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GOVERNMENT NOTICES • GOEWERMENTSKENNISGEWINGS

DEPARTMENT OF ENVIRONMENT, FORESTRY AND FISHERIES

NO. 989 **11 SEPTEMBER 2020**

DRAFT 7th NATIONAL GREENHOUSE GAS INVENTORY REPORT FOR THE REPUBLIC OF SOUTH AFRICA FOR PUBLIC COMMENT

I, Barbara Dallas Creecy, Minister of Environment, Forestry and Fisheries, hereby publish the draft 7th National Greenhouse Gas Inventory Report, which will form part of the Fourth Biennial Update Report to the United Nations Framework Convention on Climate Change (UNFCCC), for public comment. The draft 7th National Greenhouse Gas Inventory Report is available at the following website **https://www.environment.gov.za/legislation/gazetted notices**.

Members of the public are invited to submit to the Minister, within 30 days from the date of the publication of this Notice in the *Gazette,* written inputs or comments to the following addresses:

By post to: The Acting Director-General: Department of Environment, Forestry and Fisheries
Attention: Mr Jongikhaya Witi
Department of Environment, Forestry and Fisheries
Private Bag X447
Pretoria
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By email to: GHGInventory@environment.gov.za

Hand delivered at: Environment House, 473 Steve Biko Road, Arcadia, Pretoria, 0083.

Any inquiries in connection with the notice can be directed to Mr Jongikhaya Witi at Tel: 012 399 9151.

Comments received after the closing date may be disregarded.

BARBARA DALLAS CREECY
MINISTER OF FORESTRY, FISHERIES AND THE ENVIRONMENT

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NATIONAL GHG INVENTORY REPORT

SOUTH AFRICA

2000 - 2017

March 2020

environment, forestry & fisheries

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Acknowledgements

Many people and institutes were involved in the compilation of this National Inventory Report for 2017. The main information on the energy and industrial processes and product use (IPPU) sectors was provided by the Department of Mineral Resources and Energy (DMRE), Eskom, Sasol, and PetroSA. The agriculture, forestry and other land use (AFOLU) sector was prepared by Gondwana Environmental Solutions, with the major data suppliers being Tshwane University of Technology (TUT), the Department of Environment, Forestry and Fisheries (DEFF), the Department of Agriculture, Land Reform and Rural Development (DALRRD), GeoTerraImage (GTI), the Food and Agriculture Organization (FAO), Forestry SA and the Agricultural Research Council (ARC). The waste sector was compiled by the DEFF with the main data providers being Statistics South Africa (StatsSA), Department of Water and Sanitation (DWS), World Bank and the UN.

We greatly appreciate all the contributions from organizations and individuals who were involved in the process of completing this NIR. Special thanks to GIZ for providing funding for the compilation of the AFOLU sector inventory and the overall 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.

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List of abbreviations

AFOLU	Agriculture, Forestry and Other Land Use
AGB	Above-ground biomass
ARC	Agricultural Research Council
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_4	Tetrafluoroethylene
C_2F_6	Carbon hexafluoroethane
CF_4	Carbon tetrafluoromethane
CFC	Chlorofluorocarbons
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CRF	Common reporting format
DAFF	Department of Agriculture Affairs, Forestry and Fisheries
DEA	Department of Environmental Affairs
DFID	Department for International Development
DM	Dry matter
DMD	Dry matter digestibility
DMR	Department of Mineral Resources
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	Flourinated gases: e.g., HFC, PFC, SF_6 and NF_3
FOD	First order decay
FOLU	Forestry and Other Land Use
FRA	Forest resource assessment
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
ISWC	Institute of Soil, Water and Climate
KCA	Key category analysis
LC	Land cover
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
NCV	Net calorific value
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
NO	Not occurring

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
SOC	Soil organic carbon
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-derived
VS	Volatile solids

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Executive summary

ES.1 Background

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 (Van der Merwe & Scholes, 1998). 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 (DEAT, 2009), a decision was made to use the recently published 2006 IPCC Guidelines (IPCC, 2006) 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 (DEA, 2014). An update was completed for 2011 and 2012 in 2016 (DEA, 2016), and for 2013 to 2015 in 2019 (DEA, 2019).

This report documents South Africa's submission of its national greenhouse gas inventory for the year 2017. It also reports on the GHG trends for the period 2000 to 2017. It is in accordance with the guidelines provided by the UNFCCC and follows the 2006 IPCC Guidelines (IPCC, 2006) and IPCC Good Practice Guidance (GPG) (IPCC, 2000; IPCC, 2003; IPCC, 2014). 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.

National GHG Inventory System (NGHGIS)

During the compilation of the 2010 and 2015 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 recently developed a National GHG Inventory Management System (NGHGIS) to manage and simplify its climate change obligations to the UNFCCC process. This system aims to 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 ensures 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.

The NGHGIS includes:

- The formalization of a National Entity (the DEFF) 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;
- 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.

Updating of the National Atmospheric Emissions Inventory System (NAEIS)

South Africa has a National Atmospheric Emissions Inventory System (NAEIS) which is used to manage reporting of atmospheric emissions from companies. to manage the mandatory reporting of GHG emissions. DEFF has undertaken a project to modify the NAEIS to meet the requirements of the recent National Greenhouse Gas Reporting Regulations (NGER) (DEA, 2016). This component of the portal, the South African GHG Emissions Reporting System (SAGERS), will serve as a tool for the implementation of the online registration and reporting by industry in fulfilment of mandatory NGER. The key benefit of the portal is that it will enhance the data collection process for the inventory, therefore improving the quality of the national GHG inventories consistent with the requisite principles of completeness, consistency, accuracy, comparability and transparency credentials.

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). Emissions information including activity data from the NAEIS serves as input data during the national inventory compilation process. The inventory compilation process is coordinated and managed through the NGHGIS described above.

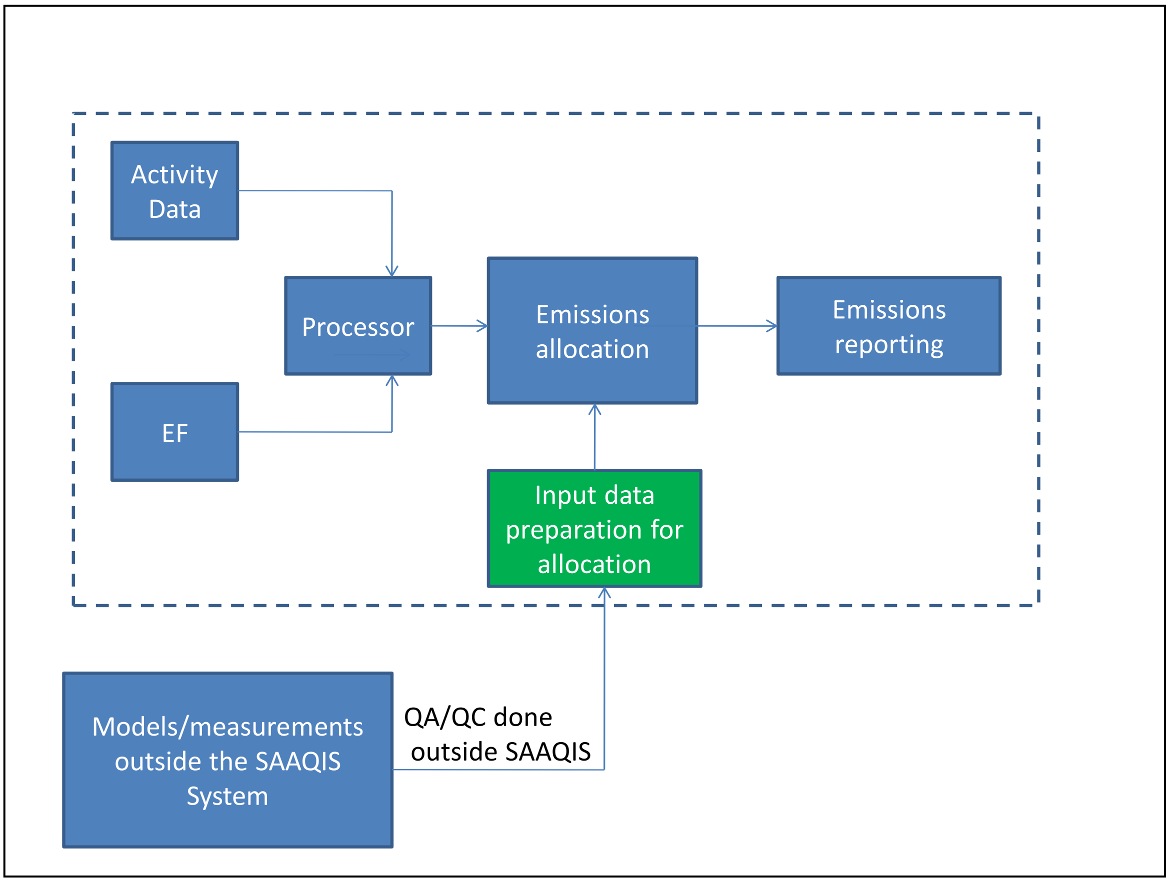

Figure A: Expected information flow in South Africa's National Atmospheric Emissions Inventory System (NAEIS).

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 (DEA, 2014) 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 2017 inventory has made use of the updated calculation files developed for the inventory, with incorporated quality control checks and list. This inventory has also made full use of the NGHGIS which has led to improved documentation, quality control and archiving of the national inventory. The transparency of the 2017 has significantly improved since 2015.

The stages and activities undertaken in the inventory update and improvement process are shown in Figure B.

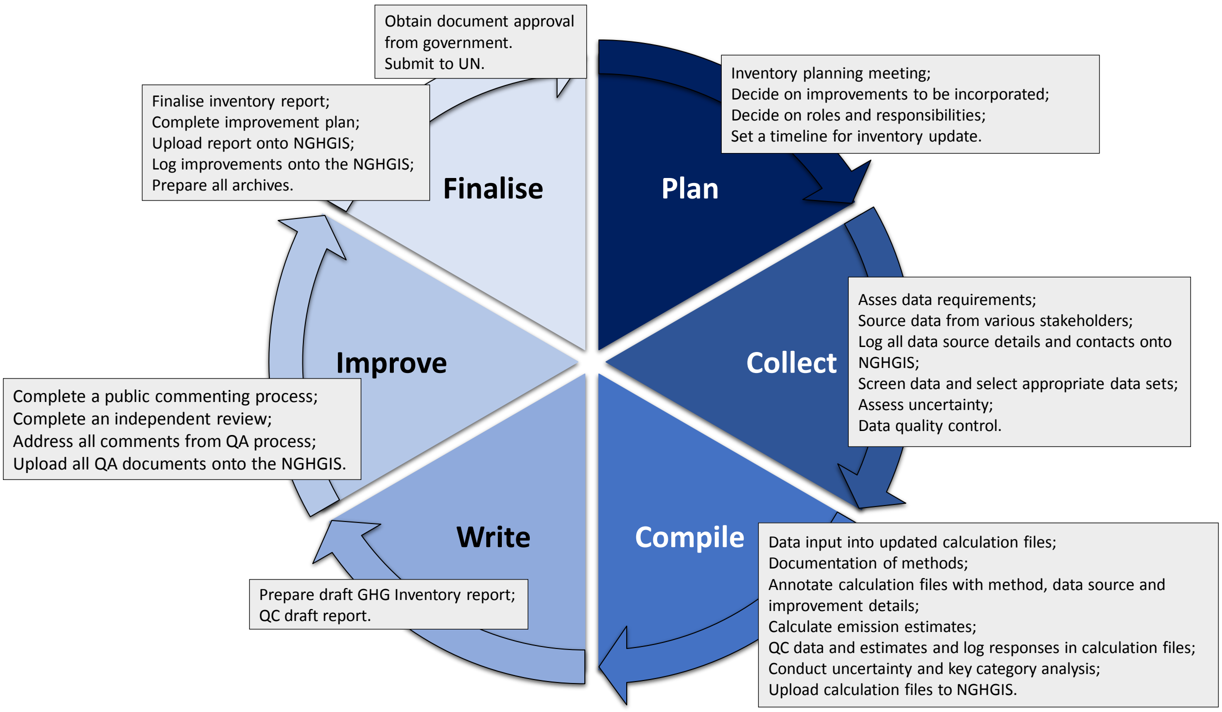

Figure B: Overview of the phases of the GHG inventory compilation and improvement process undertaken for South Africa's 2017 GHG inventory.

Institutional arrangements for inventory preparation

The DEFF 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 DEFF 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 – 2017 GHG emissions inventory.

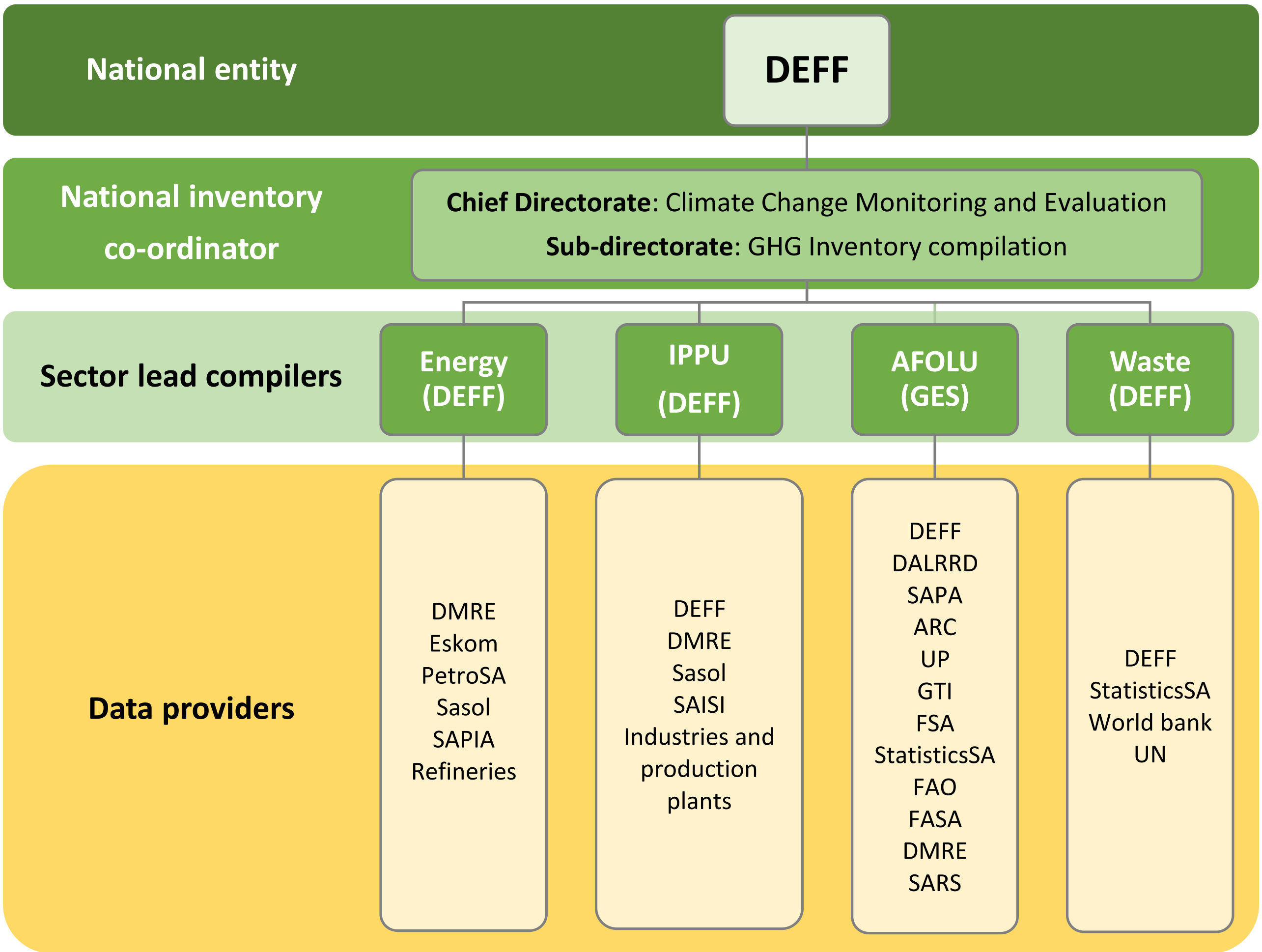

Figure C: Institutional arrangements for the compilation of the 2000 – 2017 inventory for South Africa.

Organisation of report

This report follows a standard NIR format in line with the UNFCCC Reporting Guidelines (UNFCCC, 2013). 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, emission factors, and QA/QC process. A summary of the aggregated GHG trends by gas and emission source is provided in Chapter 2. Chapters 3 to 6 deal with detailed explanations of the emissions in the energy, IPPU, AFOLU and waste sectors, respectively. They include an overall trend assessment, methodology, data sources, recalculations, uncertainty and time-series consistency, QA/QC and planned improvements and recommendations.

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ES.3 National trends

GWP

In this inventory the Second Assessment Report (SAR) (IPCC, 1996) GWP's were applied. This is consistent with the previous inventory for 2015 (DEA, 2019) and is compliant with UNFCCC reporting requirements. For purposes of comparison with past inventories, and due to the use of the Third Assessment Report (TAR) (IPCC, 2011) GWP's in other national regulations, the emissions based on TAR GWP's are also provided in the national trends summary section. All text references, tables and graphs refer to the SAR GWP estimates, unless it is otherwise stated to be a TAR GWP estimate.

Total emissions excluding FOLU[1]

2000 - 2017

South Africa's GHG emissions (excl. FOLU) were 452 347 Gg CO_2e in 2000 and these increased by 103 316 Gg CO_2e (or 22.8%) by 2017 (Table A and B). Emissions increased slowly over the 17-year period with an average annual growth rate of 1.34%. The *Energy* sector is the largest contributor (79.1% in 2017) to emissions (excl. FOLU) and is responsible for 90.3% of the increase over the 17-year period.

2015 - 2017

Emissions (excl. FOLU) increased by 0.3% between 2015 and 2017 (Table B). The increase is due to a 0.6%, 4.4% and a 3.2% increase in the emissions from the *Energy*, *Waste* and *IPPU* sectors respectively.

Net emissions (including FOLU)

2000 – 2017

The *AFOLU* sector is an overall source, however this source has been reducing due to the increasing *Land* sink. This sink meant the emissions (excl. FOLU) were reduced by 7.4%

[1] In this report FOLU refers to the Forestry and other land use component which includes all land sinks and sources (IPCC category 3B) and HWP sinks (IPCC category 3D).

in 2017. Emissions (incl. FOLU) were estimated at 513 140 Gg CO_2e in 2017 and showed an increase of 17.9% since 2000 (Table A and B). The *Land* sink increased from 2011 which caused an increase in the reduction of the emissions (incl. FOLU) between 2011 and 2017.

2015 – 2017

Emissions (incl. FOLU) for South Africa decreased by 0.5% between 2015 and 2017 (Table B). This reduction was attributed to the 56.3% decline in the *AFOLU* sector emissions.

Table A: Trends in national GHG emissions (excluding and including FOLU) between 2000 and 2017.

	SAR GWP		TAR GWP	
	Emissions (excl. FOLU)	Emissions (incl. FOLU)	Emissions (excl. FOLU)	Emissions (incl. FOLU)
	Gg CO_2e			
2000	452 347,1	431 819,2	455 470,0	435 007,1
2001	451 593,9	439 045,6	454 770,2	442 286,4
2002	465 300,5	450 080,1	468 452,7	453 296,3
2003	485 871,0	460 802,8	489 053,3	464 049,0
2004	503 082,6	484 384,3	506 287,4	487 652,4
2005	502 799,4	497 776,7	506 022,5	501 063,0
2006	509 571,7	500 262,3	512 824,3	503 577,0
2007	540 211,0	529 589,1	543 461,9	532 902,6
2008	534 953,5	531 943,0	538 339,4	535 391,5
2009	538 036,7	518 165,2	541 453,0	521 643,2
2010	549 659,5	536 938,7	553 169,7	540 509,5
2011	532 961,7	513 936,6	536 314,7	517 348,4
2012	541 628,6	523 826,7	545 010,7	527 266,4
2013	564 050,4	535 865,8	567 512,7	539 385,4
2014	560 781,6	537 547,1	564 314,5	541 137,9
2015	553 950,1	520 218,2	557 550,9	523 874,7
2016	554 156,6	508 395,5	557 709,6	511 998,5
2017	555 663,2	513 140,0	559 260,3	516 788,6

Table B: Change in emissions (excluding and including FOLU) since 2000 and 2015.

	GWP	Emissions (Gg CO_2e)			Change 2000 to 2017		Change 2015 to 2017	
		2000	2015	2017	Gg CO_2e	%	Gg CO_2e	%
Emissions (excl. FOLU)	SAR	452 347	553 950	555 663	103 316,0	22,8	1 713,1	0,3
	TAR	455 470	557 551	559 260	103 790,3	22,8	1 709,4	0,3
Emissions (incl. FOLU)	SAR	431 819	520 218	513 140	81 320,8	18,8	-7 078,2	-1,4
	TAR	435 007	523 875	516 789	81 781,4	18,8	-7 086,2	-1,4

ES.4 Gas trends

Carbon dioxide

The gas contributing the most to South Africa's emissions (excl. FOLU) was CO_2, and this contribution increased very slightly from 82.6% in 2000 to 84.8% in 2017 (Figure D). The CO_2 emissions (excl. FOLU) in 2017 were estimated at 470 936 Gg CO_2e, while CO_2 emissions (incl. FOLU) were 427 746 Gg CO_2e (Table C). The *Energy* sector is by far the largest contributor to CO_2 emissions, contributing an average of 92.0% (of emissions excluding FOLU) between 2000 and 2017, and 91.9% in 2017.

Methane

National CH_4 emissions (excl. FOLU) increased from 47 607 Gg CO_2e (2 267 Gg CH_4) to 51 545 Gg CO_2e (2 455 Gg CH_4) in 2017 (Table C), mainly due to a 58.3% increase in *Waste* sector CH_4 emissions. The CH_4 contribution to total emissions (excl. FOLU) decreased from 10.6% to 9.0% over this period (Figure D). The *Waste* sector and *AFOLU* livestock category were the major contributors, providing 38.9% and 51.3%, respectively, to the total CH_4 emissions (incl. FOLU) in 2017.

Nitrous oxide

Nitrous oxide contribution to the emissions (excl. FOLU) declined from 6.7% in 2000 to 4.7% in 2017 (Figure D). The N_2O emissions decreased over the 2000 to 2017 period from 30 117 Gg CO_2e (97 Gg N_2O) to 26 714 Gg CO_2e (86 Gg N_2O) (Table C). A 10.4% decline in the *AFOLU* N_2O emissions and an 82.2% decline in *IPPU* N_2O emissions were the main reasons for the overall reduction in N_2O. The *AFOLU* and *Energy* sectors were the largest contributors, 84.7% and 11.0% respectively, to the total N_2O emissions in 2017.

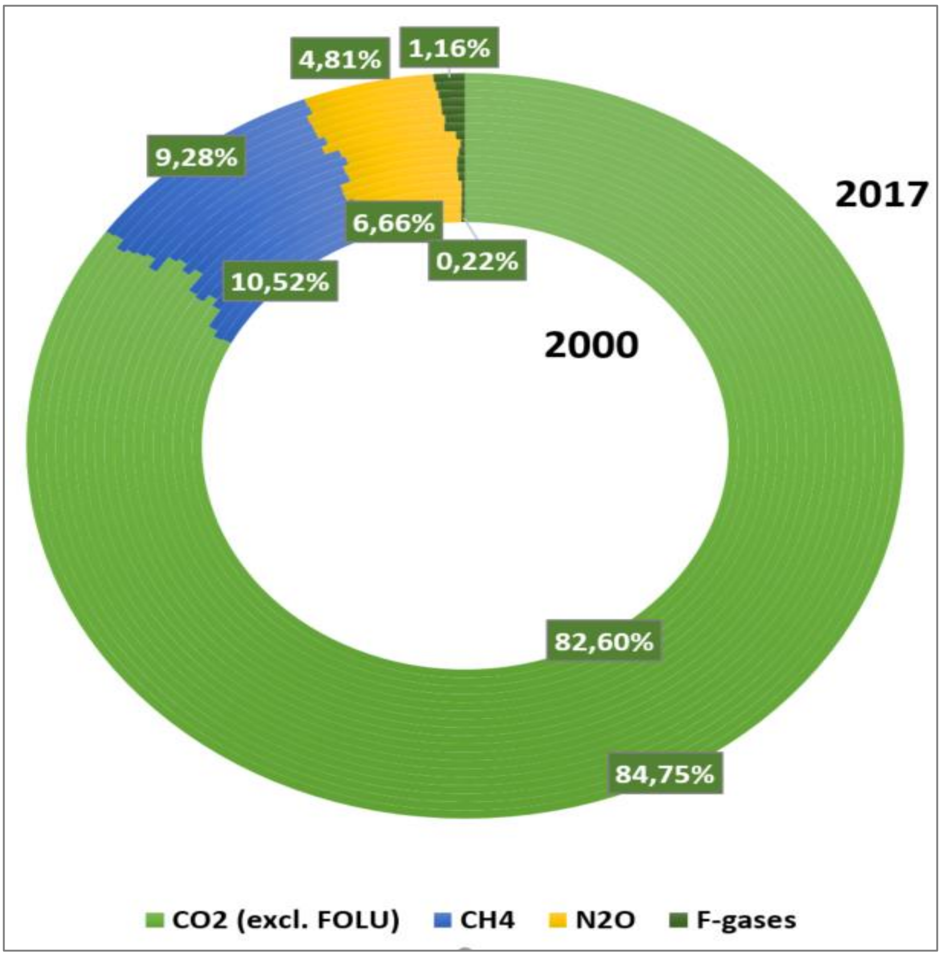

Figure D: Gas contribution to South Africa's emissions (excl. FOLU) between 2000 and 2017.

