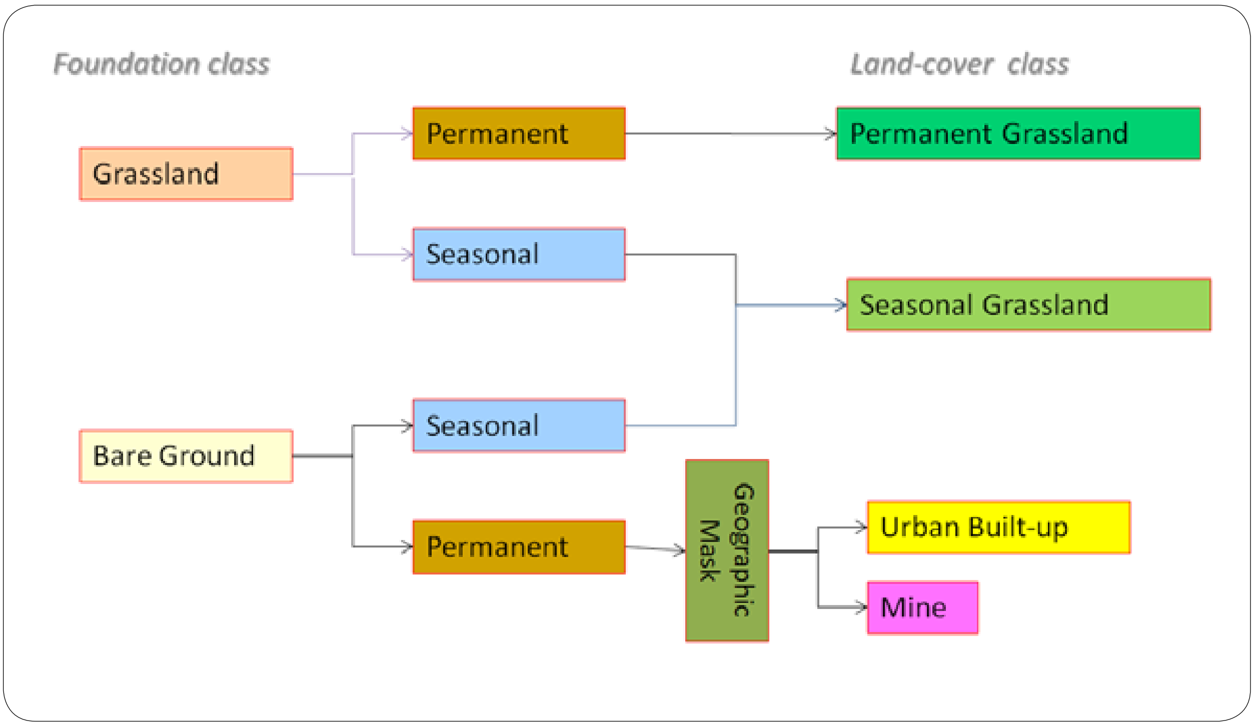



Figure 6: Processing pathways for converting spectral foundation classes to land-cover / land-use information classes, based on seasonal permanence and shared spectral characteristics.

procedure within pre-determined geographical regions. Controlled geographical recoding (i.e. masking), used pre-selected SANBI bioregion[12] boundaries to define where and how selected spectral classes were modified. Note that the final vegetative land-cover class boundary was always defined by the original spectral foundation class boundaries contained within the SANBI bioregion boundary, and not by the bioregion boundary itself, other than for the Fynbos low shrubland sub-class.

### *8.2.1 Fynbos*

The sensitivity of the automated spectral models was insufficient to determine the transition between structurally similar Fynbos low shrub communities and non-Fynbos low shrub communities, except for the boundary with the structurally different Namaqualand (SKn and SKs) and Knersvlakte (Skk) Bioregions. In these areas the boundary between the Fynbos and non-Fynbos low shrub communities has been defined on the basis of the original spectral class boundaries[13].

### *8.2.2 Indigenous Forests*

The indigenous forest land-cover class was generated in a similar manner to the previously described base vegetation classes, although the geographical masks used to control the recoding of the selected spectral foundation classes were derived from a combination of independent datasets. These included the SANBI forest biome boundaries, higher detail regional masks created in-house in support of previous provincial-level land-cover mapping, shadow and altitude terrain parameters modelled from the higher resolution 30m resolution SRTM DEM terrain data[14], and NDVI[15] spectral datasets. The NDVI dataset represented a nation-wide summary of the seasonal maximum NDVI recorded in each pixel, calculated from all image acquisition dates used in the spectral land-cover modelling. Note that separate models were required to recode the different Forest vegetation types (i.e. Northern Afromontane, Sand, Scarp etc), with each one being based on different geographical mask combinations and associated data thresholds, in order to correctly model the forest patch distributions in these regions. The final, modelled forest extents were then integrated into the base vegetation land-cover classes.

### *8.2.3 Wetlands*

The wetland class was created using independent and separate modelling routines that did not include reference to, or recoding of any of the original 51 x class spectral foundation classes. Depending on the available image acquisition dates per frame, wetland extent was modelled using either a dual or single image acquisition date process. The single date approach used the best "wettest" image date, whereas the dual date approach was based on the difference between wettest and driest image dates whereas the single (wettest) date modelling was only used as an alternative approach if the available acquisition dates

12 Sourced from "The Vegetation of South Africa, Lesotho and Swaziland". Eds Mucina L and Rutherford MC. 2006. Strelitzia 19. South African National Biodiversity Institute: associated digital GIS database. Note that SANBI Biome and Bioregion boundaries, whilst generically applicable for 1:250,000 digital map scales, is often *considerably more accurate on a local scale, even down to the nearest 100m in some cases* (refer Section 4.1.2, Mapping Scale. p 15)

13 The is primarily because satellite imagery such as Landsat, with its combination of medium spatial resolution and limited spectral capabilities (compared to hyper-spectral sensors), is primarily responsive to structural vegetation characteristics rather than community floristics. Accurate delineation of Biome-related boundaries, especially if the boundary is a *transition zone*, rather than *distinct border*, is at best, challenging with imagery such as Landsat. Especially if floristic differences play a greater role than structural differences in defining the border. This is likely to be the case between the Fynbos, Succulent Karoo, Nama Karoo and surrounding Grassland and Desert Biomes.

14 The 30m resolution SRTM terrain data for Africa was available for use at this time within the 2013-14 SA Land-Cover project, despite not having been available for the initial spectral modelling phase.

15 Normalised Difference Vegetation Index (NDVI)

did not provide suitable seasonal differences for the dual date, wet-dry date approach. Both modelling approaches only used inputs from multiple spectral indices, and not use the 51 x spectral foundation cover classes as used in the other vegetation class generation. A combination eight indices were used in the dual-date approach, with each being applied to both dates; whereas only four spectral indices were used in the single, wettest date approach. Both modelling approaches generated a dataset that represented the likelihood of wetlands occurring in the landscape, within which a threshold was determined on a frame-by-frame basis in order to best represent actual wetland extent.

The single (wettest) date modelling approach used terrain shadow masking to minimise spectral confusion with non-wetland regions, whereas the dual-date approach used more complex slope and floodplain modelling to limit the topographic areas within which wetlands were likely to occur. Both approaches used the 90m SRTM terrain data as the source for topographic modelling.

The slope and floodplain model generated potential flooding zones, based on potential flood heights, which were taken to be indicative of areas most likely to be wet, and thus contain the highest probability of having wetlands. The flood heights were created by estimating the water expansion level in river channels against a modelled stream surface height layer, (in comparison to actual terrain surface). The modelling provides an indication of potential lateral water extent at a range of heights above the stream base height in relation to the stream channel profile at that location, irrespective of flood duration or time periods. The modelling does not take account of the surface roughness or flow blockage which may result in additional lateral extension of flood waters through backup etc. The accuracy of the output is directly dependent on the scale, resolution and detail contained within the DEM. The modelled potential flooding zones were then used to restrict the dual-date wetland modelling where wetlands are most likely to occur.

Note that in some localised areas, the results of both single and dual-date wetland modelling approaches required post-modelling edits to improve the wetland delineation, especially if wetlands were not showing saturation or significant (vegetation) flushes. In such cases, analyst assisted conventional unsupervised classifications were used to locally improve the modelled wetland output.

The modelled wetland extents were then integrated into the base vegetation land-cover classes.

#### *8.2.4 Nama and Succulent Karoo*

The Nama and Succulent Karoo categories and associated sub-classes are included as a result of a specific DEA information requirement in the DEA / CARDNO land-cover data product. Since the sensitivity of the automated spectral models was insufficient to determine these Biome boundaries, they have been defined solely on the SANBI Biome boundaries, as per the previous Fynbos explanation.

However *within* these SANBI boundaries the original level of modelled land-cover detail has been retained, in terms of forest, dense bush, open bush, low shrubland, grassland and bare ground sub-classes. This is because each Biome can contain a wide range of structural vegetation types, over and above the dominant structural form. For example, localised patches of thicket, tall bush and grass-like structural communities all occur within the general low shrub matrix that comprises the Nama Karoo Biome, according to local species composition, terrain location and fire history, etc

### 8.3 Creating Land-Use Classes

Land-use classes such as cultivated lands, forest plantations, mines and settlements were all derived as separate modelling procedures, typically using independently sourced and generated geographical masks to control where and how the original 51 x seasonally defined, spectral foundation classes were re-coded and modified into the final land-use classes.

#### 8.3.1 Cultivated Lands

The Department of Agriculture, Forestry and Fisheries's (DAFF) public domain 2013 national field boundary dataset (captured from 2.5m resolution, pan-merge SPOT5 imagery), was the initial source of the cultivated land-use classes. This existing dataset was updated nationally to represent the latest cultivated land patterns present on the latest 2014 Landsat 8 imagery used in each image frame. This typically involved capturing the distribution of new, commercially cultivated fields, especially centre pivot irrigation units, although all field types, were included in the 2014 updating process, including subsistence cultivation areas, if clearly apparent.

In addition, the location, extent and distribution of all commercial pineapple and sugar cane crops were mapped from the same 2014 Landsat 8 imagery, to increase the level of crop specific sub-class detail, in-line with several of the previous Provincial land-cover datasets generated by GEOTERRAIMAGE.

All new cultivated lands (and crop types) mapped from the 2014 Landsat 8 imagery were captured manually using on-screen photo-interpretation techniques; since this facilitated and maintained similar interpretation accuracies to the source SPOT5 derived field boundary data. Furthermore it also eliminated post-classification editing necessities typically associated with field boundary (as opposed to crop type), classification attempts.

The final cultivated land boundaries were used 'as-is' to define the final geographical extent of all the cultivated land-use classes incorporated into the land-cover dataset. No use of, or reference to, the original 51 x class, seasonally defined, spectral foundation classes was made.

#### 8.3.2 Plantations

Forestry plantations were derived from selected classes from within the 51 x spectral foundation cover dataset, which were re-coded and re-grouped within controlled geographical areas, using independently sourced and generated geographic masks. The plantation area masks were sourced from several in-house provincial mapping projects, updated nationally to the plantation extent visible on the 2014 Landsat imagery.

Note that the final plantation class boundaries were always defined by the original spectral foundation class boundaries *contained within* the geographical masks, and not by the geographical mask boundaries themselves.

The geographical masks used to define the areas to be recorded for the clear-felled plantation sub-class were only mapped off the latest 2014 Landsat imagery, in order to ensure that the representation and interpretation was current.

#### 8.3.3 Mines

Mines were derived from selected classes from within the 51 x spectral foundation cover dataset, which were re-coded and re-grouped within controlled geographical areas, using independently sourced and generated geographic masks. The mine area masks were sourced from previous in-house, provincial mapping projects and national 1:50,000 scale map datasets[16], all of which were then updated nationally to the mine activity extent visible on the 2014 Landsat imagery. Note that mine water sub-classes were generated by identifying water classes that were located within the final mine geographical masks.

16 Geographic masks from the national 1:50,000 scale topographic digital map data were created by extracting the relevant vector features and buffering them by 1 x Landsat pixel extent. These were integrated with the in- house provincial mine masks, before updating to 2014 geographic extents off the 2014 Landsat 8 imagery.

Note that major road and rail features were excluded from the mine area footprint if it intersected the mine mask.

Note that the final mine class boundaries were always defined by the original spectral foundation class boundaries *contained within* the geographical masks, and not by the geographical mask boundaries themselves.

### 8.3.4 Built-Up / Settlements

Built-up areas generated independently of the spectral foundation cover dataset. The primary source for the cover class were several, internally developed GEOTERRAIMAGE urban map products and associated databases. These provided detailed information on the extent, distribution and land-use for all settlements nationally. This was verified in rural areas with the national Dwelling Frame dataset, available from STATS SA[17]. This information was then spatially re-modelled to represent built-up area outlines, which were then further updated and corrected nationally, using the 2014 Landsat imagery for visual reference. This was especially so in terms of rural village outlines.

The independently generated Built-up area class boundaries were used 'as-is' to define the final geographical extent of the settlement patterns incorporated into the land-cover dataset. No use of, or reference to, the original 51 x class, seasonally defined, spectral foundation classes was made.

### 8.3.5 Erosion

The erosion (donga) class was derived from selected classes (representative of bare ground) from within the 51 x spectral foundation cover dataset, which were re-coded and re- grouped within controlled geographical areas, using independently sourced and generated geographic masks. The erosion area masks were sourced from previous in-house, provincial mapping projects and other national erosion datasets, all of which were then updated nationally to represent the current extent of major donga's visible on the 2014 Landsat imagery. Note that as a result of spectral modelling sensitivities, and the need to be able to

separate the bare ground within donga features from the surrounding non-eroding areas, the final modelled extent of erosion features is significantly better represented both spatially and numerically in the wetter, more vegetatively lush regions of the country, where the non- vegetated erosion surface are significantly different from the surrounding vegetation cover (i.e. bushveld and grassland regions). Donga feature detection in the drier more arid region is not as accurate.

As with previous land-use classes, the final donga / erosion class boundaries were always defined by the original spectral foundation class boundaries contained within the geographical masks, and not by the geographical mask boundaries themselves.

#### *8.3.5.1 Degraded*

As part of the Department of Environment Affairs commissioned version of the 2014 GEOTERRAIMAGE South African Land-Cover dataset, and additional sub-class, defining 'Degraded' areas was also generated. This sub-class is however not part of the standard land-cover data product. Degraded areas are defined in terms of this dataset as areas of significantly reduced vegetation cover compared to immediately adjacent pristine or semi-pristine natural areas. Degraded areas were modelled from selected classes from within the 51 x spectral foundation cover dataset, which were re-coded and

17 Statistics South Africa (http://www.statssa.gov.za/)

re-grouped within controlled geographical areas, using independently generated geographic masks. The basic degraded area mask was created from image derived, seasonally summarised NDVI maximum and standard deviation datasets. The extent of this mask allocation was limited to areas outside of formally protected (conservation) areas[18], within non-arid Biome regions[19], on terrain slopes < 21 degrees[20], and not overlapping major roads, dry river beds, beaches and dune fields[21].

This modelling approach, whilst relevant in terms of practical available input data, excluded the identification of cover rich, species poor degraded areas, as well as degraded low vegetation areas within *naturally occurring low vegetation regions*. In the latter case alternate modelling options were considered, based on buffered threshold distances around settlements and mines etc, but the generic outputs were not considered universally reliable nor accurate.

As with previous land-use classes, the final degraded area boundaries were always defined by the original spectral foundation class boundaries *contained within* the geographical masks, and not by the geographical mask boundaries themselves.

# 9. ACCURACY ASSESSMENT

The 2013-14 South African National Land-Cover dataset has been verified in terms of mapping accuracy in order to provide a measure of end user confidence in data use. The satellite image generated land-cover / land-use information was verified visually, as part of a desk-top only procedure, against equivalent date, high resolution imagery and photography in Google Earth ©. Accuracies are reported using industry standard error (confusion) matrices, and include Producer, User and Kappa values.

## 9.1 Design and Approach

Sample points for verification were selected using two separate approaches that considered the validity of statistical representation, the spatial resolution of Landsat imagery in relation to landscape features, the national reporting frame extent, and the structure of the mapped land-cover information. Note that 33 x land-cover / land-use classes were verified, representing in some cases primary rather than sub-class land- cover or land-use characteristics. Were necessary these were then amalgamated into the broader DEA / CARDNO land-cover / use classes for statistical reporting. For example, water, mines and plantations were all verified at the primary level since sub-class detail was linked to short term temporal effects that could not be verified on the single Google Earth imagery.

Selection of samples representing potential commission errors was achieved by selecting ± 150 x samples for each of the 33 x classes to be verified, given a total of ± 3500 points. Points were selected randomly across the full national land-cover dataset. Typically ± 100 samples were selected from thematic class units < 100 ha, and ± 50 samples were selected from thematic class units > 100 ha, in order to ensure a balanced representation of thematic unit areas. In all cases, the actual sample point represented the centre of the selected thematic unit, with placement set to exclude areas within 50 m of thematic unit boundary, to minimise class edge effects.

18 As defined in the DEA Protected Areas 2014 PACA database.

19 To ensure that degraded areas were clearly identifiable as having a lower vegetation cover than the surrounding non-degraded areas, unless they were in located within former TBVC state boundaries and closely associated areas of dense rural settlements.

20 To exclude natural rocky slopes and cliff faces with similar non-vegetated spectral characteristics.

21 To exclude other land-cover and land-use features with similar non-vegetated spectral characteristics.

Selection of samples representing potential omission errors was achieved by selecting approximately ± 2500 samples, *without reference to class type*, on initially a stratified approach using the image frame extents, and then randomly, within the selected frames, randomly across the original spectral foundation class dataset (as opposed to the final land- cover dataset). The boundaries of the spectral foundation classes were just used as a sampling frame. Points represented the centre of the selected thematic spectral unit, with placement set to exclude areas within 50 m of thematic unit boundary, to minimise class Edge effects. This approach was deemed appropriate since it ensured that the sample points at least reflected the spatial variability of the multi-date input imagery, which in turn reflected the seasonal landscape characteristics. Approximately 1000 samples were selected from thematic class units between 100 - 200 ha in size, ± 1000 samples from thematic class units between 200 - 500 ha, ± 400 samples from thematic class units between 500 - 1000 ha, and ± 100 samples from thematic class units > 1000 ha, in order to ensure a balanced representation of thematic unit areas.

*Note that the results presented below represent the DEA / CARDNO land-cover legend content and not the full land-cover legend from which it has been derived.*

Note that no map accuracy statistics are provided at the Biome Level, other than for the Fynbos: Low Shrubland class, since the Biome defined boundaries have been derived from fixed, independent data and simply overlaid on the spectrally modelled structural vegetation categories. The Low Shrubland: Fynbos class is retained within the accuracy assessment since its delineation has, in part, been defined on modelled spectral characteristics.

Note that no map accuracy is provided for the Degraded class due to the difficulty of reliably determining, visually, that the vegetation at a specific sample point is significantly lower than that in surrounding, undisturbed natural vegetation areas, without in-field observation over wider areas. It is suggested that the calculated accuracy for bare ground and erosion are taken as indicative of the degraded mapping accuracy, since the degraded class is a modelled derivative of these classes.

**Figure 7** illustrates the number and distribution of sample points across the full country extent.

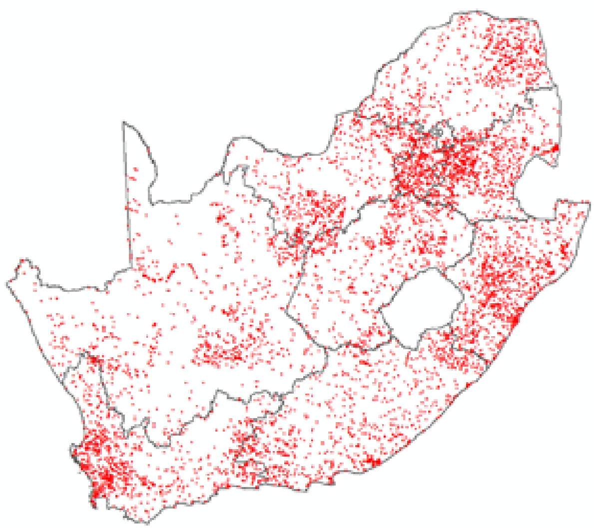


Figure 7: Number and distribution of 6415 x sample points across the full country extent.

## 9.2 Results

The map accuracy results for the 2013-14 South African National Land-Cover dataset, modelled from multi-seasonal Landsat 8 imagery, *based on the modified legend format representing the DEA-CARDNO information requirements*, are as follows:

| OVERALL SUMMARY | | |
|---|---|---|
| Overall Map Accuracy | 82.53 | % |
| Mean Class Accuracy | 88.36 | % |
| 90 % confidence limits | 81.91 | 83.14 |
| | low | high |
| Kappa Index | 80.87 | |
| Number of classes present (enter) | | 17 |
| Number of sample sites | | 6415 |

The overall map accuracy for the 2013-14 South African National Land-Cover *DEA-CARDNO format dataset*, modelled from multi-seasonal Landsat 8 imagery is 82.53%, with a mean land-cover / land-use class accuracy of 88.36 %. This has been determined from 6415 sample points representing 17 x DEA-CARDNO land-cover / use classes. The Kappa Index value of 80.87 indicates that these results are very unlikely to be the result of chance occurrence.

A breakdown of individual class accuracies is provided below

*Note: class numbers refer the class numbers in the digital land-cover data, which include additional sub-class information relating to the Fynbos, Nama and Succulent Karoo biome groupings.*

CLASS SUMARY STATISTICS

| | | | User Acc % | Prod Acc % | 90% C.L low | 90% C.L high | Omm Error | Comm Error |
|---|---|---|---|---|---|---|---|---|
| LAND-COVER CLASS | Indignenous Forest | 1 | 72.60 | 94.64 | 91.78 | 97.50 | 0.05 | 0.27 |
| | Dense Bush, Thicket | 2 | 53.74 | 83.64 | 80.72 | 86.55 | 0.16 | 0.46 |
| | Woodland, Open Bush | 3 | 60.84 | 54.13 | 51.27 | 57.00 | 0.46 | 0.39 |
| | Low Shrub: Other | 4 | 70.59 | 61.82 | 59.37 | 64.27 | 0.38 | 0.29 |
| | Forest Plantation | 5 | 89.30 | 94.35 | 92.31 | 96.39 | 0.06 | 0.11 |
| | Cultivated Commercial Crop | 6 | 91.91 | 99.54 | 98.69 | 100.00 | 0.00 | 0.08 |
| | Cultivated Pivot Crop | 7 | 95.38 | 92.42 | 91.18 | 93.66 | 0.08 | 0.05 |
| | Cultivated Orchards | 8 | 92.18 | 95.29 | 93.62 | 96.95 | 0.05 | 0.08 |
| | Cultivated Vineyard | 9 | 91.61 | 97.26 | 95.37 | 99.15 | 0.03 | 0.08 |
| | Cultivated Subsistence | 10 | 89.00 | 94.42 | 92.22 | 96.61 | 0.06 | 0.11 |
| | Settlements | 11 | 93.90 | 98.68 | 97.93 | 99.43 | 0.01 | 0.06 |
| | Wetlands | 12 | 88.07 | 91.18 | 88.30 | 94.05 | 0.09 | 0.12 |
| | Grasslands | 13 | 84.56 | 69.82 | 68.11 | 71.53 | 0.30 | 0.15 |
| | Fynbos: Low Shrubland | 17 | 79.64 | 93.31 | 91.15 | 95.46 | 0.07 | 0.20 |
| | Water | 33 | 98.77 | 97.58 | 95.89 | 99.27 | 0.02 | 0.01 |
| | Bare Ground | 34 | 78.69 | 85.92 | 83.86 | 87.97 | 0.14 | 0.21 |
| | | Total | | 82.53 | 81.91 | 83.14 | | |

These results exceed the requirements as defined in the Terms of Reference, that *"a minimum map accuracy of 70% is to be achieved at the 90% confidence limits, with a minimum 70% Kappa index value ... with a minimum of 30 x samples per class ... (and) a target of 1000 x samples in total"*.

A significant majority of individual land-cover / land-use classes achieved User and Producer accuracies of 70% or more (see yellow highlights). Fourteen out of seventeen (14/17, 82%) classes achieved a Users Accuracy greater or equal to 70%. Thirteen out of seventeen (13/17, 76%) classes achieved a Producer Accuracy greater or equal to 70%.

Producers accuracy (omission error) represents how well reference pixels of the true land- cover are classified. Users accuracy (commission error), represents the probability that a pixel classified into a given category actually represents that category on the ground.

Producers accuracy therefore represents the accuracy of the sample points whereas the Users accuracy represents what the data user will experience when using the land-cover data. The Kappa Index is measure of statistical chance, with higher values (>0.7) typically representing repeatable and reliable results.

The contingency matrix showing the per-cover class breakdown of these map accuracy statistics is shown in **Appendix E**.

## 9.3 Analysis and Conclusions

Overall the map accuracies for the 2013-14 South African National Land-Cover dataset are very good and indicate that the dataset is accurate and that data users can have confidence in the information contained within. There are however some individual classes, with less than 80% User and / or Producer accuracies that need further analysis and comment. All of these, bar one, are associated with spectrally modelled base vegetation classes, rather than the post-modelling derived land-use classes.

### *9.3.1 Dense Bush / Thicket*

The Dense Bush / Thicket class achieved a 83.64% Producers Accuracy but only a 53.86% Users Accuracy. This appears to be primarily result of confusion with Woodland / Open Bush (76/428 samples), Grassland (51/428 samples), and Low Shrubland[22] (45/428 samples). There is no clear regional pattern associated with this misclassification.

Within the Woodland / Open Bush confused samples, 52 of the 76 samples had a woody cover ≥ 55%, and 26 of the 76 samples had a woody cover ≥ ± 65%, which may explain this inter-class confusion, since the (Google Earth) observed canopy cover amounts could be considered close to the transition to dense bush cover. The confusion with observed Grassland areas is difficult to explain since there is very little woody cover observed in these samples. A possible explanation may be that localised areas of extremely high grassland biomass are (spectrally) being confused in the modelling process with woody cover. The Dense Bush / Thicket confusion with Low Shrubland may associated, in some cases, with the tall woody cover density of the Low Shrubland[23], since 24/45 of the incorrect sample sites have an observed woody cover of ≥ ± 15%, 15/45 have an observed woody cover of ≥ ± 25%, 9/45 have an observed woody cover of ≥ ± 35%, and 5/45 have an observed woody cover of ≥ ± 45%.