F-gases

The F-gas emissions increased from 983 Gg CO_2e to 6 468 Gg CO_2e over the 2000 to 2017 period (Table C). This increase is, however, due mostly to the incorporation of new sources at intervals across this time series as opposed to a true increase. In 2000 only PFC's were estimated, and in 2005 HFC emissions from ODS were included. From 2011 onwards the HFC emissions from *mobile air conditioning*, *fire protection*, *foam blowing agents* and *aerosols* were also incorporated. In 2017 HFCs contributed 62.1% to the total F-gas emissions. The total F-gas contribution to total emissions (excl. FOLU) has increased from 0.2% to 1.1% of the 17-year period (Figure D). Extrapolation of HFCs across the full time-series will be considered in the next inventory.

Table C: Trend in gas emissions between 2000 and 2017.

	Emissions						
	CO_2 (excl. FOLU)	CO_2 (incl. FOLU)	CH_4		N_2O		F-gases
	Gg CO_2 #		Gg CO_2e #	Gg CH_4	Gg CO_2e #	Gg N_2O	Gg CO_2e #
2000	373 639,5	352 445,1	47 607,0	2 267,0	30 117,4	97,2	983,2
2001	372 680,6	359 465,7	48 064,8	2 288,8	29 840,8	96,3	1 007,7
2002	386 063,5	370 176,5	48 056,5	2 288,4	30 283,4	97,7	897,1
2003	409 089,7	383 354,8	47 502,8	2 262,0	28 382,4	91,6	896,2
2004	425 865,8	406 500,9	47 847,0	2 278,4	28 480,3	91,9	889,4
2005	423 141,7	417 452,4	48 556,3	2 312,2	29 388,0	94,8	1 713,4
2006	429 631,0	419 655,1	48 575,2	2 313,1	29 384,6	94,8	1 980,9
2007	461 522,6	450 234,1	48 365,2	2 303,1	28 289,1	91,3	2 034,1
2008	454 902,5	451 225,4	49 789,7	2 370,9	28 687,8	92,5	1 573,6
2009	459 624,3	439 086,1	49 451,7	2 354,8	27 860,5	89,9	1 100,3
2010	468 535,5	455 148,1	50 736,0	2 416,0	28 184,4	90,9	2 203,7
2011	449 430,8	429 739,2	50 685,3	2 413,6	28 160,2	90,8	4 685,2
2012	459 410,7	440 942,2	50 418,7	2 400,9	27 292,5	88,0	4 506,8
2013	477 483,4	448 632,2	52 002,1	2 476,3	29 266,6	94,4	5 298,4
2014	474 070,9	450 169,8	52 321,7	2 491,5	29 040,0	93,7	5 349,1
2015	467 361,1	432 962,5	52 399,3	2 495,2	28 521,5	92,0	5 668,2
2016	470 013,3	423 585,6	51 351,2	2 445,3	26 641,0	85,9	6 151,1
2017	470 935,9	427 746,1	51 545,1	2 454,5	26 714,3	86,2	6 467,9

 # Calculated with SAR GWP

ES.5 Sector trends

Energy

2017

Total emissions from the *Energy* sector for 2017 were estimated to be 439 576 Gg CO_2e (Table D) which is 79.1% of the total emissions (excl. FOLU) for South Africa. *Energy industries* were the main contributor, accounting for 58.7% of emissions from the *Energy* sector. This was followed by *Transport* (13.0%), *other sectors* (12%) and *Manufacturing industries and construction* (6.9%).

2000 - 2017

Energy emissions showed an overall increasing trends between 2000 and 2017. The emissions in this sector increased by 26.1% over this period. Peak emissions were reached in 2013, after which there was a 2.4% decline to 2015, and an increase of 0.5% between 2015 and 2017. The overall growth in emissions is mainly due to the 17.0% increase in *Energy industries* emissions, as well as the more than doubling of the *Other sector* emissions from 19 039 Gg CO_2e to 53 775 Gg CO_2e. Emissions from *Fuel combustion activities* increased by 30%, while *Fugitive emissions from fuels* declined by 8.7%. The *Energy* sector contribution to the total emissions (excl. FOLU) increased from 77% to 79.1% over the 17-year period (Figure E).

2015 - 2017

Energy emissions increased by 0.5% between 2015 and 2017. *Fuel combustion activities* increased by 1.34%, while *Fugitive emissions from fuels* increased by (3.8%) over the same period. *Energy industries* showed a 0.7% decline in emissions since 2015.

Table D: Change in sector emissions since 2000 and 2015.

	Emissions (Gg CO_2e)#			Change 2000 to 2015		Change 2015 to 2017	
	2000	2015	2017	Gg CO_2e#	%	Gg CO_2e#	%
Energy	348 475.3	437 203.5	439 576.3	88 728.2	25.5	2 372.7	0.5
IPPU	34 070.8	41 882.3	43 229.5	9 158.7	26.9	1 347.2	3.2
AFOLU (excl. FOLU)	56 243.2	54 514.1	51 608.4	-4 634.8	-8.2	-2 905.7	-5.3
AFOLU (incl. FOLU)	35 715.3	20 782.2	9 085.2	-26 630.1	-74.6	-11 696.9	-56.3

Waste	13 557.8	20 350.2	21 249.0	7 691.1	56.7	898.8	4.4

[#] *Calculated with SAR GWP*

Industrial processes and product use (IPPU)

2017

In 2017 the *IPPU* sector produced 43 230 Gg CO_2e, which is 7.5% of South Africa's emissions (excl. FOLU) (Figure E). The largest source category is the *Metal industry* category, which contributes 72.9% to the total *IPPU* sector emissions. *Iron and steel production* and *Ferroalloys production* are the biggest CO_2 contributors to the *Metal industry* subsector, producing 15 074 Gg CO_2e and 12 757 Gg CO_2e, respectively. The *Mineral industry* and the *Product uses as substitute ODS* subsectors contribute 14.9% and 9.3%, respectively, to the *IPPU* sector emissions, with all the emissions from the *Product uses as substitute ODS* being HFCs.

2000 - 2017

Estimated emissions from the *IPPU* sector in 2017 are 26.9% higher than the emissions in 2000 (Table D). This was mainly due to the 17.9% (4 778 Gg CO_2e) increase in the *Metal industry* emissions, and the 4 015 Gg CO_2e increase in *Product uses as substitutes for ODS*. *IPPU* emissions increased by 17.9% between 2000 and 2006, after which there was a 14.5% decline to 2009 due to a recession. Emissions then increased again by 25.8% by 2017. The contribution to the national emissions (excl. FOLU) increased from 7.6% to 7.8% between 2000 and 2017 (Figure E).

2015 – 2017

IPPU emissions showed an increase of 3.2% between 2015 and 2017 (Table D). The increase was mostly due to a 547 Gg CO_2e (1.8%) increase in the *Metal industry* and a 532 Gg CO_2e (15.3%) increase in the *Product uses as substitute ODS emissions* over this period. In the 2012 inventory emissions from the categories *Mobile air conditioning*, *Foam blowing agents*, *Fire protection* and *Aerosols* were included in the inventory. This led to the apparent increase in emissions from this subcategory. The *Mineral industry* emissions increased by 4.6% (284 Gg CO_2e) between 2015 and 2017, while the *Non-energy products from fuels and solvents* increased by 0.7% (70 Gg CO_2e).

Agriculture, forestry and land use change (AFOLU)

2017

The *AFOLU* emissions (excl. FOLU) were 51 608 Gg CO_2e (or 9.0% of the total) in 2017, while emissions (incl, FOLU) were 9 085 Gg CO_2e (Figure E). *Livestock* and *Aggregated and non-CO_2 emissions from land* categories contributed 28 161 Gg CO_2e and 23 447 Gg CO_2e respectively in 2017, while the *Land* and *Other* (i.e. HWP) categories were both sinks (41 746 Gg CO_2e and 777 Gg CO_2e, respectively).

2000 - 2017

AFOLU emissions (excl. FOLU) declined by 4 635 Gg CO_2e (8.2%) and emissions (incl. FOLU) by 26 630 Gg CO_2e between 2000 and 2017. The emission (excl. FOLU) trend is dominated by the trend shown in the *Livestock* category (specifically the enteric fermentation from cattle), while for the net emissions the trend is dominated by the *Land* sector. *AFOLU* emissions (excl. FOLU) declined by 7.1% between 2000 and 2007, after which emissions began to increase (6.3% by 2014) again. Since 2014 emissions declined by 7.1%. *AFOLU* emissions (incl. FOLU) varied annually, reaching a peak in 2008, after which emissions started to decline due to increasing land sinks. The main drivers of the increased land sink were the increasing forest land area (thus increasing CO_2 gains) and the reduction in carbon losses (mostly due to reduced burning). *AFOLU* contribution to the total emissions (excl. FOLU) for South Africa declined from 12.5% in 2000 to 9.0% in 2017 (Figure E). The *AFOLU* contribution to the total emissions (incl. FOLU) declined from 8.3% to 1.7%.

2015 - 2017

AFOLU gross emissions declined by 5.3% between 2015 and 2017 (Table D), due to a 5.4% and 5.3% decline in *Livestock* and *Aggregated and non-CO_2 emissions on land*. On the other hand, *AFOLU* emissions (incl. FOLU) declined by 11 697 Gg CO_2e over the same period due to an increase of 8 622 Gg CO_2e in the *Land* sink.

Waste

2017

In 2017 the *Waste* sector produced 21 249 Gg CO_2e or 3.8% of South Africa's GHG emissions (excl. FOLU). The largest source category is the *Solid waste disposal* category which contributed 81.7% towards the total sector emissions. This was followed by *Wastewater treatment and discharge* which contributed 16.6%.

2000 - 2017

Waste sector emissions have increased by 56.7% from the 13 558 Gg CO_2e in 2000 (Table D). Emissions increased steadily between 2000 and 2017. *Solid waste disposal* was the main contributor (average of 80.2%) to these emissions. The contribution from the *Waste* sector to the national emissions (excl. FOLU) increased from 3.0% in 2000 to 3.7% in 2017 (Figure E).

2015 - 2017

The *Waste* sector emissions increased by 4.4% between 2015 and 2017 (Table D) due to an 899 Gg CO_2e (4.4%) increase in *Solid waste disposal* emissions and a 10 Gg CO_2e (2.8%) increase in *Incineration and open burning of waste* emissions.

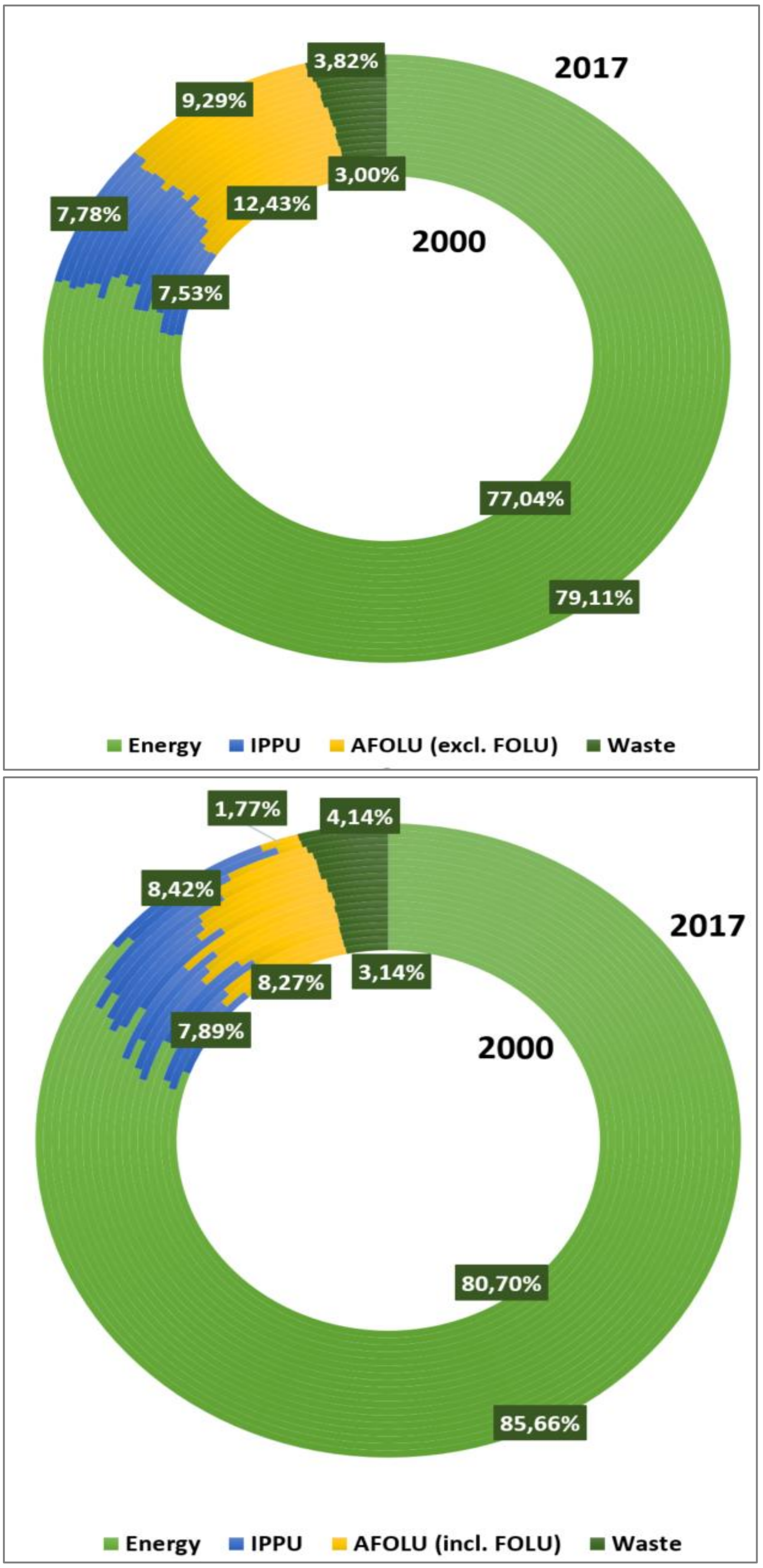

Figure E: Sector contribution to total emissions excluding FOLU) (top) and including FOLU (bottom) in South Africa between 2000 and 2017.

ES.6 Improvements and recalculations

Improvements introduced in the current inventory

Energy

A recent fuel consumption study (Top Quartile, 2019) was completed for the transport sector which provided consumption data based on vehicle kilometres travelled (VKT). In this inventory the petrol, diesel and natural gas consumption data for *Road transport* was updated. In the *Other emissions from energy production* category the charcoal production data was updated, along with charcoal consumption in *Other sectors*.

IPPU

Improvements were made to the *IPPU* sector in the recently completed 2015 inventory, so no additional updates or recalculations were completed for the *IPPU* sector.

AFOLU

In the *Livestock* category minor adjustments were made to cattle herd composition data, while for manure management updated manure management system usage data (Moeletsi & Tongwane, 2015) were incorporated. In addition, for manure N_2O the country specific N excretion rate for horses, mules and asses and poultry were included and the swine N excretion rates were updated. These improvements then also had implications for the inputs to the direct N_2O emission estimates for managed soils.

In the *Land* category several updates were made. In order to improve transparency, the land change matrix data was linked to the land areas and plantation areas were adjusted to be consistent with Forestry South Africa data. Secondly the soil area overlay data (of land use change, climate and soil type) was adjusted to account for any mapping overlay losses of area so as to ensure consistency with the biomass land area data. Probably the most significant change, was the adjustment of the data to include the 20 year default transition period for converted lands. In the previous inventory this was not accounted for. New MODIS collection 6 burnt area data was incorporated and carbon biomass and litter data was updated to be more consistent with the National Terrestrial Carbon Sinks Assessment (DEA, 2015).

In the *Aggregated and non-CO_2 sources on land* category, under *Direct N_2O from managed soils,* the crop residue calculations were adjusted to conform with IPCC methodology and the F_{SOM} component (which is the amount of N in mineral soils that is mineralised in association with loss of soil C from soil organic matter as a result of changes to land management) was included.

Updated FAO import and export data were incorporated into the HWP estimates.

Waste

In the *Waste* sector the solid waste disposal data was improved by incorporating country specific population data, waste generation rates and the percentage of waste going to solid waste management into the FOD model for the years 1950 to 1999. In addition, the fraction of methane in developed gas was previously indicated to be 0.52 and this was corrected to the IPCC default value of 0.5. The population data was also updated. No further improvements were made in the other *Waste* categories due to the recent improvements in the 2015 inventory.

Recalculations

Recalculations due to improvements led to a 5.1% and 4.4% increase in emission estimates excluding and including FOLU, respectively, for 2015 (Figure F, Table E). There were no changes in *IPPU* sector emission estimates, while *Energy*, *AFOLU* (excl. FOLU) and *Waste* were 5.1%, 10.1% and 4.2% higher than the 2015 estimates, respectively. *AFOLU* emissions (incl. FOLU), on the other hand were 1.3% lower for 2015 in this submission.

There was a 4.7% increase in the overall CO_2 emission estimates (excl. FOLU) and a 3.7% increase in estimates for CO_2 emissions (incl. FOLU) in 2015. This was due to recalculations in the *Energy* and *AFOLU* sectors. After recalculations the 2015 CH_4 emissions were estimated to be 3.2% higher due to recalculations in the *Energy, AFOLU* and *Waste* sectors. Recalculated N_2O emissions were 17.8% higher in this submission due to recalculated values in the *Energy* and *AFOLU* sectors.

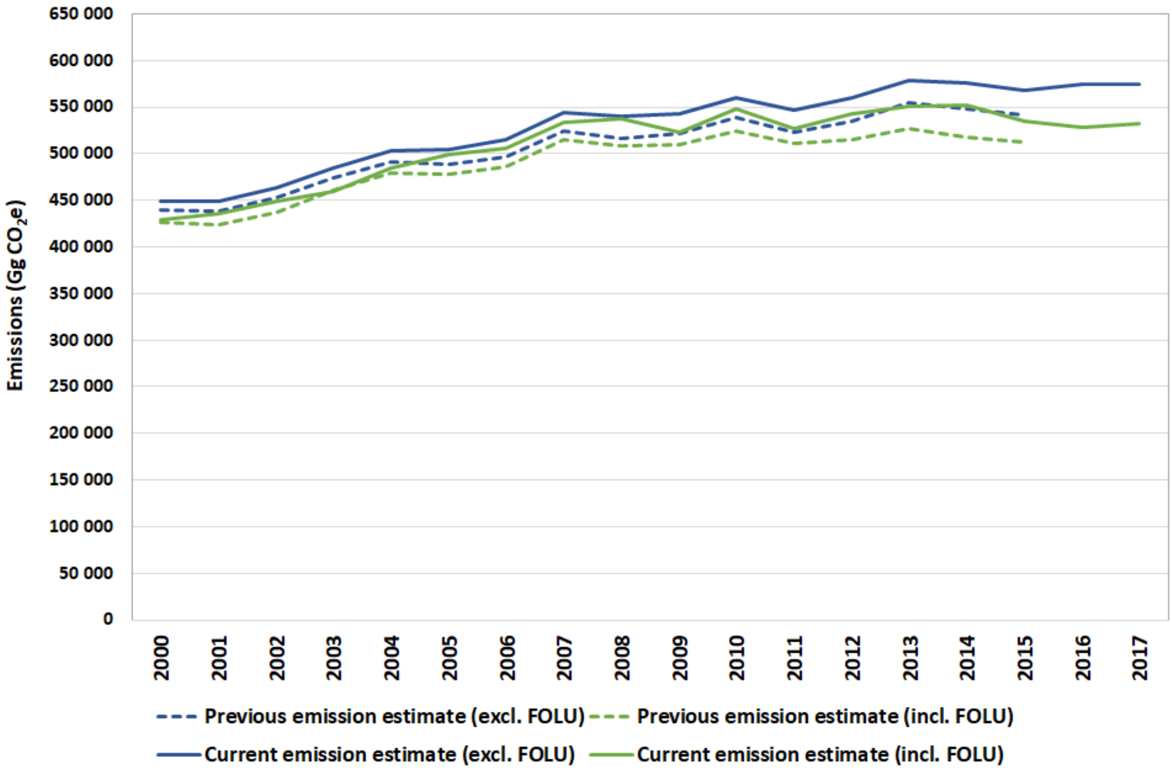

Figure F: Changes in overall emission estimates due to recalculations.

Table E: Current and previous emission estimates across the time-series and the impact of recalculations.

	Total emissions (excl. FOLU)			Total emissions (incl. FOLU)		
	Previous submission	Current submission	Difference	Previous submission	Current submission	Difference
	(Gg CO_2 e)		(%)	(Gg CO_2 e)		(%)
2000	439 237,9	452 347,1	2,98	426 213,9	431 819,2	1,32
2001	438 167,5	451 593,9	3,06	423 800,0	439 045,6	3,60
2002	452 260,9	465 300,5	2,88	436 968,8	450 080,1	3,00
2003	473 942,1	485 871,0	2,52	460 781,2	460 802,8	0,00
2004	490 972,2	503 082,6	2,47	479 410,2	484 384,3	1,04
2005	488 656,5	502 799,4	2,89	477 796,6	497 776,7	4,18
2006	496 908,3	509 571,7	2,55	485 908,7	500 262,3	2,95
2007	523 801,9	540 211,0	3,13	514 472,5	529 589,1	2,94
2008	516 256,1	534 953,5	3,62	508 699,4	531 943,0	4,57
2009	521 245,7	538 036,7	3,22	510 168,2	518 165,2	1,57

2010	538 778,1	549 659,5	2,02	524 296,5	536 938,7	2,41
2011	522 861,4	532 961,7	1,93	511 376,8	513 936,6	0,50
2012	534 696,8	541 628,6	1,30	514 519,9	523 826,7	1,81
2013	554 705,3	564 050,4	1,68	527 468,1	535 865,8	1,59
2014	547 509,5	560 781,6	2,42	518 249,7	537 547,1	3,72
2015	540 853,9	553 950,1	2,42	512 382,8	520 218,2	1,53
2016		554 156,6			508 395,5	
2017		555 663,2			513 140,0	

ES.7 Key category analysis

A level and trend assessment was conducted, following Approach 1 (IPCC, 2006), on both the emissions including and excluding FOLU to determine the key categories for South Africa. Table F and Table G show the top ten key categories in both the trend and level assessment for emissions including and excluding FOLU, while Figure G shows all the key categories and their contributions determined by level assessment (incl. FOLU).

Table F: The top ten key categories for the level and trend assessment for emissions excluding FOLU.

Level assessment (2017)			Trend assessment (2000 - 2017)		
IPCC Category code	IPCC Category	GHG	IPCC Category code	IPCC Category	GHG
1A1a	Electricity and Heat Production	CO_2	1A3b	Road Transport	CO_2
1A3b	Road Transport	CO_2	1A4b	Residential	CO_2
1A2	Manufacturing Industries and Construction	CO_2	1A1a	Electricity and Heat Production	CO_2
1A1c	Manufacture of Solid Fuels and Other Energy Industries	CO_2	1B3	Other Emissions from Energy Production	CO_2
1A4b	Residential	CO_2	1A1c	Manufacture of Solid Fuels and Other Energy Industries	CO_2
1B3	Other Emissions from Energy Production	CO_2	3A1a	Enteric fermentation - cattle	CH_4
3A1a	Enteric fermentation - cattle	CH_4	3C4	Direct N2O emissions from managed soils	N_2O
3C4	Direct N2O emissions from managed soils	N_2O	1A4a	Commercial/Institutional	CO_2

4A	Solid Waste Disposal	CH_4	2C1	Iron and Steel Production	CO_2
1A4a	Commercial/Institutional	CO_2	1A2	Manufacturing Industries and Construction	CO_2

Table G: Top ten key categories with level and trend assessment for emissions including FOLU.

Level assessment (2017)			Trend assessment (2000 - 2017)		
IPCC Category code	IPCC Category	GHG	IPCC Category code	IPCC Category	GHG
1A1a	Electricity and Heat Production	CO_2	1A3b	Road Transport	CO_2
1A3b	Road Transport	CO_2	1A4b	Residential	CO_2
1A2	Manufacturing Industries and Construction	CO_2	3B1a	Forest land remaining forest land	CO_2
1A1c	Manufacture of Solid Fuels and Other Energy Industries	CO_2	3B1b	Land converted to forest land	CO_2
1A4b	Residential	CO_2	1A1a	Electricity and Heat Production	CO_2
3B1b	Land converted to forest land	CO_2	1B3	Other Emissions from Energy Production	CO_2
1B3	Other Emissions from Energy Production	CO_2	1A1c	Manufacture of Solid Fuels and Other Energy Industries	CO_2
3A1a	Enteric fermentation - cattle	CH_4	3A1a	Enteric fermentation - cattle	CH_4
3C4	Direct N2O emissions from managed soils	N_2O	3C4	Direct N2O emissions from managed soils	N_2O
3B3b	Land converted to grassland	CO_2	1A4a	Commercial/Institutional	CO_2

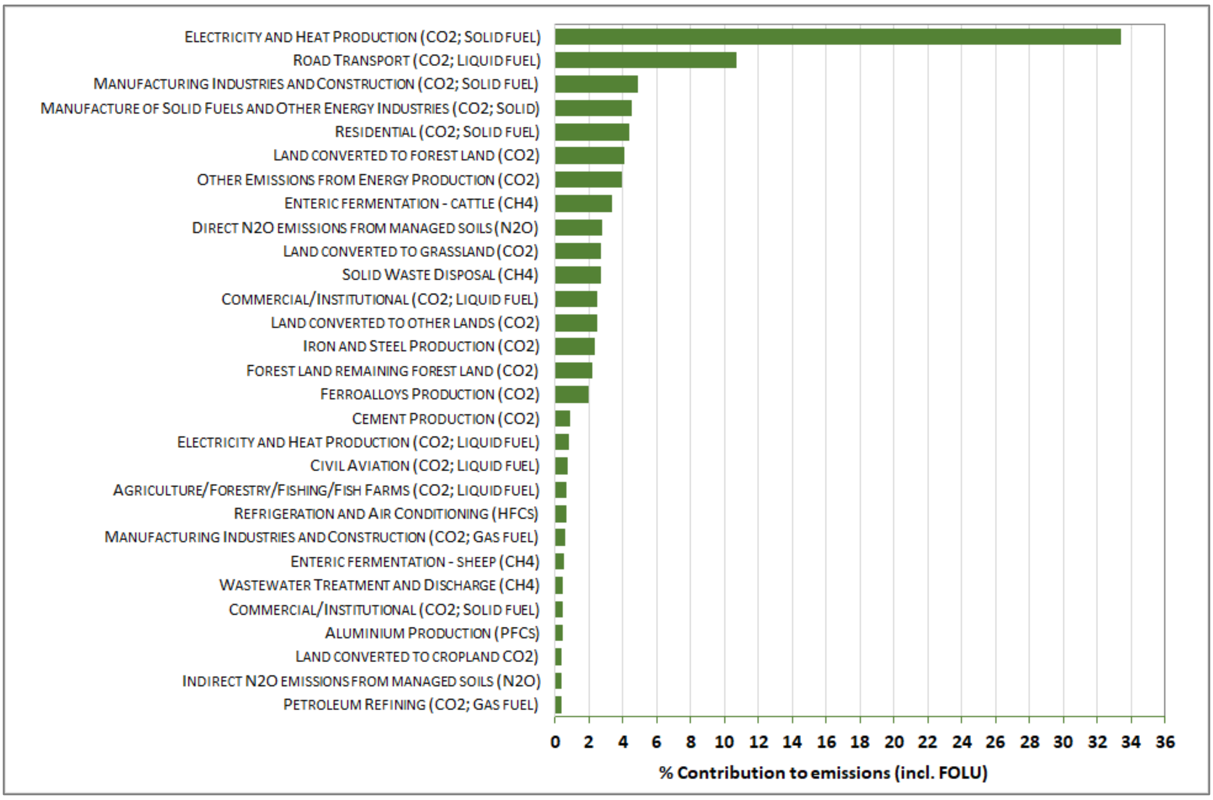

Figure G: Key category contribution determined by level assessment for 2017.

ES.8 Indicator trends

The carbon intensity of the population (i.e. total net emissions per capita) increased between 2000 and 2010 to a peak of 11.0 t CO_2e per capita, after which it declined to 9.4 t CO_2e per capita in 2017 (Figure H). The carbon intensity of the economy has shown a declining trend since 2000, and declined by 22.7% between 2000 and 2017. The carbon intensity of the energy supply (i.e. total net emissions per energy unit) remained fairly constant over the 17-year period.

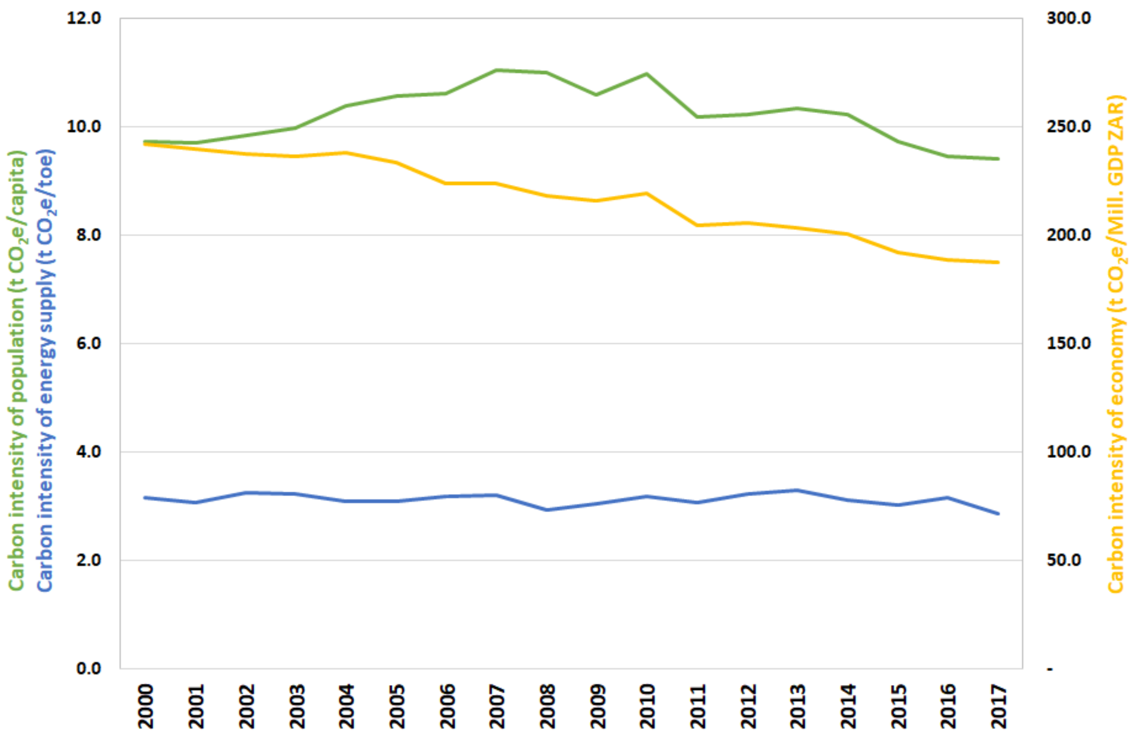

Figure H: Trend in carbon intensity indicators for South Africa between 2000 and 2017.

ES.9 Other information

General uncertainty evaluation

Uncertainty analysis is regarded by the IPPC Guidelines as an essential element of any complete inventory. The reporting of uncertainties requires a complete understanding of the processes of compiling the inventory, so that potential sources of inaccuracy can be qualified and possibly quantified. The 2010 inventory (DEA, 2014) did not incorporate an overall uncertainty assessment due to a lack of quantitative and qualitative uncertainty data. In the previous 2015 submission only uncertainty for the *Energy* and *IPPU* sectors was included, while in this submission all four sectors are included in the uncertainty evaluation. A trend uncertainty between the base year and 2017, as well as a combined uncertainty of activity data and emission factor uncertainty was determined using an Approach 1. The total uncertainty for the inventory was determined to be 9.8%, with a trend uncertainty of 8.23%. Excluding FOLU reduced the overall uncertainty to 8.76%, with the trend uncertainty dropping to 7.61%.

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. 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.

Completeness of the national inventory

The South African GHG emission inventory for the period 2000 – 2017 is not complete, mainly due to the lack of sufficient data. Table H identifies some of the sources in the 2006 IPCC Guidelines which were not included in this inventory and the reason for their omission. Some emissions are included under other categories of the inventory due to insufficient granularity in the activity data. Lastly, there are a few activities which do not occur in South Africa and these are also highlighted in the table. Further detail on completeness is provided in the various sector tables (see Annex A). It is also noted that precursor gases and SF6 have not yet been included in the inventory.

Table H: Activities in the 2017 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
	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
	CO_2 transport and storage	
	CO_2, CH_4 and N_2O emissions from Combined Heat and Power (CHP) combustion systems	
	Other process use of carbonates	
	CO_2 from non-energy products from solvent use	
	Electronics industry	A study needs to be undertaken to understand emissions from this source category
	PFCs and HFCs from solvents	
	Emissions from other product manufacture and use	
	CO_2 from organic soils	Insufficient data on the distribution and extent of organic soils. Project has just been initiated by DEA to identify and map organic soils. These emissions could potentially be included in the next inventory.
	CO_2 from changes in dead wood for all land categories	Estimates are provided for litter, but not for dead wood due to insufficient data.
	HWP from solid waste	This will be included in the next inventory
	CH_4, N_2O emissions from biological treatment of waste	
	CO_2, CH_4 and N_2O from waste incineration	
	Precursor (NOx, CO, NMVOCs) emissions	These have only been included for biomass burning.
	SO_2 emissions	
	SF6 emissions	
IE	CO_2 emissions from biomass burning	These are not included under biomass burning, but rather under disturbance losses in the Land sector.
	CO_2, CH_4 and N_2O emissions from off-road vehicles and other machinery	Included under Road transportation.
	Domestic wastewater treatment and discharge emissions	Reported under the total for Wastewater treatment and discharge
	Industrial wastewater treatment and discharge emissions	Reported under the total for Wastewater treatment and discharge
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, CH_4 and N_2O Caprolactam, Glyoxal and Glyoxylic acid production	

Planned improvements

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

DEFF has undertaken a project to modify the National Atmospheric Emissions Inventory System (NAEIS) to meet the requirements of the National Greenhouse Gas Reporting Regulations, 2016. The South African GHG Emission Reporting System (SAGERS) portal is under development as part of the project, it will serve as a tool for the implementation of the online registration and reporting by industry in fulfilment of mandatory NGERs.The key benefits of the portal to South Africa include the institutionalization of the preparation of the National GHG Inventory. In particular, the system enables the country to enhance the data collection process, therefore improving the quality of the national GHG inventories consistent with the requisite principles of completeness, consistency, accuracy, comparability and transparency credentials.

In this inventory the full-time series back to 1990 was estimated for the AFOLU sector, however the results of this are not shown since the other sectors still only have data from 2000. The inventory team is planning on extending the time-series for all sectors over the next few years and it is planned that in the 6th BUR, the time-series will be starting from 1990 and going to 2021.

GHG improvement programme

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 I and Table J summarize some of the projects that are under implementation as part of the GHGIP.

DEA has also identified the following private sectors for engagement on the GHGIP:

- Ferroalloys Industry – development of country specific emission factors;
- Cement industry – development of country specific emission factors;
- CTL-GTCs and GTLs – development of T3 methodologies;
- Aluminium production – development of T3 methodologies; and
- Petrochemical industry – development of EFs, carbon content of fuels, and NCVs of liquid fuels.

Table I: DEA driven GHGIP projects

Sector	Baseline	Nature of methodological improvement	Partner	Completion date
Transport sector [implications for other sectors]	Using IPCC default emission factors	Development of country-specific CO_2	DOT	December 2020
Coal-to-liquids (CTL)	Allocation of emissions not transparent	Improved allocation of emissions, material balance approach	Sasol	December 2019
Ferro-alloy production	Using a combination of IPCC default factors and assumptions based on material flows	Shift towards an IPCC Tier 2 approach	Xstrata, Ferro-Alloy Producers' Association	December 2020

Table J: Donor funded GHGIP projects

Project	Partner	Objective	Outcome	Timelines	Status
Development of a formal GHG National Inventory System	Norwegian Embassy	Helping South Africa develop its national system	SA GHG inventories are documented and managed centrally	2015-2020	Completed

Land-cover mapping	DFID-UK	To develop a land-use map for 1-time step 2017/18]	Land-use change matrix developed for 36 IPCC land-use classes to detect changes	2019-2020	Planned
Waste-sector data improvement project	GIZ	To improve waste-sector GHG emissions estimates and address data gaps	Waste-sector GHG inventory is complete, accurate and reflective of national circumstances	2019-2020	In Progress
2nd Energy Sector Fuel Consumption Study and VKT Study	GIZ	Improved energy activity data on fuel consumption for solid, liquid and gaseous fuels	Improved energy activity data on fuel consumption for solid, liquid and gaseous fuels	2019-2020	In Progress

ES.10 Conclusions and recommendations

The 2000 to 2017 GHG emissions results revealed an increasing trend in emissions from the *Energy*, *IPPU* and *Waste* sectors, with a decrease in the net *AFOLU* sector due to an increasing Land sink. There was an annual average increase of 2% between 2000 and 2010, and this slowed to 0.7% between 2010 and 2014. Emissions stabilised between 2014 and 2017, with an average annual decline of 0.4%.

Energy emissions were highest in 2013, after which there was a 0.9% decline to 2015 with an increase (0.2%) again towards 2017. *IPPU* emissions declined between 2006 and 2009 due to the recession, but increased again thereafter. Emissions increased by 20.4% between 2009 and 2013, after which the increase slowed to 4.6% between 2013 and 2017. *AFOLU* emissions excluding FOLU declined by 4.6% between 2002 and 2003, after which emissions remained fairly stable. There was a decline of 5.2% between 2015 and 2016 and emissions remained at the lower level during 2017. *AFOLU* emissions including *Land* fluctuate annually, reaching a peak in 2008. Emissions increased by 44.4% between 2000 and 2008, after which there was a decline of 59.7% to 2015. The Land sink continued to increase between 2015 and 2017, thereby reducing emissions by a further 56.1% by 2017. *Waste* sector has shown a steady increase since 2000.

The *Energy* sector in South Africa continued to be the main contributor of GHG emissions and was found to be a key category each year. It is therefore important that activity data from this sector always be 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. It is expected that the mandatory reporting regime which is driven by the National Greenhouse Gas Emissions Reporting Regulations (NGERs) will provide enhanced data for this sector.

The *AFOLU* sector was 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 the *AFOLU* emissions (incl. FOLU) because of its increasing land sink. South Africa continues to require a more complete picture of this subsector. It is recommended that more country-specific data and carbon modelling be incorporated to move towards a Tier 2 or 3 approach, particularly for forest land. 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.

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Chapter 1: Introduction

1.1 Background information

Greenhouse gases in the Earth's atmosphere trap warmth from the sun and make life as we know it possible. Since the beginning of the industrial revolution there has been a global increase in the atmospheric concentration of greenhouse gases, including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (IPCC, 2014). This increase is attributed to human activity, particularly the burning of fossil fuels and land-use change. Continued emissions of greenhouse gases will cause further warming and changes to all components of the climate system.

The science of climate change is assessed by the Intergovernmental Panel on Climate Change (IPCC). In 1990, the IPCC concluded that human-induced climate change was a threat to our future. In response, the United Nations General Assembly convened a series of meetings that culminated in the adoption of the United Nations Framework Convention on Climate Change. The United Nations Framework Convention on Climate Change (UNFCCC) is an international environmental treaty negotiated at the United Nations Conference on Environment and Development in Rio de Janeiro, Brazil, in June 1992. The ultimate objective of the UNFCCC is to "stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (UN, 1992: p. 9). On the 21st of March 1994, the UNFCCC came into force, requiring signatory Parties to carry out any number of tasks and/or activities relating to the implementation of the Convention.

1.1.1 South Africa's National Greenhouse Gas Inventory

The Convention was signed by South Africa in 1993 and ratified in 1997. All countries that ratify the Convention (the Parties) are required to address climate change, including monitoring trends in anthropogenic greenhouse gas emissions. One of the principal commitments made by the ratifying Parties under the Convention was to develop, publish and regularly update national emission inventories of greenhouse gases. Parties are also obligated to protect and enhance carbon sinks and reservoirs, for example forests, and implement measures that assist in national and/or regional climate change adaptation and mitigation.

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 IPCC 2006 Guidelines were introduced, although not fully implemented for the AFOLU sector. In 2014 South Africa prepared its fourth national inventory, which included annual emission estimates for 2000 to 2010. This was the first inventory to show annual emission estimates and trends across the time series. The inventory was then updated in 2016 for the years 2000 to 2012, and again in 2018 for the years 2000 - 2015.

This 2017 National Inventory Report (the Report) for South Africa provides estimates of South Africa's net greenhouse gas emissions for the period 2000 – 2017, and is South Africa's seventh inventory Report. This report is to be submitted to UNFCCC to fulfil South Africa's reporting obligations under the UNFCCC. The Report has been compiled in accordance with the *Intergovernmental Panel on Climate Change (IPCC) 2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006) and the *2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol* (IPCC, 2014a). The aim is to ensure that the estimates of emissions are accurate, transparent, consistent through time and comparable with those produced in the inventories of other countries.

The National Inventory Report covers sources of greenhouse gas emissions, and removals by sinks, resulting from human (anthropogenic) activities for the major greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), and hydrofluorocarbons (HFCs). The indirect greenhouse gases, carbon monoxide (CO), and oxides of nitrogen (NO_X), are also included for biomass burning. The gases are reported under four sectors: *Energy*; *Industrial Processes and Product Use* (IPPU); *Agriculture, Forestry and Other Land Use* (AFOLU) and *Waste*. SF6 emissions have not yet been included due to a lack of data, however DEFF are in discussions with the main electricity producer (Eskom) to obtain historical SF6 data so that it can be included in the next inventory. Furthermore, a threshold has been set for SF6 in the new GHG reporting regulation so that companies will start reporting SF6 data.

South Africa's inventory currently uses the base year of 2000. In this inventory the full-time series back to 1990 was estimated for the AFOLU sector, however the results of this are not shown since the other sectors still only have data from 2000. The inventory team is planning on extending the time-series for all sectors over the next few years and it is planned that in the 6th BUR, the time-series will be starting from 1990 and going to 2021.

1.1.2 Global warming potentials

As greenhouse gases vary in their radiative activity, and in their atmospheric residence time, converting emissions into CO_2e allows the integrated effect of emissions of the various gases to be compared. In order to comply with international reporting obligations under the UNFCCC, South Africa has chosen to present emissions for each of the major greenhouse gases as carbon dioxide equivalents (CO_2e) using the 100-year global warming potentials (GWPs) contained in the *IPCC Second Assessment Report (SAR)* (IPCC, 1996) (Table 1.1).

Table 1.1: Global warming potential (GWP) of greenhouse gases used in this report and taken from IPCC SAR (Source: IPCC, 1996).

Greenhouse gas	Chemical formula	SAR GWP
Carbon dioxide	CO_2	1
Methane	CH_4	21
Nitrous oxide	N_2O	310
Hydrofluorocarbons (HFCs)		
HFC-23	CHF_3	11 700
HFC-32	CH_2F_2	650
HFC-125	CHF_2CF_3	2 800
HFC-134a	CH_2FCF_3	1 300
HFC-143a	CF_3CH_3	3 800
HFC-227ea	C_3HF_7	2 900
HFC-365mfc	$C_4H_5F_5$	890
HFC-152a	CH_3CHF_2	140
Perfluorocarbons (PFCs)		
PFC-14	CF_4	6 500
PF-116	C_2F_6	9 200

1.1.3 Structure of the report

The Report follows a standard NIR format in line with the UNFCCC Reporting Guidelines (UNFCCC, 2013). 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 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.

1.1.4 National system

South Africa's National Climate Change Response Policy (NCCRP) stated that SA would "*Establish a national system of data collection to provide detailed, complete, accurate and up-to-date emissions data in the form of a Greenhouse Gas Inventory…. The emissions inventory will be a web-based GHG Emission Reporting System and will form part of the National Atmospheric Emission Inventory component of the SAAQIS*." (DEA, 2011). In February 2016 South Africa started the process of developing a National GHG Inventory Management System (NGHGIS).

South Africa's national inventory system is being designed and operated to ensure transparency, consistency, comparability, completeness and accuracy (TCCCA) of inventories as defined in the guidelines for preparation of inventories. The system ensures the quality of the inventory through planning, preparation and management of inventory activities in accordance with Article 5 of the Kyoto Protocol. The following processes are included and detailed in the national system:

- collection of activity data
- technical guidelines outlining methodologies and emissions factors
- estimation of GHG emissions by source and removals by sink
- quality assurance activities and
- verification at the national level.

The national inventory systems comprises both the inventory report itself and all the documents around the inventory which describe how the inventory was prepared. The system complies with Article 5 of the Kyoto Protocol (Kyoto Protocol, 1997) by also defining and allocating specific responsibilities in the inventory development process, including those related to choice of methods, data collection, processing and archiving, and quality assurance and quality control (QA/QC). South Africa has also specified the roles and cooperation between government agencies and other entities involved in the preparation of the inventory.

The NGHGIS was developed during the compilation of the 2015 inventory, therefore not all components of the NGHGIS were implemented in the 2015 inventory. The 2017 inventory is the first inventory to be compiled utilising all aspects and processes of the NGHGIS (Figure 1.1).

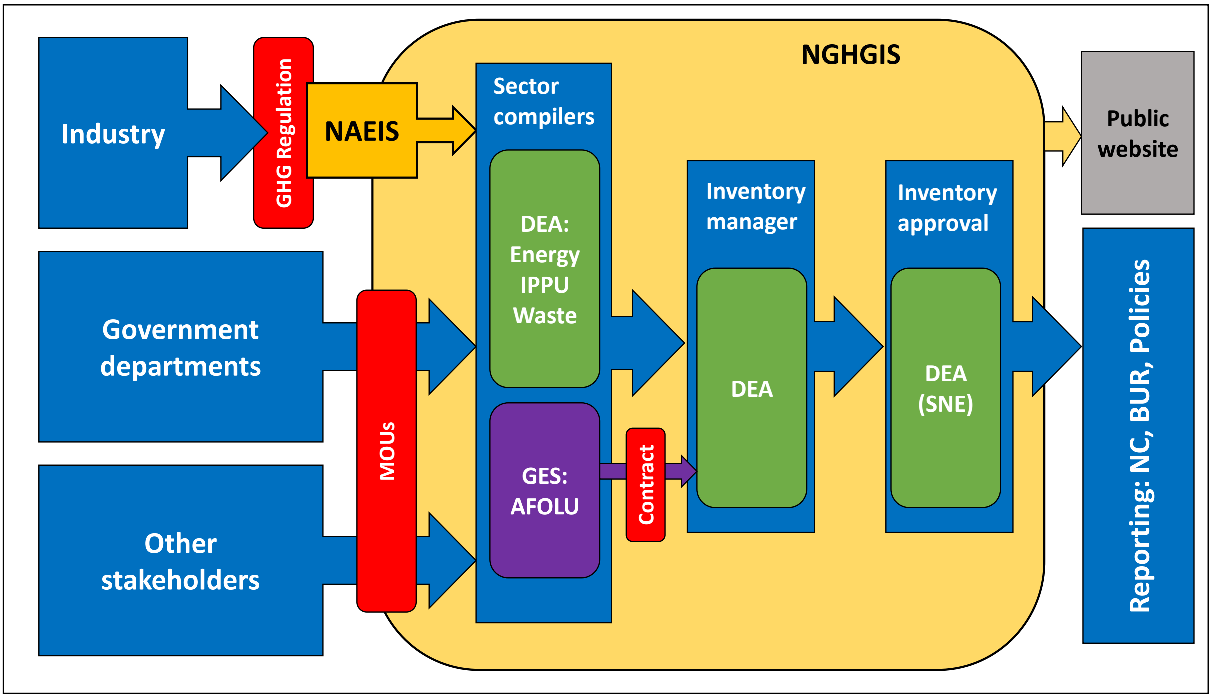

Figure 1.1: The inventory compilation process is co-ordinated through a central web-based inventory management system as depicted in this illustration.

1.2 National inventory arrangements

1.2.1 Institutional, legal and procedural arrangements

South Africa is working towards building a more sustainable national GHG inventory system. The 1990, 1994 and 2000 inventories were compiled by consultants, but since then South Africa has moved towards a more centralised system with DEA playing a more active role and taking over the management of the compilation process.

Single national entity

In South Africa the DEFF 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) (DEA, 2004) to formulate, co-ordinate and monitor national environmental information, policies, programmes and legislation. The work of the DEFF 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 DEFF 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 DEFF is the Climate Change and Air Quality Management branch, whose purpose is to monitor and ensure compliance on air and atmospheric quality, as well as support, monitor and report international, national, provincial and local responses to climate change (Figure 1.2).

DEFF is currently responsible for managing all aspects of the National GHG Inventory development. The National Inventory Co-ordinator (NIC) sits within the Climate Change Monitoring and Evaluation Directorate of DEFF (Figure 1.2) and the tasks of the coordinator include:

- Managing and supporting the National GHG Inventory staff, schedule, and budget in order to develop the inventory in a timely and efficient manner:
    - Prepare work plans
    - Establish internal processes
    - Ensure funding is in place
    - Appoint consultants where necessary
    - Oversee consultants handling the report compilation
- Identifying, assigning, and overseeing national inventory sector leads.
- Assigning cross-cutting roles and responsibilities, including those for Quality Assurance/Quality Control (QA/QC), archiving, key category analysis (KCA),

uncertainty analysis, and compilation of the inventory section of the NC and/or BUR.

- Managing the QA (external review and public comment) process:
  - Appoint external reviewers
  - Liaise between the reviewers and the NIR authors
  - Obtain approval from Cabinet for the NIR to go for public comment
  - Manage the incoming public comments and laisse with NIR authors and experts to address any issues
- Maintaining and implementing a national GHG inventory improvement plan:
  - Manage the GHG Improvement programme (including sourcing of funds and appointing service providers for required projects).
- Obtaining official approval (from Cabinet) of the GHG inventory and the NIR and submit reports (NIR, BUR, NC) to the UNFCCC; and
- Fostering and establishing links with related national projects, and other regional, international programmes as appropriate.