If all the Dense Bush / Thicket samples are grouped into tall woody versus non-woody (or low woody shrub)

22 Low Shrubland Fynbos and Other sub-classes combined.

23 The observed woody cover percentage for Low Shrubland (Fynbos and Other) as indicated in the accuracy spreadsheet represents the tall woody cover and not the general low matrix of woody shrubs.

cover[24], then 349/428 (81%) samples have a tall woody canopy cover ≥ ± 15%, regardless of observed land-cover type, 331/428 (77%) samples have a tall woody canopy cover ≥ ± 25%, 323/428 (75%) samples have a tall woody canopy cover ≥ ± 35%, 310/428 (72%) samples have a tall woody canopy cover ≥ ± 45%, and 197/428 (46%) samples have a tall woody canopy cover ≥ ± 65%.

### 9.3.2 Woodland / Open Bushland

The Woodland / Open Bushland class achieved a 60.84% Users Accuracy and Producers Accuracy of 54.13% Users Accuracy. This appears to be primarily result of confusion with Grassland (59/452 samples), and Low Shrubland[25] (80/452 samples). There is no clear regional pattern associated with this misclassification.

The confusion with Grassland is difficult to explain, other than as a result of modelling and interpretation errors associated with lower woody canopy cover densities and associated spectral characteristics, with 14/59 (23%) of the observed Grassland samples having a woody cover of ≥ 15%. Similar confusion was found with Low Shrubland, with 17/80 (21%) of the observed Low Shrubland samples having an tall woody cover of ≥ 15% cover, irrespective of the background low woody shrub matrix.

If all the Woodland / Open Bushland samples are grouped into tall woody versus non-woody (or low woody shrub) cover, then 320/452 (70%) samples have a tall woody canopy cover ≥ ± 15%, regardless of observed land-cover type, 289/452 (63%) samples have a tall woody canopy cover ≥ ± 25%, 284/452 (62%) samples have a tall woody canopy cover ≥ ± 35%, 221/452 (48%) samples have a tall woody canopy cover ≥ ± 45%, and 80/452 (17%) samples have a tall woody canopy cover ≥ ± 65%.

### 9.3.3 Grassland

The Grassland class achieved a 84.56% User Accuracy but only a 69.82% Producers Accuracy. This appears to be primarily result of confusion with Woodland / Open Bush (82/1004 samples), and Low Shrubland[26] (55/1004 samples). There is no clear regional pattern associated with this misclassification.

The confusion with Woodland / Open Bush is difficult to explain, other than as a result of modelling and interpretation errors associated, since the majority of observed Woodland / Open Bush sample sites all have tall woody cover densities ≥ ± 55%. However on the majority of observed Low Shrubland sites, the woody cover density was less than ± 5 % cover, irrespective of the background low woody shrub matrix, which is probably representative of a transitional zone.

If all the Grassland samples are grouped into tall woody versus non-woody cover, then 813/1004 (80%) samples have a tall woody canopy cover ≤ ± 15%, regardless of observed land-cover type and 711/1004 (70%) samples have a tall woody canopy cover ≤ ± 5%, regardless of observed land-cover type.

### 9.3.4 Low Shrubland (Fynbos and Other Sub-Classes combined)

The Low Shrubland classes for Fynbos and Other respectively achieved User Accuracies of 79.64% and 70.59%; and Producers Accuracies of 93.31% and 61.82%. These two classes have been assessed in combination since they are only differentiated on the basis of the overlaid SANBI Biome boundary. In both cases confusion was primarily with Grassland (142/858 samples).

24 Note that Forest Plantations do not have a woody canopy cover value recorded for either observed or mapped plantation sample sites, so it is likely that the accuracy of the modelled extent of dense woody cover is actually higher, since there are 8 x Dense Bush / Thicket sample points that were observed to be Plantation Forests.

25 Low Shrubland Fynbos and Other sub-classes combined.

26 Low Shrubland Fynbos and Other sub-classes combined.

There is no clear regional pattern associated with this misclassification.

If all the Low Shrubland samples are grouped into (tall) woody *versus* non-woody cover, then 791/858 (92%) samples have a tall woody canopy cover less than ± 15%, regardless of observed land-cover type and 691/858 (80%) samples have a tall woody canopy cover less than ± 5%, regardless of observed land-cover type.

#### *9.3.5 Bare Ground*

The Bare Ground class achieved a User Accuracy of 73.54% and a Producers Accuracy of 77.54%. This appears to be primarily result of confusion with Grassland (26/378 samples), and Low Shrubland[27] (65/378 samples). There is no clear regional pattern associated with this misclassification. The confusion with Low Shrubland is difficult to explain, other than as a result of modelling and interpretation errors associated, since the 57 / 65 observed Low Shrubland sample sites all have tall woody cover densities between ± 5 - 55%, with the majority being between ± 15 - 25%. However these percentages, as indicated, only refer to the tall woody cover component, and not the low woody shrub component, which may have been very sparse. The confusion with Grassland may be due a comparable, overall low vegetation base cover, although unlike with the observed Low Shrubland samples, the observed Grassland samples all had, bar one, zero % tall woody cover densities.

#### *9.3.6 Conclusion*

In conclusion it would seem that the majority of mapping errors associated with the base natural vegetation cover classes can be broadly associated with transitional vegetation conditions, represented by structural vegetation gradients, within which the spectral based modelling has defined a fixed boundary.

## 10. DATA USE

The digital raster data is supplied without any post modelling or classification spatial filtering. Data users may wish to consider applying spatial cleaning techniques, for example, such as applying a moving 3 x 3 pixel window filter to remove isolated single class pixels from the dataset, especially if the raster data is to be converted to vector format.

## 11. METADATA

### 2013-14 GEOTERRAIMAGE SOUTH AFRICAN NATIONAL LAND-COVER DATASET DEA / CARDNO 35 x CLASS LEGEND: CORE METADATA ELEMENTS (SANS1878)

**1(M) Dataset title:**
2013-14 GTI SA National Land-Cover (DEA / CARDNO version)
*(dea_cardno_2014_sa_lcov_utm35n_vs2b_pivot-corr.img)*

**2(M) Dataset reference date:**
April 2013 - March 2014

27 Low Shrubland Fynbos and Other sub-classes combined.

**3(O) Dataset responsible party:**
Produced by GeoTerra Image (GTI) Pty Ltd, South Africa

**4(C) Geographic location of the dataset. MBR**

| | |
|---|---|
| WestBoundLongitude: | -717294.00 (Upper Left X) |
| EastBoundLongitude: | 1301256.00 (Lower Right X) |
| NorthBoundLongitude: | -2239230.00 (Upper Left Y) |
| SouthBoundLongitude: | -4046670.00 (Lower Right Y) |

Projection coordinates based on Universal Transverse Mercator UTM 35 North, WGS84 (datum), meters.

**5(M) Dataset language:**
"English" (eng)

**6(C) Dataset character set:**
UTF8 (8-bit data)

**7(M) Dataset topic category:**
010 = Base Map earth coverage

**8(O) Scale of the dataset:**
Land-cover mapped from 30 metre resolution Landsat satellite imagery, therefore recommended for ±1:75,000 - 1: 90,000 scale or coarse mapping & modelling applications.

**9(M) Abstract describing the dataset:**
The 2013-14 South African National Land-cover dataset produced by GEOTERRAIMAGE as a commercial data product has been generated from digital, multi-seasonal Landsat 8 multispectral imagery, acquired between April 2013 and March 2014. In excess of 600 Landsat images were used to generate the land-cover information, based on an average of 8 different seasonal image acquisition dates, within each of the 76 x image frames required to cover South Africa. The land-cover dataset, which covers the whole of South Africa, is presented in a map-corrected, raster format, based on 30x30m cells equivalent to the image resolution of the source Landsat 8 multi-spectral imagery. This specific version of the 2013-14 GEOTERRAIMAGE South African National Land-Cover Dataset is supplied to the South African Department of Environmental Affairs under the DEA / CARDNO Project: SCPF002:"Implementation of Land Use Maps for South Africa". The supplied dataset referred to in this report represents a *subset* of the full 2013-14 GEOTERRAIMAGE South African National Land-Cover Dataset, in terms of supplied land- cover / land-use categories. Use of this DEA / CARDNO data version is governed by the LICENCE AGREEMENT contained on this report. The DEA / CARDNO dataset contains 35 x land-cover / use information classes, covering a wide range of natural and man-made landscape characteristics. The original land-cover dataset was processed in UTM (north) / WGS84 map projection format based on the Landsat 8 standard map projection format as provided by the USGS. The data remains the property of GEOTERRAIMAGE, and is protected by copyright laws. All Intellectual Property rights pertaining to the data remain with GEOTERRAIMAGE at all times.

*This updated 2013-14 dataset corrects the coding error for DEA - CARDNO classes #6 and #7 (cultivated fields and pivot cultivated fields) which was inadvertently swapped in the previous version. Apart from the recoding of the two field-type classes, all other details and class codes etc remain exactly the same as the previously delivered datasets.*

**10(O) Dataset format name:**
ERDAS Imagine *img raster formats

**11(O) Dataset format version:**
version 01 (file # 22)

**12(O) Additional extent information for the dataset: (vertical and temporal)**
Vertical Extent:

Minimum Value: n/a

Maximum Value: n/a

Unit Of Measure: n/a

Vertical Datum: n/a

Temporal Extent: Land-cover datasets generated in January 2015, based on April 2013 - March 2014 multi-seasonal Landsat 8 and 5 satellite imagery.

**14(O) Reference system:**

Universal Transverse Mercator (UTM) 35 North

CRS:

Projection Used: Universal Transverse Mercator (UTM) 35 North

Spheroid used: WGS84

Datum used: WGS 84

Ellipsoid parameters: Ellipsoid semimajor axis axis units denominator of flattening ratio

Projection Parameters: UTM Zone: 35 (North) Standard parallel

Longitude of central meridian: 27:00:00.00 East Latitude of projection origin: 00:00:00.00 East False easting: 500000.00 meters

False northing: 0.00 meters

Scale factor at equator: 0.999600

Projection units: meters

**15(O) Lineage statement:**

Land-cover dataset generated in-house by GeoTerraImage (Pretoria) in January 2015, based on primarily multi-date Landsat 8 imagery acquired between April 2013 and March 2014.

**16(O) On-line resource:**

n/a

**17(O) Metadata file identifier:**

n/a

**18(O) Metadata standard name:**

SANS 1878

**19(O) Metadata standard version:**

version 01

**20(C) Metadata language:**

English (eng)

**21(C) Metadata character set:**

021 (UsAscii)

**22(M) Metadata point of contact:**

| | |
|---|---|
| Name: | Mark Thompson |
| Position Name: | Director Remote Sensing |
| Organisation Name: | GeoTerraImage Pty Ltd |
| Physical Address: | |
| Building | Grain Building (1st Floor) |
| | Street Witherite |
| Street_Suffix | Street |
| Street_Nr | 477 |
| Suburb | Die Wilgers |
| City | Pretoria |
| Zip | 0041 |
| Province | Gauteng |
| Country | South Africa |
| Postal Address: | |
| Box | 295 |
| Suburb | Persequor Park |
| City | Pretoria |
| Zip | 0020 |
| Province | Gauteng |
| Country | South Africa |

**23(M) Metadata time stamp:**

31 July 2015

## APPENDIX A

### 2013-14 South African National Land-cover Legend (DEA / CARDNO legend)

The table below describes the 35 x land-cover / use classes contained in the DEA / CARDNO supplied subset of the 2013-14 South African National Land-cover dataset, generated from multi-seasonal Landsat 8 imagery.

See **Appendix D** for visual examples of percent cover densities per unit area.

| PARENT | DEA Class Name (and digital code) | Definition |
|---|---|---|
| WATER | Water (33) | Areas of open, surface water, that are detectable on all image dates used in the Landsat 8 based water modelling processes. The mapped extent represents the maximum detectable water extent from all available imagery acquired within the 2013-14 assessment period. Includes both natural and man-made water features. |
| WETLAND | Wetland (12) | Wetland areas that are primarily vegetated on a seasonal or permanent basis. Defined on the basis of seasonal image identifiable surface vegetation patterns (not subsurface soil characteristics). The vegetation can be either rooted or floating. Wetlands may be either daily (i.e. coastal), temporarily, seasonal or permanently wet and/or saturated. Vegetation is predominately herbaceous. Includes but not limited to wetlands associated with seeps/springs, marshes, floodplains, lakes / pans, swamps, estuaries, and some riparian areas. Wetlands associated with riparian zones represent image identified vegetation along the edges of watercourses that show similar spectral characteristics to nearby wetland vegetation. Excludes Mangrove swamps. Permanent or seasonal open water areas within the wetlands are classified separately. Seasonal wetland occurrences *within* commercially cultivated field boundaries are not shown, although they have been retained within subsistence level cultivation fields. |
| FOREST | Indigenous Forest (1) | Natural / semi-natural indigenous forest, dominated by tall trees, where tree canopy heights are typically > ± 5m and tree canopy densities are typically > ± 75 %, often with multiple understory vegetation canopies. Note this class refers to Grassland areas not within the Fynbos, Nama Karoo and Succulent Karoo Biome boundaries (as defined in the SANBI 2006 "Vegetation of South Africa, Swaziland and Lesotho" map data). |

| PARENT | DEA Class Name (and digital code) | Definition |
|---|---|---|
| THICKET & DENSE BUSH | Dense Bush, Thicket & Tall Dense Shrubs (2) | Natural / semi-natural tree and / or bush dominated areas, where typically canopy heights are between 2 - 5m, and canopy density is typically > ± 75%, but may include localised sparser areas down to ± 60%[22]. Includes dense bush, thicket, closed woodland, tall, dense shrubs, scrub forest and mangrove swamps. Can include self-seeded bush encroachment areas if sufficient canopy density. Note this class refers to Grassland areas not within the Fynbos, Nama Karoo and Succulent Karoo Biome boundaries (as defined in the SANBI 2006 "Vegetation of South Africa, Swaziland and Lesotho" map data). |
| WOODLAND / OPEN-BUSH | Woodland and Open Bushland (3) | Natural / semi-natural tree and / or bush dominated areas, where typically canopy heights are between ± 2 - 5 m, and canopy densities typically between 40 - 75%, but may include localised sparser areas down to ± 15 - 20 %[28]. Includes sparse - open bushland and woodland, including transitional wooded grassland areas. Can include self-seeded bush encroachment areas if canopy density is within indicated range. In the arid western regions (i.e. Northern Cape), this cover class may be associated with a transitional bush / shrub cover that is lower than typical Open Bush / Woodland cover but higher and/or more dense than typical Low Shrub cover. Note this class refers to Grassland areas not within the Fynbos, Nama Karoo and Succulent Karoo Biome boundaries (as defined in the SANBI 2006 "Vegetation of South Africa, Swaziland and Lesotho" map data). |
| GRASSLAND | Grassland (13) | Natural / semi-natural grass dominated areas, where typically the tree and / or bush canopy densities are typically < ± 20 %, but may include localised denser areas up to ± 40 %, (regardless of canopy heights)[7]. Includes open grassland, and sparse bushland and woodland areas, including transitional wooded grasslands. May include planted pasture (i.e. grazing) if not irrigated. Irrigated pastures will typically be classified as cultivated, and urban parks and golf courses etc under urban. Note this class refers to Grassland areas not within the Fynbos, Nama Karoo and Succulent Karoo Biome boundaries (as defined in the SANBI 2006 "Vegetation of South Africa, Swaziland and Lesotho" map data). |

28 Normally it is preferred that land-cover class definitions are mutually exclusive in terms of content and associated landscape characteristics. Due to the nature of the multi-seasonal spectral modelling approach used in compiling the land-cover dataset, it seems that there is some transitional overlap between "bushy / woody grassland" and "grassy woodland / bushland" in terms of woody cover densities. For this reason the class definitions for both "Woodland / Open Bush" and "Grassland" include both a class specific core woody cover definition, and a shared transitional woody cover definition. The sample points used to verify the map accuracy record the observed woody cover percentage for these vegetation types should the user wish to undertake further analysis.

| PARENT | DEA Class Name (and digital code) | Definition |
|---|---|---|
| LOW SHRUBLAND | Low Shrubland (4) | Natural / semi-natural low shrub dominated areas, typically with ≤ 2m canopy height. Includes a range of canopy densities encompassing sparse to dense canopy covers. Very sparse covers may be associated with the bare ground class. Typically associated with low, woody shrub, karoo-type vegetation communities, although can also represent locally degraded vegetation areas where there is a significantly reduced vegetation cover in comparison to surrounding, less impacted vegetation cover, including long-term wildfire scars in some mountainous areas in the western Cape. Note that taller tree / bush / shrub communities within this vegetation type are typically classified *separately* as one of the other tree or bush dominated cover classes. Note this class refers to Low Shrubland areas not within the Fynbos, Nama Karoo and Succulent Karoo Biome boundaries (as defined in the SANBI 2006 "Vegetation of South Africa, Swaziland and Lesotho" map data). |
| CULTIVATED | Commercial Annuals (rainfed) (6) | Cultivated lands used primarily for the production of rain-fed, annual crops for commercial markets. Typically represented by large field units, often in dense local or regional clusters. In most cases the defined cultivated extent represents the actual cultivated or potentially extent. Includes Sugarcane crops. |
| | Commercial Pivot (7) | Cultivated lands used primarily for the production of centre pivot irrigated, annual crops for commercial markets. In most cases the defined cultivated extent represents the actual cultivated or potentially extent. Includes Sugarcane crops. |
| | Commercial Permanent (Orchards) (8) | Cultivated lands used primarily for the production of both rain-fed and irrigated permanent orchard crops for commercial markets. Includes both tree, shrub and non-woody crops, such as citrus, tea, coffee, grapes, lavender and pineapples etc. In most cases the defined cultivated extent represents the actual cultivated or potentially extent. |
| | Commercial Permanent (Vines) (9) | Cultivated lands used primarily for the production of both rain-fed and irrigated permanent vine (grape) crops for commercial markets. In most cases the defined cultivated extent represents the actual cultivated or potentially extent. |
| | Subsistence (10) | Cultivated lands used primarily for the production of rain-fed, annual crops for local markets and / or home use. Typically represented by small field units, often in dense local or regional clusters. The defined area may include intra-field areas of non-cultivated land, which may be degraded or use-impacted, if the individual field units are too small to be defined as separate features. |

| PARENT | DEA Class Name (and digital code) | Definition |
|---|---|---|
| FOREST PLANTATION | Forest Plantations (5) | Planted forestry plantations used for growing commercial timber tree species. The single class represents a combination of mature, young and temporary clearfelled stands. The class includes spatially smaller woodlots and windbreaks with the same cover characteristics. Note that young saplings are very difficult to identify on 30 metre resolution Landsat imagery if the actual tree canopy cover density is below ± 30 - 40%, because the background cover, for example, grassland, then dominates the spectral characteristics in that pixel area. |
| MINE | Mine (32) | Mining activity footprint, which includes extraction pits, tailings, waste dumps, flooded pits and associated surface infrastructure such as roads and buildings (unless otherwise indicated), for both active and abandoned mining activities. Class may include open cast pits, sand mines, quarries and borrow pits etc. |
| BARE | Bare (Non Vegetated) (34) | Bare, non-vegetated ground, with little or very sparse vegetation cover (i.e. typically < ± 5 - 10% vegetation cover), occurring as a result of either natural or man-induced processes. Includes but not limited to natural rock exposures, dry river beds, dry pans, coastal dunes and beaches, sand and rocky desert areas, very sparse low shrublands and grasslands, erosion areas, and major road networks etc. May also include long-term wildfire scars in some mountainous areas in the western Cape. |
| | Degraded (35) | Sparsely vegetated areas, occurring as a result of man-induced processes, which show *significantly lower overall vegetation cover compared to surrounding, natural undisturbed areas.* |
| BUILT-UP | Settlements (11) | All built-up areas, represented as a single class, including but not limited to commercial, industrial, heath, education, religion, transport and residential land-uses, including both formal and informal structures, across a range of structural densities from high to low. I. high and low density Areas containing high density buildings and other built-up structures associated with mainly non-residential, commercial, administrative, sport, health, religious or transport (i.e. train station) activities. Includes agricultural smallholdings on the urban periphery. |

| PARENT | DEA Class Name (and digital code) | Definition |
|---|---|---|
| FYNBOS | Fynbos: forest (14) | Forest areas as per class (1) within the SANBI Fynbos Biome boundary. |
| | Fynbos: thicket (15) | Dense Bush and Thicket areas as per class (2) within the SANBI Fynbos Biome boundary. |
| | Fynbos: open bush (16) | Woodland and Open Bush areas as per class (3) within the SANBI Fynbos Biome boundary. |
| | Fynbos: low shrub (17) | Low Shrubland areas as per class (4) within the SANBI Fynbos Biome boundary. |
| | Fynbos: grassland (18) | Grassland areas as per class (13) within the SANBI Fynbos Biome boundary. |
| | Fynbos: bare ground (19) | Bare Ground areas as per class (14) within the SANBI Fynbos Biome boundary. |
| NAMA KAROO | Nama Karoo: forest (20) | Forest areas as per class (1) within the SANBI Nama Karoo Biome boundary. |
| | Nama Karoo: thicket (21) | Dense Bush and Thicket areas as per class (2) within the SANBI Nama Karoo Biome boundary. |
| | Nama Karoo: open bush (22) | Woodland and Open Bush areas as per class (3) within the SANBI Nama Karoo Biome boundary. |
| | Nama Karoo: low shrub (23) | Low Shrubland areas as per class (4) within the SANBI Nama Karoo Biome boundary. |
| | Nama Karoo: grassland (24) | Grassland areas as per class (13) within the SANBI Nama Karoo Biome boundary. |
| | Nama Karoo: bare ground (25) | Bare Ground areas as per class (14) within the SANBI Nama Karoo Biome boundary. |
| SUCCULENT KAROO | Succulent Karoo: forest (26) | Forest areas as per class (1) within the SANBI Succulent Karoo Biome boundary. |
| | Succulent Karoo: thicket (27) | Dense Bush and Thicket areas as per class (2) within the SANBI Succulent Karoo Biome boundary. |
| | Succulent Karoo: open bush (28) | Woodland and Open Bush areas as per class (3) within the SANBI Succulent Karoo Biome boundary. |
| | Succulent Karoo: low shrub (29) | Low Shrubland areas as per class (4) within the SANBI Succulent Karoo Biome boundary. |
| | Succulent Karoo: grassland (30) | Grassland areas as per class (13) within the SANBI Succulent Karoo Biome boundary. |
| | Succulent Karoo: bare ground (31) | Bare Ground areas as per class (14) within the SANBI Succulent Karoo Biome boundary. |

*Note: the Fynbos, Nama Karoo and Succulent Karoo vegetation sub-classes are provided with additional class codes representing the parent primary vegetation class, in order that different levels of class detail can be used and accessed by data users. This is illustrated below.*

**Dual legend system for the DEA CARDNO 2013-14 SA land-cover classes (statistics for pivot code corrected dataset).**

Class Names (Color) represents the full 35 x land-cover / use class legend (with Biome level information)
Class Names2 (Color2) represents the amalgamated 17 x land-cover / use class legend (no Biome level information)
Area refers to Hectares (Ha) and Histogram to the number of 30x30m image pixels.

dea_cardno_2014_sa_lcov_utm35n_vs2b_pivot-corr.img

| Row | Color | Class_Names | Color2 | Class_Names2 | Area | Histogram |
|---|---|---|---|---|---|---|
| 0 | | | | | 0 | 0 |
| 1 | | Indigenous Forest | | Indigenous Forest | 395720 | 4396888 |
| 2 | | Thicket /Dense bush | | Thicket /Dense bush | 7.09698e+006 | 78855335 |
| 3 | | Woodlan/Open bush | | Woodlan/Open bush | 1.09087e+007 | 121207366 |
| 4 | | Low shrubland | | Low shrubland | 1.80007e+007 | 200008268 |
| 5 | | Plantations / Woodlots | | Plantations / Woodlots | 1.8737e+006 | 20818902 |
| 6 | | Cultivated commercial annual crops non-pivot | | Cultivated commercial annual crops non-pivot | 1.06108e+007 | 117898196 |
| 7 | | Cultivated commercial annual crops pivot | | Cultivated commercial annual crops pivot | 782049 | 8689435 |
| 8 | | Cultivated commercial permanent orchards | | Cultivated commercial permanent orchards | 346950 | 3855005 |
| 9 | | Cultivated commercial permanent vines | | Cultivated commercial permanent vines | 188711 | 2096791 |
| 10 | | Cultivated subsistence crops | | Cultivated subsistence crops | 2.04053e+006 | 22672521 |
| 11 | | Settlements | | Settlements | 2.90828e+006 | 32314218 |
| 12 | | Wetlands | | Wetlands | 1.0259e+006 | 11398887 |
| 13 | | Grasslands | | Grasslands | 2.37573e+007 | 263970479 |
| 14 | | Fynbos: forest | | Indigenous Forest | 32724 | 363600 |
| 15 | | Fynbos: thicket | | Thicket /Dense bush | 691164 | 7679603 |
| 16 | | Fynbos: open bush | | Woodlan/Open bush | 307674 | 3418605 |
| 17 | | Fynbos: low shrub | | Low shrubland | 5.32864e+006 | 59207100 |
| 18 | | Fynbos: grassland | | Grasslands | 381413 | 4237918 |
| 19 | | Fynbos: bare ground | | Bare Ground | 210113 | 2334586 |
| 20 | | Nama Karoo: forest | | Indigenous Forest | 0 | 0 |
| 21 | | Nama Karoo: thicket | | Thicket /Dense bush | 328724 | 3652485 |
| 22 | | Nama Karoo: open bush | | Woodlan/Open bush | 540805 | 6008941 |
| 23 | | Nama Karoo: low shrub | | Low shrubland | 1.40578e+007 | 156197442 |
| 24 | | Nama Karoo: grassland | | Grasslands | 1.31982e+006 | 14664675 |
| 25 | | Nama Karoo: bare ground | | Bare Ground | 9.38285e+006 | 104253894 |
| 26 | | Succuelent Karoo: forest | | Indigenous Forest | 0 | 0 |
| 27 | | Succulent Karoo: thicket | | Thicket /Dense bush | 174801 | 1942236 |
| 28 | | Succulent Karoo: open bush | | Woodlan/Open bush | 677790 | 7530997 |
| 29 | | Succulent Karoo: low shrub | | Low shrubland | 4.44011e+006 | 49334527 |
| 30 | | Succulent Karoo: grassland | | Grasslands | 335397 | 3726633 |
| 31 | | Succulent Karoo: bare ground | | Bare Ground | 1.97062e+006 | 21895741 |
| 32 | | Mines | | Mines | 328973 | 3655254 |
| 33 | | Waterbodies | | Waterbodies | 2.04562e+006 | 22729092 |
| 34 | | Bare Ground | | Bare Ground | 1.49435e+006 | 16603927 |
| 35 | | Degraded | | Degraded | 944061 | 10489566 |

# APPENDIX B

## List of accompanying documents and files.

Excel spreadsheet containing full list of Landsat 8 and 5 acquisition dates, per image frame, as used in the generation of the 2013-14 South African National Land-Cover dataset[29].

ESRI ArcGIS point coverage (UTM35 north) representing the sample points used to verify the 2013-14 South African National Land-Cover dataset (version 4), and calculate the *DEA-CARDNO legend format* mapping accuracies.

29 Note that the listed acquisition dates represent the primary dates used in the land-cover modelling, and not any additional image dates that were only used for localised cloud masking on the primary image date. Additional image dates are however listed if they themselves were also considered primary acquisition dates and used as modelling inputs.

## APPENDIX C

### 51 x Class Seasonally Defined Spectral Foundation Class Legend.

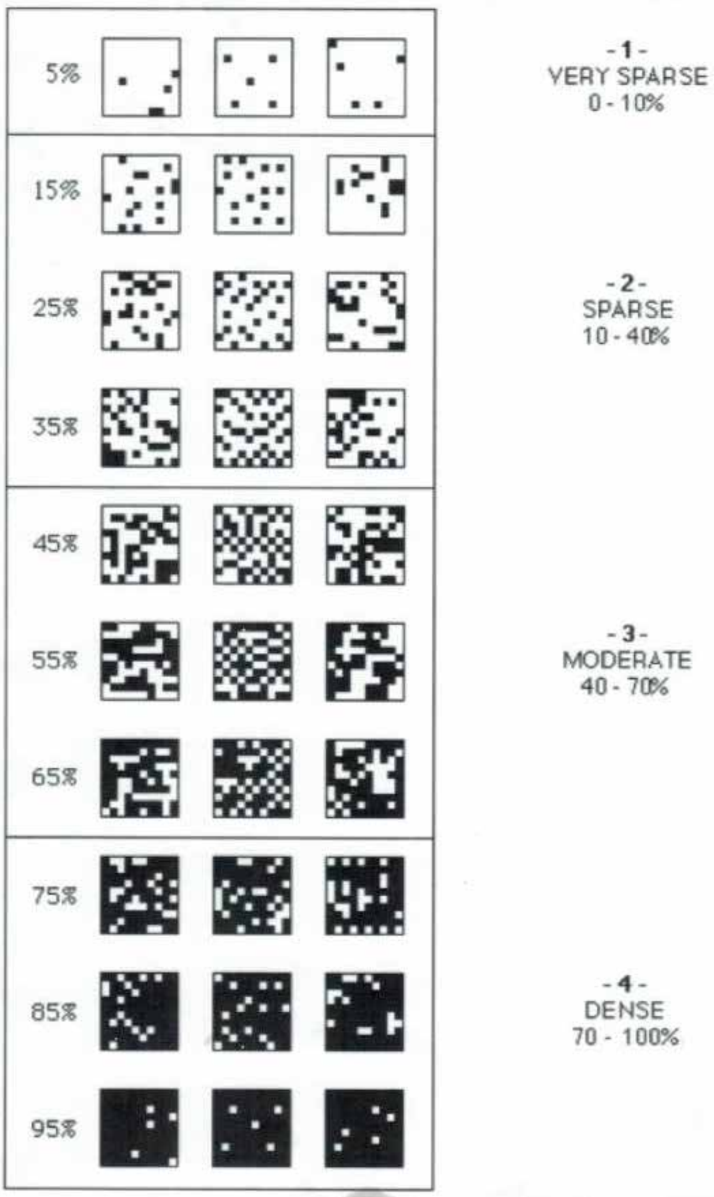
Excel spreadsheet containing full list of Landsat 8 and 5 acquisition dates, per image frame, as used in the generation of the 2013-14 South African National Land-Cover dataset[29].

ESRI ArcGIS point coverage (UTM35 north) representing the sample points used to verify the 2013-14 South African National Land-Cover dataset (version 4), and calculate the *DEA-CARDNO legend format* mapping accuracies.

| Row | Color | Class_Names |
|---|---|---|
| 0 | | |
| 1 | | water seasonal |
| 2 | | water permanent |
| 3 | | bare mix 1 date only, no overlap with any pure bare class |
| 4 | | bare mix >1 but < all dates, no overlap with any pure bare class |
| 5 | | bare mix all dates, no overlap witrh any pure bare class |
| 6 | | bare pure 1 date only |
| 7 | | bare pure >1 but < all dates |
| 8 | | bare pure all dates |
| 9 | | Tree/Bush mix 1 date only |
| 10 | | Tree 1 date only |
| 11 | | Tree/Bush mix >1 but < all dates |
| 12 | | Tree >1 but <all dates |
| 13 | | Tree/Bush mix all dates |
| 14 | | Tree all dates |
| 15 | | golf-irrig combo Tree/Bush mix 1 date only |
| 16 | | golf-irrig combo Tree 1 date only |
| 17 | | golf-irrig combo Tree/Bush mix >1 but < all dates |
| 18 | | golf-irrig combo Tree >1 but < all dates |
| 19 | | golf-irrig combo Tree/Bush mix all dates |
| 20 | | golf-irrig combo Tree all dates |
| 21 | | Tree/Bush 1 date only + Bare pure 1 date only |
| 22 | | Tree 1 date only + Bare pure 1 date only |
| 23 | | Tree/Bush multi dates + Bare pure 1 date only |
| 24 | | Tree multi dates + Bare pure 1 date only |
| 25 | | Tree/Bush multi dates + Bare pure multi dates |
| 26 | | Tree multi dates + Bare pure multi dates |
| 27 | | Tree/Bush 1 date only + Bare pure multi dates |
| 28 | | Tree 1 date only + Bare pure multi dates |
| 29 | | golf-irrig combo / Tree/Bush mix 1 date only + Bare pure 1 date |
| 30 | | golf-irrig combo / Tree 1 date only + Bare pure 1 date only |
| 31 | | golf-irrig combo / Tree/Bush mix multi dates + Bare pure 1 date |
| 32 | | golf-irrig combo / Tree multi dates + Bare pure 1 date only |
| 33 | | golf-irrig combo / Tree/Bush mix multi dates + Bare pure multi dates |
| 34 | | golf-irrig combo / Tree multi dates + Bare pure multi dates |
| 35 | | golf-irrig combo / Tree/Bush mix 1 date only + Bare multi dates |
| 36 | | golf-irrig combo / Tree 1 date only + Bare pure multi dates |
| 37 | | Grass (all dates) |
| 38 | | Grass (any date) / Bare pure 1 date |
| 39 | | Grass (any date) / Bare mix 1 date |
| 40 | | Grass (any date) / Bare pure multi dates |
| 41 | | Grass (any date) / Bare mix multi dates (model overlap) |
| 42 | | Grass (any date) / Bare mix all dates (model overlap) |
| 43 | | Tree/Bush mix 1 date only + Bare 1 date only + burn (any date) |
| 44 | | Tree 1 date only + Bare pure 1 date only + burn (any date) |
| 45 | | Tree/Bush mix multi dates + Bare pure 1 date only + burn (any date) |
| 46 | | Tree multi dates + Bare pure 1 date only + burn (any date) |
| 47 | | golf-irrig combo / Tree/Bush mix 1 date only + Bare pure 1 date only + burn (any date) |
| 48 | | golf-irrig combo / Tree 1 date only + Bare pure 1 date only + burn (any date) |
| 49 | | golf-irrig combo / Tree/Bush mix multi dates + Bare pure 1 date only + burn (any date) |
| 50 | | golf-irrig combo / Tree multi dates + Bare pure 1 date only + burn (any date) |
| 51 | | grass (all dates) + burn (any date) |

## APPENDIX D

**Visual representation of canopy cover density percentages per unit area.**




Adapted from Paine, D.P., 1981, Aerial photography and image interpretation for resource management: New York, John Wiley & Sons, 422 p.

## APPENDIX E

**Contingency Matrix representing the Map Accuracy Results for all 33 x Land-Cover / Use Classes.**

CLASSIFIED LAND-COVER (IMAGE)

| ACTUAL LAND COVER (FIELD) | | Indigenous Forest 1 | Dense Bush, Thicket 2 | Woodland, Open Bush 3 | Low Shrub: Other 4 | Forest Plantation 5 | Cultivated Commercial Crop 6 | Cultivated Pivot Crop 7 | Cultivated Orchards 8 | Cultivated Vineyard 9 | Cultivated Subsistence 10 | Settlements 11 | Wetlands 12 | Grasslands 13 | Fynbos: Low Shrubland 17 | Mines 32 | Water 33 | Bare Ground 34 | S | Pr | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Indigenous Forest | 1 | 106 | 2 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 112 | 0.017 | 6 |
| Dense Bush, Thicket | 2 | 22 | 230 | 7 | 3 | 5 | 0 | 0 | 1 | 0 | 0 | 2 | 1 | 1 | 3 | 0 | 0 | 0 | 275 | 0.043 | 45 |
| Woodland, Open Bush | 3 | 5 | 76 | 275 | 10 | 7 | 4 | 3 | 0 | 0 | 7 | 4 | 11 | 82 | 12 | 5 | 0 | 7 | 508 | 0.079 | 233 |
| Low Shrub: Other | 4 | 0 | 33 | 80 | 400 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 54 | 9 | 0 | 0 | 74 | 660 | 0.103 | 252 |
| Forest Plantation | 5 | 1 | 0 | 1 | 0 | 217 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 230 | 0.036 | 13 |
| Cultivated Commercial Crop | 6 | 0 | 0 | 0 | 0 | 0 | 216 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 217 | 0.034 | 1 |
| Cultivated Pivot Crop | 7 | 0 | 3 | 2 | 1 | 2 | 14 | 744 | 18 | 7 | 2 | 4 | 1 | 5 | 2 | 0 | 0 | 0 | 805 | 0.125 | 61 |
| Cultivated Orchards | 8 | 0 | 0 | 0 | 1 | 1 | 1 | 5 | 283 | 5 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 297 | 0.046 | 14 |
| Cultivated Vineyard | 9 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 3 | 142 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 146 | 0.023 | 4 |
| Cultivated Subsistence | 10 | 0 | 1 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 186 | 0 | 0 | 3 | 0 | 0 | 0 | 2 | 197 | 0.031 | 11 |
| Settlements | 11 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 523 | 0 | 2 | 0 | 1 | 0 | 1 | 530 | 0.083 | 7 |
| Wetlands | 12 | 0 | 5 | 7 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 155 | 0 | 0 | 0 | 0 | 0 | 170 | 0.027 | 15 |
| Grasslands | 13 | 12 | 51 | 59 | 112 | 9 | 0 | 24 | 2 | 0 | 11 | 20 | 6 | 849 | 30 | 3 | 0 | 28 | 1216 | 0.190 | 367 |
| Fynbos: Low Shrubland | 17 | 0 | 12 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 223 | 0 | 0 | 2 | 239 | 0.037 | 16 |
| Mines | 32 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 155 | 1 | 0 | 158 | 0.025 | 3 |
| Water | 33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 181 | 0 | 165 | 0.026 | 4 |
| Bare Ground | 34 | 0 | 6 | 14 | 37 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 7 | 1 | 2 | 0 | 421 | 490 | 0.076 | 69 |
| | S | 146 | 420 | 452 | 578 | 243 | 235 | 780 | 307 | 155 | 209 | 557 | 176 | 1004 | 280 | 167 | 163 | 535 | 6415 | | 459 |
| | Pc | 0.023 | 0.067 | 0.070 | 0.090 | 0.038 | 0.037 | 0.122 | 0.048 | 0.024 | 0.033 | 0.087 | 0.027 | 0.157 | 0.044 | 0.026 | 0.025 | 0.083 | | 0.00659 | |
| | | 40 | 198 | 177 | 170 | 26 | 19 | 36 | 24 | 13 | 23 | 34 | 21 | 155 | 57 | 12 | 2 | 114 | 1121 | | |

# 14. Appendix G

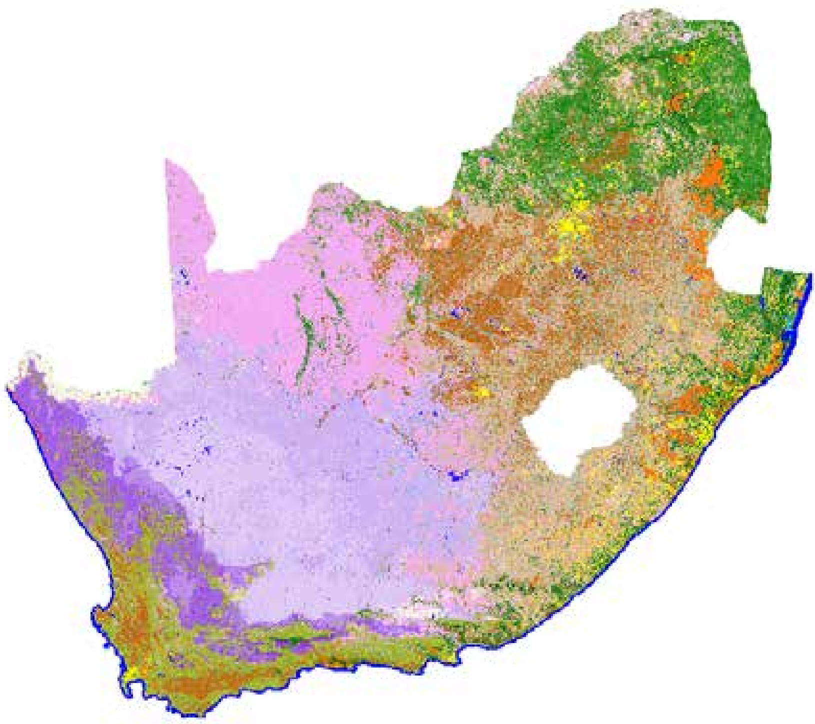
## 14.2 1990 – 2013-14 Land use change report

GEOTERRA IMAGE

# 1990 - 2013/14 South African National Land-Cover Change

DEA/CARDNO SCPF002: Implementation of Land-Use Maps for South Africa

**Project Specific Data Report**



DATA PRODUCT CREATED BY

**GEOTERRAIMAGE (South Africa),**

www.geoterraimage.com

August 2015, version 01

## LIABILITY

The Client has to verify prior to his commitment, the adequacy of GEOTERRAIMAGE datasets and products to the specific data and analyses needs as set out by the client. GEOTERRAIMAGE will in no event be liable for any direct, indirect, incidental or consequential damages including lost savings or profit, legal fees, lost data, lost sales, loss of commitments, business interruption, including loss of or other damage, resulting from its datasets and products, whether or not GEOTERRAIMAGE has been advised of the possibility of such damage. This includes damages incurred by the client or any third party.

GEOTERRAIMAGE datasets and products are processed from sources like topographic maps and satellite images. The quality of these sources is not the responsibility of GEOTERRAIMAGE. The data and data products are provided "as is", without warranty of any kind, either express or implied, including, but not limited to, the implied warranties of merchantability and fitness for a particular purpose.

Whilst all possible care and attention has been taken in the production of the data, neither GEOTERRAIMAGE or any of its respective sub-organisations or employees, accept any liability whatsoever for any perceived or actual inaccuracies or misrepresentations in the supplied data or accompanying report(s), as a result of the nature of mapping from coarse and medium scale satellite imagery. Any mapped boundaries either implied or inferred within the data do not have any legal status whatsoever.

All rights not specifically granted or specified in this agreement, pertaining to this data are reserved to GEOTERRAIMAGE Pty Ltd.

## PLEASE NOTE

This report provides information on the land-cover change statistics derived from a comparison of the specific versions of the 1990 and 2013/14 GEOTERRAIMAGE South African National Land-Cover Dataset supplied to the South African Department of Environmental Affairs under the DEA / CARDNO Project: SCPF002:"Implementation of Land Use Maps for South Africa". These datasets represent information subsets of the full 1990 and 2013/14 GEOTERRAIMAGE South African National Land-Cover Datasets, in terms of supplied land-cover / land-use categories and associated class legend.

## CONTENTS

# 1. BACKROUND

An assessment of land-cover change has been undertaken using the 1990 and 2013-14 South African National Land-Cover Datasets. Both of these dataset have been generated from comparable historical and current Landsat satellite imagery, using the same model-based mapping techniques.

The two source datasets are therefore, as far as possible, directly comparable in terms of land-cover content, spatial detail and associated mapping accuracies. The production of both of these national land-cover datasets is fully documented in separate reports pertaining to each land-cover dataset. **It is assumed that a user of the statistical land-cover change data is fully aware and appreciative of the information contained in these land-cover data generation reports.**

In preparation for the land-cover change assessment, the original 35 x class national land-cover datasets were re-formatted into the DEA requested, simplified 17 x class legend format to be used for land-cover change reporting.

The tables (**1** & **2**) illustrate the class and code conversions that were used to collapse the 35 x class legend into the 17 x class legend.

# 2. COMMENTS ON 1990 - 2014 SA LAND-COVER CHANGE ASSESSMENT

There are three basic factors that may have influenced land-cover change results and associated statistics, namely land-cover mapping accuracies, seasonal / climatic conditions under which the original source imagery was acquired, and the level of (landscape) detail that is being compared over time.

## 2.1 Influence of Mapping Accuracies on Land-Cover Change

Mapping accuracies have been calculated for the 2013-14 land-cover dataset and are reported in the 2013-14 Data User's report. The results of the 2013-14 map accuracy assessment are assumed to be representative of the 1990 accuracies, since comparable image data and modelling / mapping techniques were used for both datasets. No independent map accuracy assessment was undertaken for the 1990 dataset due to the unavailability of suitable reference data. The reliability of (land-cover) change statistics are greatly influenced by the accuracy of the input data against which change is determined. In simplistic terms, the sum of the known mapping error associated with a particular land-cover class over two time periods can indicate the level of 'statistical change' that is in fact a result of compounded mapping errors over time, and not actual land-cover change. For this reason all statistical (land-cover) change values must be interpreted and evaluated in the context of the reported land-cover class mapping accuracy, especially the User (as opposed to the Producers) accuracy. Class specific mapping accuracies are included in the land-cover change results reported below and in the accompanying spreadsheet.

## 2.2 Influence of Seasonal / Climatic Differences on Land-Cover Change

It is important to understand the influence that seasonal, and possible climatic differences between 1990 and 2013-14 may have had on the generation of each land-cover dataset in terms of landscape characteristics, and the possible effect of such differences on the change assessment results and associated spatial statistics.

The seasonal representation and range of monthly acquisition dates is generally better for the 1990 land-cover dataset, than used for the 2013-14 dataset, despite the same average number of acquisition dates per frame for the two datasets. This is because the 2013-14 dataset was limited to what cloud free imagery was recorded dea_cardno_2014_sa_lcov_utm35n_vs2b.img

| Row | Color | Class_Names | Color2 | Class_Names2 | Area | Histogram | Opacity |
|---|---|---|---|---|---|---|---|
| 0 | | | | | 0 | 0 | 0 |
| 1 | | Indigenous Forest | | Indigenous Forest | 395720 | 4396888 | 1 |
| 2 | | Thicket /Dense bush | | Thicket /Dense bush | 7.09698e+006 | 78855335 | 1 |
| 3 | | Woodlan/Open bush | | Woodlan/Open bush | 1.09087e+007 | 121207366 | 1 |
| 4 | | Low shrubland | | Low shrubland | 1.80007e+007 | 200008268 | 1 |
| 5 | | Plantations / Woodlots | | Plantations / Woodlots | 1.8737e+006 | 20818902 | 1 |
| 6 | | Cultivated commercial annual crops non-pivot | | Cultivated commercial annual crops non-pivot | 782049 | 8689435 | 1 |
| 7 | | Cultivated commercial annual crops pivot | | Cultivated commercial annual crops pivot | 1.06108e+007 | 117898196 | 1 |
| 8 | | Cultivated commercial permanent orchards | | Cultivated commercial permanent orchards | 346950 | 3855005 | 1 |
| 9 | | Cultivated commercial permanent vines | | Cultivated commercial permanent vines | 188711 | 2096791 | 1 |
| 10 | | Cultivated subsistence crops | | Cultivated subsistence crops | 2.04053e+006 | 22672521 | 1 |
| 11 | | Settlements | | Settlements | 2.90828e+006 | 32314218 | 1 |
| 12 | | Wetlands | | Wetlands | 1.0259e+006 | 11398887 | 1 |
| 13 | | Grasslands | | Grasslands | 2.37573e+007 | 263970479 | 1 |
| 14 | | Fynbos: forest | | Indigenous Forest | 32724 | 363600 | 1 |
| 15 | | Fynbos: thicket | | Thicket /Dense bush | 691164 | 7679603 | 1 |
| 16 | | Fynbos: open bush | | Woodlan/Open bush | 307674 | 3418605 | 1 |
| 17 | | Fynbos: low shrub | | Low shrubland | 5.32864e+006 | 59207100 | 1 |
| 18 | | Fynbos: grassland | | Grasslands | 381413 | 4237918 | 1 |
| 19 | | Fynbos: bare ground | | Bare Ground | 210113 | 2334586 | 1 |
| 20 | | Nama Karoo: forest | | Indigenous Forest | 0 | 0 | 1 |
| 21 | | Nama Karoo: thicket | | Thicket /Dense bush | 328724 | 3652485 | 1 |
| 22 | | Nama Karoo: open bush | | Woodlan/Open bush | 540805 | 6008941 | 1 |
| 23 | | Nama Karoo: low shrub | | Low shrubland | 1.40578e+007 | 156197442 | 1 |
| 24 | | Nama Karoo: grassland | | Grasslands | 1.31982e+006 | 14664675 | 1 |
| 25 | | Nama Karoo: bare ground | | Bare Ground | 9.38285e+006 | 104253894 | 1 |
| 26 | | Succuelent Karoo: forest | | Indigenous Forest | 0 | 0 | 1 |
| 27 | | Succulent Karoo: thicket | | Thicket /Dense bush | 174801 | 1942236 | 1 |
| 28 | | Succulent Karoo: open bush | | Woodlan/Open bush | 677790 | 7530997 | 1 |
| 29 | | Succulent Karoo: low shrub | | Low shrubland | 4.44011e+006 | 49334527 | 1 |
| 30 | | Succulent Karoo: grassland | | Grasslands | 335397 | 3726633 | 1 |
| 31 | | Succulent Karoo: bare ground | | Bare Ground | 1.97062e+006 | 21895741 | 1 |
| 32 | | Mines | | Mines | 328973 | 3655254 | 1 |
| 33 | | Waterbodies | | Waterbodies | 2.04562e+006 | 22729092 | 1 |
| 34 | | Bare Ground | | Bare Ground | 1.49435e+006 | 16603927 | 1 |
| 35 | | Degraded | | Degraded | 944061 | 10489566 | 1 |

| 35 x Class Full DEA / CARDNO Legend | Simplified 17 x Class DEA / CARDNO legend | |
|---|---|---|
| Indigenous forests | Indigenous forests | 1 |
| Forest: Fynbos | | |
| Thicket/dense bush | Thicket/dense bush | 2 |
| Thicket: Fynbos | | |
| Thicket: Nama-Karoo | | |
| Thicket: Succulent Karoo | | |
| Woodland/open bush | Woodland/open bush | 3 |
| Open bush: Fynbos | | |
| Open bush: Nama-Karoo | | |
| Open bush: Succulent Karoo | | |
| Low shrubland | Low shrubland | 4 |
| Low shrubland: Fynbos | | |
| Low shrubland: Nama-Karoo | | |
| Low shrubland: Succulent Karoo | | |
| Plantations/woodlots | Plantations/woodlots | 5 |
| Cultivated commercial annual: non-pivot | Cultivated commercial annual: non-pivot | 6 |
| Cultivated commercial annual: pivot | Cultivated commercial annual: pivot | 7 |
| Cultivated commercial permanent orchards | Cultivated commercial permanent orchards | 8 |
| Cultivated commercial permanent vines | Cultivated commercial permanent vines | 9 |
| Cultivated subsistence crops | Cultivated subsistence crops | 10 |
| Settlements | Settlements | 11 |
| Wetlands | Wetlands | 12 |
| Grasslands | Grasslands | 13 |
| Grasslands: Fynbos | | |
| Grasslands: Nama-Karoo | | |
| Grasslands: Succulent Karoo | | |
| Mines | Mines | 14 |
| Waterbodies | Waterbodies | 15 |
| Bare ground | Bare ground | 16 |
| Bare ground: Fynbos | | |
| Bare ground: Nama-Karoo | | |
| Bare ground: Succulent Karoo | | |
| Degraded | Degraded | 17 |

between April 2013 and the designated March 2014 cut-off, whereas the 1990 dataset had access to a wider range of imagery from 1989 - 1993. This greater seasonal representation may have influenced the modelling results in terms of the distribution and extent of some of the natural vegetation classes (excluding indigenous forests), since a better seasonal profile was often possible in 1990 compared to 2014 in some image frame locations.