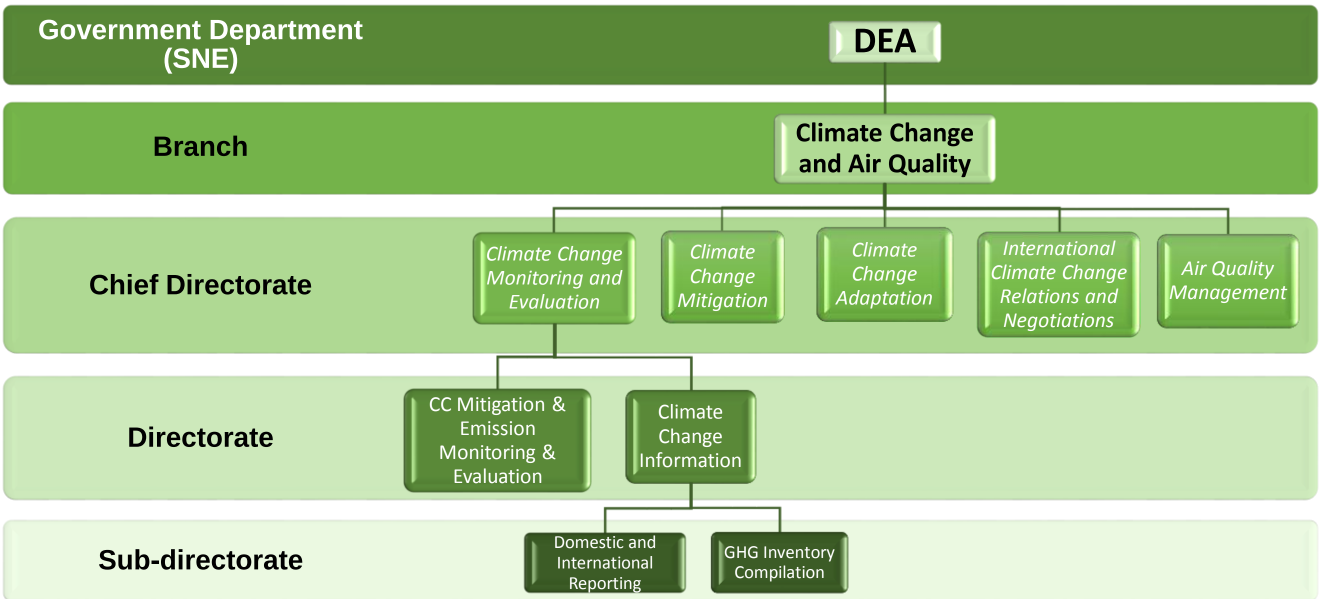

Figure 1.2: Organogram showing where the GHG Inventory compilation occurs within DEA.

Legal arrangements

Data is sourced from many institutes, associations, companies and ministerial branches (Figure 1.3). At this stage there is still 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 continue to be developed over time as part of the National GHG Inventory Management System (NGHGIS).

At this stage these two template MoU's have been developed but have not yet been signed or implemented. DEFF has begun discussions with several government departments, such as the Department of Mineral Resources and Energy (DMRE) and Department of Agriculture, Land Reform and Rural Development (DALRRD), regarding the collection and provision of activity data for the GHG inventory.

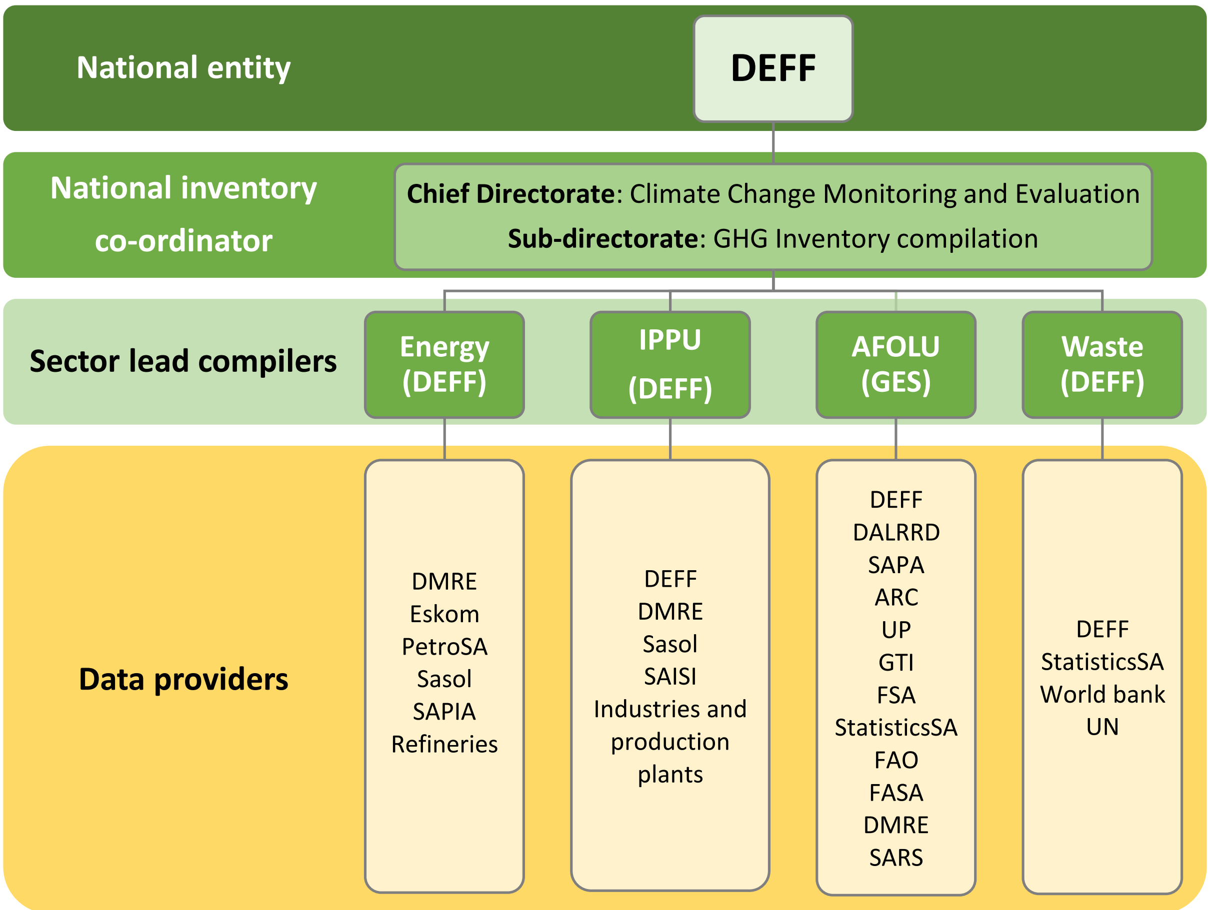

Figure 1.3: Current institutional arrangements for South Africa's GHG Inventory compilation.

GHG Regulation

The purpose of the GHG Regulations is to introduce a single national reporting system for the transparent reporting of greenhouse gas emissions, which will be used (a) to update and maintain a National Greenhouse Gas Inventory; (b) for the Republic of South Africa to meet its reporting obligations under the United Framework Convention on Climate Change (UNFCCC) and instrument treaties to which it is bound; and (c) to inform the formulation and implementation of legislation and policy.

1.2.2 Inventory planning, preparation and management

Inventory management

South Africa uses a hybrid (centralised/distributed) approach to programme management for the Inventory. Management and coordination of the inventory programme, as well as compilation, publication and submission of the Inventory are carried out by the Single National Entity (being the DEFF) in a centralised manner. Currently DEA is responsible for collecting data, compiling and QC of the Energy, IPPU and Waste sector inventories, while the AFOLU sector is compiled by external consultants (Gondwana Environmental Solutions (GES)) who are appointed via a formal contract (Figure 1.3). The consultants are also responsible for combining and compiling the overall inventory and providing the draft National Inventory Report to DEFF.

Inventory preparation

There are six main steps in the preparation of a National GHG Inventory:

- Plan;
- Collect;
- Compile;
- Write;
- Improve and
- Finalize.

The collection phase is dedicated to data collection and preliminary processing, such as data cleansing, data checks and preliminary formatting for further use. The compilation phase involves the preparation and QC of initial estimates, as well as the uncertainty and key category analysis. This phase may also include analysis of potential recalculations involved in the inventory.

The writing phase is where the draft inventory report is prepared, including all cross-cutting components (KCA, trends by gas and sector, etc) and QC of the draft is completed. At the end of this component the draft document is subjected to a QA, or review process. The review is done by independent consultants and/or public commenting process. Comments from the review process are used to improve the Report, after which it is finalized. During the finalization phase the archives are prepared and final Report approvals are obtained before being submitted to UNFCCC.

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.

1.2.3 Changes in the national inventory arrangements since previous annual GHG inventory submission

The institutional arrangements for the national inventory compilation has not changed since the 2015 submission.

1.3 Inventory preparation: data collection, processing and storage

1.3.1 Data collection

Currently there are no formal data collection procedures in place. The responsibility of collecting input data for the inventory falls on the individual sector compilers. Through the NGHGIS data collection templates and plans have been developed. Ongoing discussions with various government departments are expected to lead to the signing of MoUs and more formalisation of the data collection process in the future.

Energy data

The main sources of data for the *Energy* sector are the energy balance data compiled by the DMRE and data supplied by the main electricity provider, Eskom. In addition data is also sourced from the companies PetroSA and Sasol, as well as annual reports from South African Petroleum Industry Association (SAPIA) and the DMRE. There are currently no formal processes in place for requesting or obtaining this data.

Industry data

There was some formality in the collection of data for the *IPPU* sector. Information from industries was requested through the umbrella organization Business Unity South Africa (BUSA). This data collection process is expected to change in the next year due to the recent National GHG Regulation which DEFF has brought into effect (see section 1.2.1). Industries will then be required to submit information via the NAEIS system described below.

National Atmospheric Emission Inventory System (NAEIS)

DEFF has setup the National Atmospheric Emissions Inventory System (NAEIS), which is an online reporting platform for air quality and GHG emissions. In this system organizations submit their information in a standard format so that data can be compared and analysed. The system is part of the South African Air Quality Information System (SAAQIS). An upgrade is being planned for the NAEIS system (2019) so that it can manage the mandatory reporting of GHG emissions, as it is currently aimed at air quality information. This component of NAEIS will be the South African GHG Reporting System (SAGERS). 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 1.4).

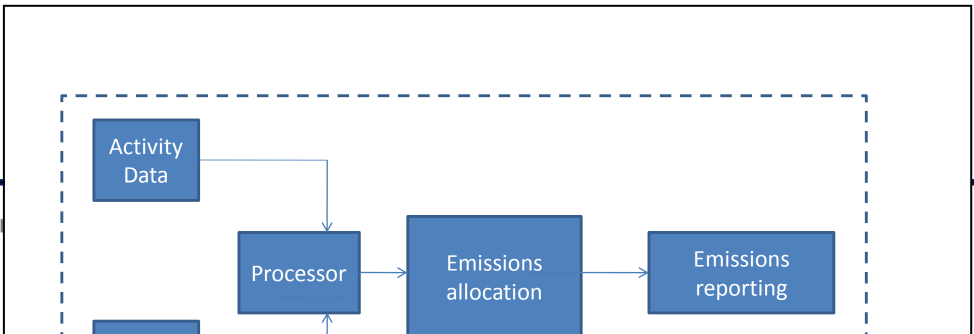

Figure 1.4: Information flow in the National Atmospheric Emissions Inventory System (NAEIS).

HFC and PFC data

The HFC and PFC data is supplied by the DEFF waste branch and supplemented with the 2016 5-year periodic survey conducted by DEFF.

Land cover and change maps

The DEFF employs consultants to process the satellite imagery used to determine land cover change for the *AFOLU* sector. This is usually done on a project by project basis. For this inventory the 1990 and 2013-14 national land-cover datasets were produced by GeoTerraImage and are based on 30x30m raster cells. The dataset has been derived from multi-seasonal Landsat 8 imagery.

Agricultural data

The main sources of data for this section are provided by DALRRD and ARC. There are currently no formal procedure for obtaining this data, but the NGHGIS has set up template MOUs and DEFF is currently in discussion with these two groups to formalize the data collection process.

Land data

Plantation data is supplied by Forestry SA, and the cropland data is supplied by DALRRD. Burnt area data is obtained from the MODIS burnt area product which is processed by Gondwana Environmental Solutions. Fertiliser and liming data is sources from South African Revenue Service (SARS), DMRE and Fertilizer Association of South Africa (FertASA). Small amounts of crop statistics data is obtained from Statistics SA. As with the Agricultural data, there are no formal agreements with any of these organizations. However template MOUs have been developed for implementation in future.

Waste data

The main data providers for the *Waste* sector are Statistics SA, DEFF, DWS and the UN.

1.3.2 Data storage and archiving

The NGHGIS for South Africa will assist in managing and storing the inventory related documents and processes. The NGHGIS will, amongst other things, keep records of the following:

(a) Stakeholder list with full contact details and responsibilities
(b) List of input datasets which are linked to the stakeholder list
(c) QA/QC plan
(d) QA/QC checks
(e) QA/QC logs which will provide details of all QA/QC activities
(f) All method statements
(g) IPCC categories and their links to the relevant method statements together with details of the type of method (Tier 1, 2 or 3) and emission factors (default or country-specific) applied
(h) Calculation and supporting files
(i) Key references
(j) Key categories; and
(k) All inventory reports.

The procedures for data storage and archiving are described in detail in the QA/QC plan that has been developed and is discussed in the section below. The NGHGIS will be used to archive inventory data.

1.3.3 Quality assurance, quality control and verification plan

As part of the NGHGIS South Africa developed a formal quality assurance/quality control plan (see Appendix 1.A of 2015 NIR (DEA, 2018)). This provides a list of QC procedures that are to be undertaken during the preparation of the inventory. Since the QA/QC plan and the NGHGIS were being developed at the same time as the previous (2015) inventory not all the QC procedures were implemented. In this 2017 inventory, however, all QA/QC procedures mentioned in the QA/QC plan were undertaken.

General QC procedures

The quality control (QC) procedures are performed by the experts during inventory calculation and compilation. QC measures are aimed at the attainment of the quality objectives. The QC procedures comply with the IPCC good practice guidance and the 2006 IPCC Guidelines. General inventory QC checks include routine checks of the integrity, correctness and completeness of data, identification of errors and deficiencies and documentation and archiving of inventory data and quality control actions.

In addition to general QC checks, category-specific QC checks including technical reviews of the source categories, activity data, emission factors and methods are applied on a case-by-case basis focusing on key categories and on categories where significant methodological and data revisions have taken place.

The general quality checks are used routinely throughout the inventory compilation process. Although general QC procedures are designed to be implemented for all categories and on a routine basis, it is not always necessary or possible to check all aspects of inventory input data, parameters and calculations every year. Checks are then performed on selected sets of data and processes. A representative sample of data and calculations from every category may be subjected to general QC procedures each year.

The general QC checks carried out on South Africa's 2017 inventory are provided in Table 1.2.

Table 1.2: Quality control checks carried out on South Africa's 2017 GHG inventory.

ID	Type of check	Description	Level
QC001	Activity data source	Is the appropriate data source being used for activity data?	Calculation file

ID	Type of check	Description	Level
QC002	Correct units	Check that the correct units are being used	Calculation file
QC003	Unit carry through	Are all units correctly carried through calculations to the summary table? This includes activity data and emission factors.	Calculation file
QC004	Method validity	Are the methods used valid and appropriate?	Calculation file
QC005	Uncertainties	Carry out uncertainties analysis	Supporting file
QC006	Double counting – Categories	Check to ensure no double counting is present at category level	Calculation file
QC007	Notation keys	Review the use of notation keys and the associated assumption to ensure they are correct.	Calculation file
QC008	Trend check	Carry out checks on the trend to identify possible errors. Document any stand out data points.	Calculation file
QC009	Emission factor applicability	Where default emission factors are used, are they correct? Is source information provided?	Calculation file
QC010	Emission factor applicability	Where country specific emission factors are used, are they correct? Is source information provided?	Calculation file
QC011	Recalculations	Check values against previous submission. Explain any changes in data due to recalculations.	Calculation file
QC012	Sub-category completeness	Is the reporting of each sub-category complete? If not this should be highlighted.	Calculation file
QC013	Time series consistency	Are activity data and emission factor time series consistent?	Calculation file
QC014	Colour coding	Has colour coding been used in a consistent and accurate manner? Are there any significant data gaps of weaknesses?	Calculation file
QC015	Cross check data	Where possible cross check data against an alternative data sources. This includes activity data and EF. If CS EF are used they must be compared to IPCC values as well as any other available data sets.	Supporting file
QC016	Spot checks	Complete random spot checks on a data set.	Calculation file
QC017	Transcription checks	Complete checks to ensure data has been transcribed from models to spreadsheet correctly.	Calculation file
QC018	Transcription to document	Complete checks to ensure data has been transcribed from spreadsheets to documents correctly.	Sector report
QC019	Data source referencing	All source data submitted must be referenced	Calculation file
QC020	Data traceability	Can data be traced back to its original source?	Calculation file
QC021	Links to source data	Where possible, links to the source data must be provided	Calculation file

ID	Type of check	Description	Level
QC022	Raw primary data	All raw primary data must be present in the workbook	Calculation file
QC023	QA review	Data must be reviewed and checked by a second person	Calculation file
QC024	Verification	Where possible has calculated emissions been checked against other data sets?	Sector report
QC025	Archiving	Are all supporting files and references supplied?	Archive manager
QC026	Data calculations	Can a representative sample of the emission calculations be reproduced?	Calculation file
QC027	Unit conversions	Have the correct conversion factors been used?	Calculation file
QC028	Common factor consistency	Is there consistency in common factor use between sub-categories (such as GWP, Carbon content, Calorific values)?	Calculation file
QC029	Data aggregation	Has the data been correctly aggregated within a sector?	Calculation file
QC030	Trend documentation	Have significant trend changes been adequately explained?	Sector report
QC031	Consistency between sectors	Identify parameters that are common across sectors and check for consistency.	Draft NIR
QC032	Data aggregation	Has the data been correctly aggregated across the sectors?	Draft NIR
QC033	Documentation - CRF tables	Check CRF tables are included.	Draft NIR
QC034	Documentation - KCA	Check that key category analyses have been included.	Draft NIR
QC035	Documentation - Uncertainty	Check uncertainty analysis have been included.	Draft NIR
QC036	Documentation - Overall trends	Check overall trends are described both by sector and gas species.	Draft NIR
QC037	Documentation - NIR sections complete	Check all relevant sections are included in the NIR.	Draft NIR
QC038	Documentation - Improvement plan	Check that the improvement plan has been included.	Draft NIR
QC039	Documentation - Completeness	Check for completeness	Draft NIR
QC040	Documentation - Tables and figures	Check numbers in tables match spreadsheet; check for consistent table formatting; check the table and figure numbers are correct.	Draft NIR
QC041	Documentation - References	Check consistency of references.	Draft NIR

ID	Type of check	Description	Level
QC042	Documentation - General format	Check general NIR format - acronyms, spelling, all notes removed; size, style and indenting of bullets are consistent.	Draft NIR
QC043	Documentation - Updated	Check that each section is updated with current year information.	Draft NIR
QC044	Double counting - Sectors	Check there is no double counting between the sectors.	Draft NIR
QC045	National coverage	Check that activity data is representative of the national territory.	Calculation file
QC046	Review comments implemented	Check that review comments have been implemented.	Calculation file
QC047	Methodology documentation	Are the methods described in sufficient detail?	Sector report
QC048	Recalculation documentation	Are changes due to recalculations explained?	Sector report
QC049	Trend documentation	Are any significant changes in the trend explained?	Sector report
QC050	Documentation - QA/QC	Check the QA/QC procedure is adequately described.	Draft NIR
QC051	Complete uncertainty check	Check that the uncertainty analysis is complete.	Draft NIR
QC052	Consistency in methodology	Check that there is consistency in the methodology across the time series	Calculation file
QC053	Data gaps	Is there sufficient documentation of data gaps?	Sector report
QC054	Steering committee review	Has the draft NIR been approved by the steering committee? Was there public consultation?	Draft NIR
QC055	Check calorific values	Have the correct net calorific values been used? Are they consistent between sectors? Are they documented?	Calculation file
QC056	Check carbon content	Have the correct carbon content values been used? Are they consistent between sectors? Are they documented?	Calculation file
QC057	Supplied emission check	If emissions are supplied by industry have they been calculated using international standards? Have the methods been adequately described?	Sector report
QC058	Livestock population checks	Have the livestock population data been checked against the FAO database?	Calculation file
QC059	Land area consistency	Do the land areas for the land classes add up to the total land area for South Africa?	Calculation file
QC060	Biomass data checks	Have the biomass factors been compared to IPCC default values or the EFDB?	Calculation file

ID	Type of check	Description	Level
QC061	Fertilizer data checks	Has the fertilizer consumption data been compared to the FAO database?	Calculation file
QC062	Waste water flow checks	Do the wastewater flows to the various treatments add up to 100?	Calculation file
QC063	Reference approach	Has the reference approach been completed for the Energy sector? Have the values been compared to the sector approach? Has sufficient explanation of differences been given?	Calculation file
QC064	Coal production checks	Has the industry-specific coal production been checked against the coal production statistics from Department of Mineral Resources?	Calculation file

Quality assurance

Quality Assurance, as defined in the *IPCC Good Practice Guidanc*e, comprises a “planned system of review procedures conducted by personnel not directly involved in the inventory compilation and development process.” The quality assurance process includes both expert review and a general public review (Figure 1.5). The expert and public reviews each present opportunity to uncover technical issues related to the application of methodologies, selection of activity data, or the development and choice of emission factors. The expert and public reviews of the draft document offer a broader range of researchers and practitioners in government, industry and academia, as well as the general public, the opportunity to contribute to the final document. The comments received during these processes are reviewed and, as appropriate, incorporated into the Inventory Report or reflected in the inventory estimates.

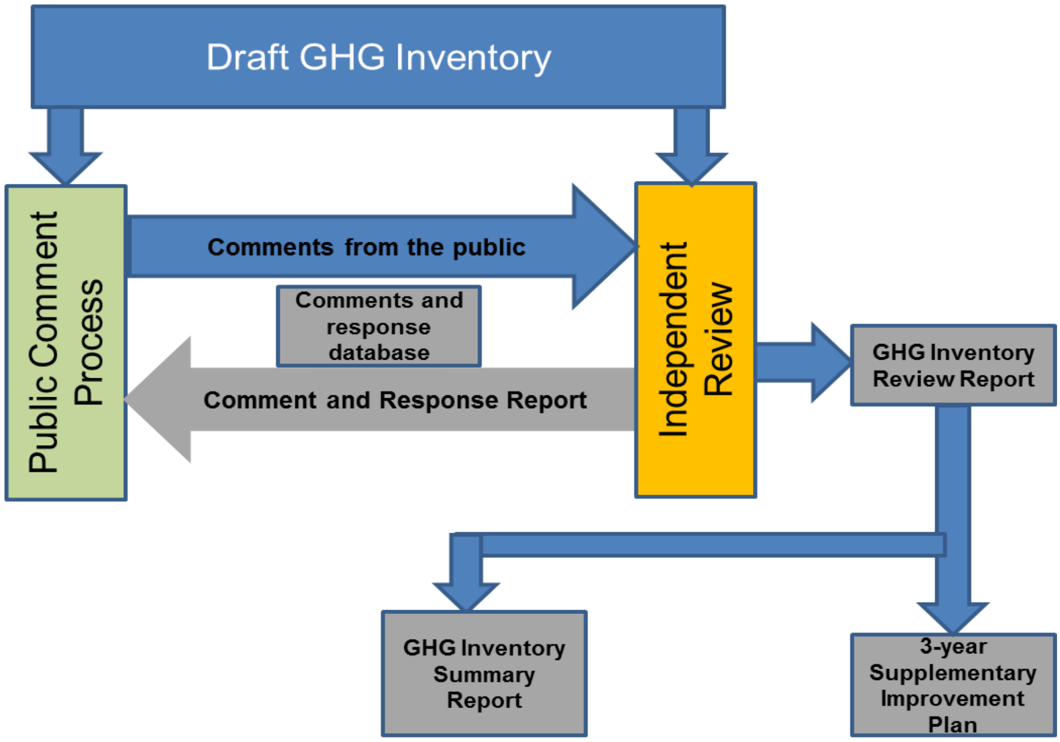

Figure 1.5: The independent review process for the 2000 – 2017 inventory.

Verification

Emission and activity data are verified by comparing them with other available data compiled independently of the GHG inventory system. These include measurement and research projects and programmes initiated to support the inventory system, or for other purposes, but producing information relevant to the inventory preparation. The specific verification activities are described in detail in the relevant category sections in the following chapters.

1.4 Brief general description of methodologies and data sources

1.4.1 General estimation methods

The guiding documents in the inventory's preparation are the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006). The methodologies are provided in a structure of three tiers that describe and connect the various levels of detail at which estimates can be made. The choice of method depends on factors such as the importance of the source category and availability of data. The tiered structure ensures that estimates calculated at a highly detailed level can be aggregated up to a common minimum level of detail for comparison with all other reporting countries. The methods for estimating emissions and/or removals are distinguished between the tiers as follows:

- Tier 1 methods apply IPCC default emission factors and use IPCC default models
- Tier 2 methods apply country-specific emission factors and use IPCC default models
- Tier 3 methods apply country-specific emission factors and use country-specific models.

Methodology for each sector in the inventory is described briefly here. Refer to each sector chapter for more detail.

Energy

Greenhouse gas emissions from the *Energy* sector are estimated using a detailed sectoral or bottom-up approach. As a way of verifying CO_2 emissions from fuel combustion for the time series 2000-2017, South Africa also applied the top-down IPCC reference approach. Most of the emission estimates in the sectoral approach for the *Energy* sector are calculated using IPCC Tier 1 and 2 methods. Tier 3 methods were used to estimate emissions from *Manufacture of solid fuels and other energy industries* (1.A.c.), fugitive emissions from the category *Venting* (1.B.2.a.i) and *Other emissions from energy production* (1.B.3).

IPPU

Activity data in the *IPPU* sector are derived from a variety of sources. For this sector, South Africa uses a combination of Tier 1, Tier 2 and Tier 3 methods. The *Mineral industry* applies a T1 method. The *Chemical industry* data are reported as amalgamated as there are a number of industries where there is only one company involved and so the data is reported as confidential. Estimates for this category mostly use a Tier 3 approach, except *Titanium dioxide production* and *Petrochemical and carbon black production* where a Tier 2 and Tier 1 methods apply. The Metal industries used a mixture of Tier 1, 2 and 3. A Tier

1 was also used to calculate emissions from *Non-energy products from fuels and solvents* and HFC emissions from *Product uses as substitutes for ODS* category.

AFOLU

Livestock population data are obtained from DAFF Agricultural Abstracts and herd composition from various livestock associations. A Tier 2 approach (IPCC, 2006) is used to estimate CH_4 emissions, with country-specific emission factors, from all livestock. Dry matter intake is estimated for these calculations. The same dry-matter intake data are used to calculate N_2O emissions from animal excreta.