The 1990 period appears to have been ***generally wetter*** than the 2013-14 period in most regions, as observed through the increase in observable surface water features in 1990. This is especially evident in the pans across the central regions of the Free State and Northern Cape, where many pans are water filled in 1990 and dry in 2013-14. These differences will reflect as changes between the two assessment periods but do not necessarily represent a permanent loss of water bodies over the ± 24 year period, but rather a seasonal (or climatic) induced difference. This fact needs to be noted during modelling and the interpretation of land-cover change results and associated statistics.

The wetter conditions prevalent in the 1990 dataset have allowed the wetland modelling to be extended across the full national coverage, unlike the drier 2013-14 image data which restricted wetland modelling to the wetter eastern and southern regions. These differences will reflect as changes between the two assessment periods but do not necessarily represent a permanent loss of wetlands over the ± 24 year period, but rather a seasonal (or climatic) induced difference. This fact needs to be noted during modelling and interpretation of land-cover change results.

The wetter conditions prevalent in the 1990 dataset may have influenced the boundary between low-shrub (i.e. karoo type) and highveld grassland vegetation, since the 1990 grassland / low shrub transition in the western Free State region appears to have shifted generally to the west compared to 2013-14, which may be a result of a greater grass component being present in the karoo / grass transition zone in 1990.

The (highveld, montane and coastal) grassland correction procedures applied to the 1990 dataset are considered to be slightly more accurate than those applied to the 2013-14 data, as a result of both modified procedures used and better image seasonal representation in 1990. It is therefore potentially possible that some of the 'grassland' to 'open woody vegetation' changes in these regions may be a result of the improved grassland delineation in 1990 and not actual bush cover increases in 2013-14.

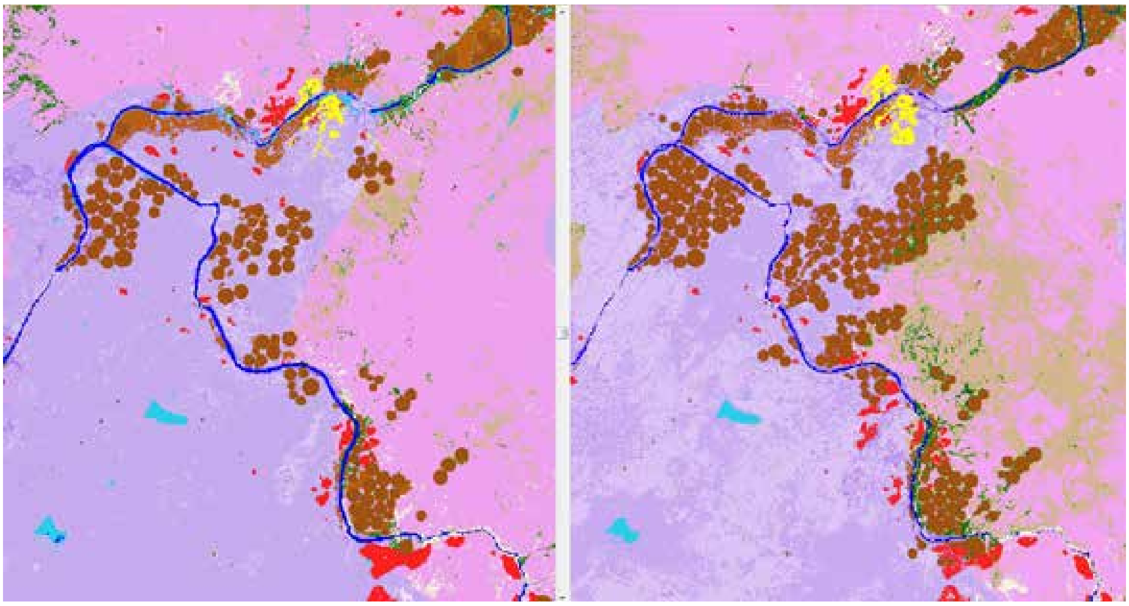
### 2.3 Influence of Mapping Detail on Land-Cover Change

The ability to determine change is obviously dependent on the level of detail that is being observed and compared. For example, changes in the extent of urban areas between 1990 and 2013-14 may not be as locally significant as maybe expected, since the total built-up footprint defined in the "settlements" class in both the 1990 and 2013-14 datasets includes peripheral smallholding areas around the main built-up areas; and these tend to be the first land-use that is converted to formal urban areas, before further expansion into natural and cultivated lands.

## 3. QUALITATIVE EXAMPLES OF LAND-COVER CHANGE 1990 - 2013/14.

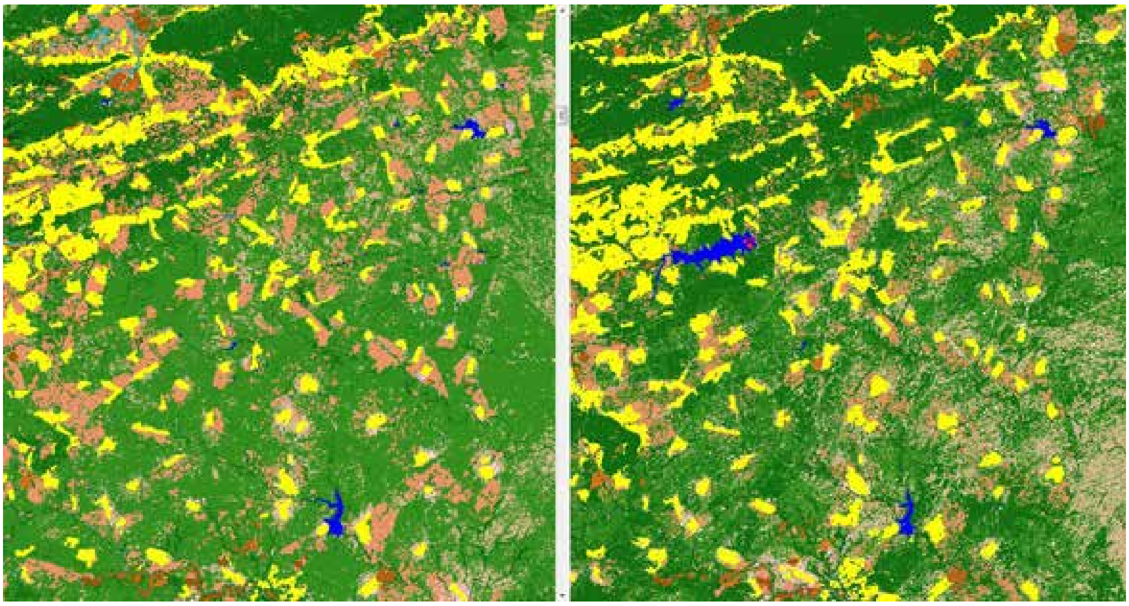
The following screen-shots provide visual examples of the type of land-cover changes that have been observed and mapped over the ± 24 year period between 1990 and 2013/14, based on the Landsat derived land-cover datasets. 1990 land-cover is on the LEFT and 2013/14 land-cover is on the RIGHT in all examples.

**Orange / Vaal River Confluence, Douglas, Northern Cape**



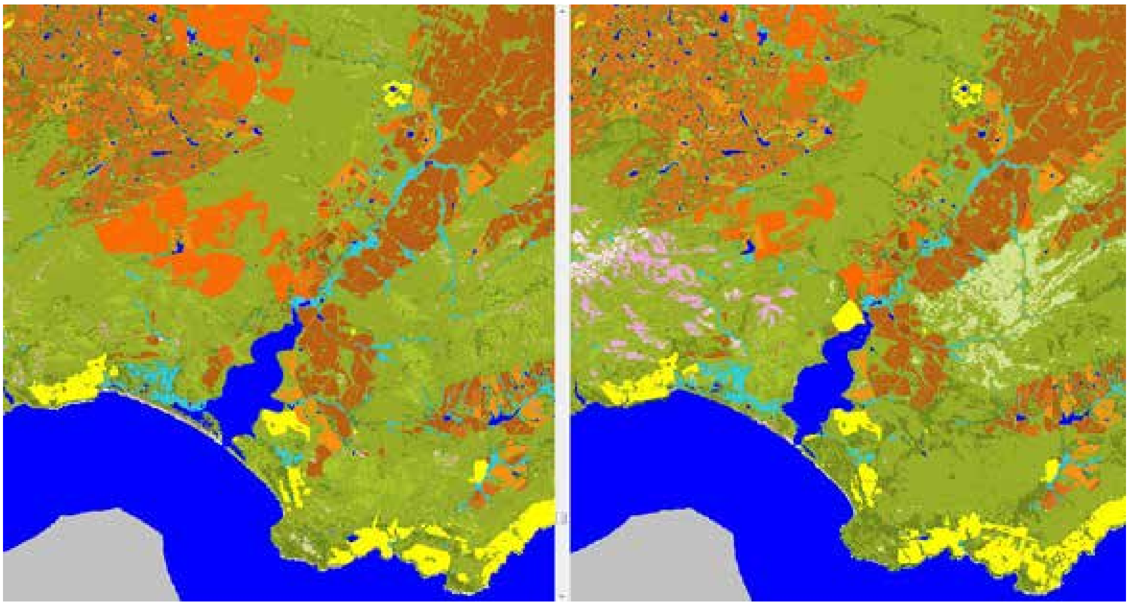
Note significant increase in centre pivot irrigation fields in 2013/14 compared to 1990.

**Villages, Giyani, Limpopo**



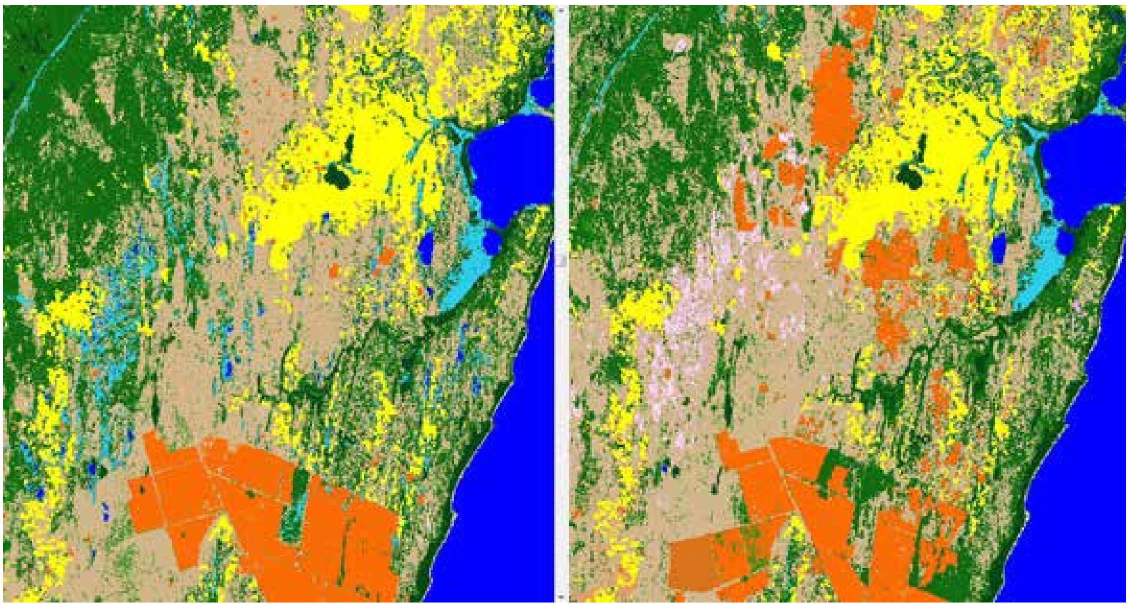
Note the bush clearing effects around villages in 2013/14 compared to 1990, and new dam in 2013/14.

**Kleinmond, Western Cape**



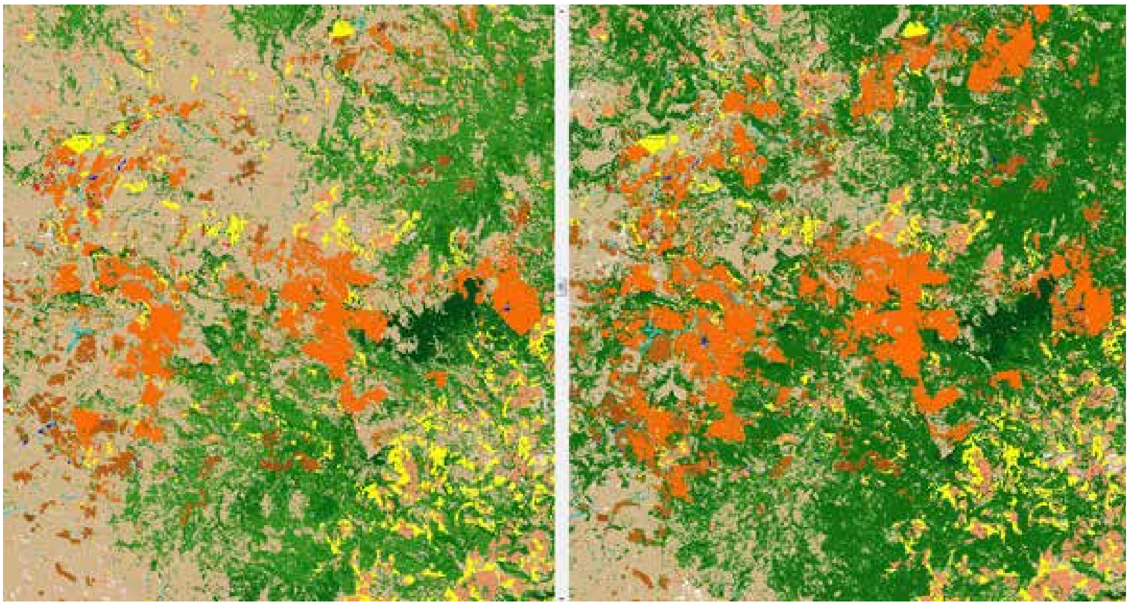
Note new settlements and reduction of plantations (orange) in 2013/14 compared to 1990. The light green and pink areas in 2013/14 are low vegetation areas are likely to be the result of mountain fire scars that were not evident in 1990.

**Kosi Bay, KwaZulu Natal**



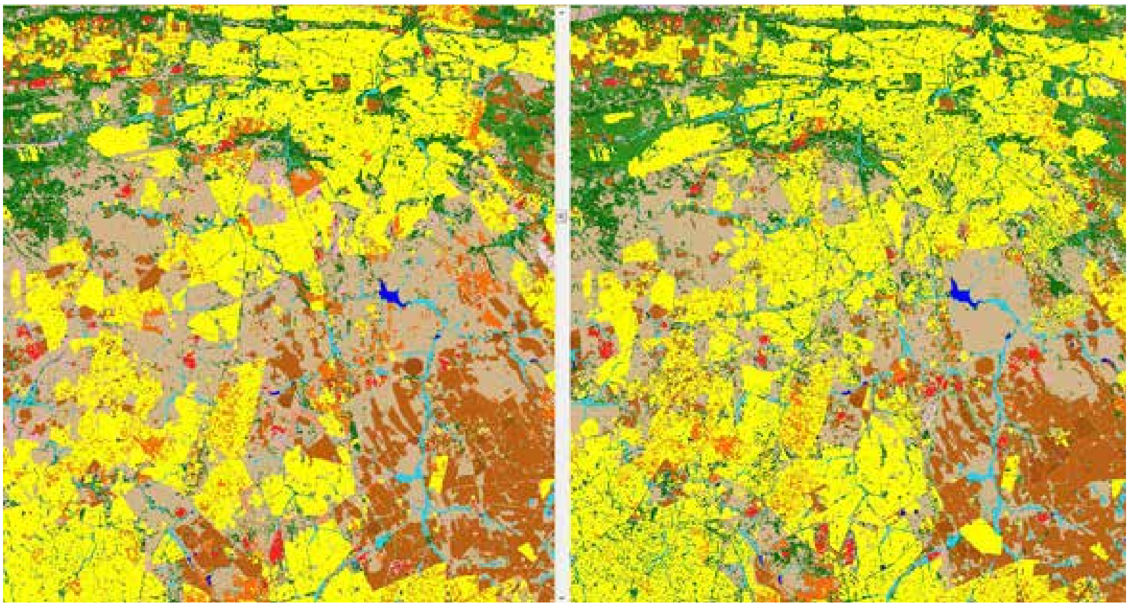
Note the increase in plantation forestry (orange) in 2013/14 and the greater extent of wetlands (light blue) in 1990 as a result of the (generally) wetter conditions.

**KZN Midlands, KwaZulu Natal**



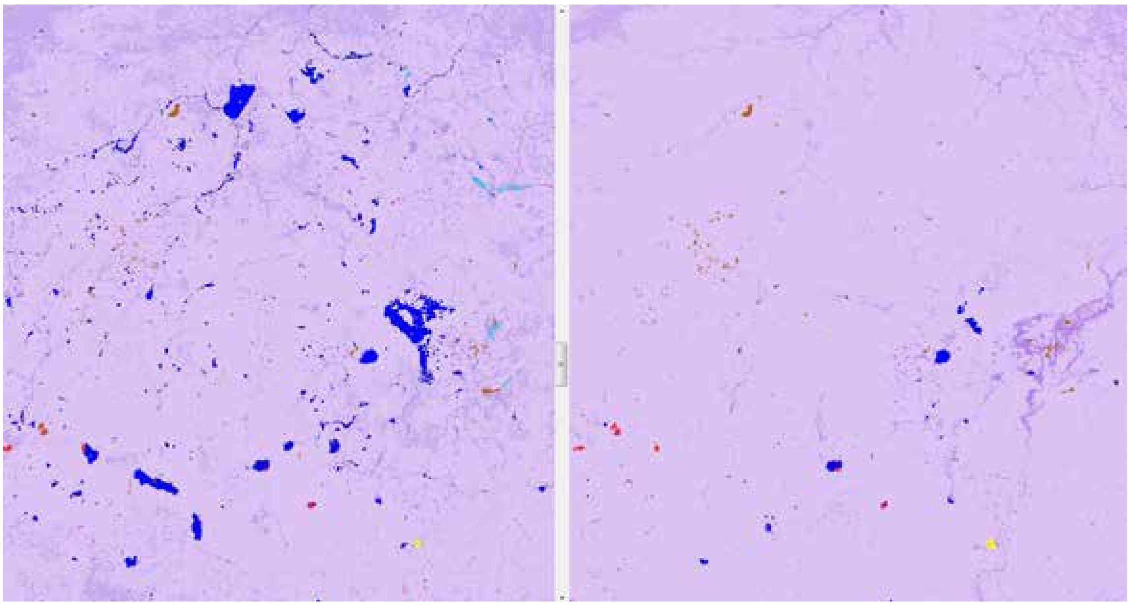
Note the increase in plantation forestry (orange) in 2013/14.

**Midrand, Gauteng**



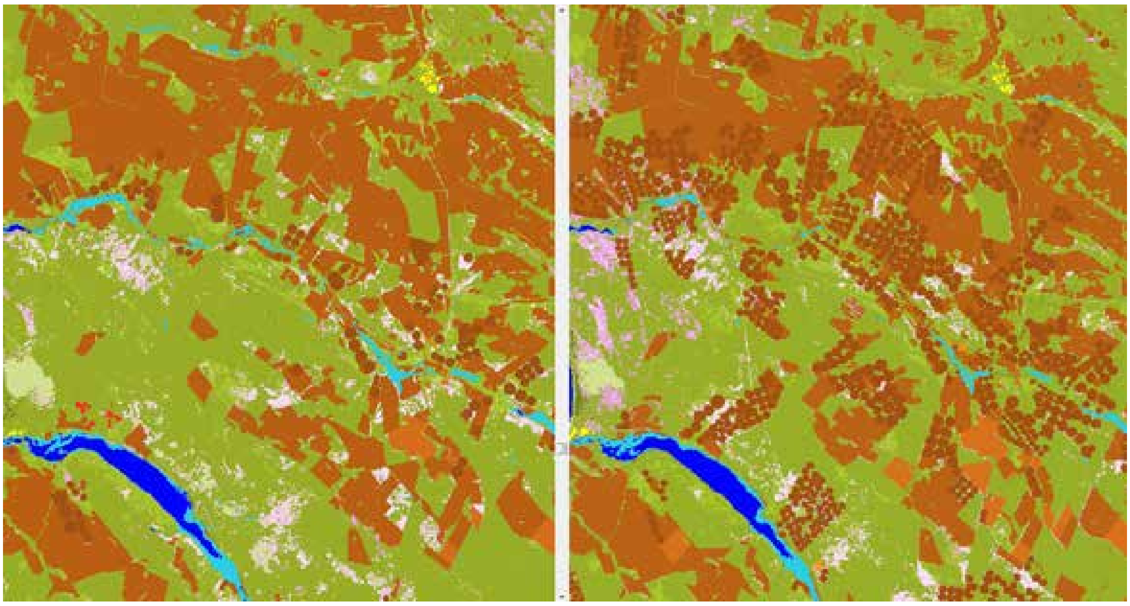
Note significant expansion of settlements (yellow) in 2013/14 compared to 1990. Note that the settlement class includes smallholdings, so in this area the expansion of settlements has gone into other land-cover classes as well, such as natural grasslands.

**Pan (wetlands), Northern Cape**



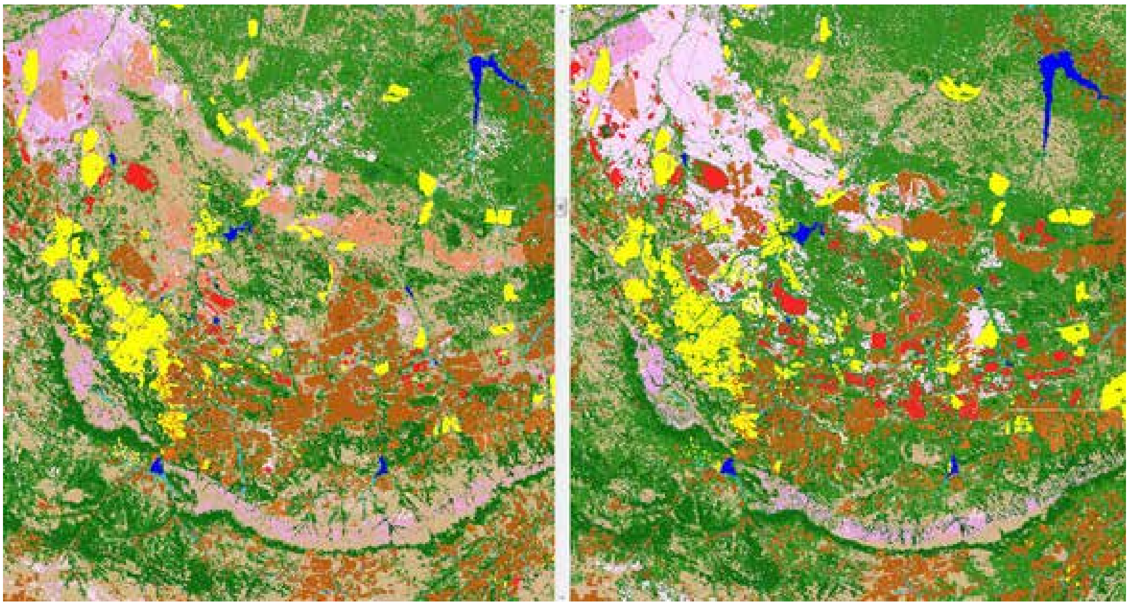
Note significantly greater extent and number of water features evident in the pans in 1990 as result of the wetter conditions compared to 2013/14.

**Olifants River, Western Cape**



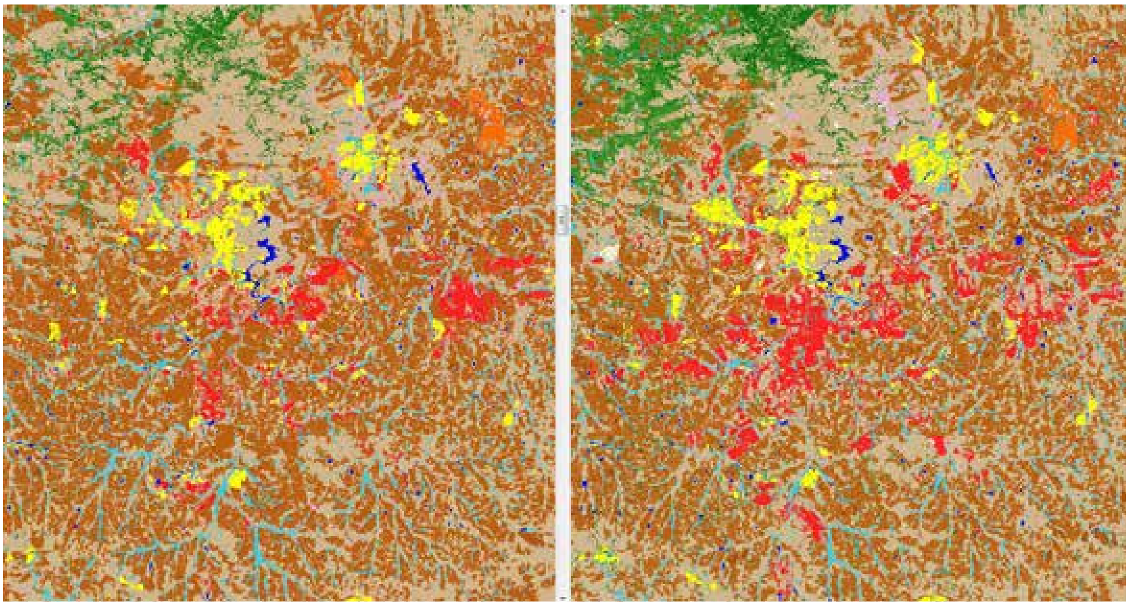
Note significant increase in centre pivot irrigation fields in 2013/14 compared to 1990.

**Rustenburg, North West**



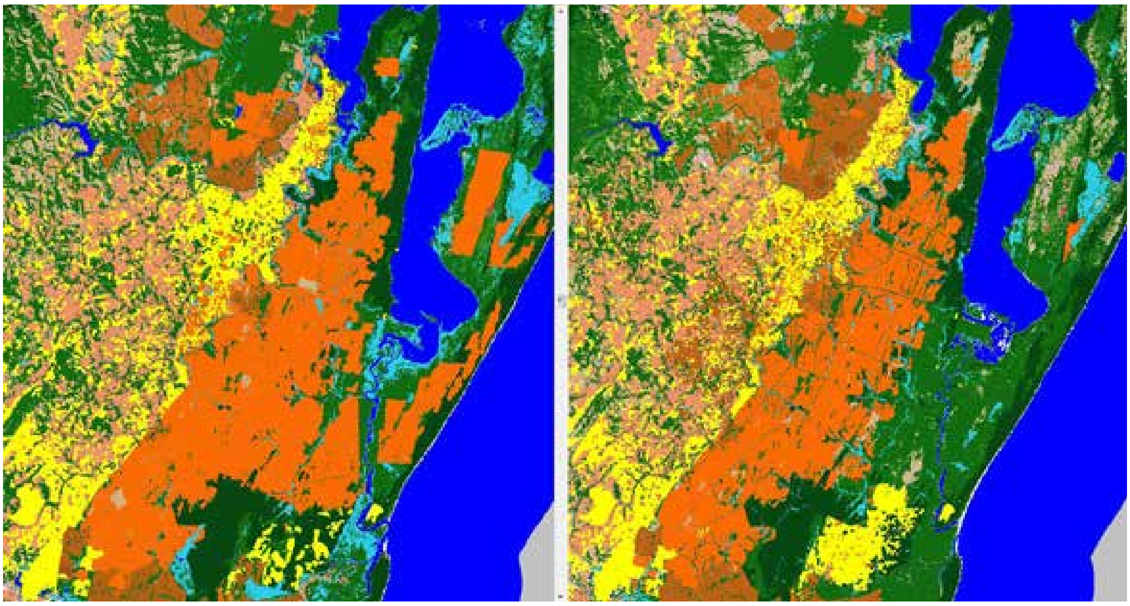
Note the significant increase in mining activity (red) in 2013/14 compared to 1990.

**Witbank / eMalahleni, Mpumalanga**



Note the significant increase in mining activity (red) in 2013/14 compared to 1990, and the urban expansion.

**St. Lucia, KwaZulu Natal**



Note the reduction of plantations (orange) on the eastern shores of St Lucia in 2013/14 and the significant settlement expansion (yellow) and loss of indigenous forest (dark green) in Dukuduku Forest in 2013/14, in the southern central section. The wetter conditions in 1990 have resulted in more observable wetlands (light blue) compared to 2013/14.

# 4. QUANTITATIVE ASSESSMENT OF LAND-COVER CHANGE 1990 - 2013/14.

A quantitative assessment of land-cover change between 1990 and 2013/14 has been completed, with the results presented below in terms of both change reported in terms of the original 30m resolution raster cell format, and also in terms of a spatially re-sampled 90x90 cell format.

The re-sampled 90m cell format data was created by a spatial aggregation process that determined the majority land-cover from a window of 3 x 3 original 30m cells and returned this to a new, single 90m raster cell representing the equivalent spatial area. Comparison of (national) change statistics derived from both the original 30m resolution raster cell data and the re-sampled 90m resolution cell data would provide an indication of whether or not a significant level of variation was introduced into the change results from pixel level mapping anomalies compared to the local majority land-cover characteristics.

## 4.1 National Level Land-Cover Change Results

The tables below show the results of comparing the 1990 land-cover data to the 2013/14 land-cover, on a national basis, based on both the original 30m raster format data and the spatially re-sampled 90m raster cell format data, which represents the majority land-cover class in a ± 1 ha area. Users are reminded again to interpret all statistical (land-cover) change values in the context of the reported land-cover class mapping accuracy (especially

Users Accuracy), and overall number of mapped image pixels. Class specific mapping accuracies are included in the land-cover change results reported below and in the accompanying spreadsheet.

The percentage change results for all classes show very similar values in both the original 30m and re-sampled 90m datasets, which indicates that the comparison of the original 30m datasets is not introducing any significant difference as a result of single pixel anomalies. The 2013/14 land-cover mapping accuracies have been included in the tables to allow the change results to be assessed in terms of the class mapping accuracies achieved, so that classes.

### (3) National Change Statistics 1990 - 2013/14, based on original 30m raster data.

| National change based on the 30m pixels | | | *(change based on standardised areas)* | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1990 Land Cover | | 2014 Land Cover | | Change from 1990 to 2014 | | | *Class mapping* |
| | Pixels | Hectares | Pixels | Hectares | Pixels | Hectares | % | *accuracy (2013)* |
| Indigenous Forest | 4185008 | 376650.72 | 4760488 | 428443.92 | 575480 | 51793.20 | 13.75 | 72.6 / 94.64 |
| Thicket /Dense bush | 73844264 | 6645983.76 | 92129659 | 8291669.31 | 18285395 | 1645685.55 | 24.76 | 53.74 / 83.64 |
| Woodlan/Open bush | 122308776 | 11007789.84 | 138165909 | 12434931.81 | 15857133 | 1427141.97 | 12.96 | 60.84 / 54.13 |
| Low shrubland | 457109576 | 41139861.84 | 464747337 | 41827260.33 | 7637761 | 687398.49 | 1.67 | 70.59 / 61.82 |
| Plantations / Woodlots | 21364651 | 1922818.59 | 20818902 | 1873701.18 | -545749 | -49117.41 | -2.55 | 89.3 / 94.35 |
| Cultivated commercial annual crops non-pivot | 127628703 | 11486583.27 | 117898196 | 10610837.64 | -9730507 | -875745.63 | -7.62 | 91.91 / 99.54 |
| Cultivated commercial annual crops pivot | 2714095 | 244268.55 | 8689435 | 782049.15 | 5975340 | 537780.60 | 220.16 | 95.38 / 92.42 |
| Cultivated commercial permanent orchards | 3484129 | 313571.61 | 3855005 | 346950.45 | 370876 | 33378.84 | 10.64 | 92.18 / 95.29 |
| Cultivated commercial permanent vines | 1803936 | 162354.24 | 2096791 | 188711.19 | 292855 | 26356.95 | 16.23 | 91.61 / 97.26 |
| Cultivated subsistence crops | 22047815 | 1984303.35 | 22672521 | 2040526.89 | 624706 | 56223.54 | 2.83 | 89.00 / 94.00 |
| Settlements (incl smallholdings) | 30476891 | 2742920.19 | 32314218 | 2908279.62 | 1837327 | 165359.43 | 6.03 | 93.90 / 98.68 |
| Wetlands | 16957092 | 1526138.28 | 11398887 | 1025899.83 | -5558205 | -500238.45 | -32.78 | 88.07 / 91.18 |
| Grasslands | 305455194 | 27490967.46 | 286599705 | 25793973.45 | -18855489 | -1696994.01 | -6.17 | 84.56 / 69.82 |
| Mines | 3241741 | 291756.69 | 3655254 | 328972.86 | 413513 | 37216.17 | 12.76 | 92.82 / 98.10 |
| Waterbodies | 24467125 | 2202041.25 | 22729092 | 2045618.28 | -1738033 | -156422.97 | -7.10 | 79.64 / 93.31 |
| Bare Ground | 154471675 | 13902450.75 | 145088148 | 13057933.32 | -9383527 | -844517.43 | -6.07 | 98.77 / 97.58 |
| Degraded | 16548442 | 1489359.78 | 10489566 | 944060.94 | -6058876 | -545298.84 | -36.61 | 78.69 / 85.95 |
| *totals* | *1388109113* | *124929820* | *1388109113* | *124929820* | | | | *User / Producer* |
| | | | | | | | | *class accuracies* |

### (4) National Change Statistics 1990 - 2013/14, based on re-sampled 90m raster data.

| National change based on the resampled 90m pixels (ha majority equivalent) | | | *(change based on standardised areas)* | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1990 Land Cover | | 2014 Land Cover | | Change from 1990 to 2014 | | | *Class mapping* |
| | Pixels | Hectares | Pixels | Hectares | Pixels | Hectares | % | *accuracy (2013)* |
| Indigenous Forest | 4319408 | 3498720.48 | 4760488 | 3855995.28 | 441080 | 357274.80 | 10.21 | 72.6 / 94.64 |
| Thicket /Dense bush | 73624120 | 59635537.20 | 92129659 | 74625023.79 | 18505539 | 14989486.59 | 25.14 | 53.74 / 83.64 |
| Woodlan/Open bush | 119332961 | 96659698.41 | 138165909 | 111914386.29 | 18832948 | 15254687.88 | 15.78 | 60.84 / 54.13 |
| Low shrubland | 464138942 | 375952543.02 | 464747337 | 376445342.97 | 608395 | 492799.95 | 0.13 | 70.59 / 61.82 |
| Plantations / Woodlots | 21680621 | 17561303.01 | 20818902 | 16863310.62 | -861719 | -697992.39 | -3.97 | 89.3 / 94.35 |
| Cultivated commercial annual crops non-pivot | 132002937 | 106922378.97 | 117898196 | 95497538.76 | -14104741 | -11424840.21 | -10.69 | 91.91 / 99.54 |
| Cultivated commercial annual crops pivot | 2763000 | 2238030.00 | 8689435 | 7038442.35 | 5926435 | 4800412.35 | 214.49 | 95.38 / 92.42 |
| Cultivated commercial permanent orchards | 3626973 | 2937848.13 | 3855005 | 3122554.05 | 228032 | 184705.92 | 6.29 | 92.18 / 95.29 |
| Cultivated commercial permanent vines | 1911159 | 1548038.79 | 2096791 | 1698400.71 | 185632 | 150361.92 | 9.71 | 91.61 / 97.26 |
| Cultivated subsistence crops | 22763294 | 18438268.14 | 22672521 | 18364742.01 | -90773 | -73526.13 | -0.40 | 89.00 / 94.00 |
| Settlements | 31096545 | 25188201.45 | 32314218 | 26174516.58 | 1217673 | 986315.13 | 3.92 | 93.90 / 98.68 |
| Wetlands | 15706154 | 12721984.74 | 11398887 | 9233098.47 | -4307267 | -3488886.27 | -27.42 | 88.07 / 91.18 |
| Grasslands | 298885099 | 242096930.19 | 286599705 | 232145761.05 | -12285394 | -9951169.14 | -4.11 | 84.56 / 69.82 |
| Mines | 3193829 | 2587001.49 | 3655254 | 2960755.74 | 461425 | 373754.25 | 14.45 | 92.82 / 98.10 |
| Waterbodies | 24456512 | 19809774.72 | 22729092 | 18410564.52 | -1727420 | -1399210.20 | -7.06 | 79.64 / 93.31 |
| Bare Ground | 154114261 | 124832551.41 | 145088148 | 117521399.88 | -9026113 | -7311151.53 | -5.86 | 98.77 / 97.58 |
| Degraded | 14341471 | 11616591.51 | 10489566 | 8496548.46 | -3851905 | -3120043.05 | -26.86 | 78.69 / 85.95 |
| *totals* | *1387957286* | *1124245402* | *1388109113* | *1124368382* | | | | *User / Producer* |
| | | | | | | | | *class accuracies* |

## 4.2 Provincial Level Land-Cover Change Results

The change statistics for each Province are shown below. These have been generated from the original 30m resolution format data, and show regional trends in land-cover / land-use change over the ±24 year period between 1990 and 2013/14. The 2013/14 land-cover mapping accuracies have been included in the tables (5 - 13) below to allow the provincial change results to be assessed in terms of the associated class mapping accuracies.

| Limpopo Province change based on the 30m pixels | | | *(change based on standardised areas)* | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1990 Land Cover | | 2014 Land Cover | | Change from 1990 to 2014 | | | *Class mapping* |
| | Pixels | Hectares | Pixels | Hectares | Pixels | Hectares | % | *accuracy (2013)* |
| Indigenous Forest | 439022 | 39511.98 | 512695 | 46142.55 | 73673 | 6630.57 | 16.78 | 72.6 / 94.64 |
| Thicket /Dense bush | 18813387 | 1693204.83 | 19466135 | 1751952.15 | 652748 | 58747.32 | 3.47 | 53.74 / 83.64 |
| Woodlan/Open bush | 59679073 | 5371116.57 | 69245654 | 6232108.86 | 9566581 | 860992.29 | 16.03 | 60.84 / 54.13 |
| Low shrubland | 3289562 | 296060.58 | 2712468 | 244122.12 | -577094 | -51938.46 | -17.54 | 70.59 / 61.82 |
| Plantations / Woodlots | 1141021 | 102691.89 | 867962 | 78116.58 | -273059 | -24575.31 | -23.93 | 89.3 / 94.35 |
| Cultivated commercial annual crops non-pivot | 7921472 | 712932.48 | 6317003 | 568530.27 | -1604469 | -144402.21 | -20.25 | 91.91 / 99.54 |
| Cultivated commercial annual crops pivot | 870662 | 78359.58 | 1862126 | 167591.34 | 991464 | 89231.76 | 113.87 | 95.38 / 92.42 |
| Cultivated commercial permanent orchards | 865438 | 77889.42 | 1213977 | 109257.93 | 348539 | 31368.51 | 40.27 | 92.18 / 95.29 |
| Cultivated commercial permanent vines | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0.00 | 91.61 / 97.26 |
| Cultivated subsistence crops | 5179200 | 466128.00 | 4488068 | 403926.12 | -691132 | -62201.88 | -13.34 | 89.00 / 94.00 |
| Settlements (incl smallholdings) | 3932762 | 353948.58 | 5066036 | 455943.24 | 1133274 | 101994.66 | 28.82 | 93.90 / 98.68 |
| Wetlands | 890913 | 80182.17 | 525103 | 47259.27 | -365810 | -32922.90 | -41.06 | 88.07 / 91.18 |
| Grasslands | 30503379 | 2745304.11 | 21863009 | 1967670.81 | -8640370 | -777633.30 | -28.33 | 84.56 / 69.82 |
| Mines | 316164 | 28454.76 | 312494 | 28124.46 | -3670 | -330.30 | -1.16 | 92.82 / 98.10 |
| Waterbodies | 176402 | 15876.18 | 221105 | 19899.45 | 44703 | 4023.27 | 25.34 | 79.64 / 93.31 |
| Bare Ground | 107769 | 9699.21 | 792185 | 71296.65 | 684416 | 61597.44 | 635.08 | 98.77 / 97.58 |
| Degraded | 5766293 | 518966.37 | 4426499 | 398384.91 | -1339794 | -120581.46 | -23.23 | 78.69 / 85.95 |
| *totals* | *139892519* | *12590327* | *139892519* | *12590327* | | | | *User / Producer* |
| | | | | | | | | *class accuracies* |

| Mpumalanga Province change based on the 30m pixels | | | *(change based on standardised areas)* | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1990 Land Cover | | 2014 Land Cover | | Change from 1990 to 2014 | | | *Class mapping* |
| | Pixels | Hectares | Pixels | Hectares | Pixels | Hectares | % | *accuracy (2013)* |
| Indigenous Forest | 258220 | 23239.80 | 346439 | 31179.51 | 88219 | 7939.71 | 34.16 | 72.6 / 94.64 |
| Thicket /Dense bush | 7046448 | 634180.32 | 9615408 | 865386.72 | 2568960 | 231206.40 | 36.46 | 53.74 / 83.64 |
| Woodlan/Open bush | 15095444 | 1358589.96 | 14380996 | 1294289.64 | -714448 | -64300.32 | -4.73 | 60.84 / 54.13 |
| Low shrubland | 856885 | 77119.65 | 416834 | 37515.06 | -440051 | -39604.59 | -51.35 | 70.59 / 61.82 |
| Plantations / Woodlots | 8261786 | 743560.74 | 8358195 | 752237.55 | 96409 | 8676.81 | 1.17 | 89.3 / 94.35 |
| Cultivated commercial annual crops non-pivot | 14511612 | 1306045.08 | 12676152 | 1140853.68 | -1835460 | -165191.40 | -12.65 | 91.91 / 99.54 |
| Cultivated commercial annual crops pivot | 176799 | 15911.91 | 640740 | 57666.60 | 463941 | 41754.69 | 262.41 | 95.38 / 92.42 |
| Cultivated commercial permanent orchards | 352775 | 31749.75 | 477595 | 42983.55 | 124820 | 11233.80 | 35.38 | 92.18 / 95.29 |
| Cultivated commercial permanent vines | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0.00 | 91.61 / 97.26 |
| Cultivated subsistence crops | 1020965 | 91886.85 | 742550 | 66829.50 | -278415 | -25057.35 | -27.27 | 89.00 / 94.00 |
| Settlements (incl smallholdings) | 1987731 | 178895.79 | 2382966 | 214466.94 | 395235 | 35571.15 | 19.88 | 93.90 / 98.68 |
| Wetlands | 2641304 | 237717.36 | 2270547 | 204349.23 | -370757 | -33368.13 | -14.04 | 88.07 / 91.18 |
| Grasslands | 31813622 | 2863225.98 | 31198853 | 2807896.77 | -614769 | -55329.21 | -1.93 | 84.56 / 69.82 |
| Mines | 516604 | 46494.36 | 861892 | 77570.28 | 345288 | 31075.92 | 66.84 | 92.82 / 98.10 |
| Waterbodies | 456789 | 41111.01 | 508625 | 45776.25 | 51836 | 4665.24 | 11.35 | 79.64 / 93.31 |
| Bare Ground | 81686 | 7351.74 | 273093 | 24578.37 | 191407 | 17226.63 | 234.32 | 98.77 / 97.58 |
| Degraded | 136047 | 12244.23 | 63832 | 5744.88 | -72215 | -6499.35 | -53.08 | 78.69 / 85.95 |
| *totals* | *85214717* | *7669325* | *85214717* | *7669325* | | | | *User / Producer* |
| | | | | | | | | *class accuracies* |

Free State Province change based on the 30m pixels *(change based on standardised areas)*

| | 1990 Land Cover | | 2014 Land Cover | | Change from 1990 to 2014 | | | *Class mapping* |
|---|---|---|---|---|---|---|---|---|
| | Pixels | Hectares | Pixels | Hectares | Pixels | Hectares | % | *accuracy (2013)* |
| Indigenous Forest | 68057 | 6125.13 | 75559 | 6800.31 | 7502 | 675.18 | 11.02 | 72.6 / 94.64 |
| Thicket /Dense bush | 1303575 | 117321.75 | 1665474 | 149892.66 | 361899 | 32570.91 | 27.76 | 53.74 / 83.64 |
| Woodlan/Open bush | 1559397 | 140345.73 | 1255780 | 113020.20 | -303617 | -27325.53 | -19.47 | 60.84 / 54.13 |
| Low shrubland | 24740213 | 2226619.17 | 36760959 | 3308486.31 | 12020746 | 1081867.14 | 48.59 | 70.59 / 61.82 |
| Plantations / Woodlots | 584008 | 52560.72 | 563687 | 50731.83 | -20321 | -1828.89 | -3.48 | 89.3 / 94.35 |
| Cultivated commercial annual crops non-pivot | 42092634 | 3788337.06 | 39985067 | 3598656.03 | -2107567 | -189681.03 | -5.01 | 91.91 / 99.54 |
| Cultivated commercial annual crops pivot | 306826 | 27614.34 | 1810827 | 162974.43 | 1504001 | 135360.09 | 490.18 | 95.38 / 92.42 |
| Cultivated commercial permanent orchards | 26126 | 2351.34 | 38406 | 3456.54 | 12280 | 1105.20 | 47.00 | 92.18 / 95.29 |
| Cultivated commercial permanent vines | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0.00 | 91.61 / 97.26 |
| Cultivated subsistence crops | 209381 | 18844.29 | 327142 | 29442.78 | 117761 | 10598.49 | 56.24 | 89.00 / 94.00 |
| Settlements (incl smallholdings) | 994363 | 89492.67 | 1147053 | 103234.77 | 152690 | 13742.10 | 15.36 | 93.90 / 98.68 |
| Wetlands | 4145335 | 373080.15 | 2500935 | 225084.15 | -1644400 | -147996.00 | -39.67 | 88.07 / 91.18 |
| Grasslands | 65232798 | 5870951.82 | 55751383 | 5017624.47 | -9481415 | -853327.35 | -14.53 | 84.56 / 69.82 |
| Mines | 268735 | 24186.15 | 265584 | 23902.56 | -3151 | -283.59 | -1.17 | 92.82 / 98.10 |
| Waterbodies | 1780207 | 160218.63 | 1085829 | 97724.61 | -694378 | -62494.02 | -39.01 | 79.64 / 93.31 |
| Bare Ground | 416832 | 37514.88 | 920003 | 82800.27 | 503171 | 45285.39 | 120.71 | 98.77 / 97.58 |
| Degraded | 499721 | 44974.89 | 74520 | 6706.80 | -425201 | -38268.09 | -85.09 | 78.69 / 85.95 |
| *totals* | *144228208* | *12980539* | *144228208* | *12980539* | | | | *User / Producer* |
| | | | | | | | | *class accuracies* |

N.West Province change based on the 30m pixels *(change based on standardised areas)*

| | 1990 Land Cover | | 2014 Land Cover | | Change from 1990 to 2014 | | | *Class mapping* |
|---|---|---|---|---|---|---|---|---|
| | Pixels | Hectares | Pixels | Hectares | Pixels | Hectares | % | *accuracy (2013)* |
| Indigenous Forest | 8124 | 731.16 | 10737 | 966.33 | 2613 | 235.17 | 32.16 | 72.6 / 94.64 |
| Thicket /Dense bush | 3462931 | 311663.79 | 2577328 | 231959.52 | -885603 | -79704.27 | -25.57 | 53.74 / 83.64 |
| Woodlan/Open bush | 17937089 | 1614338.01 | 19385150 | 1744663.50 | 1448061 | 130325.49 | 8.07 | 60.84 / 54.13 |
| Low shrubland | 30934272 | 2784084.48 | 33918389 | 3052655.01 | 2984117 | 268570.53 | 9.65 | 70.59 / 61.82 |
| Plantations / Woodlots | 218282 | 19645.38 | 188391 | 16955.19 | -29891 | -2690.19 | -13.69 | 89.3 / 94.35 |
| Cultivated commercial annual crops non-pivot | 24511201 | 2206008.09 | 21195525 | 1907597.25 | -3315676 | -298410.84 | -13.53 | 91.91 / 99.54 |
| Cultivated commercial annual crops pivot | 274098 | 24668.82 | 958619 | 86275.71 | 684521 | 61606.89 | 249.74 | 95.38 / 92.42 |
| Cultivated commercial permanent orchards | 58982 | 5308.38 | 59651 | 5368.59 | 669 | 60.21 | 1.13 | 92.18 / 95.29 |
| Cultivated commercial permanent vines | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0.00 | 91.61 / 97.26 |
| Cultivated subsistence crops | 2977197 | 267947.73 | 2545552 | 229099.68 | -431645 | -38848.05 | -14.50 | 89.00 / 94.00 |
| Settlements (incl smallholdings) | 2121938 | 190974.42 | 2407802 | 216702.18 | 285864 | 25727.76 | 13.47 | 93.90 / 98.68 |
| Wetlands | 1061447 | 95530.23 | 405520 | 36496.80 | -655927 | -59033.43 | -61.80 | 88.07 / 91.18 |
| Grasslands | 32352041 | 2911683.69 | 28742737 | 2586846.33 | -3609304 | -324837.36 | -11.16 | 84.56 / 69.82 |
| Mines | 533282 | 47995.38 | 668719 | 60184.71 | 135437 | 12189.33 | 25.40 | 92.82 / 98.10 |
| Waterbodies | 365068 | 32856.12 | 284141 | 25572.69 | -80927 | -7283.43 | -22.17 | 79.64 / 93.31 |
| Bare Ground | 21952 | 1975.68 | 487730 | 43895.70 | 465778 | 41920.02 | 2121.80 | 98.77 / 97.58 |
| Degraded | 1567497 | 141074.73 | 4569410 | 411246.90 | 3001913 | 270172.17 | 191.51 | 78.69 / 85.95 |
| *totals* | *118405401* | *10656486* | *118405401* | *10656486* | | | | *User / Producer* |
| | | | | | | | | *class accuracies* |

| N.Cape Province change based on the 30m pixels | 1990 Land Cover | | 2014 Land Cover (change based on standardised areas) | | Change from 1990 to 2014 | | | Class mapping |
|---|---|---|---|---|---|---|---|---|
| | Pixels | Hectares | Pixels | Hectares | Pixels | Hectares | % | accuracy (2013) |
| Indigenous Forest | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0.00 | 72.6 / 94.64 |
| Thicket /Dense bush | 3366213 | 302959.17 | 2620780 | 235870.20 | -745433 | -67088.97 | -22.14 | 53.74 / 83.64 |
| Woodlan/Open bush | 12906026 | 1161542.34 | 12308962 | 1107806.58 | -597064 | -53735.76 | -4.63 | 60.84 / 54.13 |
| Low shrubland | 273284146 | 24595573.14 | 266589150 | 23993023.50 | -6694996 | -602549.64 | -2.45 | 70.59 / 61.82 |
| Plantations / Woodlots | 16021 | 1441.89 | 10553 | 949.77 | -5468 | -492.12 | -34.13 | 89.3 / 94.35 |
| Cultivated commercial annual crops non-pivot | 1878099 | 169028.91 | 1524185 | 137176.65 | -353914 | -31852.26 | -18.84 | 91.91 / 99.54 |
| Cultivated commercial annual crops pivot | 487327 | 43859.43 | 1034169 | 93075.21 | 546842 | 49215.78 | 112.21 | 95.38 / 92.42 |
| Cultivated commercial permanent orchards | 64495 | 5804.55 | 82917 | 7462.53 | 18422 | 1657.98 | 28.56 | 92.18 / 95.29 |
| Cultivated commercial permanent vines | 325303 | 29277.27 | 358636 | 32277.24 | 33333 | 2999.97 | 10.25 | 91.61 / 97.26 |
| Cultivated subsistence crops | 48383 | 4354.47 | 43488 | 3913.92 | -4895 | -440.55 | -10.12 | 89.00 / 94.00 |
| Settlements (incl smallholdings) | 505185 | 45466.65 | 595935 | 53634.15 | 90750 | 8167.50 | 17.96 | 93.90 / 98.68 |
| Wetlands | 1383159 | 124484.31 | 508456 | 45761.04 | -874703 | -78723.27 | -63.24 | 88.07 / 91.18 |
| Grasslands | 16278690 | 1465082.10 | 22292088 | 2006287.92 | 6013398 | 541205.82 | 36.94 | 84.56 / 69.82 |
| Mines | 1150633 | 103556.97 | 1128435 | 101559.15 | -22198 | -1997.82 | -1.93 | 92.82 / 98.10 |
| Waterbodies | 1484259 | 133583.31 | 597399 | 53765.91 | -886860 | -79817.40 | -59.75 | 79.64 / 93.31 |
| Bare Ground | 102786035 | 9250743.15 | 107782286 | 9700405.74 | 4996251 | 449662.59 | 4.86 | 98.77 / 97.58 |
| Degraded | 1516457 | 136481.13 | 2992 | 269.28 | -1513465 | -136211.85 | -99.80 | 78.69 / 85.95 |
| *totals* | *417480431* | *37573239* | *417480431* | *37573239* | | | | *User / Producer class accuracies* |