Lime and urea application emissions are determined with a Tier 1 approach, with activity data being obtained from South African Fertilizer Association, DMRE and South African Revenue Service (SARS). A mix of Tier 1 and 2 methods are applied for *Direct N_2O emissions*, while a Tier 1 approach is utilized for *Indirect N_2O emissions*. Biomass burning emissions are estimated with a Tier 1 method. Burnt area data are obtained from MODIS.

The *Land* category in South Africa applies a mix of Tier 1 and Tier 2 approaches. A Tier 2 approach is used for all biomass and DOM changes, and SOC changes were mostly estimated with a Tier 1 method except for croplands which used Tier 2. A wall-to-wall map, based on Landsat images, forms the main input for the *Land* sector. *Harvested wood products* emissions were estimated with a Tier 2 approach.

Waste

Solid waste is determined with the IPCC first order decay model. Tier 1 methods are used to estimate all emissions in the *Waste* sector.

1.4.2 Data sources

The inventory is prepared using a mix of sources for activity data. The principal data sources are set out in Table 1.3.

Table 1.3: Principal data sources for South Africa's inventory.

Category	Principal data source	Principal data collection mechanism
1A Fuel combustion activities	DMRE Energy Balance Data	Discussions are on-going between DEFF and DMRE to develop an MoU
	Eskom	No formal mechanism in place but draft MoU has been developed as part of the NGHGIS process
1B Fugitive emissions from fuels	DMRE, SASOL, PetroSA	Annual data collection programme
2A Mineral industry	South African Mineral Industry Report compiled by DMR	No formal mechanism in place but data is currently publicly available.
2B Chemical industry	Individual industries through BUSA	Data from individual industries is requested via BUSA
2C Metal industry	South African Mineral Industry Report compiled by DMRE	No formal mechanism in place but data is currently publicly available.
2D Non-energy products from fuels and solvent use	DMRE Energy Balance Data	Discussions are on-going between DEFF and DMRE to develop an MoU
2F Product uses as substitutes for ozone depleting substances	DEFF	ODS databases and 5-year periodic surveys
3A Livestock	DALRRD	DEFF is in the process of developing an MOU with DAFF
	FAO	Statistics available on FAO Stats website
	South African Poultry Association (SAPA)	Information obtained through direct contact. No formal mechanism is in place.
	TUT and University of Pretoria	Data is available through scientific publications.
3B Land	DALRRD	DEFF is in the process of developing an MOU with DALRRD
	GeoTerraImage	Developed land cover maps as a once off project for DEA. Future consistent sources for this data are being sort.
	Forestry South Africa	Data obtained through direct request, no formal mechanism in place.
	DEA	Some data and land maps are developed or funded through DEFF.
	ARC	DEFF is in the process of developing an MOU with ARC.

3C Aggregated and non-CO_2 emissions from land	South African Mineral Industry Report compiled by DMR	No formal mechanism in place but data is currently publicly available.
	MODIS burnt area data – obtained from website but processed by Gondwana Environmental Solutions	No formal process for obtaining this data but DEFF is considering compiling this data in-house.
	FAO	Statistics available on FAO Stats website
	ARC	DEFF is in the process of developing an MOU with ARC.
	Statistics SA	Agricultural census data are available from Statistics SA. No formal agreement exists between DEFF and Statistics SA.
4A Solid waste disposal	Statistics SA, World bank	Statistics available on the StatsSA website
4C Open burning of waste	Statistics SA	Statistics available on the StatsSA website
4D Wastewater treatment and discharge	Statistics SA, World bank	Statistics available on the StatsSA website

1.5 Brief description of key source categories

A key category is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of greenhouse gases in terms of the absolute level, the trend, or the uncertainty in emissions and removals (IPCC, 2006). 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 level assessment determines the contribution from the categories to the total national inventory. The trend assessment identifies categories that may not be large enough to be identified by the level assessment, but whose trend is significantly different from the trend of the overall inventory, and should therefore receive particular attention. The trend can be an increase or a decrease in emissions. This 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 2017, or the trend of emissions.

Identifying key categories will allow resources to be allocated to the appropriate activities so as to improve those specific subcategory emissions in future submissions. The key categories identified in 2017 are summarised in Table 1.4 and Table 1.5. 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 full key category analysis is provided in Appendix 1.A. It should be noted that HFC and PFC emissions from *Product uses as substitute ODS* are not included in the trend assessment due to the fact that there was no data for the initial year 2000.

In the level assessment *Electricity and heat production* still remains the key category, contributing 38.1% and 33.5% to total emissions excluding and including FOLU, respectively (Table 1.4). This is similar to its contribution in the previous submission. *Road transport* was the second key category with a contribution of 10.7% to emissions (incl. FOLU), which is a 2.8% increase on the previous submission. With the trend assessment *Road transport* took the top position ahead of *Residential* and contributed 17.3% and 15.3% to the trend including and excluding FOLU, respectively (Table 1.5).

Table 1.4: **Top ten key categories for South Africa for 2017 (excluding and including FOLU) determined by level (L1) assessment.**

Key category number	IPCC code	IPCC category	GHG	2017 Emissions (Gg CO_2e)	% Contribution
Emissions excluding FOLU - Level assessment (2017)					
1	1A1a	Electricity and Heat Production (Solid fuel)	CO_2	218 959.2	38.10
2	1A3b	Road Transport (Liquid fuel)	CO_2	69 816.6	12.15
3	1A2	Manufacturing Industries and Construction (Solid fuel)	CO_2	31 855.1	5.54
4	1A1c	Manufacture of Solid Fuels and Other Energy Industries (Solid fuel)	CO_2	29 270.6	5.09
5	1A4b	Residential (Solid fuel)	CO_2	28 337.4	4.93
6	1B3	Other Emissions from Energy Production	CO_2	25 746.5	4.48
7	3A1a	Enteric fermentation – cattle	CH_4	21 589.7	3.76
8	3C4	Direct N2O emissions from managed soils	N_2O	18 081.0	3.15

9	4A	Solid Waste Disposal	CH_4	17 366.0	3.02
10	1A4a	Commercial/Institutional (Liquid fuel)	CO_2	16 176.0	2.81
Emissions including FOLU - Level assessment (2017)					
1	1A1a	Electricity and Heat Production (Solid fuel)	CO_2	218 959.2	33.54
2	1A3b	Road Transport (Liquid fuel)	CO_2	48 618.7	10.69
3	1A2	Manufacturing Industries and Construction (Solid fuel)	CO_2	31 855.1	4.88
4	1A1c	Manufacture of Solid Fuels and Other Energy Industries (Solid fuel)	CO_2	29 270.6	4.48
5	1A4b	Residential (Solid fuel)	CO_2	28 337.4	4.34
6	3B1b	Land converted to forest land[a]	CO_2	-26 613.8	4.08
7	1B3	Other Emissions from Energy Production	CO_2	25 746.5	3.94
8	3A1a	Enteric fermentation – cattle	CH_4	21 589.7	3.31
9	3C4	Direct N2O emissions from managed soils	N_2O	18 081.0	2.77
10	3B3b	Land converted to grassland	CO_2	-17 662.3	2.71

[a] *For forest land it is the biomass carbon pool that is the key category.*

Table 1.5: Top ten key categories contributing to the trend in emissions in South Africa between 2000 and 2017 (excluding and including FOLU) as determined by trend (L1) assessment.

Key category number	IPCC code	IPCC category	GHG	Emissions (Gg CO_2e)		% Contribution
				2000	2017	
Emissions excluding FOLU - Trend assessment (2000 - 2015)						
1	1A3b	Road Transport (Liquid fuel)	CO_2	34 053.1	69 816.6	17.26
2	1A4b	Residential (Solid fuel)	CO_2	3 604.2	28 337.4	15.60
3	1A1a	Electricity and Heat Production (Solid fuel)	CO_2	185 027.4	218 959.2	11.69
4	1B3	Other Emissions from Energy Production	CO_2	28 146.6	25 746.5	6.75
5	1A1c	Manufacture of Solid Fuels and Other Energy Industries (Solid fuel)	CO_2	30 454.7	29 270.6	6.38
6	3A1a	Enteric fermentation – cattle	CH_4	23 344.7	21 589.7	5.44
7	3C4	Direct N_2O emissions from managed soils	N_2O	20 072.5	18 081.0	5.00
8	1A4a	Commercial/Institutional (Liquid fuel)	CO_2	7 690.5	16 176.0	4.17
9	2C1	Iron and Steel Production	CO_2	16 410.5	15 074.3	3.89
10	1A2	Manufacturing Industries and Construction (Solid fuel)	CO_2	29 509.4	31 855.1	3.88
Emissions including FOLU - Trend assessment (2000 - 2017)						

1	1A3b	Road Transport (Liquid fuel)	CO_2	34 053.1	69 816.6	15.34
2	1A4b	Residential (Solid fuel)	CO_2	3 604.2	28 337.4	13.29
3	3B1a	Forest land remaining forest land[a]	CO_2	1 633.2	-14 093.6	8.98
4	3B1b	Land converted to forest land[a]	CO_2	-20 846.1	-26 613.8	6.02
5	1A1a	Electricity and heat production (Solid fuel)	CO_2	185 027.4	218 959.2	5.99
6	1B3	Other Emissions from Energy Production	CO_2	28 146.6	25 746.5	5.12
7	1A1c	Manufacture of Solid Fuels and Other Energy Industries (Solid fuel)	CO_2	30 454.7	29 270.6	4.76
8	3A1a	Enteric fermentation – cattle	CH_4	23 344.7	21 589.7	4.12
9	3C4	Direct N_2O emissions from managed soils	N_2O	20 072.5	18 081.0	3.81
10	1A4a	Commercial/Institutional (Liquid fuel)	CO_2	7 690.5	16 176.0	3.69

[a] *For forest land it is the biomass carbon pool that is the key category.*

1.5.1 Changes since the 2015 submission

In the level assessment of emissions (excl. FOLU) there are two new key categories in this submission which are *Aluminium production* (PFCs) and *Indirect N_2O from managed soils* (N_2O). These categories are at the bottom of the key category list, just above *Petroleum refining*. These two categories are, however, included in the key categories for level assessment of emissions (incl. FOLU). Considering the difference in contribution of each category to the current submission and the 2015 submission, *Road transport* increased its contribution by 3.5% and *Electricity and heat production* reduced its contribution by 2.5% (Figure 1.6). The increase in *Road transport* emissions could be due to the updated values based on VKT data. The *Commercial/institutional* category appears to have moved down the list slightly, however in this submission emissions were divided by fuel type (i.e. solid, liquid or gas) which was not done in 2015 so this could be the reason for this. The top five key categories remain unchanged.

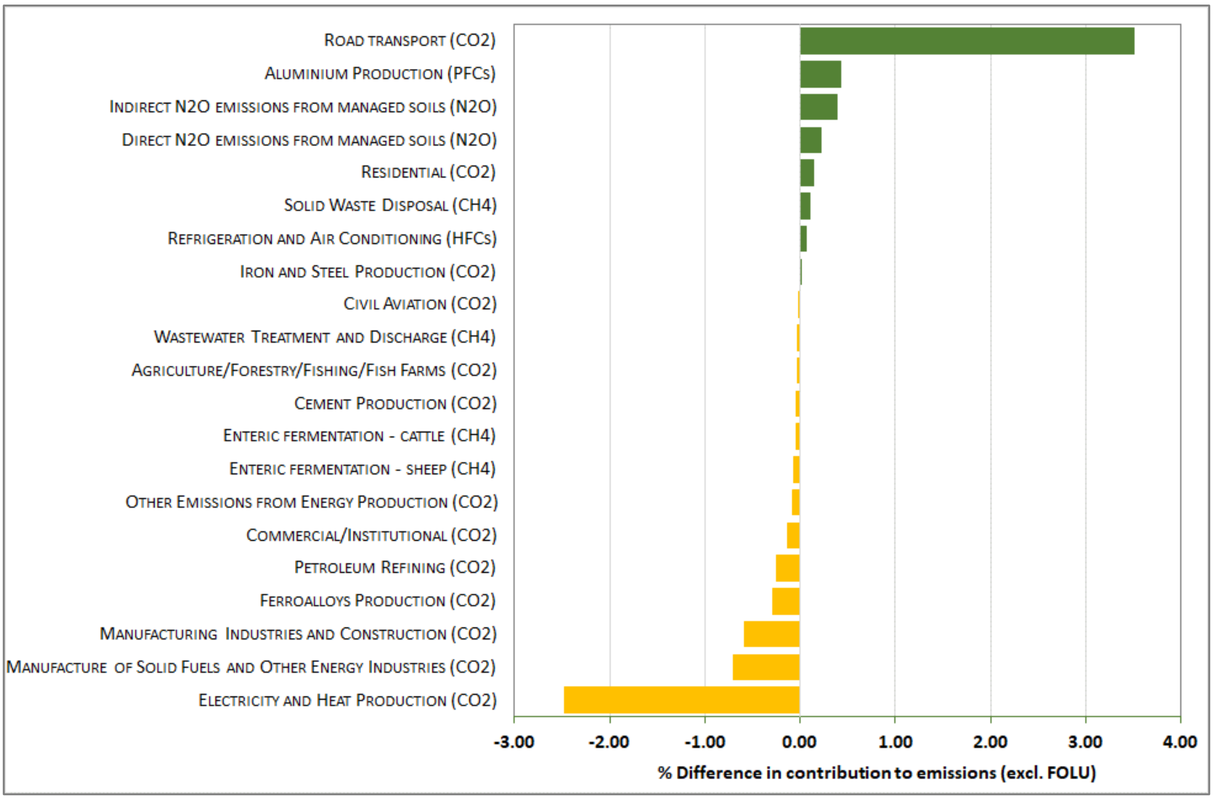

Figure 1.6: Difference in contribution to the level assessment (excl. FOLU) key category analysis between the current submission and the 2015 submission.

In the level assessment of emissions (incl. FOLU) there was one additional key category, namely *Land converted to grasslands* (CO_2) (Figure 1.7). Several updates were made to the AFOLU sector which has led this category to be the tenth key category in this list. Otherwise all the rest of the key categories remain, with the top five key categories remaining and other categories showing some movement. The main movements were *Commercial/institutional* CO_2 emissions moving down the list (as mentioned this maybe be due to splitting of fuel types), along with *Land converted to croplands* (CO_2). *Land converted to other lands* has moved up the level key category list from 25th position to 13th position. The categories *Grassland remaining grassland* and *Land converted to settlements* were identified as key categories in 2015 but these are not included in 2017.

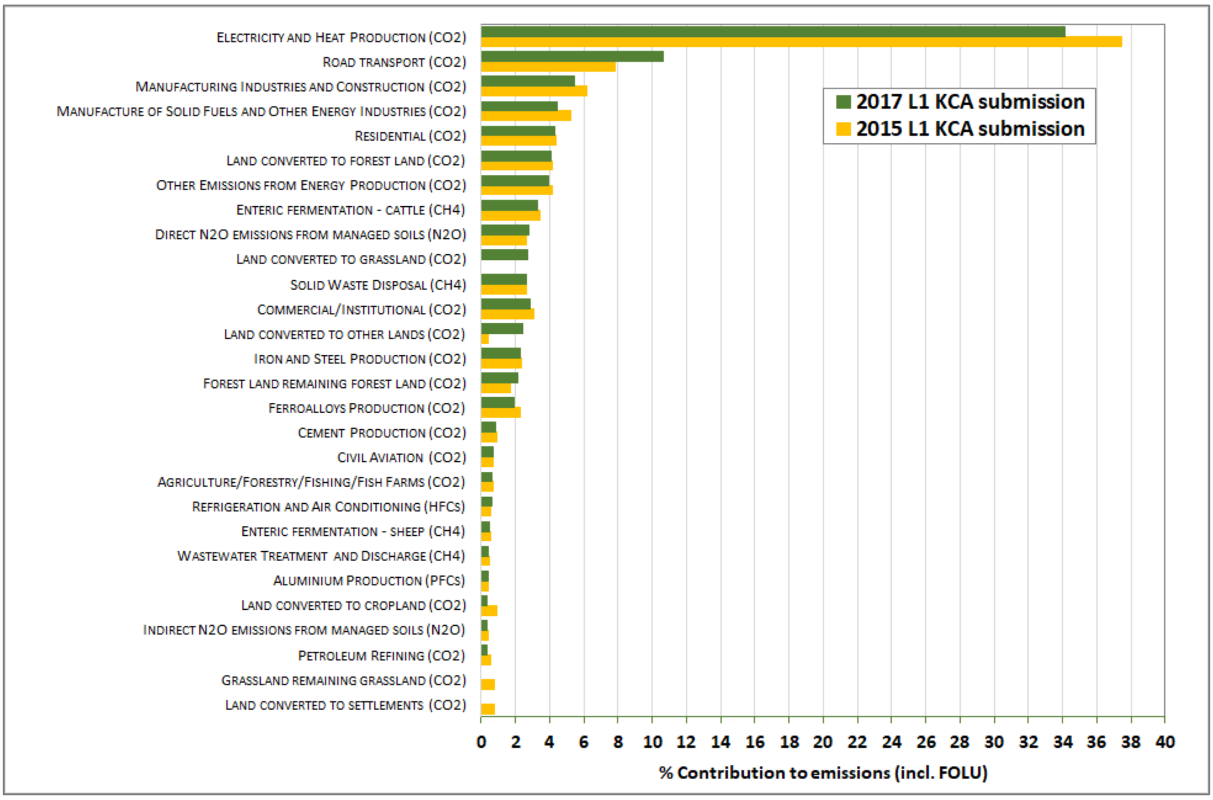

Figure 1.7: Comparison of level assessment key categories and their contribution to emissions (incl. FOLU) in the current and previous 2015 submission.

With the trend analysis on emissions (excl. FOLU) the *Cement industry* was previously identified but was no longer on the key category list in this submission. This submission identified three new key categories, namely, *Liming*, *Chemical industry* and *Biomass burning in grasslands*. Most importantly, the *Residential* category was identified as the top key category, but this has now been replaced by *Road transport*. The *Residential* contribution declined by 3.3%, while *Road transport* increased its contribution by 10.4% (Figure 1.8). *Electricity and heat production* also increased it contribution, while *Solid waste disposal* (CH_4), *Other emissions from energy production* and *Other sectors* (which includes residential and commercial/institutional) all showed a reduction in their contribution compared to the previous submission.

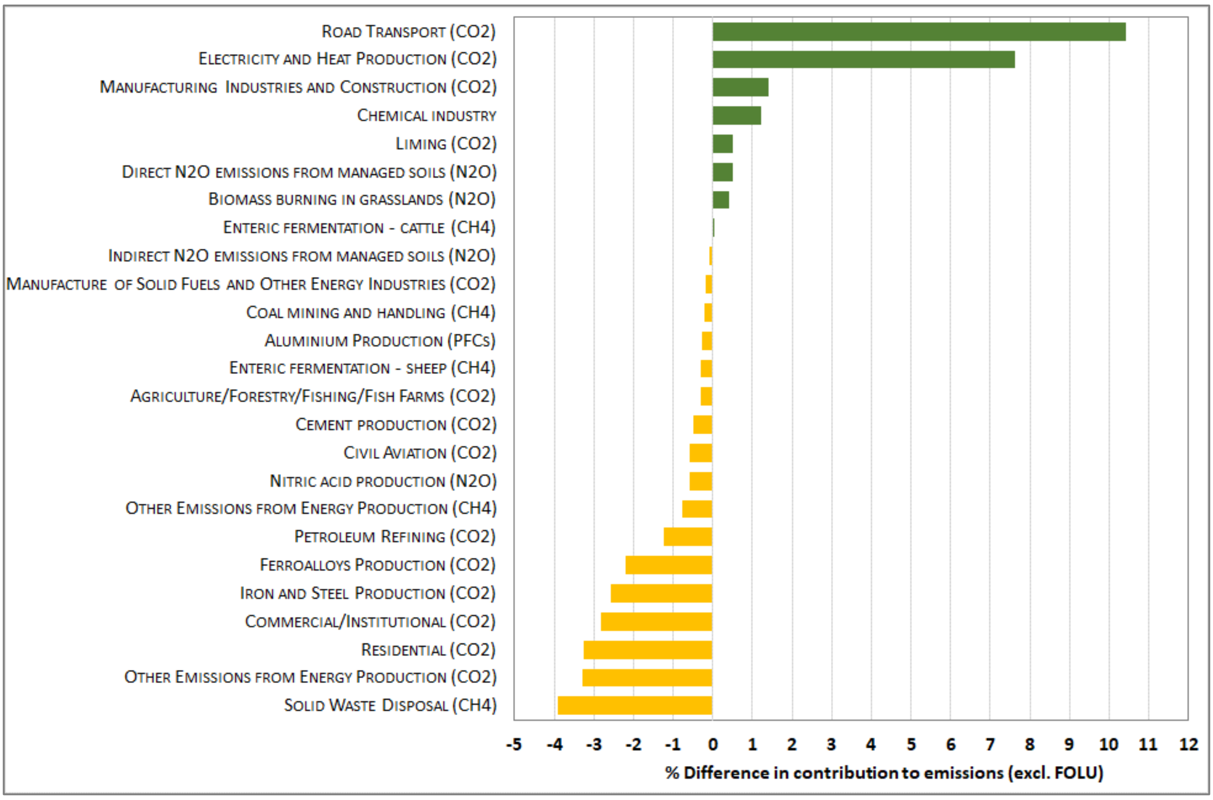

Figure 1.8: Difference in contribution to the trend assessment (excl. FOLU) key category analysis between the current submission and the 2015 submission.

Including FOLU in the trend analysis led to the removal of the categories *Grassland remaining grassland*, *Land converted to settlements*, *Nitric Acid production* and *Cement productions* from the key category list (Figure 1.9). These were replaced by *Chemical industry*, *Indirect N_2O from managed soils*, *Liming*, *Cropland remaining cropland*, *Biomass burning in grasslands* and *Harvested wood products*. In the 2015 submission *Land converted to forest land* was identified as the third key category and *Forest land remaining forest land* as the fourth, but in this submission these have swapped around due to the 20-year transition correction. For similar reasons there are several changes in the order and contribution from the various land categories.

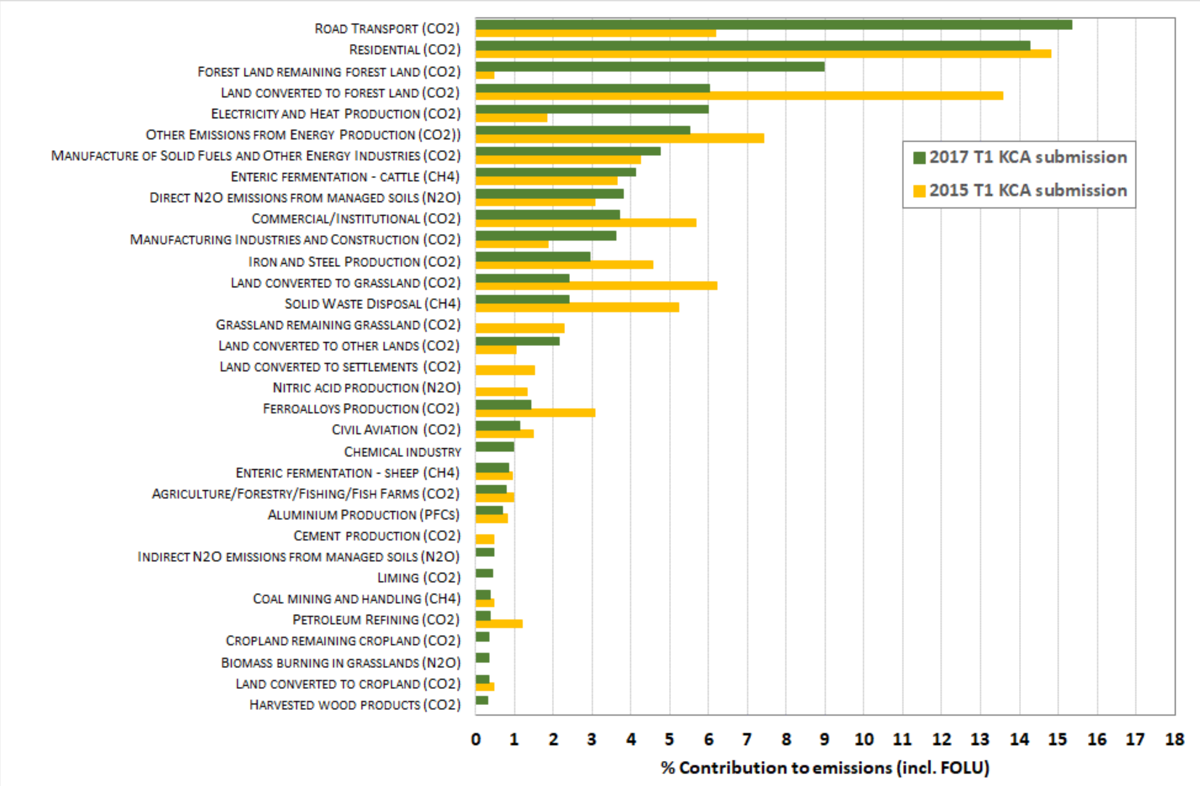

Figure 1.9: Comparison of trend assessment key categories and their contribution to emissions (incl. FOLU) in the current and previous 2015 submission.

1.6 General uncertainty evaluation

Uncertainty is inherent within any kind of estimation and arises from the limitations of the measuring instruments, sampling processes and model complexities and assumptions. Managing these uncertainties, and reducing them over time, is recognised by IPCC 2006 as an important element of inventory preparation and development. Chapter 3 of the 2006 IPCC Guidelines describes the methodology for estimating and reporting uncertainties associated with annual estimates of emissions and removals. There are two methods for determining uncertainty:

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

The reporting of uncertainties requires a complete understanding of the processes of compiling the inventory, so that potential sources of inaccuracy can be qualified and possibly quantified. The 2010 inventory (DEA, 2014) did not incorporate an overall uncertainty assessment due to a lack of quantitative and qualitative uncertainty data. In the previous submission uncertainty for the *Energy* and *IPPU* sectors was included, while in this submission all four sectors are included.