| W.Cape Province change based on the 30m pixels | 1990 Land Cover | | 2014 Land Cover (change based on standardised areas) | | Change from 1990 to 2014 | | | Class mapping |
|---|---|---|---|---|---|---|---|---|
| | Pixels | Hectares | Pixels | Hectares | Pixels | Hectares | % | accuracy (2013) |
| Indigenous Forest | 613558 | 55220.22 | 620891 | 55880.19 | 7333 | 659.97 | 1.20 | 72.6 / 94.64 |
| Thicket /Dense bush | 6566621 | 590995.89 | 8837553 | 795379.77 | 2270932 | 204383.88 | 34.58 | 53.74 / 83.64 |
| Woodlan/Open bush | 4529692 | 407672.28 | 5983259 | 538493.31 | 1453567 | 130821.03 | 32.09 | 60.84 / 54.13 |
| Low shrubland | 68281558 | 6145340.22 | 73218655 | 6589678.95 | 4937097 | 444338.73 | 7.23 | 70.59 / 61.82 |
| Plantations / Woodlots | 1335352 | 120181.68 | 902534 | 81228.06 | -432818 | -38953.62 | -32.41 | 89.3 / 94.35 |
| Cultivated commercial annual crops non-pivot | 18774280 | 1689685.20 | 18150014 | 1633501.26 | -624266 | -56183.94 | -3.33 | 91.91 / 99.54 |
| Cultivated commercial annual crops pivot | 209325 | 18839.25 | 816599 | 73493.91 | 607274 | 54654.66 | 290.11 | 95.38 / 92.42 |
| Cultivated commercial permanent orchards | 1182748 | 106447.32 | 1158901 | 104301.09 | -23847 | -2146.23 | -2.02 | 92.18 / 95.29 |
| Cultivated commercial permanent vines | 1478633 | 133076.97 | 1738155 | 156433.95 | 259522 | 23356.98 | 17.55 | 91.61 / 97.26 |
| Cultivated subsistence crops | 11463 | 1031.67 | 8049 | 724.41 | -3414 | -307.26 | -29.78 | 89.00 / 94.00 |
| Settlements (incl smallholdings) | 1152346 | 103711.14 | 1296109 | 116649.81 | 143763 | 12938.67 | 12.48 | 93.90 / 98.68 |
| Wetlands | 1597375 | 143763.75 | 1201787 | 108160.83 | -395588 | -35602.92 | -24.76 | 88.07 / 91.18 |
| Grasslands | 7856963 | 707126.67 | 5774440 | 519699.60 | -2082523 | -187427.07 | -26.51 | 84.56 / 69.82 |
| Mines | 68726 | 6185.34 | 103314 | 9298.26 | 34588 | 3112.92 | 50.33 | 92.82 / 98.10 |
| Waterbodies | 624675 | 56220.75 | 632120 | 56890.80 | 7445 | 670.05 | 1.19 | 79.64 / 93.31 |
| Bare Ground | 30290215 | 2726119.35 | 24439993 | 2199599.37 | -5850222 | -526519.98 | -19.31 | 98.77 / 97.58 |
| Degraded | 578680 | 52081.20 | 269837 | 24285.33 | -308843 | -27795.87 | -53.37 | 78.69 / 85.95 |
| *totals* | *145152210* | *13063699* | *145152210* | *13063699* | | | | *User / Producer class accuracies* |

### 4.3 Inter-Class Land-Cover Change Results

The tables below illustrate the inter-class changes between 1990 and 2013/14, and allow an interpretation of (a) what the 1990 extent of land-cover class X has changed to in 2013/14, or (b) what the current extent of class Y in 2013/14 was, in terms of 1990 land-cover characteristics. These statistics are based on the fact that a 17 x class land-cover legend in both 1990 and 2013/14 means that there are 289 possible solutions to what a 1990 class can become in 2013/14. Interpretation of these inter-class changes should again be assessed in terms of the associated class mapping accuracies. Note that the table statistics are based on the original 30m resolution datasets.

The table (14) on the right shows the numeric codes used to represent all possible 289 inter-class changes between 1990 and 2013/14.

The table (15) on the opposite page provides the definition of each of the 289 inter-class changes, in terms of what 1990 class changed to what 2013/14 class, together with the number of 30m resolution pixel (not ha) occurrences.

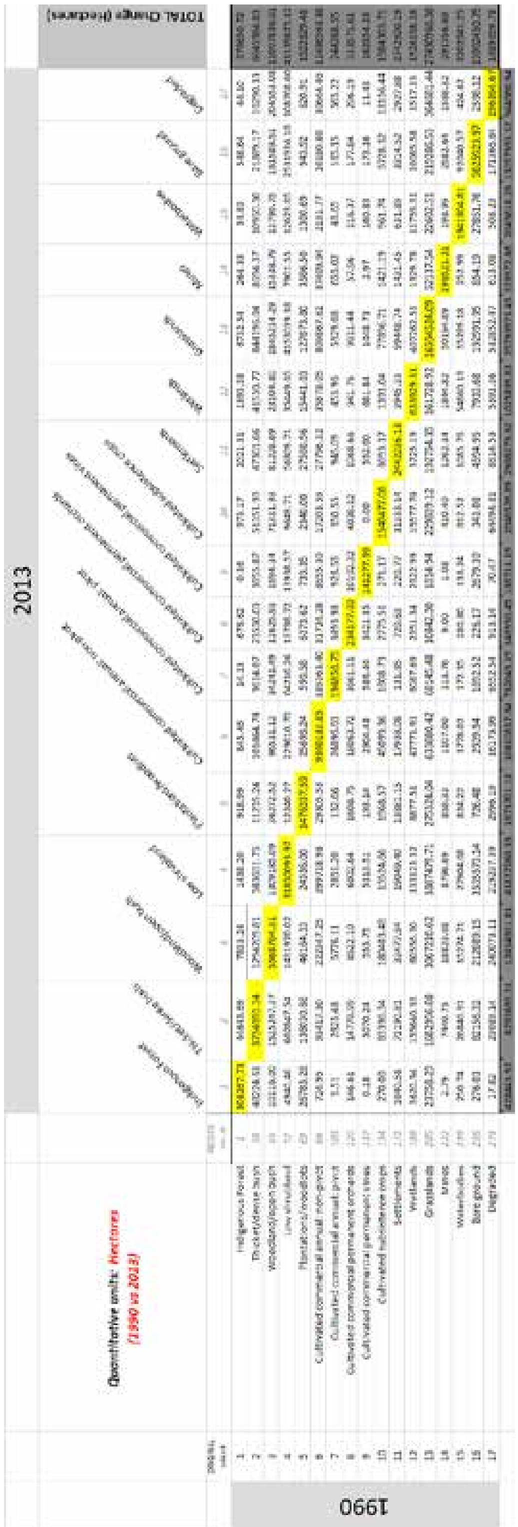
| | | | | 2013 | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Indigenous Forest | Thicket/dense bush | Woodland/open bush | Low shrubland | Plantations/woodlots | Cultivated commercial annual: non-pivot | Cultivated commercial annual: pivot | Cultivated commercial permanent orchards | Cultivated commercial permanent vines | Cultivated subsistence crops | Settlements | Wetlands | Grasslands | Mines | Waterbodies | Bare ground | Degraded |
| | ORIGINAL VALUE | | RECODE VALUE | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| 1990 | 1 | Indigenous Forest | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| | 2 | Thicket/dense bush | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 |
| | 3 | Woodland/open bush | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 |
| | 4 | Low shrubland | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 |
| | 5 | Plantations/woodlots | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 |
| | 6 | Cultivated commercial annual: non-pivot | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 |
| | 7 | Cultivated commercial annual: pivot | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 | 115 | 116 | 117 | 118 | 119 | 120 |
| | 8 | Cultivated commercial permanent orchards | 120 | 121 | 122 | 123 | 124 | 125 | 126 | 127 | 128 | 129 | 130 | 131 | 132 | 133 | 134 | 135 | 136 | 137 |
| | 9 | Cultivated commercial permanent vines | 137 | 138 | 139 | 140 | 141 | 142 | 143 | 144 | 145 | 146 | 147 | 148 | 149 | 150 | 151 | 152 | 153 | 154 |
| | 10 | Cultivated subsistence crops | 154 | 155 | 156 | 157 | 158 | 159 | 160 | 161 | 162 | 163 | 164 | 165 | 166 | 167 | 168 | 169 | 170 | 171 |
| | 11 | Settlements | 171 | 172 | 173 | 174 | 175 | 176 | 177 | 178 | 179 | 180 | 181 | 182 | 183 | 184 | 185 | 186 | 187 | 188 |
| | 12 | Wetlands | 188 | 189 | 190 | 191 | 192 | 193 | 194 | 195 | 196 | 197 | 198 | 199 | 200 | 201 | 202 | 203 | 204 | 205 |
| | 13 | Grasslands | 205 | 206 | 207 | 208 | 209 | 210 | 211 | 212 | 213 | 214 | 215 | 216 | 217 | 218 | 219 | 220 | 221 | 222 |
| | 14 | Mines | 222 | 223 | 224 | 225 | 226 | 227 | 228 | 229 | 230 | 231 | 232 | 233 | 234 | 235 | 236 | 237 | 238 | 239 |
| | 15 | Waterbodies | 239 | 240 | 241 | 242 | 243 | 244 | 245 | 246 | 247 | 248 | 249 | 250 | 251 | 252 | 253 | 254 | 255 | 256 |
| | 16 | Bare ground | 256 | 257 | 258 | 259 | 260 | 261 | 262 | 263 | 264 | 265 | 266 | 267 | 268 | 269 | 270 | 271 | 272 | 273 |
| | 17 | Degraded | 273 | 274 | 275 | 276 | 277 | 278 | 279 | 280 | 281 | 282 | 283 | 284 | 285 | 286 | 287 | 288 | 289 | 290 |

| Change Map Codes | 1990 Class | 2013 Class | Class names in Change Dataset | Histogram Values in Change Dataset |
|---|---|---|---|---|
| 2 | Indigenous Forest | Indigenous Forest | Indigenous Forest-NO_CHANGE | 5423197 |
| 3 | Indigenous Forest | Thicket/dense bush | Indigenous Forest-CHANGE-TO-Thicket/dense bush | 496041 |
| 4 | Indigenous Forest | Woodland/open bush | Indigenous Forest-CHANGE-TO-Woodland/open bush | 87036 |
| 5 | Indigenous Forest | Low shrubland | Indigenous Forest-CHANGE-TO-Low shrubland | 15980 |
| 6 | Indigenous Forest | Plantations/woodlots | Indigenous Forest-CHANGE-TO-Plantations/woodlots | 20211 |
| 7 | Indigenous Forest | Cultivated commercial annuals non-pivot | Indigenous Forest-CHANGE-TO-Cultivated commercial annuals non-pivot | 9294 |
| 8 | Indigenous Forest | Cultivated commercial annuals pivot | Indigenous Forest-CHANGE-TO-Cultivated commercial annuals pivot | 157 |
| 9 | Indigenous Forest | Cultivated commercial permanent orchards | Indigenous Forest-CHANGE-TO-Cultivated commercial permanent orchards | 7518 |
| 10 | Indigenous Forest | Cultivated commercial permanent vines | Indigenous Forest-CHANGE-TO-Cultivated commercial permanent vines | 4 |
| 11 | Indigenous Forest | Cultivated subsistence crops | Indigenous Forest-CHANGE-TO-Cultivated subsistence crops | 10853 |
| 12 | Indigenous Forest | Settlements | Indigenous Forest-CHANGE-TO-Settlements | 22459 |
| 13 | Indigenous Forest | Wetlands | Indigenous Forest-CHANGE-TO-Wetlands | 15482 |
| 14 | Indigenous Forest | Grasslands | Indigenous Forest-CHANGE-TO-Grasslands | 34800 |
| 15 | Indigenous Forest | Mines | Indigenous Forest-CHANGE-TO-Mines | 2937 |
| 16 | Indigenous Forest | Waterbodies | Indigenous Forest-CHANGE-TO-Waterbodies | 387 |
| 17 | Indigenous Forest | Bare ground | Indigenous Forest-CHANGE-TO-Bare ground | 8056 |
| 18 | Indigenous Forest | Degraded | Indigenous Forest-CHANGE-TO-Degraded | 490 |
| 19 | Indigenous Forest | Indigenous Forest | Indigenous Forest-CHANGE-TO-Indigenous Forest | 545829 |
| 20 | Thicket/dense bush | Thicket/dense bush | Thicket/dense bush-NO_CHANGE | 41485926 |
| 21 | Thicket/dense bush | Woodland/open bush | Thicket/dense bush-CHANGE-TO-Woodland/open bush | 14380109 |
| 22 | Thicket/dense bush | Low shrubland | Thicket/dense bush-CHANGE-TO-Low shrubland | 4262575 |
| 23 | Thicket/dense bush | Plantations/woodlots | Thicket/dense bush-CHANGE-TO-Plantations/woodlots | 124836 |
| 24 | Thicket/dense bush | Cultivated commercial annuals non-pivot | Thicket/dense bush-CHANGE-TO-Cultivated commercial annuals non-pivot | 1127598 |
| 25 | Thicket/dense bush | Cultivated commercial annuals pivot | Thicket/dense bush-CHANGE-TO-Cultivated commercial annuals pivot | 108823 |
| 26 | Thicket/dense bush | Cultivated commercial permanent orchards | Thicket/dense bush-CHANGE-TO-Cultivated commercial permanent orchards | 282867 |
| 27 | Thicket/dense bush | Cultivated commercial permanent vines | Thicket/dense bush-CHANGE-TO-Cultivated commercial permanent vines | 42843 |
| 28 | Thicket/dense bush | Cultivated subsistence crops | Thicket/dense bush-CHANGE-TO-Cultivated subsistence crops | 570577 |
| 29 | Thicket/dense bush | Settlements | Thicket/dense bush-CHANGE-TO-Settlements | 525574 |
| 30 | Thicket/dense bush | Wetlands | Thicket/dense bush-CHANGE-TO-Wetlands | 401453 |
| 31 | Thicket/dense bush | Grasslands | Thicket/dense bush-CHANGE-TO-Grasslands | 9179998 |
| 32 | Thicket/dense bush | Mines | Thicket/dense bush-CHANGE-TO-Mines | 55493 |
| 33 | Thicket/dense bush | Waterbodies | Thicket/dense bush-CHANGE-TO-Waterbodies | 121670 |
| 34 | Thicket/dense bush | Bare ground | Thicket/dense bush-CHANGE-TO-Bare ground | 243213 |
| 35 | Thicket/dense bush | Degraded | Thicket/dense bush-CHANGE-TO-Degraded | 104337 |
| 36 | Woodland/open bush | Indigenous Forest | Woodland/open bush-CHANGE-TO-Indigenous Forest | 112400 |
| 37 | Woodland/open bush | Thicket/dense bush | Woodland/open bush-CHANGE-TO-Thicket/dense bush | 15967193 |
| 38 | Woodland/open bush | Woodland/open bush | Woodland/open bush-NO_CHANGE | 61875159 |
| 39 | Woodland/open bush | Low shrubland | Woodland/open bush-CHANGE-TO-Low shrubland | 14546501 |
| 40 | Woodland/open bush | Plantations/woodlots | Woodland/open bush-CHANGE-TO-Plantations/woodlots | 473028 |
| 41 | Woodland/open bush | Cultivated commercial annuals non-pivot | Woodland/open bush-CHANGE-TO-Cultivated commercial annuals non-pivot | 3072568 |
| 42 | Woodland/open bush | Cultivated commercial annuals pivot | Woodland/open bush-CHANGE-TO-Cultivated commercial annuals pivot | 380461 |
| 43 | Woodland/open bush | Cultivated commercial permanent orchards | Woodland/open bush-CHANGE-TO-Cultivated commercial permanent orchards | 125177 |
| 44 | Woodland/open bush | Cultivated commercial permanent vines | Woodland/open bush-CHANGE-TO-Cultivated commercial permanent vines | 18829 |
| 45 | Woodland/open bush | Cultivated subsistence crops | Woodland/open bush-CHANGE-TO-Cultivated subsistence crops | 732577 |
| 46 | Woodland/open bush | Settlements | Woodland/open bush-CHANGE-TO-Settlements | 302541 |
| 47 | Woodland/open bush | Wetlands | Woodland/open bush-CHANGE-TO-Wetlands | 256720 |
| 48 | Woodland/open bush | Grasslands | Woodland/open bush-CHANGE-TO-Grasslands | 20902181 |
| 49 | Woodland/open bush | Mines | Woodland/open bush-CHANGE-TO-Mines | 170431 |
| 50 | Woodland/open bush | Waterbodies | Woodland/open bush-CHANGE-TO-Waterbodies | 131075 |
| 51 | Woodland/open bush | Bare ground | Woodland/open bush-CHANGE-TO-Bare ground | 1795439 |
| 52 | Woodland/open bush | Degraded | Woodland/open bush-CHANGE-TO-Degraded | 2272812 |
| 53 | Low shrubland | Indigenous Forest | Low shrubland-CHANGE-TO-Indigenous Forest | 54898 |
| 54 | Low shrubland | Thicket/dense bush | Low shrubland-CHANGE-TO-Thicket/dense bush | 6698308 |
| 55 | Low shrubland | Woodland/open bush | Low shrubland-CHANGE-TO-Woodland/open bush | 13330778 |
| 56 | Low shrubland | Low shrubland | Low shrubland-NO_CHANGE | 325889931 |
| 57 | Low shrubland | Plantations/woodlots | Low shrubland-CHANGE-TO-Plantations/woodlots | 130003 |
| 58 | Low shrubland | Cultivated commercial annuals non-pivot | Low shrubland-CHANGE-TO-Cultivated commercial annuals non-pivot | 2551230 |
| 59 | Low shrubland | Cultivated commercial annuals pivot | Low shrubland-CHANGE-TO-Cultivated commercial annuals pivot | 753514 |
| 60 | Low shrubland | Cultivated commercial permanent orchards | Low shrubland-CHANGE-TO-Cultivated commercial permanent orchards | 155208 |
| 61 | Low shrubland | Cultivated commercial permanent vines | Low shrubland-CHANGE-TO-Cultivated commercial permanent vines | 154873 |
| 62 | Low shrubland | Cultivated subsistence crops | Low shrubland-CHANGE-TO-Cultivated subsistence crops | 107219 |
| 63 | Low shrubland | Settlements | Low shrubland-CHANGE-TO-Settlements | 591219 |
| 64 | Low shrubland | Wetlands | Low shrubland-CHANGE-TO-Wetlands | 218085 |
| 65 | Low shrubland | Grasslands | Low shrubland-CHANGE-TO-Grasslands | 41544882 |
| 66 | Low shrubland | Mines | Low shrubland-CHANGE-TO-Mines | 87795 |
| 67 | Low shrubland | Waterbodies | Low shrubland-CHANGE-TO-Waterbodies | 140265 |
| 68 | Low shrubland | Bare ground | Low shrubland-CHANGE-TO-Bare ground | 23832624 |
| 69 | Low shrubland | Degraded | Low shrubland-CHANGE-TO-Degraded | 1208340 |
| 70 | Plantations/woodlots | Indigenous Forest | Plantations/woodlots-CHANGE-TO-Indigenous Forest | 297592 |
| 71 | Plantations/woodlots | Thicket/dense bush | Plantations/woodlots-CHANGE-TO-Thicket/dense bush | 1511482 |
| 72 | Plantations/woodlots | Woodland/open bush | Plantations/woodlots-CHANGE-TO-Woodland/open bush | 312557 |
| 73 | Plantations/woodlots | Low shrubland | Plantations/woodlots-CHANGE-TO-Low shrubland | 270600 |
| 74 | Plantations/woodlots | Plantations/woodlots | Plantations/woodlots-NO_CHANGE | 18403751 |
| 75 | Plantations/woodlots | Cultivated commercial annuals non-pivot | Plantations/woodlots-CHANGE-TO-Cultivated commercial annuals non-pivot | 282536 |
| 76 | Plantations/woodlots | Cultivated commercial annuals pivot | Plantations/woodlots-CHANGE-TO-Cultivated commercial annuals pivot | 8562 |
| 77 | Plantations/woodlots | Cultivated commercial permanent orchards | Plantations/woodlots-CHANGE-TO-Cultivated commercial permanent orchards | 70818 |
| 78 | Plantations/woodlots | Cultivated commercial permanent vines | Plantations/woodlots-CHANGE-TO-Cultivated commercial permanent vines | 8215 |
| 79 | Plantations/woodlots | Cultivated subsistence crops | Plantations/woodlots-CHANGE-TO-Cultivated subsistence crops | 26000 |
| 80 | Plantations/woodlots | Settlements | Plantations/woodlots-CHANGE-TO-Settlements | 338544 |
| 81 | Plantations/woodlots | Wetlands | Plantations/woodlots-CHANGE-TO-Wetlands | 171567 |
| 82 | Plantations/woodlots | Grasslands | Plantations/woodlots-CHANGE-TO-Grasslands | 1428820 |
| 83 | Plantations/woodlots | Mines | Plantations/woodlots-CHANGE-TO-Mines | 29850 |
| 84 | Plantations/woodlots | Waterbodies | Plantations/woodlots-CHANGE-TO-Waterbodies | 15341 |
| 85 | Plantations/woodlots | Bare ground | Plantations/woodlots-CHANGE-TO-Bare ground | 10488 |
| 86 | Plantations/woodlots | Degraded | Plantations/woodlots-CHANGE-TO-Degraded | 8899 |
| 87 | Cultivated commercial annuals non-pivot | Indigenous Forest | Cultivated commercial annuals non-pivot-CHANGE-TO-Indigenous Forest | 8055 |
| 88 | Cultivated commercial annuals non-pivot | Thicket/dense bush | Cultivated commercial annuals non-pivot-CHANGE-TO-Thicket/dense bush | 1017970 |
| 89 | Cultivated commercial annuals non-pivot | Woodland/open bush | Cultivated commercial annuals non-pivot-CHANGE-TO-Woodland/open bush | 2170529 |
| 90 | Cultivated commercial annuals non-pivot | Low shrubland | Cultivated commercial annuals non-pivot-CHANGE-TO-Low shrubland | 4441322 |
| 91 | Cultivated commercial annuals non-pivot | Plantations/woodlots | Cultivated commercial annuals non-pivot-CHANGE-TO-Plantations/woodlots | 325617 |
| 92 | Cultivated commercial annuals non-pivot | Cultivated commercial annuals non-pivot | Cultivated commercial annuals non-pivot-NO_CHANGE | 163779280 |