Emission estimate uncertainties typically are low for CO_2 from energy consumption as well as from some industrial process emissions. Uncertainty surrounding estimates of emissions are higher for *AFOLU* and synthetic gases. Uncertainty ranges for the various sectors (Appendix 1.B) are largely consistent with typical uncertainty ranges expected for each sector (IPCC, 2014).

The IPCC good practice tier 1 method was used to determine the overall aggregated uncertainty on South Africa's inventory estimate for 2017. The analysis (Appendix 1.B) shows that the overall uncertainty on the 2017 estimate is 9.8%, while the uncertainty in the emission trend is estimated at 8.23%. If FOLU is excluded, then the overall uncertainty is reduced to 8.76% with the uncertainty on trend being 7.61%.

1.7 General assessment of completeness

The South African GHG emission inventory for the period 2000 – 2017 is not complete, mainly due to the lack of sufficient data. Table 1.6 identifies the sources in the 2006 IPCC Guidelines which were not included or included elsewhere in this inventory and the reason for their omissions is discussed further in the appropriate chapters. The table also indicates which activities do not occur in South Africa.

Table 1.6: Activities in the 2015 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

	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
	CO_2 transport and storage	
	CO_2, CH_4 and N_2O emissions from Combined Heat and Power (CHP) combustion systems	
	Other process use of carbonates	
	CO_2 from non-energy products from solvent use	
	Electronics industry	A study needs to be undertaken to understand emissions from this source category
	PFCs and HFCs from solvents	
	Emissions from other product manufacture and use	
	CO_2 from organic soils	Insufficient data on the distribution and extent of organic soils. Project has just been initiated by DEA to identify and map organic soils. These emissions could potentially be included in the next inventory.
	CO_2 from changes in dead wood for all land categories	Estimates are provided for litter, but not for dead wood due to insufficient data.
	HWP from solid waste	This will be included in the next inventory
	CH_4, N_2O emissions from biological treatment of waste	
	CO_2, CH_4 and N_2O from waste incineration	
	Precursor (NOx, CO, NMVOCs) emissions	These have only been included for biomass burning.
	SO_2 emissions	
	SF6 emissions	
IE	CO_2 emissions from biomass burning	These are not included under biomass burning, but rather under disturbance losses in the Land sector.
	CO_2, CH_4 and N_2O emissions from off-road vehicles and other machinery	Included under Road transportation.
	N_2O emissions from sewage sludge application to agricultural soils	Included in the Waste sector.
	Domestic wastewater treatment and discharge emissions	Reported under the total for Wastewater treatment and discharge

	Industrial wastewater treatment and discharge emissions	Reported under the total for Wastewater treatment and discharge
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, CH_4 and N_2O Caprolactam, Glyoxal and Glyoxylic acid production	

1.8 Inventory improvements introduced

1.8.1 Energy

In the *Energy* sector the charcoal production data for *Other emissions from energy production* were updated, charcoal consumption in the residential category were updated, and in *road transport* petrol and diesel consumption was determined using vehicle kilometres travelled (VKT) and natural gas consumption was added.

1.8.2 IPPU

Improvements were made to the IPPU sector in the recently completed 2015 inventory, so only a few very minor changes and updates were included in this inventory. One change was to correct the hydrated lime emission factor for lime production emissions.

1.8.3 AFOLU

Livestock

In the *Livestock* category the dairy, other cattle and feedlot herd composition was adjusted slightly. Manure management data was updated to incorporate data from Moeletsi and Tongwane (2015). Lastly, country-specific N-excretion rates for horses, mules and asses and poultry were included and *swine* N excretion rates were updated.

Land

In the *Land* category several updates were made. In order to improve transparency, the land change matrix data was linked to the land areas and plantation areas were adjusted to Forestry SA data. The soil area overlay data (of land use change, climate and soil type) was adjusted to account for any mapping overlay losses of area so as to ensure consistency with the biomass land area data. Updates were made to biomass, DOM and SOC factors where new data was available. Burnt area data was changed from 5-year average data to annual data. Lastly, and probably the most significant change, was the adjustment of the data to include the 20-year default transition period for converted lands. In the previous inventory this was not accounted for.

Aggregated and non-CO_2 sources on land

In the *Aggregated and non-CO_2 sources on land* category, under *Direct N_2O from managed soils*, the crop residue calculations were adjusted to conform with IPCC methodology and the F_{SOM} component (which is the amount of N in mineral soils that is mineralised in association with loss of soil C from soil organic matter as a result of changes to land management) was included. For biomass burning the burnt area data was updated to the MODIS collection 6 data, and annual burnt area was applied instead of 5-year averages.

Other

Updated FAO data were incorporated into the HWP estimates.

1.8.4 Waste

In the *Waste* sector the solid waste disposal data was improved by incorporating country specific population data, waste generation rates and the percentage of waste going to solid waste management into the FOD model for the years 1950 to 1999. In addition the fraction of methane in developed gas was previously indicated to be 0.52 and this was corrected to the IPCC default value of 0.5. No further improvements were made in the other waste categories due to the recent improvements in the 2015 inventory.

Appendix 1.A Key category analysis

Table A.1: Level assessment on emissions excluding FOLU for South Africa (2017) with the key categories highlighted in green.

IPCC Category code	IPCC Category	Fuel type	GHG	2017 Ex,t (Gg CO_2 Eq)	Lx,t	Cumulative Total
1A1a	Electricity and Heat Production	Solid	CO_2	21 8959.2	0.381	0.381
1A3b	Road Transport	Liquid	CO_2	69 816.6	0.121	0.502
1A2	Manufacturing Industries and Construction	Solid	CO_2	31 855.1	0.055	0.558
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	CO_2	29 270.6	0.051	0.609
1A4b	Residential	Solid	CO_2	28 337.4	0.049	0.658
1B3	Other Emissions from Energy Production		CO_2	25 746.5	0.045	0.703
3A1a	Enteric fermentation - cattle		CH_4	21 589.7	0.038	0.741
3C4	Direct N2O emissions from managed soils		N_2O	18 081.0	0.031	0.772
4A	Solid Waste Disposal		CH_4	17 366.0	0.030	0.802
1A4a	Commercial/Institutional	Liquid	CO_2	16 176.0	0.028	0.830
2C1	Iron and Steel Production		CO_2	15 074.3	0.026	0.857
2C2	Ferroalloys Production		CO_2	12 572.3	0.022	0.878
2A1	Cement Production		CO_2	5 295.9	0.009	0.888
1A1a	Electricity and Heat Production	Liquid	CO_2	5 166.7	0.009	0.897
1A3a	Civil Aviation	Liquid	CO_2	4 539.7	0.008	0.905
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	CO_2	4 161.3	0.007	0.912
2F1	Refrigeration and Air Conditioning		HFCs	3 963.5	0.007	0.919

1A2	Manufacturing Industries and Construction	Gas	CO_2	3 817.9	0.007	0.925
3A1c	Enteric fermentation - sheep		CH_4	3 214.6	0.006	0.931
4D1	Wastewater Treatment and Discharge		CH_4	2 753.3	0.005	0.936
1A4a	Commercial/Institutional	Solid	CO_2	2 565.5	0.004	0.940
2C3	Aluminium Production		PFCs	2 453.4	0.004	0.944
3C5	Indirect N2O emissions from managed soils		N_2O	2 236.3	0.004	0.948
1A1b	Petroleum Refining	Gas	CO_2	2 215.0	0.004	0.952
1B3	Other Emissions from Energy Production		CH_4	2 183.9	0.004	0.956
1A4b	Residential	Liquid	CO_2	1 829.2	0.003	0.959
1A3d	Water-Borne Navigation	Liquid	CO_2	1 606.3	0.003	0.962
1A2	Manufacturing Industries and Construction	Liquid	CO_2	1 591.4	0.003	0.965
1B1a	Coal mining and handling		CH_4	1 587.4	0.003	0.968
2C3	Aluminium Production		CO_2	1 322.5	0.002	0.970
3C2	Liming		CO_2	1 222.1	0.002	0.972
1A5a	Stationary	Liquid	CO_2	1 199.3	0.002	0.974
1A3b	Road Transport	Liquid	N_2O	1 066.8	0.002	0.976
1A1a	Electricity and Heat Production	Solid	N_2O	1 057.8	0.002	0.978
2A2	Lime Production		CO_2	1 045.3	0.002	0.980
1A1b	Petroleum Refining	Solid	CO_2	934.9	0.002	0.981
3A2a	Manure management - cattle		N_2O	889.5	0.002	0.983
4D1	Wastewater Treatment and Discharge		N_2O	769.6	0.001	0.984
3A1d	Enteric fermentation - goats		CH_4	709.2	0.001	0.985
3C3	Urea application		CO_2	679.6	0.001	0.986

1B2a	Oil		CO_2	641.8	0.001	0.988
3A2i	Manure management - poultry		N_2O	641.3	0.001	0.989
3C6	Indirect N2O emissions from manure management		N_2O	469.3	0.001	0.990
1A3c	Railways	Liquid	CO_2	442.8	0.001	0.990
3A2h	Manure management - swine		CH_4	438.6	0.001	0.991
1A3b	Road Transport	Liquid	CH_4	397.6	0.001	0.992
1A4b	Residential	Solid	N_2O	381.4	0.001	0.992
2B	Chemical industry		C	C	0.001	0.993
2D1	Lubricant Use		CO_2	272.9	0.000	0.993
3A2a	Manure management - cattle		CH_4	245.0	0.000	0.994
3C1c	Biomass burning in grasslands		N_2O	241.8	0.000	0.994
2B	Chemical industry		C	C	0.000	0.995
4C2	Open Burning of Waste		CH_4	240.7	0.000	0.995
3C1c	Biomass burning in grasslands		CH_4	204.8	0.000	0.995
1A1b	Petroleum Refining	Liquid	CO_2	178.1	0.000	0.996
2B	Chemical industry		C	C	0.000	0.996
2B	Chemical industry		C	C	0.000	0.996
1A2	Manufacturing Industries and Construction	Solid	N_2O	151.8	0.000	0.997
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	N_2O	141.4	0.000	0.997
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	CO_2	135.0	0.000	0.997
2B	Chemical industry		C	C	0.000	0.997
3A1f	Enteric fermentation - horses		CH_4	122.0	0.000	0.997
2A3	Glass Production		CO_2	120.9	0.000	0.998

3C1a	Biomass burning in forest land		CH_4	107.2	0.000	0.998
3A2c	Manure management - sheep		N_2O	103.6	0.000	0.998
3C1a	Biomass burning in forest land		N_2O	98.2	0.000	0.998
4C2	Open Burning of Waste		N_2O	82.0	0.000	0.998
1A3b	Road Transport	Gas	CO_2	70.7	0.000	0.998
1A4b	Residential	Solid	CH_4	60.8	0.000	0.999
3A2i	Manure management - poultry		CH_4	59.2	0.000	0.999
3C1b	Biomass burning in croplands		CH_4	57.2	0.000	0.999
2F3	Fire Protection		HFCs	51.1	0.000	0.999
1A1a	Electricity and Heat Production	Solid	CH_4	47.8	0.000	0.999
1A3c	Railways	Liquid	N_2O	47.0	0.000	0.999
2C6	Zinc Production		CO_2	46.3	0.000	0.999
1A4a	Commercial/Institutional	Liquid	N_2O	40.4	0.000	0.999
3A1h	Enteric fermentation - swine		CH_4	39.1	0.000	0.999
4C2	Open Burning of Waste		CO_2	37.5	0.000	0.999
3A2h	Manure management - swine		N_2O	37.1	0.000	0.999
3A2d	Manure management - goats		N_2O	36.3	0.000	0.999
3A1g	Enteric fermentation - mules and asses		CH_4	34.2	0.000	1.000
1A4a	Commercial/Institutional	Gas	CO_2	30.4	0.000	1.000
1A4a	Commercial/Institutional	Solid	N_2O	24.8	0.000	1.000
3C1b	Biomass burning in croplands		N_2O	21.9	0.000	1.000
2C5	Lead Production		CO_2	21.7	0.000	1.000
1B1a	Coal mining and handling		CO_2	20.8	0.000	1.000

3C1d	Biomass burning in wetlands		N_2O	13.8	0.000	1.000
1A4a	Commercial/Institutional	Liquid	CH_4	13.7	0.000	1.000
1A1a	Electricity and Heat Production	Liquid	N_2O	12.9	0.000	1.000
1A3a	Civil Aviation	Liquid	N_2O	11.8	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	N_2O	10.5	0.000	1.000
3C1d	Biomass burning in wetlands		CH_4	10.2	0.000	1.000
1A3d	Water-Borne Navigation	Liquid	N_2O	9.7	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	CH_4	7.6	0.000	1.000
1A2	Manufacturing Industries and Construction	Solid	CH_4	7.4	0.000	1.000
1A1a	Electricity and Heat Production	Liquid	CH_4	4.4	0.000	1.000
1A3a	Civil Aviation	Liquid	CH_4	4.0	0.000	1.000
1A2	Manufacturing Industries and Construction	Liquid	N_2O	4.0	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	CH_4	3.6	0.000	1.000
1A5a	Stationary	Liquid	N_2O	3.2	0.000	1.000
2C2	Ferroalloys Production		CH_4	3.1	0.000	1.000
1A3d	Water-Borne Navigation	Liquid	CH_4	3.1	0.000	1.000
2B	Chemical industry		C	C	0.000	1.000
2D2	Paraffin Wax Use		CO_2	2.7	0.000	1.000
1A4b	Residential	Liquid	N_2O	2.4	0.000	1.000
3C1e	Biomass burning in settlements		N_2O	2.1	0.000	1.000
1A2	Manufacturing Industries and Construction	Gas	N_2O	2.1	0.000	1.000
1A1b	Petroleum Refining	Solid	N_2O	1.8	0.000	1.000
3C1e	Biomass burning in settlements		CH_4	1.6	0.000	1.000

1A2	Manufacturing Industries and Construction	Gas	CH_4	1.4	0.000	1.000
1A2	Manufacturing Industries and Construction	Liquid	CH_4	1.3	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	N_2O	1.3	0.000	1.000
1A1b	Petroleum Refining	Gas	N_2O	1.2	0.000	1.000
1A5a	Stationary	Liquid	CH_4	1.1	0.000	1.000
1A4b	Residential	Liquid	CH_4	1.0	0.000	1.000
3A2c	Manure management - sheep		CH_4	0.9	0.000	1.000
1A1b	Petroleum Refining	Gas	CH_4	0.8	0.000	1.000
3A2d	Manure management - goats		CH_4	0.8	0.000	1.000
1A1b	Petroleum Refining	Solid	CH_4	0.6	0.000	1.000
1A4a	Commercial/Institutional	Solid	CH_4	0.6	0.000	1.000
1A3c	Railways	Liquid	CH_4	0.5	0.000	1.000
1A1b	Petroleum Refining	Liquid	N_2O	0.4	0.000	1.000
1A1b	Petroleum Refining	Liquid	CH_4	0.1	0.000	1.000
3A2f	Manure management - horses		CH_4	0.1	0.000	1.000
2B	Chemical industry		C	C	0.000	1.000
1A3b	Road Transport	Gas	N_2O	0.0	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	CH_4	0.0	0.000	1.000
1A3b	Road Transport	Gas	CH_4	0.0	0.000	1.000
1A4a	Commercial/Institutional	Gas	N_2O	0.0	0.000	1.000
3A2g	Manure management - mules and asses		CH_4	0.0	0.000	1.000
1A4a	Commercial/Institutional	Gas	CH_4	0.0	0.000	1.000
1A1a	Electricity and Heat Production	Gas	CO_2	0.0	0.000	1.000

1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	CO_2	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	CO_2	0.0	0.000	1.000
1A1a	Electricity and Heat Production	Gas	CH_4	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	CH_4	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	CH_4	0.0	0.000	1.000
1A1a	Electricity and Heat Production	Gas	N_2O	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	N_2O	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	N_2O	0.0	0.000	1.000
1A3a	Civil Aviation	Gas	CO_2	0.0	0.000	1.000
1A3c	Railways	Gas	CO_2	0.0	0.000	1.000
1A3d	Water-Borne Navigation	Gas	CO_2	0.0	0.000	1.000
1A3a	Civil Aviation	Gas	CH_4	0.0	0.000	1.000
1A3c	Railways	Gas	CH_4	0.0	0.000	1.000
1A3d	Water-Borne Navigation	Gas	CH_4	0.0	0.000	1.000
1A3a	Civil Aviation	Gas	N_2O	0.0	0.000	1.000
1A3c	Railways	Gas	N_2O	0.0	0.000	1.000
1A3d	Water-Borne Navigation	Gas	N_2O	0.0	0.000	1.000
1A5a	Stationary	Solid	CO_2	0.0	0.000	1.000
1A5a	Stationary	Solid	CH_4	0.0	0.000	1.000
1A5a	Stationary	Solid	N_2O	0.0	0.000	1.000
2F2	Foam Blowing Agents		HFCs	0.0	0.000	1.000
2F4	Aerosols		HFCs	0.0	0.000	1.000
3A1j	Enteric fermentation - other game		CH_4	0.0	0.000	1.000

3A2j	Manure management - other game		CH_4	0.0	0.000	1.000
3C1f	Biomass burning in other lands		CH_4	0.0	0.000	1.000
3C1f	Biomass burning in other lands		N_2O	0.0	0.000	1.000

C=Confidential data

Table A.2: Level assessment on emissions including FOLU for South Africa (2017) with the key categories highlighted in green.

IPCC Category code	IPCC Category	Fuel type	GHG	2017 Ex,t (Gg CO_2 Eq)	Lx,t	Cumulative Total
1A1a	Electricity and Heat Production	Solid	CO_2	218 959.2	0.334	0.334
1A3b	Road Transport	Liquid	CO_2	69 816.6	0.106	0.440
1A2	Manufacturing Industries and Construction	Solid	CO_2	31 855.1	0.049	0.488
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	CO_2	29 270.6	0.045	0.533
1A4b	Residential	Solid	CO_2	28 337.4	0.043	0.576
3B1b	Land converted to forest land - Net CO2		CO_2	-26 613.8	0.041	0.617
1B3	Other Emissions from Energy Production		CO_2	25 746.5	0.039	0.656
3A1a	Enteric fermentation - cattle		CH_4	21 589.7	0.033	0.689
3C4	Direct N2O emissions from managed soils		N_2O	18 081.0	0.028	0.716
3B3b	Land converted to grassland - Net CO2		CO_2	-17 662.3	0.027	0.743

4A	Solid Waste Disposal		CH_4	17 366.0	0.026	0.770
1A4a	Commercial/Institutional	Liquid	CO_2	16 176.0	0.025	0.794
3B6b	Land converted to other lands - Net CO2		CO_2	16 044.8	0.024	0.819
2C1	Iron and Steel Production		CO_2	15 074.3	0.023	0.842
3B1a	Forest land remaining forest land - Net CO2		CO_2	-14 093.6	0.021	0.863
2C2	Ferroalloys Production		CO_2	12 572.3	0.019	0.882
2A1	Cement Production		CO_2	5 295.9	0.008	0.890
1A1a	Electricity and Heat Production	Liquid	CO_2	5 166.7	0.008	0.898
1A3a	Civil Aviation	Liquid	CO_2	4 539.7	0.007	0.905
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	CO_2	4 161.3	0.006	0.912
2F1	Refrigeration and Air Conditioning		HFCs	3 963.5	0.006	0.918
1A2	Manufacturing Industries and Construction	Gas	CO_2	3 817.9	0.006	0.923
3A1c	Enteric fermentation - sheep		CH_4	3 214.6	0.005	0.928
4D1	Wastewater Treatment and Discharge		CH_4	2 753.3	0.004	0.933
1A4a	Commercial/Institutional	Solid	CO_2	2 565.5	0.004	0.936
2C3	Aluminium Production		PFCs	2 453.4	0.004	0.940
3B2b	Land converted to cropland - Net CO2		CO_2	2 321.3	0.004	0.944
3C5	Indirect N2O emissions from managed soils		N_2O	2 236.3	0.003	0.947
1A1b	Petroleum Refining	Gas	CO_2	2 215.0	0.003	0.951
1B3	Other Emissions from Energy Production		CH_4	2 183.9	0.003	0.954
1A4b	Residential	Liquid	CO_2	1 829.2	0.003	0.957
3B2a	Cropland remaining cropland - Net CO2		CO_2	-1 793.0	0.003	0.959
1A3d	Water-Borne Navigation	Liquid	CO_2	1 606.3	0.002	0.962

1A2	Manufacturing Industries and Construction	Liquid	CO_2	1 591.4	0.002	0.964
1B1a	Coal mining and handling		CH_4	1 587.4	0.002	0.967
2C3	Aluminium Production		CO_2	1 322.5	0.002	0.969
3C2	Liming		CO_2	1 222.1	0.002	0.971
1A5a	Stationary	Liquid	CO_2	1 199.3	0.002	0.972
1A3b	Road Transport	Liquid	N_2O	1 066.8	0.002	0.974
1A1a	Electricity and Heat Production	Solid	N_2O	1 057.8	0.002	0.976
2A2	Lime Production		CO_2	1 045.3	0.002	0.977
1A1b	Petroleum Refining	Solid	CO_2	934.9	0.001	0.979
3A2a	Manure management - cattle		N_2O	889.5	0.001	0.980
3D1	Harvested wood products		CO_2	-776.9	0.001	0.981
4D1	Wastewater Treatment and Discharge		N_2O	769.6	0.001	0.982
3A1d	Enteric fermentation - goats		CH_4	709.2	0.001	0.983
3B5a	Settlements remaining settlements - Net CO2		CO_2	-686.2	0.001	0.984
3C3	Urea application		CO_2	679.6	0.001	0.985
3B4	Wetland		CH_4	666.6	0.001	0.986
1B2a	Oil		CO_2	641.8	0.001	0.987
3A2i	Manure management - poultry		N_2O	641.3	0.001	0.988
3B5b	Land converted to settlements - Net CO2		CO_2	580.3	0.001	0.989
3B3a	Grassland remaining grassland - Net CO2		CO_2	-510.3	0.001	0.990
3C6	Indirect N2O emissions from manure management		N_2O	469.3	0.001	0.991
1A3c	Railways	Liquid	CO_2	442.8	0.001	0.992
3A2h	Manure management - swine		CH_4	438.6	0.001	0.992

1A3b	Road Transport	Liquid	CH_4	397.6	0.001	0.993
1A4b	Residential	Solid	N_2O	381.4	0.001	0.993
2B	Chemical industry		C	C	0.000	0.994
2D1	Lubricant Use		CO_2	272.9	0.000	0.994
3A2a	Manure management - cattle		CH_4	245.0	0.000	0.995
3C1c	Biomass burning in grasslands		N_2O	241.8	0.000	0.995
2B	Chemical industry		C	C	0.000	0.995
4C2	Open Burning of Waste		CH_4	240.7	0.000	0.996
3C1c	Biomass burning in grasslands		CH_4	204.8	0.000	0.996
1A1b	Petroleum Refining	Liquid	CO_2	178.1	0.000	0.996
2B	Chemical industry		C	C	0.000	0.997
2B	Chemical industry		C	C	0.000	0.997
1A2	Manufacturing Industries and Construction	Solid	N_2O	151.8	0.000	0.997
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	N_2O	141.4	0.000	0.997
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	CO_2	135.0	0.000	0.997
2B	Chemical industry		C	C	0.000	0.998
3A1f	Enteric fermentation - horses		CH_4	122.0	0.000	0.998
2A3	Glass Production		CO_2	120.9	0.000	0.998
3C1a	Biomass burning in forest land		CH_4	107.2	0.000	0.998
3A2c	Manure management - sheep		N_2O	103.6	0.000	0.998
3C1a	Biomass burning in forest land		N_2O	98.2	0.000	0.998
4C2	Open Burning of Waste		N_2O	82.0	0.000	0.999
1A3b	Road Transport	Gas	CO_2	70.7	0.000	0.999

1A4b	Residential	Solid	CH_4	60.8	0.000	0.999
3A2i	Manure management - poultry		CH_4	59.2	0.000	0.999
3C1b	Biomass burning in croplands		CH_4	57.2	0.000	0.999
2F3	Fire Protection		HFCs	51.1	0.000	0.999
1A1a	Electricity and Heat Production	Solid	CH_4	47.8	0.000	0.999
1A3c	Railways	Liquid	N_2O	47.0	0.000	0.999
2C6	Zinc Production		CO_2	46.3	0.000	0.999
1A4a	Commercial/Institutional	Liquid	N_2O	40.4	0.000	0.999
3A1h	Enteric fermentation - swine		CH_4	39.1	0.000	0.999
4C2	Open Burning of Waste		CO_2	37.5	0.000	0.999
3A2h	Manure management - swine		N_2O	37.1	0.000	0.999
3A2d	Manure management - goats		N_2O	36.3	0.000	1.000
3A1g	Enteric fermentation - mules and asses		CH_4	34.2	0.000	1.000
1A4a	Commercial/Institutional	Gas	CO_2	30.4	0.000	1.000
1A4a	Commercial/Institutional	Solid	N_2O	24.8	0.000	1.000
3C1b	Biomass burning in croplands		N_2O	21.9	0.000	1.000
2C5	Lead Production		CO_2	21.7	0.000	1.000
1B1a	Coal mining and handling		CO_2	20.8	0.000	1.000
3C1d	Biomass burning in wetlands		N_2O	13.8	0.000	1.000
1A4a	Commercial/Institutional	Liquid	CH_4	13.7	0.000	1.000
1A1a	Electricity and Heat Production	Liquid	N_2O	12.9	0.000	1.000
1A3a	Civil Aviation	Liquid	N_2O	11.8	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	N_2O	10.5	0.000	1.000