| | | | | |
|---|---|---|---|---|
| 93 | Cultivated commercial annual: non-pivot | Cultivated commercial annual: pivot | Cultivated commercial annual: non-pivot-CHANGE-TO-Cultivated commercial annual: pivot | 4126280 |
| 94 | Cultivated commercial annual: non-pivot | Cultivated commercial permanent orchards | Cultivated commercial annual: non-pivot-CHANGE-TO-Cultivated commercial permanent orchards | 352492 |
| 95 | Cultivated commercial annual: non-pivot | Cultivated commercial permanent vines | Cultivated commercial annual: non-pivot-CHANGE-TO-Cultivated commercial permanent vines | 98170 |
| 96 | Cultivated commercial annual: non-pivot | Cultivated subsistence crops | Cultivated commercial annual: non-pivot-CHANGE-TO-Cultivated subsistence crops | 131151 |
| 97 | Cultivated commercial annual: non-pivot | Settlements | Cultivated commercial annual: non-pivot-CHANGE-TO-Settlements | 938848 |
| 98 | Cultivated commercial annual: non-pivot | Wetlands | Cultivated commercial annual: non-pivot-CHANGE-TO-Wetlands | 338645 |
| 99 | Cultivated commercial annual: non-pivot | Grasslands | Cultivated commercial annual: non-pivot-CHANGE-TO-Grasslands | 8998529 |
| 100 | Cultivated commercial annual: non-pivot | Mines | Cultivated commercial annual: non-pivot-CHANGE-TO-Mines | 425666 |
| 101 | Cultivated commercial annual: non-pivot | Waterbodies | Cultivated commercial annual: non-pivot-CHANGE-TO-Waterbodies | 24333 |
| 102 | Cultivated commercial annual: non-pivot | Bare ground | Cultivated commercial annual: non-pivot-CHANGE-TO-Bare ground | 112120 |
| 103 | Cultivated commercial annual: non-pivot | Degraded | Cultivated commercial annual: non-pivot-CHANGE-TO-Degraded | 340494 |
| 104 | Cultivated commercial annual: pivot | Indigenous Forest | Cultivated commercial annual: pivot-CHANGE-TO-Indigenous Forest | 59 |
| 105 | Cultivated commercial annual: pivot | Thicket/dense bush | Cultivated commercial annual: pivot-CHANGE-TO-Thicket/dense bush | 11172 |
| 106 | Cultivated commercial annual: pivot | Woodland/open bush | Cultivated commercial annual: pivot-CHANGE-TO-Woodland/open bush | 64179 |
| 107 | Cultivated commercial annual: pivot | Low shrubland | Cultivated commercial annual: pivot-CHANGE-TO-Low shrubland | 11680 |
| 108 | Cultivated commercial annual: pivot | Plantations/woodlots | Cultivated commercial annual: pivot-CHANGE-TO-Plantations/woodlots | 1474 |
| 109 | Cultivated commercial annual: pivot | Cultivated commercial annual: non-pivot | Cultivated commercial annual: pivot-CHANGE-TO-Cultivated commercial annual: non-pivot | 276629 |
| 110 | Cultivated commercial annual: pivot | Cultivated commercial annual: pivot | Cultivated commercial annual: pivot-NO_CHANGE | 2160070 |
| 111 | Cultivated commercial annual: pivot | Cultivated commercial permanent orchards | Cultivated commercial annual: pivot-CHANGE-TO-Cultivated commercial permanent orchards | 18822 |
| 112 | Cultivated commercial annual: pivot | Cultivated commercial permanent vines | Cultivated commercial annual: pivot-CHANGE-TO-Cultivated commercial permanent vines | 20317 |
| 113 | Cultivated commercial annual: pivot | Cultivated subsistence crops | Cultivated commercial annual: pivot-CHANGE-TO-Cultivated subsistence crops | 3855 |
| 114 | Cultivated commercial annual: pivot | Settlements | Cultivated commercial annual: pivot-CHANGE-TO-Settlements | 10501 |
| 115 | Cultivated commercial annual: pivot | Wetlands | Cultivated commercial annual: pivot-CHANGE-TO-Wetlands | 5044 |
| 116 | Cultivated commercial annual: pivot | Grasslands | Cultivated commercial annual: pivot-CHANGE-TO-Grasslands | 19212 |
| 117 | Cultivated commercial annual: pivot | Mines | Cultivated commercial annual: pivot-CHANGE-TO-Mines | 7278 |
| 118 | Cultivated commercial annual: pivot | Waterbodies | Cultivated commercial annual: pivot-CHANGE-TO-Waterbodies | 485 |
| 119 | Cultivated commercial annual: pivot | Bare ground | Cultivated commercial annual: pivot-CHANGE-TO-Bare ground | 1855 |
| 120 | Cultivated commercial annual: pivot | Degraded | Cultivated commercial annual: pivot-CHANGE-TO-Degraded | 8258 |
| 121 | Cultivated commercial permanent orchards | Indigenous Forest | Cultivated commercial permanent orchards-CHANGE-TO-Indigenous Forest | 1829 |
| 122 | Cultivated commercial permanent orchards | Thicket/dense bush | Cultivated commercial permanent orchards-CHANGE-TO-Thicket/dense bush | 184211 |
| 123 | Cultivated commercial permanent orchards | Woodland/open bush | Cultivated commercial permanent orchards-CHANGE-TO-Woodland/open bush | 54690 |
| 124 | Cultivated commercial permanent orchards | Low shrubland | Cultivated commercial permanent orchards-CHANGE-TO-Low shrubland | 66698 |
| 125 | Cultivated commercial permanent orchards | Plantations/woodlots | Cultivated commercial permanent orchards-CHANGE-TO-Plantations/woodlots | 17875 |
| 126 | Cultivated commercial permanent orchards | Cultivated commercial annual: non-pivot | Cultivated commercial permanent orchards-CHANGE-TO-Cultivated commercial annual: non-pivot | 200708 |
| 127 | Cultivated commercial permanent orchards | Cultivated commercial annual: pivot | Cultivated commercial permanent orchards-CHANGE-TO-Cultivated commercial annual: pivot | 40679 |
| 128 | Cultivated commercial permanent orchards | Cultivated commercial permanent orchards | Cultivated commercial permanent orchards-NO_CHANGE | 2681867 |
| 129 | Cultivated commercial permanent orchards | Cultivated commercial permanent vines | Cultivated commercial permanent orchards-CHANGE-TO-Cultivated commercial permanent vines | 112248 |
| 130 | Cultivated commercial permanent orchards | Cultivated subsistence crops | Cultivated commercial permanent orchards-CHANGE-TO-Cultivated subsistence crops | 44838 |
| 131 | Cultivated commercial permanent orchards | Settlements | Cultivated commercial permanent orchards-CHANGE-TO-Settlements | 11874 |
| 132 | Cultivated commercial permanent orchards | Wetlands | Cultivated commercial permanent orchards-CHANGE-TO-Wetlands | 20484 |
| 133 | Cultivated commercial permanent orchards | Grasslands | Cultivated commercial permanent orchards-CHANGE-TO-Grasslands | 179016 |
| 134 | Cultivated commercial permanent orchards | Mines | Cultivated commercial permanent orchards-CHANGE-TO-Mines | 844 |
| 135 | Cultivated commercial permanent orchards | Waterbodies | Cultivated commercial permanent orchards-CHANGE-TO-Waterbodies | 1253 |
| 136 | Cultivated commercial permanent orchards | Bare ground | Cultivated commercial permanent orchards-CHANGE-TO-Bare ground | 1576 |
| 137 | Cultivated commercial permanent orchards | Degraded | Cultivated commercial permanent orchards-CHANGE-TO-Degraded | 8291 |
| 138 | Cultivated commercial permanent vines | Indigenous Forest | Cultivated commercial permanent vines-CHANGE-TO-Indigenous Forest | 2 |
| 139 | Cultivated commercial permanent vines | Thicket/dense bush | Cultivated commercial permanent vines-CHANGE-TO-Thicket/dense bush | 56336 |
| 140 | Cultivated commercial permanent vines | Woodland/open bush | Cultivated commercial permanent vines-CHANGE-TO-Woodland/open bush | 8175 |
| 141 | Cultivated commercial permanent vines | Low shrubland | Cultivated commercial permanent vines-CHANGE-TO-Low shrubland | 59039 |
| 142 | Cultivated commercial permanent vines | Plantations/woodlots | Cultivated commercial permanent vines-CHANGE-TO-Plantations/woodlots | 2546 |
| 143 | Cultivated commercial permanent vines | Cultivated commercial annual: non-pivot | Cultivated commercial permanent vines-CHANGE-TO-Cultivated commercial annual: non-pivot | 12272 |
| 144 | Cultivated commercial permanent vines | Cultivated commercial annual: pivot | Cultivated commercial permanent vines-CHANGE-TO-Cultivated commercial annual: pivot | 8516 |
| 145 | Cultivated commercial permanent vines | Cultivated commercial permanent orchards | Cultivated commercial permanent vines-CHANGE-TO-Cultivated commercial permanent orchards | 18815 |
| 146 | Cultivated commercial permanent vines | Cultivated commercial permanent vines | Cultivated commercial permanent vines-NO_CHANGE | 1569751 |
| 147 | Cultivated commercial permanent vines | Cultivated subsistence crops | Cultivated commercial permanent vines-CHANGE-TO-Cultivated subsistence crops | 8 |
| 148 | Cultivated commercial permanent vines | Settlements | Cultivated commercial permanent vines-CHANGE-TO-Settlements | 6340 |
| 149 | Cultivated commercial permanent vines | Wetlands | Cultivated commercial permanent vines-CHANGE-TO-Wetlands | 7576 |
| 150 | Cultivated commercial permanent vines | Grasslands | Cultivated commercial permanent vines-CHANGE-TO-Grasslands | 16097 |
| 151 | Cultivated commercial permanent vines | Mines | Cultivated commercial permanent vines-CHANGE-TO-Mines | 32 |
| 152 | Cultivated commercial permanent vines | Waterbodies | Cultivated commercial permanent vines-CHANGE-TO-Waterbodies | 1787 |
| 153 | Cultivated commercial permanent vines | Bare ground | Cultivated commercial permanent vines-CHANGE-TO-Bare ground | 1924 |
| 154 | Cultivated commercial permanent vines | Degraded | Cultivated commercial permanent vines-CHANGE-TO-Degraded | 127 |
| 155 | Cultivated subsistence crops | Indigenous Forest | Cultivated subsistence crops-CHANGE-TO-Indigenous Forest | 3000 |
| 156 | Cultivated subsistence crops | Thicket/dense bush | Cultivated subsistence crops-CHANGE-TO-Thicket/dense bush | 920626 |
| 157 | Cultivated subsistence crops | Woodland/open bush | Cultivated subsistence crops-CHANGE-TO-Woodland/open bush | 2005372 |
| 158 | Cultivated subsistence crops | Low shrubland | Cultivated subsistence crops-CHANGE-TO-Low shrubland | 150274 |
| 159 | Cultivated subsistence crops | Plantations/woodlots | Cultivated subsistence crops-CHANGE-TO-Plantations/woodlots | 21873 |
| 160 | Cultivated subsistence crops | Cultivated commercial annual: non-pivot | Cultivated subsistence crops-CHANGE-TO-Cultivated commercial annual: non-pivot | 531104 |
| 161 | Cultivated subsistence crops | Cultivated commercial annual: pivot | Cultivated subsistence crops-CHANGE-TO-Cultivated commercial annual: pivot | 20897 |
| 162 | Cultivated subsistence crops | Cultivated commercial permanent orchards | Cultivated subsistence crops-CHANGE-TO-Cultivated commercial permanent orchards | 30833 |
| 163 | Cultivated subsistence crops | Cultivated commercial permanent vines | Cultivated subsistence crops-CHANGE-TO-Cultivated commercial permanent vines | 9013 |
| 164 | Cultivated subsistence crops | Cultivated subsistence crops | Cultivated subsistence crops-NO_CHANGE | 17186412 |
| 165 | Cultivated subsistence crops | Settlements | Cultivated subsistence crops-CHANGE-TO-Settlements | 56593 |
| 166 | Cultivated subsistence crops | Wetlands | Cultivated subsistence crops-CHANGE-TO-Wetlands | 13430 |
| 167 | Cultivated subsistence crops | Grasslands | Cultivated subsistence crops-CHANGE-TO-Grasslands | 885519 |
| 168 | Cultivated subsistence crops | Mines | Cultivated subsistence crops-CHANGE-TO-Mines | 15791 |
| 169 | Cultivated subsistence crops | Waterbodies | Cultivated subsistence crops-CHANGE-TO-Waterbodies | 10680 |
| 170 | Cultivated subsistence crops | Bare ground | Cultivated subsistence crops-CHANGE-TO-Bare ground | 63648 |
| 171 | Cultivated subsistence crops | Degraded | Cultivated subsistence crops-CHANGE-TO-Degraded | 203516 |
| 172 | Settlements | Indigenous Forest | Settlements-CHANGE-TO-Indigenous Forest | 11552 |
| 173 | Settlements | Thicket/dense bush | Settlements-CHANGE-TO-Thicket/dense bush | 793009 |
| 174 | Settlements | Woodland/open bush | Settlements-CHANGE-TO-Woodland/open bush | 372976 |
| 175 | Settlements | Low shrubland | Settlements-CHANGE-TO-Low shrubland | 211060 |
| 176 | Settlements | Plantations/woodlots | Settlements-CHANGE-TO-Plantations/woodlots | 154235 |
| 177 | Settlements | Cultivated commercial annual: non-pivot | Settlements-CHANGE-TO-Cultivated commercial annual: non-pivot | 199113 |
| 178 | Settlements | Cultivated commercial annual: pivot | Settlements-CHANGE-TO-Cultivated commercial annual: pivot | 1465 |
| 179 | Settlements | Cultivated commercial permanent orchards | Settlements-CHANGE-TO-Cultivated commercial permanent orchards | 8007 |
| 180 | Settlements | Cultivated commercial permanent vines | Settlements-CHANGE-TO-Cultivated commercial permanent vines | 2453 |
| 181 | Settlements | Cultivated subsistence crops | Settlements-CHANGE-TO-Cultivated subsistence crops | 348146 |
| 182 | Settlements | Settlements | Settlements-NO_CHANGE | 27532957 |
| 183 | Settlements | Wetlands | Settlements-CHANGE-TO-Wetlands | 43837 |
| 184 | Settlements | Grasslands | Settlements-CHANGE-TO-Grasslands | 1104986 |
| 185 | Settlements | Mines | Settlements-CHANGE-TO-Mines | 15905 |
| 186 | Settlements | Waterbodies | Settlements-CHANGE-TO-Waterbodies | 7021 |

| | | | | |
|---|---|---|---|---|
| 201 | Wetlands | Grasslands | Wetlands-CHANGE-TO-Grasslands | 4525139 |
| 202 | Wetlands | Mines | Wetlands-CHANGE-TO-Mines | 21442 |
| 203 | Wetlands | Waterbodies | Wetlands-CHANGE-TO-Waterbodies | 180659 |
| 204 | Wetlands | Bare ground | Wetlands-CHANGE-TO-Bare ground | 112062 |
| 205 | Wetlands | Degraded | Wetlands-CHANGE-TO-Degraded | 16857 |
| 206 | Grasslands | Indigenous Forest | Grasslands-CHANGE-TO-Indigenous Forest | 259981 |
| 207 | Grasslands | Thicket/dense bush | Grasslands-CHANGE-TO-Thicket/dense bush | 13809512 |
| 208 | Grasslands | Woodland/open bush | Grasslands-CHANGE-TO-Woodland/open bush | 34080118 |
| 209 | Grasslands | Low shrubland | Grasslands-CHANGE-TO-Low shrubland | 43256219 |
| 210 | Grasslands | Plantations/woodlots | Grasslands-CHANGE-TO-Plantations/woodlots | 3059156 |
| 211 | Grasslands | Cultivated commercial annual: non-pivot | Grasslands-CHANGE-TO-Cultivated commercial annual: non-pivot | 7065338 |
| 212 | Grasslands | Cultivated commercial annual: pivot | Grasslands-CHANGE-TO-Cultivated commercial annual: pivot | 752172 |
| 213 | Grasslands | Cultivated commercial permanent orchards | Grasslands-CHANGE-TO-Cultivated commercial permanent orchards | 120470 |
| 214 | Grasslands | Cultivated commercial permanent vines | Grasslands-CHANGE-TO-Cultivated commercial permanent vines | 20156 |
| 215 | Grasslands | Cultivated subsistence crops | Grasslands-CHANGE-TO-Cultivated subsistence crops | 2551798 |
| 216 | Grasslands | Settlements | Grasslands-CHANGE-TO-Settlements | 2141715 |
| 217 | Grasslands | Wetlands | Grasslands-CHANGE-TO-Wetlands | 1756308 |
| 218 | Grasslands | Grasslands | Grasslands-NO_CHANGE | 184385901 |
| 219 | Grasslands | Mines | Grasslands-CHANGE-TO-Mines | 375006 |
| 220 | Grasslands | Waterbodies | Grasslands-CHANGE-TO-Waterbodies | 251139 |
| 221 | Grasslands | Bare ground | Grasslands-CHANGE-TO-Bare ground | 2438517 |
| 222 | Grasslands | Degraded | Grasslands-CHANGE-TO-Degraded | 4052306 |
| 223 | Mines | Indigenous Forest | Mines-CHANGE-TO-Indigenous Forest | 31 |
| 224 | Mines | Thicket/dense bush | Mines-CHANGE-TO-Thicket/dense bush | 82675 |
| 225 | Mines | Woodland/open bush | Mines-CHANGE-TO-Woodland/open bush | 209132 |
| 226 | Mines | Low shrubland | Mines-CHANGE-TO-Low shrubland | 57741 |
| 227 | Mines | Plantations/woodlots | Mines-CHANGE-TO-Plantations/woodlots | 9537 |
| 228 | Mines | Cultivated commercial annual: non-pivot | Mines-CHANGE-TO-Cultivated commercial annual: non-pivot | 12300 |
| 229 | Mines | Cultivated commercial annual: pivot | Mines-CHANGE-TO-Cultivated commercial annual: pivot | 1264 |
| 230 | Mines | Cultivated commercial permanent orchards | Mines-CHANGE-TO-Cultivated commercial permanent orchards | 100 |
| 231 | Mines | Cultivated commercial permanent vines | Mines-CHANGE-TO-Cultivated commercial permanent vines | 12 |
| 232 | Mines | Cultivated subsistence crops | Mines-CHANGE-TO-Cultivated subsistence crops | 4560 |
| 233 | Mines | Settlements | Mines-CHANGE-TO-Settlements | 34025 |
| 234 | Mines | Wetlands | Mines-CHANGE-TO-Wetlands | 20498 |
| 235 | Mines | Grasslands | Mines-CHANGE-TO-Grasslands | 557721 |
| 236 | Mines | Mines | Mines-NO_CHANGE | 2183309 |
| 237 | Mines | Waterbodies | Mines-CHANGE-TO-Waterbodies | 2211 |
| 238 | Mines | Bare ground | Mines-CHANGE-TO-Bare ground | 28636 |
| 239 | Mines | Degraded | Mines-CHANGE-TO-Degraded | 17648 |
| 240 | Waterbodies | Indigenous Forest | Waterbodies-CHANGE-TO-Indigenous Forest | 7386 |
| 241 | Waterbodies | Thicket/dense bush | Waterbodies-CHANGE-TO-Thicket/dense bush | 296299 |
| 242 | Waterbodies | Woodland/open bush | Waterbodies-CHANGE-TO-Woodland/open bush | 100719 |
| 243 | Waterbodies | Low shrubland | Waterbodies-CHANGE-TO-Low shrubland | 160052 |
| 244 | Waterbodies | Plantations/woodlots | Waterbodies-CHANGE-TO-Plantations/woodlots | 3158 |
| 245 | Waterbodies | Cultivated commercial annual: non-pivot | Waterbodies-CHANGE-TO-Cultivated commercial annual: non-pivot | 41978 |
| 246 | Waterbodies | Cultivated commercial annual: pivot | Waterbodies-CHANGE-TO-Cultivated commercial annual: pivot | 1515 |
| 247 | Waterbodies | Cultivated commercial permanent orchards | Waterbodies-CHANGE-TO-Cultivated commercial permanent orchards | 3120 |
| 248 | Waterbodies | Cultivated commercial permanent vines | Waterbodies-CHANGE-TO-Cultivated commercial permanent vines | 1536 |
| 249 | Waterbodies | Cultivated subsistence crops | Waterbodies-CHANGE-TO-Cultivated subsistence crops | 9018 |
| 250 | Waterbodies | Settlements | Waterbodies-CHANGE-TO-Settlements | 12864 |
| 251 | Waterbodies | Wetlands | Waterbodies-CHANGE-TO-Wetlands | 605557 |
| 252 | Waterbodies | Grasslands | Waterbodies-CHANGE-TO-Grasslands | 392102 |
| 253 | Waterbodies | Mines | Waterbodies-CHANGE-TO-Mines | 2811 |
| 254 | Waterbodies | Waterbodies | Waterbodies-NO_CHANGE | 21575409 |
| 255 | Waterbodies | Bare ground | Waterbodies-CHANGE-TO-Bare ground | 1622575 |
| 256 | Waterbodies | Degraded | Waterbodies-CHANGE-TO-Degraded | 4718 |
| 257 | Bare ground | Indigenous Forest | Bare ground-CHANGE-TO-Indigenous Forest | 3067 |
| 258 | Bare ground | Thicket/dense bush | Bare ground-CHANGE-TO-Thicket/dense bush | 912848 |
| 259 | Bare ground | Woodland/open bush | Bare ground-CHANGE-TO-Woodland/open bush | 2169435 |
| 260 | Bare ground | Low shrubland | Bare ground-CHANGE-TO-Low shrubland | 33264146 |
| 261 | Bare ground | Plantations/woodlots | Bare ground-CHANGE-TO-Plantations/woodlots | 9072 |
| 262 | Bare ground | Cultivated commercial annual: non-pivot | Bare ground-CHANGE-TO-Cultivated commercial annual: non-pivot | 12660 |
| 263 | Bare ground | Cultivated commercial annual: pivot | Bare ground-CHANGE-TO-Cultivated commercial annual: pivot | 21028 |
| 264 | Bare ground | Cultivated commercial permanent orchards | Bare ground-CHANGE-TO-Cultivated commercial permanent orchards | 2515 |
| 265 | Bare ground | Cultivated commercial permanent vines | Bare ground-CHANGE-TO-Cultivated commercial permanent vines | 29770 |
| 266 | Bare ground | Cultivated subsistence crops | Bare ground-CHANGE-TO-Cultivated subsistence crops | 3812 |
| 267 | Bare ground | Settlements | Bare ground-CHANGE-TO-Settlements | 51865 |
| 268 | Bare ground | Wetlands | Bare ground-CHANGE-TO-Wetlands | 88152 |
| 269 | Bare ground | Grasslands | Bare ground-CHANGE-TO-Grasslands | 2144455 |
| 270 | Bare ground | Mines | Bare ground-CHANGE-TO-Mines | 3451 |
| 271 | Bare ground | Waterbodies | Bare ground-CHANGE-TO-Waterbodies | 329664 |
| 272 | Bare ground | Bare ground | Bare ground-NO_CHANGE | 109179883 |
| 273 | Bare ground | Degraded | Bare ground-CHANGE-TO-Degraded | 28868 |
| 274 | Degraded | Indigenous Forest | Degraded-CHANGE-TO-Indigenous Forest | 198 |
| 275 | Degraded | Thicket/dense bush | Degraded-CHANGE-TO-Thicket/dense bush | 256346 |
| 276 | Degraded | Woodland/open bush | Degraded-CHANGE-TO-Woodland/open bush | 2067475 |
| 277 | Degraded | Low shrubland | Degraded-CHANGE-TO-Low shrubland | 2433871 |
| 278 | Degraded | Plantations/woodlots | Degraded-CHANGE-TO-Plantations/woodlots | 14291 |
| 279 | Degraded | Cultivated commercial annual: non-pivot | Degraded-CHANGE-TO-Cultivated commercial annual: non-pivot | 175711 |
| 280 | Degraded | Cultivated commercial annual: pivot | Degraded-CHANGE-TO-Cultivated commercial annual: pivot | 72836 |
| 281 | Degraded | Cultivated commercial permanent orchards | Degraded-CHANGE-TO-Cultivated commercial permanent orchards | 26149 |
| 282 | Degraded | Cultivated commercial permanent vines | Degraded-CHANGE-TO-Cultivated commercial permanent vines | 783 |
| 283 | Degraded | Cultivated subsistence crops | Degraded-CHANGE-TO-Cultivated subsistence crops | 716609 |
| 284 | Degraded | Settlements | Degraded-CHANGE-TO-Settlements | 93717 |
| 285 | Degraded | Wetlands | Degraded-CHANGE-TO-Wetlands | 59904 |
| 286 | Degraded | Grasslands | Degraded-CHANGE-TO-Grasslands | 5920588 |
| 287 | Degraded | Mines | Degraded-CHANGE-TO-Mines | 9812 |
| 288 | Degraded | Waterbodies | Degraded-CHANGE-TO-Waterbodies | 5647 |
| 289 | Degraded | Bare ground | Degraded-CHANGE-TO-Bare ground | 1904036 |
| 290 | Degraded | Degraded | Degraded-NO_CHANGE | 2182159 |

The table (16) describes the actual 1990 - 2013/14 inter-class land-cover changes for the whole of South Africa, in terms of Hectares (Ha):



The table (17) describes the actual 1990 - 2013/14 inter-class land-cover changes for the whole of South Africa, expressed in terms of the percentage of the original 1990 class extent and what it has become in 2013/14. For example, 81.84 % of what was mapped as indigenous forest in 1990 is still indigenous forest in 2013/14, and 11.85% of what was indigenous forest in 1990 is now mapped as thicket / dense bush in 2013/14:

| | ORIGINAL VALUE | Quantitative units: Percentage of original 1990 extent in 2013 (only read table across rows) | PRESENT VALUE | 2013 | | | | | | | | | | | | | | | | | TOTAL Change (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Indigenous Forest | Thicket/dense bush | Woodland/open bush | Low shrubland | Plantations/woodlots | Cultivated commercial annual: non-pivot | Cultivated commercial annual: pivot | Cultivated commercial permanent orchards | Cultivated commercial permanent vines | Cultivated subsistence crops | Settlements | Wetlands | Grasslands | Mines | Waterbodies | Bare ground | Degraded | |
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | |
| 1990 | 1 | Indigenous Forest | 1 | 81.84 | 11.85 | 2.88 | 0.48 | 0.24 | 0.22 | 0.02 | 0.18 | 0.00 | 0.26 | 0.54 | 0.27 | 1.79 | 0.07 | 0.01 | 0.15 | 0.01 | 100 |
| | 2 | Thicket/dense bush | 18 | 0.71 | 56.19 | 15.67 | 5.77 | 0.17 | 1.55 | 0.14 | 0.35 | 0.05 | 0.77 | 0.71 | 0.62 | 12.70 | 0.15 | 0.15 | 0.33 | 0.15 | 100 |
| | 3 | Woodland/open bush | 35 | 0.09 | 12.06 | 50.59 | 11.05 | 0.33 | 0.88 | 0.31 | 0.11 | 0.02 | 0.65 | 0.74 | 0.21 | 16.76 | 0.14 | 0.11 | 1.47 | 1.06 | 100 |
| | 4 | Low shrubland | 52 | 0.01 | 1.47 | 4.44 | 77.42 | 0.08 | 0.36 | 0.16 | 0.03 | 0.01 | 0.02 | 0.14 | 0.09 | 10.09 | 0.02 | 0.04 | 4.15 | 0.26 | 100 |
| | 5 | Plantations/woodlots | 69 | 1.39 | 7.07 | 2.40 | 1.27 | 76.78 | 1.34 | 0.05 | 0.55 | 0.04 | 0.32 | 1.43 | 0.80 | 5.85 | 0.19 | 0.07 | 0.05 | 0.03 | 100 |
| | 6 | Cultivated commercial annual: non-pivot | 86 | 0.01 | 0.81 | 1.94 | 3.48 | 0.26 | 81.31 | 3.39 | 0.20 | 0.00 | 0.15 | 0.24 | 0.11 | 7.05 | 0.33 | 0.02 | 0.05 | 0.27 | 100 |
| | 7 | Cultivated commercial annual: pivot | 103 | 0.00 | 1.16 | 2.16 | 1.17 | 0.05 | 10.19 | 79.77 | 1.45 | 0.38 | 0.34 | 0.19 | 0.19 | 2.18 | 0.27 | 0.02 | 0.07 | 0.23 | 100 |
| | 8 | Cultivated commercial permanent orchards | 120 | 0.05 | 4.71 | 2.72 | 1.91 | 0.51 | 5.76 | 1.17 | 74.68 | 1.22 | 1.29 | 0.34 | 0.30 | 3.13 | 0.02 | 0.04 | 0.06 | 0.09 | 100 |
| | 9 | Cultivated commercial permanent vines | 137 | 0.00 | 3.12 | 0.24 | 3.27 | 0.52 | 1.79 | 0.16 | 2.11 | 87.02 | 0.00 | 0.45 | 0.42 | 0.89 | 0.00 | 0.10 | 0.11 | 0.01 | 100 |
| | 10 | Cultivated subsistence crops | 154 | 0.01 | 4.20 | 9.10 | 0.68 | 0.10 | 2.27 | 0.09 | 0.14 | 0.01 | 77.03 | 0.44 | 0.07 | 5.95 | 0.07 | 0.05 | 0.29 | 0.51 | 100 |
| | 11 | Settlements | 171 | 0.04 | 2.60 | 1.22 | 0.69 | 0.51 | 0.65 | 0.00 | 0.03 | 0.01 | 1.24 | 89.04 | 0.34 | 3.62 | 0.05 | 0.02 | 0.12 | 0.11 | 100 |
| | 12 | Wetlands | 188 | 0.24 | 10.20 | 5.26 | 8.72 | 0.58 | 1.13 | 0.40 | 0.15 | 0.15 | 1.02 | 0.28 | 41.56 | 26.69 | 0.13 | 0.77 | 0.86 | 0.18 | 100 |
| | 13 | Grasslands | 205 | 0.09 | 6.12 | 11.16 | 14.14 | 1.00 | 2.51 | 0.73 | 0.04 | 0.01 | 0.84 | 0.70 | 0.59 | 60.36 | 0.19 | 0.08 | 0.80 | 1.31 | 100 |
| | 14 | Mines | 222 | 0.00 | 2.56 | 6.45 | 1.02 | 0.29 | 0.38 | 0.08 | 0.00 | 0.00 | 0.24 | 0.43 | 0.62 | 17.28 | 67.36 | 0.07 | 0.89 | 0.54 | 100 |
| | 15 | Waterbodies | 239 | 0.01 | 1.22 | 0.64 | 1.27 | 0.04 | 0.17 | 0.01 | 0.01 | 0.01 | 0.04 | 0.05 | 2.49 | 1.00 | 0.01 | 88.18 | 4.18 | 0.02 | 100 |
| | 16 | Bare ground | 256 | 0.00 | 0.59 | 1.53 | 25.41 | 0.01 | 0.02 | 0.01 | 0.00 | 0.02 | 0.00 | 0.03 | 0.06 | 1.33 | 0.01 | 0.20 | 70.68 | 0.02 | 100 |
| | 17 | Degraded | 273 | 0.00 | 1.55 | 16.12 | 14.72 | 0.30 | 1.09 | 0.48 | 0.06 | 0.00 | 4.33 | 0.58 | 0.38 | 35.78 | 0.04 | 0.03 | 11.51 | 18.19 | 100 |