3C1d	Biomass burning in wetlands		CH_4	10.2	0.000	1.000
1A3d	Water-Borne Navigation	Liquid	N_2O	9.7	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	CH_4	7.6	0.000	1.000
1A2	Manufacturing Industries and Construction	Solid	CH_4	7.4	0.000	1.000
1A1a	Electricity and Heat Production	Liquid	CH_4	4.4	0.000	1.000
1A3a	Civil Aviation	Liquid	CH_4	4.0	0.000	1.000
1A2	Manufacturing Industries and Construction	Liquid	N_2O	4.0	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	CH_4	3.6	0.000	1.000
1A5a	Stationary	Liquid	N_2O	3.2	0.000	1.000
2C2	Ferroalloys Production		CH_4	3.1	0.000	1.000
1A3d	Water-Borne Navigation	Liquid	CH_4	3.1	0.000	1.000
2B	Chemical industry		C	C	0.000	1.000
2D2	Paraffin Wax Use		CO_2	2.7	0.000	1.000
1A4b	Residential	Liquid	N_2O	2.4	0.000	1.000
3C1e	Biomass burning in settlements		N_2O	2.1	0.000	1.000
1A2	Manufacturing Industries and Construction	Gas	N_2O	2.1	0.000	1.000
1A1b	Petroleum Refining	Solid	N_2O	1.8	0.000	1.000
3C1e	Biomass burning in settlements		CH_4	1.6	0.000	1.000
1A2	Manufacturing Industries and Construction	Gas	CH_4	1.4	0.000	1.000
1A2	Manufacturing Industries and Construction	Liquid	CH_4	1.3	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	N_2O	1.3	0.000	1.000
1A1b	Petroleum Refining	Gas	N_2O	1.2	0.000	1.000
1A5a	Stationary	Liquid	CH_4	1.1	0.000	1.000

1A4b	Residential	Liquid	CH_4	1.0	0.000	1.000
3A2c	Manure management - sheep		CH_4	0.9	0.000	1.000
1A1b	Petroleum Refining	Gas	CH_4	0.8	0.000	1.000
3A2d	Manure management - goats		CH_4	0.8	0.000	1.000
1A1b	Petroleum Refining	Solid	CH_4	0.6	0.000	1.000
1A4a	Commercial/Institutional	Solid	CH_4	0.6	0.000	1.000
1A3c	Railways	Liquid	CH_4	0.5	0.000	1.000
1A1b	Petroleum Refining	Liquid	N_2O	0.4	0.000	1.000
1A1b	Petroleum Refining	Liquid	CH_4	0.1	0.000	1.000
3A2f	Manure management - horses		CH_4	0.1	0.000	1.000
2B	Chemical industry		C	C	0.000	1.000
1A3b	Road Transport	Gas	N_2O	0.0	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	CH_4	0.0	0.000	1.000
1A3b	Road Transport	Gas	CH_4	0.0	0.000	1.000
1A4a	Commercial/Institutional	Gas	N_2O	0.0	0.000	1.000
3A2g	Manure management - mules and asses		CH_4	0.0	0.000	1.000
1A4a	Commercial/Institutional	Gas	CH_4	0.0	0.000	1.000
1A1a	Electricity and Heat Production	Gas	CO_2	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	CO_2	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	CO_2	0.0	0.000	1.000
1A1a	Electricity and Heat Production	Gas	CH_4	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	CH_4	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	CH_4	0.0	0.000	1.000

1A1a	Electricity and Heat Production	Gas	N_2O	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	N_2O	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	N_2O	0.0	0.000	1.000
1A3a	Civil Aviation	Gas	CO_2	0.0	0.000	1.000
1A3c	Railways	Gas	CO_2	0.0	0.000	1.000
1A3d	Water-Borne Navigation	Gas	CO_2	0.0	0.000	1.000
1A3a	Civil Aviation	Gas	CH_4	0.0	0.000	1.000
1A3c	Railways	Gas	CH_4	0.0	0.000	1.000
1A3d	Water-Borne Navigation	Gas	CH_4	0.0	0.000	1.000
1A3a	Civil Aviation	Gas	N_2O	0.0	0.000	1.000
1A3c	Railways	Gas	N_2O	0.0	0.000	1.000
1A3d	Water-Borne Navigation	Gas	N_2O	0.0	0.000	1.000
1A5a	Stationary	Solid	CO_2	0.0	0.000	1.000
1A5a	Stationary	Solid	CH_4	0.0	0.000	1.000
1A5a	Stationary	Solid	N_2O	0.0	0.000	1.000
2F2	Foam Blowing Agents		HFCs	0.0	0.000	1.000
2F4	Aerosols		HFCs	0.0	0.000	1.000
3A1j	Enteric fermentation - other game		CH_4	0.0	0.000	1.000
3A2j	Manure management - other game		CH_4	0.0	0.000	1.000
3B4a	Wetland remaining wetland		CO_2	0.0	0.000	1.000
3B4b	Land converted to wetland		CO_2	0.0	0.000	1.000
3C1f	Biomass burning in other lands		CH_4	0.0	0.000	1.000
3C1f	Biomass burning in other lands		N_2O	0.0	0.000	1.000

C=Confidential data

Table A.3: Trend assessment on emissions excluding FOLU for South Africa (2000 - 2017) with the key categories highlighted in green.

IPCC Category code	IPCC Category	Fuel type	Greenhouse gas	2000 Ex,t (Gg CO_2 Eq)	2017 Ex,t (Gg CO_2 Eq)	Lx,t	Cumulative Total
1A3b	Road Transport	Liquid	CO_2	34 053.1	69 816.6	0.173	0.173
1A4b	Residential	Solid	CO_2	3 604.2	28 337.4	0.156	0.329
1A1a	Electricity and Heat Production	Solid	CO_2	185 027.4	218 959.2	0.117	0.446
1B3	Other Emissions from Energy Production		CO_2	28 146.6	25 746.5	0.068	0.513
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	CO_2	30 454.7	29 270.6	0.064	0.577
3A1a	Enteric fermentation - cattle		CH_4	23 344.7	21 589.7	0.054	0.631
3C4	Direct N2O emissions from managed soils		N_2O	20 072.5	18 081.0	0.050	0.681
1A4a	Commercial/Institutional	Liquid	CO_2	7 690.5	16 176.0	0.042	0.723
2C1	Iron and Steel Production		CO_2	16 410.5	15 074.3	0.039	0.762
1A2	Manufacturing Industries and Construction	Solid	CO_2	29 509.4	31 855.1	0.039	0.801
4A	Solid Waste Disposal		CH_4	10 533.9	17 366.0	0.026	0.826
2C2	Ferroalloys Production		CO_2	8 079.1	12 572.3	0.015	0.841
1A3a	Civil Aviation	Liquid	CO_2	2 040.0	4 539.7	0.013	0.854
1A4b	Chemical industry	Liquid	C	C	C	0.012	0.866
2B	Nitric Acid Production		N_2O	1 644.5	292.6	0.012	0.878
3A1c	Enteric fermentation - sheep		CH_4	3 800.5	3 214.6	0.011	0.888

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1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	CO_2	2 207.2	4 161.3	0.009	0.897
2C3	Aluminium Production		PFCs	983.2	2 453.4	0.008	0.905
1A2	Manufacturing Industries and Construction	Gas	CO_2	2 217.7	3 817.9	0.006	0.912
3C5	Indirect N2O emissions from managed soils		N_2O	2 463.3	2 236.3	0.006	0.918
1B3	Other Emissions from Energy Production		CH_4	2 318.6	2 183.9	0.005	0.923
1A1b	Petroleum Refining	Gas	CO_2	2 307.1	2 215.0	0.005	0.928
3C2	Liming		CO_2	384.1	1 222.1	0.005	0.932
1B1a	Coal mining and handling		CH_4	1 806.8	1 587.4	0.005	0.937
1A1b	Petroleum Refining	Liquid	CO_2	670.0	178.1	0.004	0.942
3C1c	Biomass burning in grasslands		N_2O	668.6	241.8	0.004	0.946
1A2	Manufacturing Industries and Construction	Liquid	CO_2	778.3	1 591.4	0.004	0.950
2A2	Lime Production		CO_2	441.4	1 045.3	0.003	0.953
3A1d	Enteric fermentation - goats		CH_4	906.2	709.2	0.003	0.956
3C1c	Biomass burning in grasslands		CH_4	508.9	204.8	0.003	0.959
1A1b	Petroleum Refining	Solid	CO_2	1 065.5	934.9	0.003	0.961
1A3b	Chemical industry	Liquid	C	C	C	0.003	0.964
2B	Titanium Dioxide Production		CO_2	437.6	152.4	0.003	0.967
2B	Chemical industry		C	C	C	0.002	0.969
2A1	Cement Production		CO_2	3 870.6	5 295.9	0.002	0.972
1A3d	Water-Borne Navigation	Liquid	CO_2	1 513.5	1 606.3	0.002	0.974
1B2a	Oil		CO_2	752.0	641.8	0.002	0.976
3C3	Urea application		CO_2	297.3	679.6	0.002	0.978
3C1a	Biomass burning in forest land		N_2O	287.0	98.2	0.002	0.980

1A3c	Railways	Liquid	CO_2	551.5	442.8	0.002	0.981
1A4a	Commercial/Institutional	Solid	CO_2	1 800.9	2 565.5	0.002	0.983
3C1a	Biomass burning in forest land		CH_4	270.6	107.2	0.002	0.985
3C1b	Biomass burning in croplands		CH_4	220.7	57.2	0.001	0.986
1A4b	Residential	Solid	CH_4	198.5	60.8	0.001	0.987
3A2a	Manure management - cattle		N_2O	844.1	889.5	0.001	0.989
3A2h	Manure management - swine		CH_4	487.7	438.6	0.001	0.990
1A4b	Residential	Solid	N_2O	424.0	381.4	0.001	0.991
1A3b	Road Transport	Liquid	CH_4	215.6	397.6	0.001	0.992
2C6	Zinc Production		CO_2	108.4	46.3	0.001	0.992
3C1b	Chemical industry		C	C	C	0.001	0.993
1A1a	Electricity and Heat Production	Solid	N_2O	893.9	1 057.8	0.001	0.993
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	CO_2	171.5	135.0	0.001	0.994
2B	Ammonia Production		CH_4	65.6	167.2	0.001	0.995
2C3	Aluminium Production		CO_2	1 091.3	1 322.5	0.000	0.995
1A3b	Road Transport	Gas	CO_2	3.4	70.7	0.000	0.995
1A5a	Chemical industry	Liquid	C	C	C	0.000	0.996
3C6	Indirect N2O emissions from manure management		N_2O	408.9	469.3	0.000	0.996
3A2c	Manure management - sheep		N_2O	122.5	103.6	0.000	0.997
2B	Petrochemical and Carbon Black Production		CO_2	138.6	127.2	0.000	0.997
3A2a	Manure management - cattle		CH_4	230.3	245.0	0.000	0.997
3A2i	Manure management - poultry		N_2O	466.5	641.3	0.000	0.998
1A3c	Railways	Liquid	N_2O	66.0	47.0	0.000	0.998

2D1	Lubricant Use		CO_2	188.5	272.9	0.000	0.998
1A2	Manufacturing Industries and Construction	Solid	N_2O	141.5	151.8	0.000	0.998
2C5	Lead Production		CO_2	39.2	21.7	0.000	0.998
2A3	Glass Production		CO_2	74.4	120.9	0.000	0.999
3A2d	Manure management - goats		N_2O	46.4	36.3	0.000	0.999
3C1e	Biomass burning in settlements		N_2O	15.1	2.1	0.000	0.999
3A1h	Enteric fermentation - swine		CH_4	43.5	39.1	0.000	0.999
1A4a	Commercial/Institutional	Liquid	N_2O	19.1	40.4	0.000	0.999
3A2h	Manure management - swine		N_2O	41.3	37.1	0.000	0.999
3C1e	Biomass burning in settlements		CH_4	11.2	1.6	0.000	0.999
3C1d	Biomass burning in wetlands		N_2O	20.2	13.8	0.000	0.999
4D1	Wastewater Treatment and Discharge		CH_4	2 144.1	2 753.3	0.000	0.999
3A1g	Enteric fermentation - mules and asses		CH_4	34.4	34.2	0.000	0.999
1B1a	Coal mining and handling		CO_2	23.7	20.8	0.000	0.999
3C1d	Biomass burning in wetlands		CH_4	15.0	10.2	0.000	1.000
3A1f	Enteric fermentation - horses		CH_4	102.1	122.0	0.000	1.000
2D2	Paraffin Wax Use		CO_2	7.4	2.7	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	CH_4	10.6	7.6	0.000	1.000
1A4a	Commercial/Institutional	Liquid	CH_4	6.5	13.7	0.000	1.000
1A3a	Civil Aviation	Liquid	N_2O	5.3	11.8	0.000	1.000
1A4b	Residential	Liquid	N_2O	5.4	2.4	0.000	1.000
3A2i	Manure management - poultry		CH_4	43.1	59.2	0.000	1.000
1A1a	Electricity and Heat Production	Solid	CH_4	40.4	47.8	0.000	1.000

1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	N_2O	5.6	10.5	0.000	1.000
4D1	Wastewater Treatment and Discharge		N_2O	599.3	769.6	0.000	1.000
1A4a	Commercial/Institutional	Solid	N_2O	17.4	24.8	0.000	1.000
1A3d	Water-Borne Navigation	Liquid	N_2O	9.1	9.7	0.000	1.000
1A3a	Civil Aviation	Liquid	CH_4	1.8	4.0	0.000	1.000
1A1b	Petroleum Refining	Liquid	N_2O	1.6	0.4	0.000	1.000
1A4b	Residential	Liquid	CH_4	2.0	1.0	0.000	1.000
1A2	Manufacturing Industries and Construction	Liquid	N_2O	1.9	4.0	0.000	1.000
2C2	Ferroalloys Production		CH_4	3.3	3.1	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	CH_4	1.9	3.6	0.000	1.000
1A2	Manufacturing Industries and Construction	Solid	CH_4	6.7	7.4	0.000	1.000
4C2	Open Burning of Waste		CH_4	187.5	240.7	0.000	1.000
1A1b	Petroleum Refining	Solid	N_2O	2.0	1.8	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	N_2O	1.7	1.3	0.000	1.000
1A4a	Commercial/Institutional	Gas	CO_2	23.2	30.4	0.000	1.000
1A3d	Water-Borne Navigation	Liquid	CH_4	2.9	3.1	0.000	1.000
1A1b	Petroleum Refining	Liquid	CH_4	0.5	0.1	0.000	1.000
1A2	Manufacturing Industries and Construction	Gas	N_2O	1.2	2.1	0.000	1.000
3A2d	Manure management - goats		CH_4	1.0	0.8	0.000	1.000
1A2	Manufacturing Industries and Construction	Liquid	CH_4	0.7	1.3	0.000	1.000
3A2c	Manure management - sheep		CH_4	1.0	0.9	0.000	1.000
1A1b	Petroleum Refining	Gas	N_2O	1.2	1.2	0.000	1.000
1A2	Manufacturing Industries and Construction	Gas	CH_4	0.8	1.4	0.000	1.000

1A3c	Railways	Liquid	CH_4	0.6	0.5	0.000	1.000
4C2	Open Burning of Waste		N_2O	63.9	82.0	0.000	1.000
2B	Chemical industry		C	C	C	0.000	1.000
1A1b	Petroleum Refining	Solid	CH_4	0.7	0.6	0.000	1.000
1A1b	Petroleum Refining	Gas	CH_4	0.8	0.8	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	N_2O	110.3	141.4	0.000	1.000
1A5a	Stationary	Liquid	N_2O	2.6	3.2	0.000	1.000
4C2	Open Burning of Waste		CO_2	29.2	37.5	0.000	1.000
1A3b	Road Transport	Gas	CH_4	0.1	0.0	0.000	1.000
1A4a	Commercial/Institutional	Solid	CH_4	0.4	0.6	0.000	1.000
1A5a	Chemical industry	Liquid	C	C	C	0.000	1.000
1A3b	Road Transport	Gas	N_2O	0.0	0.0	0.000	1.000
2B	Petrochemical and Carbon Black Production		CH_4	0.1	0.1	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	CH_4	0.0	0.0	0.000	1.000
3A2f	Manure management - horses		CH_4	0.1	0.1	0.000	1.000
3A2g	Manure management - mules and asses		CH_4	0.0	0.0	0.000	1.000
1A4a	Commercial/Institutional	Gas	N_2O	0.0	0.0	0.000	1.000
1A4a	Commercial/Institutional	Gas	CH_4	0.0	0.0	0.000	1.000
1A1a	Electricity and Heat Production	Liquid	CO_2	0.0	5 166.7	0.000	1.000
1A1a	Electricity and Heat Production	Gas	CO_2	0.0	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	CO_2	0.0	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	CO_2	0.0	0.0	0.000	1.000
1A1a	Electricity and Heat Production	Liquid	CH_4	0.0	4.4	0.000	1.000

1A1a	Electricity and Heat Production	Gas	CH_4	0.0	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	CH_4	0.0	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	CH_4	0.0	0.0	0.000	1.000
1A1a	Electricity and Heat Production	Liquid	N_2O	0.0	12.9	0.000	1.000
1A1a	Electricity and Heat Production	Gas	N_2O	0.0	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	N_2O	0.0	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	N_2O	0.0	0.0	0.000	1.000
1A3a	Civil Aviation	Gas	CO_2	0.0	0.0	0.000	1.000
1A3c	Railways	Gas	CO_2	0.0	0.0	0.000	1.000
1A3d	Water-Borne Navigation	Gas	CO_2	0.0	0.0	0.000	1.000
1A3a	Civil Aviation	Gas	CH_4	0.0	0.0	0.000	1.000
1A3c	Railways	Gas	CH_4	0.0	0.0	0.000	1.000
1A3d	Water-Borne Navigation	Gas	CH_4	0.0	0.0	0.000	1.000
1A3a	Civil Aviation	Gas	N_2O	0.0	0.0	0.000	1.000
1A3c	Railways	Gas	N_2O	0.0	0.0	0.000	1.000
1A3d	Water-Borne Navigation	Gas	N_2O	0.0	0.0	0.000	1.000
1A5a	Stationary	Solid	CO_2	0.0	0.0	0.000	1.000
1A5a	Stationary	Solid	CH_4	0.0	0.0	0.000	1.000
1A5a	Stationary	Solid	N_2O	0.0	0.0	0.000	1.000
2F1	Refrigeration and Air Conditioning		HFCs	0.0	3 963.5	0.000	1.000
2F2	Foam Blowing Agents		HFCs	0.0	0.0	0.000	1.000
2F3	Fire Protection		HFCs	0.0	51.1	0.000	1.000
2F4	Aerosols		HFCs	0.0	0.0	0.000	1.000

3A1j	Enteric fermentation - other game		CH_4	0.0	0.0	0.000	1.000
3A2j	Manure management - other game		CH_4	0.0	0.0	0.000	1.000
3C1f	Biomass burning in other lands		CH_4	0.0	0.0	0.000	1.000
3C1f	Biomass burning in other lands		N_2O	0.0	0.0	0.000	1.000

C=Confidential data

Table A.4: Trend assessment on emissions including FOLU for South Africa (2000 - 2017) with the key categories highlighted in green.

IPCC Category code	IPCC Category	Fuel type	Greenhouse gas	2000 Ex,t (Gg CO_2 Eq)	2017 Ex,t (Gg CO_2 Eq)	Lx,t	Cumulative Total
1A3b	Road Transport	Liquid	CO_2	34 053.1	69 816.6	0.153	0.153
1A4b	Residential	Solid	CO_2	3 604.2	28 337.4	0.133	0.286
3B1a	Forest land remaining forest land - Net CO2		CO_2	1 633.2	-14 093.6	0.090	0.376
3B1b	Land converted to forest land - Net CO2		CO_2	-20 846.1	-26 613.8	0.060	0.436
1A1a	Electricity and Heat Production	Solid	CO_2	185 027.4	218 959.2	0.060	0.496
1B3	Other Emissions from Energy Production		CO_2	28 146.6	25 746.5	0.051	0.547
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	CO_2	30 454.7	29 270.6	0.048	0.595
3A1a	Enteric fermentation - cattle		CH_4	23 344.7	21 589.7	0.041	0.636
3C4	Direct N2O emissions from managed soils		N_2O	20 072.5	18 081.0	0.038	0.674
1A4a	Commercial/Institutional	Liquid	CO_2	7 690.5	16 176.0	0.037	0.711
2C1	Iron and Steel Production		CO_2	16 410.5	15 074.3	0.030	0.741
1A2	Manufacturing Industries and Construction	Solid	CO_2	29 509.4	31 855.1	0.027	0.767

3B3b	Land converted to grassland - Net CO2		CO_2	-17 631.1	-17 662.3	0.024	0.791
4A	Solid Waste Disposal		CH_4	10 533.9	17 366.0	0.024	0.815
3B6b	Land converted to other lands - Net CO2		CO_2	16 044.8	16 044.8	0.022	0.837
2C2	Ferroalloys Production		CO_2	8 079.1	12 572.3	0.014	0.851
1A3a	Civil Aviation	Liquid	CO_2	2 040.0	4 539.7	0.011	0.862
2B	Chemical industry		C	C	C	0.010	0.872
1A4b	Residential	Liquid	CO_2	2 868.9	1 829.2	0.010	0.881
3A1c	Enteric fermentation - sheep		CH_4	3 800.5	3 214.6	0.008	0.890
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	CO_2	2 207.2	4 161.3	0.008	0.898
2C3	Aluminium Production		PFCs	983.2	2 453.4	0.007	0.905
1A2	Manufacturing Industries and Construction	Gas	CO_2	2 217.7	3 817.9	0.006	0.910
3C5	Indirect N2O emissions from managed soils		N_2O	2 463.3	2 236.3	0.005	0.915
3C2	Liming		CO_2	384.1	1 222.1	0.004	0.919
1B3	Other Emissions from Energy Production		CH_4	2 318.6	2 183.9	0.004	0.923
1B1a	Coal mining and handling		CH_4	1 806.8	1 587.4	0.004	0.927
1A1b	Petroleum Refining	Liquid	CO_2	670.0	178.1	0.004	0.930
1A1b	Petroleum Refining	Gas	CO_2	2 307.1	2 215.0	0.004	0.934
1A2	Manufacturing Industries and Construction	Liquid	CO_2	778.3	1 591.4	0.003	0.937
3B2a	Cropland remaining cropland - Net CO2		CO_2	-1 569.4	-1 793.0	0.003	0.941
3C1c	Biomass burning in grasslands		N_2O	668.6	241.8	0.003	0.944
3B2b	Land converted to cropland - Net CO2		CO_2	2 337.6	2 321.3	0.003	0.947
3D1	Harvested wood products		CO_2	-290.4	-776.9	0.003	0.950
3B5a	Settlements remaining settlements - Net CO2		CO_2	-245.4	-686.2	0.003	0.953

2A2	Lime Production		CO_2	441.4	1 045.3	0.003	0.956
2A1	Cement Production		CO_2	3 870.6	5 295.9	0.003	0.959
3B3a	Grassland remaining grassland - Net CO2		CO_2	-1 272.6	-510.3	0.003	0.961
1A3b	Road Transport	Liquid	N_2O	515.1	1 066.8	0.002	0.964
3C1c	Biomass burning in grasslands		CH_4	508.9	204.8	0.002	0.966
3A1d	Enteric fermentation - goats		CH_4	906.2	709.2	0.002	0.968
2B	Chemical industry		C	C	C	0.002	0.970
1A1b	Petroleum Refining	Solid	CO_2	1 065.5	934.9	0.002	0.973
2B	Chemical industry		C	C	C	0.002	0.975
1A4a	Commercial/Institutional	Solid	CO_2	1 800.9	2 565.5	0.002	0.977
3C3	Urea application		CO_2	297.3	679.6	0.002	0.978
1B2a	Oil		CO_2	752.0	641.8	0.002	0.980
1A3d	Water-Borne Navigation	Liquid	CO_2	1 513.5	1 606.3	0.002	0.981
3C1a	Biomass burning in forest land		N_2O	287.0	98.2	0.001	0.983
1A3c	Railways	Liquid	CO_2	551.5	442.8	0.001	0.984
3C1a	Biomass burning in forest land		CH_4	270.6	107.2	0.001	0.985
3B5b	Land converted to settlements - Net CO2		CO_2	644.9	580.3	0.001	0.987
3C1b	Biomass burning in croplands		CH_4	220.7	57.2	0.001	0.988
1A4b	Residential	Solid	CH_4	198.5	60.8	0.001	0.989
3A2h	Manure management - swine		CH_4	487.7	438.6	0.001	0.990
3B4	Wetland		CH_4	666.6	666.6	0.001	0.991
3A2a	Manure management - cattle		N_2O	844.1	889.5	0.001	0.992
1A4b	Residential	Solid	N_2O	424.0	381.4	0.001	0.992

1A3b	Road Transport	Liquid	CH_4	215.6	397.6	0.001	0.993
4D1	Wastewater Treatment and Discharge		CH_4	2 144.1	2 753.3	0.001	0.994
2C6	Zinc Production		CO_2	108.4	46.3	0.000	0.994
2B	Chemical industry		C	C	C	0.000	0.995
3C1b	Biomass burning in croplands		N_2O	84.5	21.9	0.000	0.995
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	CO_2	171.5	135.0	0.000	0.996
1A3b	Road Transport	Gas	CO_2	3.4	70.7	0.000	0.996
3A2i	Manure management - poultry		N_2O	466.5	641.3	0.000	0.996
1A1a	Electricity and Heat Production	Solid	N_2O	893.9	1 057.8	0.000	0.997
3A2c	Manure management - sheep		N_2O	122.5	103.6	0.000	0.997
2B	Chemical industry		C	C	C	0.000	0.997
3A2a	Manure management - cattle		CH_4	230.3	245.0	0.000	0.997
2D1	Lubricant Use		CO_2	188.5	272.9	0.000	0.997
3C6	Indirect N2O emissions from manure management		N_2O	408.9	469.3	0.000	0.998
1A3c	Railways	Liquid	N_2O	66.0	47.0	0.000	0.998
2C3	Aluminium Production		CO_2	1 091.3	1 322.5	0.000	0.998
2A3	Glass Production		CO_2	74.4	120.9	0.000	0.998
2C5	Lead Production		CO_2	39.2	21.7	0.000	0.998
4D1	Wastewater Treatment and Discharge		N_2O	599.3	769.6	0.000	0.999
1A5a	Stationary	Liquid	CO_2	985.6	1 199.3	0.000	0.999
1A2	Manufacturing Industries and Construction	Solid	N_2O	141.5	151.8	0.000	0.999
3A2d	Manure management - goats		N_2O	46.4	36.3	0.000	0.999
1A4a	Commercial/Institutional	Liquid	N_2O	19.1	40.4	0.000	0.999