The table (18) describes the actual 1990 - 2013/14 inter-class land-cover changes for the whole of South Africa, expressed in terms of the percentage of the current 2013/14 class extent and what it was originally in 1990. For example, 71.95 % of what was mapped as indigenous forest in 2013/14 was also indigenous forest in 1990, and 11.26% of what is indigenous forest in 2013/14 was mapped as thicket / dense bush in 1990:

**Quantitative units:** ***Percentage of final 2013 extent in 1990 (only read table down columns)***

| | | | | 2013 | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Original value | | Remap value | Indigenous Forest | Thicket/dense bush | Woodland/open bush | Low shrubland | Plantations/woodlots | Cultivated commercial annuals: non-pivot | Cultivated commercial annuals: pivot | Cultivated commercial permanent orchards | Cultivated commercial permanent vines | Cultivated subsistence crops | Settlements | Wetlands | Grasslands | Mines | Waterbodies | Bare ground | Degraded |
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| 1990 | 1 | Indigenous Forest | 1 | 71.95 | 0.54 | 0.06 | 0.00 | 0.05 | 0.01 | 0.00 | 0.20 | 0.00 | 0.05 | 0.07 | 0.14 | 0.02 | 0.08 | 0.00 | 0.00 | 0.00 |
| | 2 | Thicket/dense bush | [illegible] | 11.26 | 45.03 | 10.41 | 0.92 | 0.60 | 0.96 | 1.33 | 6.79 | 2.04 | 2.52 | 1.63 | 4.85 | 3.27 | 2.43 | 0.54 | 0.17 | 3.09 |
| | 3 | Woodland/open bush | [illegible] | 2.36 | 18.39 | 64.78 | 3.13 | 3.04 | 0.91 | 4.38 | 3.35 | 0.90 | 3.50 | 2.79 | 2.25 | 7.15 | 4.66 | 0.58 | 1.24 | 21.67 |
| | 4 | Low shrubland | [illegible] | 1.15 | 7.27 | 11.32 | 76.15 | 0.65 | 2.16 | 8.21 | 3.57 | 7.39 | 0.87 | 1.85 | 3.46 | 16.10 | 2.40 | 0.62 | 19.39 | 11.52 |
| | 5 | Plantations/woodlots | [illegible] | 6.25 | 1.66 | 0.57 | 0.06 | 78.79 | 0.26 | 0.86 | 1.84 | 0.39 | 0.11 | 0.95 | 1.51 | 0.50 | 1.05 | 0.07 | 0.01 | 0.07 |
| | 6 | Cultivated commercial annuals: non-pivot | [illegible] | 0.17 | 1.13 | 1.79 | 0.96 | 1.56 | 88.02 | 49.75 | 9.14 | 4.59 | 0.84 | 0.96 | 5.50 | 3.14 | 11.57 | 0.11 | 0.08 | 3.25 |
| | 7 | Cultivated commercial annuals: pivot | [illegible] | 0.00 | 0.05 | 0.05 | 0.01 | 0.01 | 0.23 | 24.92 | 1.01 | 0.49 | 0.02 | 0.03 | 0.04 | 0.02 | 0.20 | 0.00 | 0.00 | 0.06 |
| | 8 | Cultivated commercial permanent orchards | [illegible] | 0.05 | 0.18 | 0.07 | 0.01 | 0.09 | 0.17 | 0.47 | 67.30 | 3.35 | 0.20 | 0.04 | 0.09 | 0.04 | 0.02 | 0.01 | 0.00 | 0.03 |
| | 9 | Cultivated commercial permanent vines | [illegible] | 0.00 | 0.06 | 0.00 | 0.01 | 0.01 | 0.03 | 0.07 | 0.55 | 74.86 | 0.00 | 0.02 | 0.07 | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 |
| | 10 | Cultivated subsistence crops | 154 | 0.06 | 1.01 | 1.45 | 0.03 | 0.11 | 0.42 | 0.23 | 0.00 | 0.14 | 75.49 | 0.10 | 0.14 | 0.30 | 0.43 | 0.05 | 0.04 | 1.02 |
| | 11 | Settlements | 171 | 0.24 | 0.86 | 0.27 | 0.05 | 0.74 | 0.17 | 0.02 | 0.21 | 0.12 | 1.54 | 83.58 | 0.18 | 0.26 | 0.44 | 0.03 | 0.03 | 0.31 |
| | 12 | Wetlands | [illegible] | 0.88 | 1.88 | 0.65 | 0.12 | 0.47 | 0.65 | 0.78 | 0.68 | 1.23 | 0.76 | 0.13 | 61.76 | 1.56 | 0.58 | 0.57 | 0.08 | 0.16 |
| | 13 | Grasslands | [illegible] | 5.55 | 20.83 | 24.87 | 9.29 | 14.89 | 5.95 | 8.71 | 8.11 | 8.96 | 11.78 | 8.61 | 15.20 | 64.33 | 15.85 | 1.10 | 1.68 | 48.65 |
| | 14 | Mines | [illegible] | 0.00 | 0.09 | 0.15 | 0.02 | 0.05 | 0.01 | 0.01 | 0.00 | 0.00 | 0.02 | 0.04 | 0.18 | 0.19 | 59.74 | 0.01 | 0.02 | 0.17 |
| | 15 | Waterbodies | [illegible] | 0.06 | 0.32 | 0.12 | 0.07 | 0.04 | 0.04 | 0.02 | 0.08 | 0.07 | 0.04 | 0.04 | 5.35 | 0.34 | 0.08 | 94.93 | 0.70 | 0.04 |
| | 16 | Bare ground | [illegible] | 0.00 | 0.99 | 1.71 | 8.43 | 0.04 | 0.03 | 0.24 | 0.07 | 1.42 | 0.02 | 0.16 | 0.77 | 0.75 | 0.26 | 1.35 | 75.25 | 0.28 |
| | 17 | Degraded | [illegible] | 0.00 | 0.28 | 1.39 | 0.52 | 0.10 | 0.15 | 0.84 | 0.26 | 0.04 | 3.16 | 0.30 | 0.53 | 2.07 | 0.15 | 0.02 | 1.31 | 20.00 |
| | | TOTAL Change (%) | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

# 5. 1990 - 2013/14 CHANGE RESULTS ANALYSIS

## 5.1 Indigenous Forest

According to the land-cover data there was nationally a 13.75% increase in the indigenous forest class extent between 1990 and 2013/14. However the 2013/14 map accuracy results indicate a 72.6 % Users Accuracy, which may mean that in many cases the reported change is a result of mapping error between true forest and the spectrally similar woody vegetation classes such as 'thicket / dense bush', as indicated in the 2013/14 accuracy report. In Gauteng Province there is a 1350% (!) statistical increase in the extent of indigenous forest in 2013/14, but this is simply due to the fact that in 1990 2 pixels were mapped as forest whereas in 2013/14 29 pixels were mapped. This difference is likely to be a result of the reported mapping inaccuracies; with 29 pixels representing only 0.0006 % of the total mapped area of indigenous forest in 2013/14. National and provincial statistics should not however detract from the very relevant and real changes in indigenous forest cover change that are contained within the land-cover datasets in a local basis, such as around Dukuduku, St Lucia (see previous picture example).

## 5.2 Thicket / Dense Bush

According to the land-cover data there was nationally a 24.76% increase in the thicket / dense bush class extent between 1990 and 2013/14. However the 2013/14 map accuracy results indicate only a 53.74 % Users Accuracy, which may mean that in many cases the reported change will be a result of mapping error between this class and other spectrally similar woody vegetation classes, as indicated in the 2013/14 accuracy report. Provincial changes, in the woody dominated areas vary from +16.03% in Limpopo, +18.77% in KZN, +36.46% in Mpumalanga, +79.52% in Eastern Cape and -25.57 % in North West. It is recommended that such statistical changes are treated with caution unless validated by corroborating evidence of plausible local change within the actual land-cover map datasets.

## 5.3 Woodland/ Open Bush

According to the land-cover data there was nationally a 12.96% increase in the woodland / open bush class extent between 1990 and 2013/14. However the 2013/14 map accuracy results indicate only a 60.84 % Users Accuracy, which may mean that in many cases the reported change will be a result of mapping error between this class and other spectrally similar woody vegetation classes, as indicated in the 2013/14 accuracy report. Provincial changes, in the woody dominated areas vary from +3.47% in Limpopo, +20.57% in KZN, - 4.73% in Mpumalanga, +115.79% in Eastern Cape and +8.07% in North West. It is recommended that such statistical changes are treated with caution unless validated by corroborating evidence of plausible local change within the actual land-cover map datasets.

## 5.4 Low Shrubland

According to the land-cover data there was nationally a 1.67% increase in the low shrub class extent between 1990 and 2013/14. The 2013/14 map accuracy results indicate a 70.59 % Users Accuracy, which may mean that the limited amount of change is a function of both increasing map accuracy and the extremely large national class footprint within which any local change is insignificant in terms of total area affected. Provincial changes low shrub / karoo / Fynbos dominated areas vary from +48.59% in Free State, -2.45% in Northern Cape and +7.23% in Western Cape. In most cases the changes in low shrub extent seem to be along a transitional gradient with grasslands, and may be reflecting local annual changes in grass component cover in response to different annual rainfall conditions, as is evident in the difference in open water / wetland areas between 1990 and 2013/14. It is recommended that such statistical changes are treated with caution unless validated by corroborating evidence of plausible local change within the actual land-cover map datasets.

### 5.5 Plantations / Woodlots

According to the land-cover data there was nationally a 2.55% decrease in the plantation / woodlot class extent between 1990 and 2013/14. The 2013/14 map accuracy results indicate a 89.3 % Users Accuracy, which should mean that both the mapped and statistical representations of change are plausible and likely to be accurate. The national statistic does not however reflect provincial or local area changes over the same ± 24 year period, with some areas definitely showing losses and others expansion. Provincial changes in traditional forestry areas vary from -23.93% in Limpopo, +1.1% in Mpumalanga, +1.02% in Eastern Cape and +3.57% in KZN.

### 5.6 Cultivated Commercial Annual Crops Non-Pivot

According to the land-cover data there was nationally a 7.62% decrease in the cultivated commercial annual crop non-pivot class extent between 1990 and 2013/14. The 2013/14 map accuracy results indicate a 91.91 % Users Accuracy, which should mean that both the mapped and statistical representations of change are plausible and likely to be accurate. The national statistic does not however reflect provincial or local area changes over the same ± 24 year period, with some areas definitely showing losses and others expansion. Provincial changes in traditional forestry areas vary from -20.25% in Limpopo, -12.65% in Mpumalanga, +11.64% in KZN, -10.30% in Eastern Cape and -3.33% in Western Cape for example. On a local scale, many of these losses and expansions also appear to relate to associated increases in other cultivation land-uses, such as orchards, vines and pivots, and losses due to new mining and urban areas.

### 5.7 Cultivated Commercial Annual Crops Pivots

According to the land-cover data there was nationally a 220.16% increase in the cultivated commercial annual crop pivot class extent between 1990 and 2013/14. This is by far the biggest increase in any land-cover class extent over the ±24 year period and represents a huge increase in irrigation activities and associated water consumption. The 2013/14 map accuracy results indicate a 95.381 % Users Accuracy, which should mean that both the mapped and statistical representations of change are plausible and very likely to be accurate. The national statistic does not however reflect provincial or local area changes over the same ± 24 year period, with provincial changes in pivot class extent varying from +113.87% in Limpopo, +262.41% in Mpumalanga, +261.41% in KZN, +413.66% in Eastern Cape and +290.11% in Western Cape for example. All provinces showed increases in pivot class extent since 1990. On a local scale this expansion appears to have resulted in losses to both other cultivated land-uses and natural vegetation types, depending on location.

### 5.8 Cultivated Commercial Permanent Orchards

According to the land-cover data there was nationally a 10.64% increase in the cultivated commercial permanent orchard class extent between 1990 and 2013/14. The 2013/14 map accuracy results indicate a 92.18 % Users Accuracy, which should mean that both the mapped and statistical representations of change are plausible and likely to be accurate. The national statistic does not however reflect provincial or local area changes over the same ± 24 year period, with some areas definitely showing losses and others expansion. Provincial changes in traditional orchard areas vary from +40.27% in Limpopo, +35.38% in Mpumalanga, +28.56% in Northern Cape, and -18.18 in Eastern Cape for example. On a local scale, many of these losses and expansions also appear to relate to associated increases in other cultivation land-uses, such as orchards, vines and pivots, and losses due to new mining and urban areas.

### 5.9 Cultivated Commercial Permanent Vines

According to the land-cover data there was nationally a

16.23% increase in the cultivated commercial permanent vines class extent between 1990 and 2013/14. The 2013/14 map accuracy results indicate a 91.61% Users Accuracy, which should mean that both the mapped and statistical representations of change are plausible and likely to be accurate. The national statistic does reflect provincial level changes over the same ± 24 year period, with similar percent increases being reported in both the Western and Northern Cape. All provinces with vines in 1990 show an increase in 2013/14.

## 5.10 Cultivated Subsistence Crops

According to the land-cover data there was nationally only a 2.83% increase in the cultivated subsistence crop class extent between 1990 and 2013/14. The 2013/14 map accuracy results indicate a 89.00 % Users Accuracy, which should mean that both the mapped and statistical representations of change are plausible and likely to be accurate. It is important to note however that unlike commercial fields which were (originally) mapped on an individual field unit basis, subsistence fields were mapped according to the outer extent of clusters of subsistence fields, as necessitated by their characteristically small areas compared to image resolution. This resulted in varies levels and patterns of inter-field non-crop land being included in the subsistence cluster boundaries. During the land-cover mapping these inter-field non-crop areas have been re-classified, where possible, into their basic vegetation cover types, i.e. grass, dense bush etc. Since this was based on a generic modelling procedure as opposed to image-specific classification routines, it is possible that the extent and coverage of such inter-field non-crop areas has been influenced by (a) the accuracies associated with these vegetation classes, and (b) any modifying effect resulting from 1990 conditions appearing to be generally wetter than those in 2013/14. Furthermore, the actual intensity of land-use (i.e. subsistence crop yield) cannot be gauged from the single 'subsistence class' defined in the 17x class legend format, since all subsistence fields have been included within one amalgamated class on the basis of (image) observable field boundaries, regardless of whether such fields were cultivated, temporary or long term fallow (i.e. abandoned) in the assessment year. A subdivision of land-use activity intensity (a.k.a. cropping), based on annual Normalised Difference Vegetation Index (NDVI) profiles is available as part of the associated 72 x class DEA / GTI national land-cover dataset for 2013/14, but not presently for 1990. This may be a consideration for future work and analysis since it will allow the historical and current extents of high intensity subsistence cropping units to be compared, as opposed to just the overall extent of image observable field cluster boundaries.

The national statistic does not however reflect provincial or local area changes over the same ± 24 year period, with areas showing losses and others expansion. Provincial changes in subsistence cropping vary from -13.34% in Limpopo, -27.27% in Mpumalanga, and +30.29% in KZN. . It is recommended that until such time that that subsistence changes can be validated in terms of land-use intensity changes (i.e. productive-to-productive, productive-to-fallow,, fallow-to-productive etc), such statistical changes are treated with caution unless validated by corroborating evidence of plausible local change within the actual land-cover map datasets.

## 5.11 Settlements (including Smallholdings)

According to the land-cover data there was nationally only a 6.03% increase in the settlement class extent between 1990 and 2013/14. The 2013/14 map accuracy results indicate a 93.90 % Users Accuracy, which should mean that both the mapped and statistical representations of change are plausible and likely to be accurate. The national statistic does not however reflect provincial or local area changes over the same ± 24 year period, with some areas definitely showing losses and others expansion, ranging from +28.82% in Limpopo to (surprisingly) -2.93% in KZN. Gauteng only shows a +10.58% increase, which from an anecdotal perspective may be lower than expected, but this is potentially explained by the fact that the settlement footprint defined in the two land-cover datasets includes a variety of urban sub-classes, including commercial, residential, village, schools etc, as well as smallholdings. Peripheral smallholdings around urban centres are typically the first land-use class to convert to formal urban areas under urban expansion. Thus the total settlement footprint as defined in terms of the DEA / CARDNO national land-cover datasets will not change over time when smallholdings are converted to formal residential or industrial areas. Settlement sub-classes defining separate commercial, industrial, residential, informal, village and smallholding categories are available within the full 72 x class DEA / GTI national land-cover dataset for 2013/14, but not presently for 1990. This may be a consideration for future work and analysis since it will allow a more representative interpretation of urban expansion to be evaluated.

### 5.12 Wetlands

According to the land-cover data there was nationally a 32.78% decrease in the wetland class extent between 1990 and 2013/14. The 2013/14 map accuracy results indicate a 88.07 % Users Accuracy, which should mean that both the mapped and statistical representations of change are plausible and likely to be accurate. However wetlands is one specific land-cover class that has been significantly affected by the general wetter landscape conditions in 1990 compared to 2013/14, especially in the more conventionally drier western areas. The generally wetter landscape conditions in 1990 allowed wetland modelling to be undertaken across the entire country, whereas in 2013/14, because of drier conditions, wetland modelling was restricted to the southern and eastern regions. Thus any wetlands in the normally drier western regions that were mapped in 1990 have not been re-mapped in 2013/14 simply because they were not visible as such on the imagery under these drier conditions. This does not mean that such wetlands have been 'lost' but rather are temporary absent in terms of surface representation in 2013/14. This must be noted when interpreting the statistics. A possible solution may be to take the combined area of wetlands from 1990 and 2013/14 and subtract appropriate non-wetland land-use class extents from this for both 1990 and 2013/14 landscapes in order to derive a more accurate picture of wetland loss, irrespective of whether the wetlands

The national statistic does not however reflect provincial or local area changes over the same ± 24 year period, with losses ranging from -63.24% in Northern Cape to -12.13% in Gauteng, where the Northern Cape difference is likely to be a result of the landscape wetness differences already discussed, and the Gauteng difference probably being more representative of actual loss. All provinces showed a loss in wetland extent between 1990 and 2013/14. It is therefore recommended that such statistical changes are treated with caution unless validated by corroborating evidence of plausible local change within the actual land-cover map datasets.

### 5.13 Grasslands

According to the land-cover data there was nationally a 6.17% decrease in the grassland class extent between 1990 and 2013/14. The 2013/14 map accuracy results indicate a 84.56% Users Accuracy, which should mean that both the mapped and statistical representations of change are plausible and likely to be accurate. As indicated in the 1990 DEA / CARDNO SA land-cover data report the post-modelling grassland correction edits are potentially more accurate than those applied to the 2013/14 land-cover dataset, as a result of better image dates and modified correction procedures. This may mean that the actual grassland extent as represented in the 1990 dataset is slightly more accurate than that represented in the 2013/14 dataset, and that there could be a corresponding increase in the level of grassland / woody vegetation cover confusion in 2013/14. It is recommended that such statistical changes are treated with caution unless validated by corroborating evidence of plausible local change within the actual land-cover map datasets.

The generally wetter landscape conditions in 1990, especially in the more typically arid karoo regions may also have experienced a regional annual increase in the grass component in the low shrub / grassland transition zone, also increasing the extent of the grassland class mapped in 1990.

The national statistic does not however reflect provincial or local area changes over the same ± 24 year period, with some areas showing losses and others expansion. Provincial changes vary from -28.33% in Limpopo, +1.93% in Mpumalanga, and +36.94% in Northern Cape.

## 5.14 Mines

According to the land-cover data there was nationally a 12.76% increase in the mining class extent between 1990 and 2013/14. The 2013/14 map accuracy results indicate a 92.82% Users Accuracy, which should mean that both the mapped and statistical representations of change are plausible and very likely to be accurate. The national statistic does not however reflect provincial or local area changes over the same ± 24 year period, with both losses and increases being recorded, ranging from -46.22% in Eastern Cape to +66.84% in Mpumalanga (as would be expected due to the expansion of open cast coal mining in this area). Since mapping accuracies are high for this class, interpretation of the statistical changes must be made in the context of the original and current spatial extents.

## 5.15 Waterbodies

According to the land-cover data there was nationally a -7.10% decrease in the water class extent between 1990 and 2013/14, which includes both natural, man-made, seasonal and permanent water features. The 2013/14 map accuracy results indicate a 79.64% Users Accuracy, which should mean that both the mapped and statistical representations of change are plausible and likely to be accurate. The national statistic does not however reflect provincial or local area changes over the same ± 24 year period, with both losses and increases being recorded, ranging from +25.34% in Limpopo, 11.35% in Mpumalanga, and -59.75% in Northern Cape. These regional differences are likely to have been influenced by a combination of both the generally wetter landscape conditions in 1990, especially in the typically drier western regions, and by the construction of several new major dams after 1990 that are observable in 2013/14. Since mapping accuracies are high for this class, interpretation of the statistical changes must be made in the context of the original and current spatial extents, so that small spatial features do not become over-represented statistically if they have shown significant statistical but not necessarily spatial growth.

## 5.16 Bare Ground

According to the land-cover data there was nationally a -6.07% decrease in the bare ground class extent between 1990 and 2013/14. The 2013/14 map accuracy results indicate a 98.77% Users Accuracy, which should mean that both the mapped and statistical representations of change are plausible and very likely to be accurate. The national statistic does not however reflect provincial or local area changes over the same ± 24 year period, with both losses and increases being recorded, ranging from +635.08% in Limpopo, 2121.80% in North West and -63.01% in Eastern Cape. Since mapping accuracies are high for this class, interpretation of the statistical changes must be made in the context of the original and current spatial extents in any given area, so that small spatial features do not become over-represented statistically if they have shown significant statistical but not necessarily spatial growth. The 2013/14 dataset may have been influenced by the generally drier conditions in some areas, perhaps resulting in lower vegetative cover, although in some regions human activity will have increased the bare ground extent.

## 5.17 Degraded

According to the land-cover data there was nationally a -36.61% decrease in the degraded class extent between 1990 and 2013/14. The 2013/14 map accuracy results indicate a 78.69 % Users Accuracy, which should mean that both the mapped and statistical representations of change are plausible and likely to be accurate. However, degraded is defined as areas showing significant lower total vegetation cover to surrounding non-impacted areas, in terms of the viewed landscape. It is feasible therefore that a significant portion of the difference in degraded areas between 1990 and 2013/14 could be attributed to the generally wetter conditions in 1990 compared to the drier 2013/14 conditions. The provincial results show a significantly higher area of bare ground in 1990 than 2013/14, apart from North West. This would appear to be the opposite of what would be expected give that 1990 was the wetter period, and thus the vegetation cover would be assumed to be more extensive. However an alternative suggestion maybe that, in terms of the generic modelling procedures used to define this class, when all the vegetation is generally lower (as in a drier period) then the difference between impacted (i.e. degraded) land and non-impacted land is harder to determine; compared to when non-impacted land is much greener in wetter conditions.

It is recommended that such statistical changes are treated with caution unless validated by corroborating evidence of plausible local change within the actual land-cover map datasets.

## ADDITIONAL INFORMATION

**PLEASE NOTE THAT THIS IS NOT A LAND-COVER MAP DATASET BUT A SPATIAL REPRESENTATION OF 1990 TO 2013/14 LAND-COVER CHANGE ON A PER-PIXEL BASIS.**

Environment House
473 Steve Biko
cnr Steve Biko and Soutpansberg Road
Arcadia
Pretoria, 0083
South Africa

Postal Address
Department of Environmental Affairs
P O Box 447
Pretoria
0001

Publishing date: August 2017

www.environment.gov.za