3C1e	Biomass burning in settlements		N_2O	15.1	2.1	0.000	0.999
3A1h	Enteric fermentation - swine		CH_4	43.5	39.1	0.000	0.999
3A2h	Manure management - swine		N_2O	41.3	37.1	0.000	0.999
3C1e	Biomass burning in settlements		CH_4	11.2	1.6	0.000	0.999
3C1d	Biomass burning in wetlands		N_2O	20.2	13.8	0.000	0.999
1B1a	Coal mining and handling		CO_2	23.7	20.8	0.000	0.999
3A1g	Enteric fermentation - mules and asses		CH_4	34.4	34.2	0.000	0.999
3C1d	Biomass burning in wetlands		CH_4	15.0	10.2	0.000	1.000
4C2	Open Burning of Waste		CH_4	187.5	240.7	0.000	1.000
2D2	Paraffin Wax Use		CO_2	7.4	2.7	0.000	1.000
3A2i	Manure management - poultry		CH_4	43.1	59.2	0.000	1.000
1A4a	Commercial/Institutional	Liquid	CH_4	6.5	13.7	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	CH_4	10.6	7.6	0.000	1.000
1A3a	Civil Aviation	Liquid	N_2O	5.3	11.8	0.000	1.000
3A1f	Enteric fermentation - horses		CH_4	102.1	122.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	N_2O	110.3	141.4	0.000	1.000
1A4b	Residential	Liquid	N_2O	5.4	2.4	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	N_2O	5.6	10.5	0.000	1.000
1A4a	Commercial/Institutional	Solid	N_2O	17.4	24.8	0.000	1.000
4C2	Open Burning of Waste		N_2O	63.9	82.0	0.000	1.000
1A1a	Electricity and Heat Production	Solid	CH_4	40.4	47.8	0.000	1.000
1A3a	Civil Aviation	Liquid	CH_4	1.8	4.0	0.000	1.000
1A3d	Water-Borne Navigation	Liquid	N_2O	9.1	9.7	0.000	1.000

1A1b	Petroleum Refining	Liquid	N_2O	1.6	0.4	0.000	1.000
1A2	Manufacturing Industries and Construction	Liquid	N_2O	1.9	4.0	0.000	1.000
1A4a	Commercial/Institutional	Gas	CO_2	23.2	30.4	0.000	1.000
1A4b	Residential	Liquid	CH_4	2.0	1.0	0.000	1.000
4C2	Open Burning of Waste		CO_2	29.2	37.5	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	CH_4	1.9	3.6	0.000	1.000
2C2	Ferroalloys Production		CH_4	3.3	3.1	0.000	1.000
1A2	Manufacturing Industries and Construction	Solid	CH_4	6.7	7.4	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	N_2O	1.7	1.3	0.000	1.000
1A1b	Petroleum Refining	Solid	N_2O	2.0	1.8	0.000	1.000
1A2	Manufacturing Industries and Construction	Gas	N_2O	1.2	2.1	0.000	1.000
1A1b	Petroleum Refining	Liquid	CH_4	0.5	0.1	0.000	1.000
1A2	Manufacturing Industries and Construction	Liquid	CH_4	0.7	1.3	0.000	1.000
1A3d	Water-Borne Navigation	Liquid	CH_4	2.9	3.1	0.000	1.000
3A2d	Manure management - goats		CH_4	1.0	0.8	0.000	1.000
3A2c	Manure management - sheep		CH_4	1.0	0.9	0.000	1.000
1A2	Manufacturing Industries and Construction	Gas	CH_4	0.8	1.4	0.000	1.000
2B	Chemical industry		C	C	C	0.000	1.000
1A1b	Petroleum Refining	Gas	N_2O	1.2	1.2	0.000	1.000
1A3c	Railways	Liquid	CH_4	0.6	0.5	0.000	1.000
1A1b	Petroleum Refining	Solid	CH_4	0.7	0.6	0.000	1.000
1A1b	Petroleum Refining	Gas	CH_4	0.8	0.8	0.000	1.000
1A4a	Commercial/Institutional	Solid	CH_4	0.4	0.6	0.000	1.000

1A5a	Stationary	Liquid	N_2O	2.6	3.2	0.000	1.000
1A3b	Road Transport	Gas	CH_4	0.1	0.0	0.000	1.000
1A3b	Road Transport	Gas	N_2O	0.0	0.0	0.000	1.000
1A5a	Stationary	Liquid	CH_4	0.9	1.1	0.000	1.000
2B	Chemical industry		C	C	C	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	CH_4	0.0	0.0	0.000	1.000
3A2g	Manure management - mules and asses		CH_4	0.0	0.0	0.000	1.000
3A2f	Manure management - horses		CH_4	0.1	0.1	0.000	1.000
1A4a	Commercial/Institutional	Gas	N_2O	0.0	0.0	0.000	1.000
1A4a	Commercial/Institutional	Gas	CH_4	0.0	0.0	0.000	1.000
1A1a	Electricity and Heat Production	Liquid	CO_2	0.0	5 166.7	0.000	1.000
1A1a	Electricity and Heat Production	Gas	CO_2	0.0	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	CO_2	0.0	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	CO_2	0.0	0.0	0.000	1.000
1A1a	Electricity and Heat Production	Liquid	CH_4	0.0	4.4	0.000	1.000
1A1a	Electricity and Heat Production	Gas	CH_4	0.0	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	CH_4	0.0	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	CH_4	0.0	0.0	0.000	1.000
1A1a	Electricity and Heat Production	Liquid	N_2O	0.0	12.9	0.000	1.000
1A1a	Electricity and Heat Production	Gas	N_2O	0.0	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	N_2O	0.0	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	N_2O	0.0	0.0	0.000	1.000
1A3a	Civil Aviation	Gas	CO_2	0.0	0.0	0.000	1.000

1A3c	Railways	Gas	CO_2	0.0	0.0	0.000	1.000
1A3d	Water-Borne Navigation	Gas	CO_2	0.0	0.0	0.000	1.000
1A3a	Civil Aviation	Gas	CH_4	0.0	0.0	0.000	1.000
1A3c	Railways	Gas	CH_4	0.0	0.0	0.000	1.000
1A3d	Water-Borne Navigation	Gas	CH_4	0.0	0.0	0.000	1.000
1A3a	Civil Aviation	Gas	N_2O	0.0	0.0	0.000	1.000
1A3c	Railways	Gas	N_2O	0.0	0.0	0.000	1.000
1A3d	Water-Borne Navigation	Gas	N_2O	0.0	0.0	0.000	1.000
1A5a	Stationary	Solid	CO_2	0.0	0.0	0.000	1.000
1A5a	Stationary	Solid	CH_4	0.0	0.0	0.000	1.000
1A5a	Stationary	Solid	N_2O	0.0	0.0	0.000	1.000
2F1	Refrigeration and Air Conditioning		HFCs	0.0	3 963.5	0.000	1.000
2F2	Foam Blowing Agents		HFCs	0.0	0.0	0.000	1.000
2F3	Fire Protection		HFCs	0.0	51.1	0.000	1.000
2F4	Aerosols		HFCs	0.0	0.0	0.000	1.000
3A1j	Enteric fermentation - other game		CH_4	0.0	0.0	0.000	1.000
3A2j	Manure management - other game		CH_4	0.0	0.0	0.000	1.000
3B4a	Wetland remaining wetland		CO_2	0.0	0.0	0.000	1.000
3B4b	Land converted to wetland		CO_2	0.0	0.0	0.000	1.000
3C1f	Biomass burning in other lands		CH_4	0.0	0.0	0.000	1.000
3C1f	Biomass burning in other lands		N_2O	0.0	0.0	0.000	1.000

C=Confidential data

environment, forestry & fisheries

Department:
Environment, Forestry and Fisheries
REPUBLIC OF SOUTH AFRICA

Appendix 1.B Uncertainty analysis

Table B.1: Overall uncertainty analysis for 2000 to 2017.

IPCC Category		Gas	Base year emissions/ removals (2000)	Year t emissions/ removals (2017)	Activity data uncertainty		Emission factor/estimation parameter uncertainty		Combined uncertainty		Contribution to variance in Year t	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
			Gg CO2e	Gg CO2e	(-)%	(+)%	(-)%	(+)%	(-)%	(+)%	(fraction)	%	%	%
1A1a	Electricity and Heat Production	CO_2	185 027.4	224 125.9	3	5	7	7	7.62	8.60	13.13	0.09	3.70	13.68
1A1b	Petroleum Refining	CO_2	4 042.6	3 328.0	3	5	7	7	7.62	8.60	0.00	0.03	0.05	0.00
1A1c	Manufacture of Solid Fuels and Other Energy Industries	CO_2	30 454.7	29 270.6	3	5	7	7	7.62	8.60	0.22	0.14	0.48	0.25
1A1a	Electricity and Heat Production	CH_4	40.4	52.1	3	5	75	75	75.06	75.17	0.00	0.00	0.00	0.00
1A1b	Petroleum Refining	CH_4	2.1	1.6	3	5	75	75	75.06	75.17	0.00	0.00	0.00	0.00
1A1c	Manufacture of Solid Fuels and Other Energy Industries	CH_4	10.6	7.6	3	5	75	75	75.06	75.17	0.00	0.00	0.00	0.00

1A1a	Electricity and Heat Production	N_2O	893.9	1 070.7	3	5	75	75	75.06	75.17	0.02	0.01	0.02	0.00
1A1b	Petroleum Refining	N_2O	4.9	3.4	3	5	75	75	75.06	75.17	0.00	0.00	0.00	0.00
1A1c	Manufacture of Solid Fuels and Other Energy Industries	N_2O	110.3	141.4	3	5	75	75	75.06	75.17	0.00	0.00	0.00	0.00
1A2	Manufacturing Industries and Construction	CO_2	32 505.4	37 264.4	5	10	7	7	8.60	12.21	0.73	0.05	1.23	1.51
1A2	Manufacturing Industries and Construction	CH_4	8.2	10.2	5	10	75	75	75.17	75.66	0.00	0.00	0.00	0.00
1A2	Manufacturing Industries and Construction	N_2O	144.7	157.9	5	10	75	75	75.17	75.66	0.00	0.00	0.01	0.00
1A3a	Civil Aviation	CO_2	2 040.0	4 539.7	5	5	1.5	1.5	5.22	5.22	0.00	0.01	0.07	0.01
1A3b	Road Transport	CO_2	34 056.5	69 887.3	5	5	2	2	5.39	5.39	0.50	0.13	1.15	1.35
1A3c	Railways	CO_2	551.5	442.8	5	5	2	2	5.39	5.39	0.00	0.00	0.01	0.00
1A3d	Water-Borne Navigation	CO_2	1 513.5	1 606.3	5	5	3	3	5.83	5.83	0.00	0.00	0.03	0.00
1A3a	Civil Aviation	CH_4	1.8	4.0	5	5	70	50	70.18	50.25	0.00	0.00	0.00	0.00
1A3b	Road Transport	CH_4	215.7	397.6	5	5	9	9	10.30	10.30	0.00	0.00	0.01	0.00
1A3c	Railways	CH_4	0.6	0.5	5	5	9	9	10.30	10.30	0.00	0.00	0.00	0.00
1A3d	Water-Borne Navigation	CH_4	2.9	3.1	5	5	50	50	50.25	50.25	0.00	0.00	0.00	0.00
1A3a	Civil Aviation	N_2O	5.3	11.8	5	5	70	50	70.18	50.25	0.00	0.00	0.00	0.00
1A3b	Road Transport	N_2O	515.1	1 066.8	5	5	70	72	70.18	72.17	0.02	0.07	0.02	0.01
1A3c	Railways	N_2O	66.0	47.0	5	5	70	72	70.18	72.17	0.00	0.01	0.00	0.00
1A3d	Water-Borne Navigation	N_2O	9.1	9.7	5	5	40	140	40.31	140.09	0.00	0.00	0.00	0.00
1A4a	Commercial/Institutional	CO_2	9 514.6	18 771.9	5	10	7	7	8.60	12.21	0.19	0.11	0.62	0.40

1A4b	Residential	CO_2	6 473.1	30 166.6	5	10	7	7	8.60	12.21	0.48	0.36	1.00	1.12
1A4c	Agriculture/Forestry/Fishing/ Fish Farms	CO_2	2 378.7	4 296.4	5	10	7	7	8.60	12.21	0.01	0.02	0.14	0.02
1A4a	Commercial/Institutional	CH_4	6.9	14.3	5	10	75	75	75.17	75.66	0.00	0.00	0.00	0.00
1A4b	Residential	CH_4	200.5	61.8	5	10	75	75	75.17	75.66	0.00	0.03	0.00	0.00
1A4c	Agriculture/Forestry/Fishing/ Fish Farms	CH_4	1.9	3.6	5	10	75	75	75.17	75.66	0.00	0.00	0.00	0.00
1A4a	Commercial/Institutional	N_2O	36.6	65.2	5	10	75	75	75.17	75.66	0.00	0.00	0.00	0.00
1A4b	Residential	N_2O	429.4	383.7	5	10	75	75	75.17	75.66	0.00	0.03	0.01	0.00
1A4c	Agriculture/Forestry/Fishing/ Fish Farms	N_2O	7.2	11.8	5	10	75	75	75.17	75.66	0.00	0.00	0.00	0.00
1A5a	Stationary	CO_2	985.6	1 199.3	3	5	7	7	7.62	8.60	0.00	0.00	0.02	0.00
1A5a	Stationary	CH_4	0.9	1.1	3	5	75	75	75.06	75.17	0.00	0.00	0.00	0.00
1A5a	Stationary	N_2O	2.6	3.2	3	5	75	75	75.06	75.17	0.00	0.00	0.00	0.00
1B1a	Coal mining and handling	CO_2	23.7	20.8	10	10	63	63	63.79	63.79	0.00	0.00	0.00	0.00
1B1a	Coal mining and handling	CH_4	1 806.8	1 587.4	10	10	63	63	63.79	63.79	0.04	0.10	0.05	0.01
1B2a	Oil	CO_2	752.0	641.8	25	25	75	75	79.06	79.06	0.01	0.05	0.05	0.01
1B3	Other Emissions from Energy Production	CO_2	28 146.6	25 746.5	25	25	75	75	79.06	79.06	14.63	1.61	2.12	7.10
1B3	Other Emissions from Energy Production	CH_4	2 318.6	2 183.9	25	25	75	75	79.06	79.06	0.11	0.12	0.18	0.05
2A1	Cement Production	CO_2	3 870.6	5 295.9	30	30	4.5	4.5	30.34	30.34	0.09	0.01	0.52	0.27
2A2	Lime Production	CO_2	441.4	1 045.3	30	30	6	6	30.59	30.59	0.00	0.01	0.10	0.01
2A3	Glass Production	CO_2	74.4	120.9	5	5	60	60	60.21	60.21	0.00	0.00	0.00	0.00
2B1	Ammonia Production	CO_2	485.3	241.4	5	5	6	6	7.81	7.81	0.00	0.01	0.00	0.00

2B1	Ammonia Production	CH_4	C	C	5	5	6	6	7.81	7.81	0.00	0.00	0.00	0.00
2B2	Nitric Acid Production	N_2O	C	C	2	2	10	10	10.20	10.20	0.00	0.04	0.00	0.00
2B5	Carbide Production	CO_2	C	C	5	5	10	10	11.18	11.18	0.00	0.00	0.00	0.00
2B6	Titanium Dioxide Production	CO_2	C	C	5	5	10	10	11.18	11.18	0.00	0.01	0.00	0.00
2B8	Petrochemical and Carbon Black Production	CO_2	C	C	10	10	85	85	85.59	85.59	0.00	0.01	0.00	0.00
2B8	Petrochemical and Carbon Black Production	CH_4	C	C	10	10	85	85	85.59	85.59	0.00	0.00	0.00	0.00
2C1	Iron and Steel Production	CO_2	16 410.5	15 074.3	5	5	10	10	11.18	11.18	0.10	0.12	0.25	0.08
2C2	Ferroalloys Production	CO_2	8 079.1	12 572.3	5	5	10	10	11.18	11.18	0.07	0.06	0.21	0.05
2C2	Ferroalloys Production	CH_4	3.3	3.1	5	5	25	25	25.50	25.50	0.00	0.00	0.00	0.00
2C3	Aluminium Production	CO_2	1 091.3	1 322.5	5	5	10	10	11.18	11.18	0.00	0.00	0.02	0.00
2C3	Aluminium Production	PFCs	983.2	2 453.4	5	5	24	24	24.52	24.52	0.01	0.07	0.04	0.01
2C5	Lead Production	CO_2	39.2	21.7	5	5	15	15	15.81	15.81	0.00	0.00	0.00	0.00
2C6	Zinc Production	CO_2	108.4	46.3	10	10	50	50	50.99	50.99	0.00	0.01	0.00	0.00
2D1	Lubricant Use	CO_2	188.5	272.9	10	10	50	50	50.99	50.99	0.00	0.00	0.01	0.00
2D2	Paraffin Wax Use	CO_2	7.4	2.7	10	10	50	50	50.99	50.99	0.00	0.00	0.00	0.00
2F1	Refrigeration and Air Conditioning	HFC	0.0	3 963.5	25	25	25	25	35.36	35.36	0.07	0.23	0.33	0.16
2F2	Foam Blowing Agents	HFC	0.0	0.0	25	25	25	25	35.36	35.36	0.00	0.00	0.00	0.00
2F3	Fire Protection	HFC	0.0	51.1	25	25	25	25	35.36	35.36	0.00	0.00	0.00	0.00
2F4	Aerosols	HFC	0.0	0.0	25	25	25	25	35.36	35.36	0.00	0.00	0.00	0.00
3A1a	Enteric fermentation - cattle	CH_4	23 344.7	21 589.7	5.1	20.62	20	20	20.64	28.72	1.36	0.34	1.47	2.28

3A1c	Enteric fermentation - sheep	CH_4	3 800.5	3 214.6	11.2	20.62	20	20	22.91	28.72	0.03	0.07	0.22	0.05
3A1d	Enteric fermentation - goats	CH_4	906.2	709.2	11.2	20.62	20	20	22.91	28.72	0.00	0.02	0.05	0.00
3A1f	Enteric fermentation - horses	CH_4	102.1	122.0	11.2	11.18	30	50	32.02	51.23	0.00	0.00	0.00	0.00
3A1g	Enteric fermentation - mules and asses	CH_4	34.4	34.2	11.2	11.18	30	50	32.02	51.23	0.00	0.00	0.00	0.00
3A1h	Enteric fermentation - swine	CH_4	43.5	39.1	11.2	20.62	20	20	22.91	28.72	0.00	0.00	0.00	0.00
3A1j	Enteric fermentation - other game	CH_4	0.0	0.0					0.00	0.00	0.00	0.00	0.00	0.00
3A2a	Manure management - cattle	CH_4	230.3	245.0	15.8	28.72	20	20	25.51	35.00	0.00	0.00	0.02	0.00
3A2c	Manure management - sheep	CH_4	1.0	0.9	12.2	21.21	20	20	23.45	29.15	0.00	0.00	0.00	0.00
3A2d	Manure management - goats	CH_4	1.0	0.8	12.2	21.21	20	20	23.45	29.15	0.00	0.00	0.00	0.00
3A2f	Manure management - horses	CH_4	0.1	0.1	12.2	12.25	20	20	23.45	23.45	0.00	0.00	0.00	0.00
3A2g	Manure management - mules and asses	CH_4	0.0	0.0	11.4	11.36	20	20	23.00	23.00	0.00	0.00	0.00	0.00
3A2h	Manure management - swine	CH_4	487.7	438.6	18.7	18.71	20	20	27.39	27.39	0.00	0.01	0.03	0.00
3A2i	Manure management - poultry	CH_4	43.1	59.2	18.7	25.5	20	20	27.39	32.40	0.00	0.00	0.00	0.00
3A2j	Manure management - other game	CH_4	0.0	0.0					0.00	0.00	0.00	0.00	0.00	0.00

3A2a	Manure management - cattle	N_2O	844.1	889.5	52.7	57.88	25	50	58.32	76.49	0.02	0.02	0.17	0.03
3A2c	Manure management - sheep	N_2O	122.5	103.6	51.7	54.54	25	50	57.45	73.99	0.00	0.01	0.02	0.00
3A2d	Manure management - goats	N_2O	46.4	36.3	51.7	54.54	25	50	57.45	73.99	0.00	0.00	0.01	0.00
3A2h	Manure management - swine	N_2O	41.3	37.1	27.8	32.79	25	50	37.42	59.79	0.00	0.00	0.00	0.00
3A2i	Manure management - poultry	N_2O	466.5	641.3	27.8	32.79	25	50	37.42	59.79	0.01	0.01	0.07	0.00
3B1a	Forest land remaining forest land - Net CO2	CO_2	1 633.2	-14 093.6	18	18.03	25	25	30.82	30.82	0.67	0.94	0.84	1.59
3B1b	Land converted to forest land - Net CO2	CO_2	-20 846.1	-26 613.8	21.2	21.21	30	30	36.74	36.74	3.38	0.05	1.86	3.47
3B2a	Cropland remaining cropland - Net CO2	CO_2	-1 569.4	-1 793.0	12.8	12.81	20	20	23.75	23.75	0.01	0.01	0.08	0.01
3B2b	Land converted to cropland - Net CO2	CO_2	2 337.6	2 321.3	15.6	15.62	30	30	33.82	33.82	0.02	0.04	0.12	0.02
3B3a	Grassland remaining grassland - Net CO2	CO_2	-1 272.6	-510.3	14.1	14.14	25	25	28.72	28.72	0.00	0.06	0.02	0.00
3B3b	Land converted to grassland - Net CO2	CO_2	-17 631.1	-17 662.3	18	18.03	30	30	35.00	35.00	1.35	0.30	1.05	1.19
3B4a	Wetland remaining wetland	CO_2	0.0	0.0	11.2	11.18	30	30	32.02	32.02	0.00	0.00	0.00	0.00
3B4b	Land converted to wetland	CO_2	0.0	0.0	14.1	14.14	30	30	33.17	33.17	0.00	0.00	0.00	0.00
3B4	Wetland	CH_4	666.6	666.6	11.2	11.18	20	20	22.91	22.91	0.00	0.01	0.02	0.00

3B5a	Settlements remaining settlements - Net CO2	CO_2	-245.4	-686.2	14.1	14.14	30	30	33.17	33.17	0.00	0.03	0.03	0.00
3B5b	Land converted to settlements - Net CO2	CO_2	644.9	580.3	14.1	14.14	30	30	33.17	33.17	0.00	0.02	0.03	0.00
3B6b	Land converted to other lands - Net CO2	CO_2	16 044.8	16 044.8	18	18.03	30	30	35.00	35.00	1.11	0.27	0.95	0.98
3C1a	Biomass burning in forest land	CH_4	270.6	107.2	40.6	40.62	40	40	57.01	57.01	0.00	0.02	0.01	0.00
3C1b	Biomass burning in croplands	CH_4	220.7	57.2	21.2	21.21	40	40	45.28	45.28	0.00	0.02	0.00	0.00
3C1c	Biomass burning in grasslands	CH_4	508.9	204.8	75.8	75.83	40	40	85.73	85.73	0.00	0.04	0.05	0.00
3C1d	Biomass burning in wetlands	CH_4	15.0	10.2	75.2	75.17	40	40	85.15	85.15	0.00	0.00	0.00	0.00
3C1e	Biomass burning in settlements	CH_4	11.2	1.6	40.3	40.31	40	40	56.79	56.79	0.00	0.00	0.00	0.00
3C1f	Biomass burning in other lands	CH_4	0.0	0.0	11.2	11.18	40	40	41.53	41.53	0.00	0.00	0.00	0.00
3C1a	Biomass burning in forest land	N_2O	287.0	98.2	40.3	40.31	27	27	48.52	48.52	0.00	0.02	0.01	0.00
3C1b	Biomass burning in croplands	N_2O	84.5	21.9	20.6	20.62	27	27	33.97	33.97	0.00	0.01	0.00	0.00
3C1c	Biomass burning in grasslands	N_2O	668.6	241.8	75.2	75.17	48	48	89.19	89.19	0.00	0.07	0.06	0.01
3C1d	Biomass burning in wetlands	N_2O	20.2	13.8	75.2	75.17	48	48	89.19	89.19	0.00	0.00	0.00	0.00
3C1e	Biomass burning in settlements	N_2O	15.1	2.1	40.3	40.31	27	27	48.52	48.52	0.00	0.00	0.00	0.00

3C1f	Biomass burning in other lands	N_2O	0.0	0.0	11.2	11.18	48	48	49.28	49.28	0.00	0.00	0.00	0.00
3C2	Liming	CO_2	384.1	1 222.1	75	75	50	50	90.14	90.14	0.04	0.09	0.30	0.10
3C3	Urea application	CO_2	297.3	679.6	10	10	50	50	50.99	50.99	0.00	0.04	0.02	0.00
3C4	Direct N2O emissions from managed soils	N_2O	20 072.5	18 081.0	15	53.81	70	200	71.59	207.11	49.52	3.19	3.21	20.48
3C5	Indirect N2O emissions from managed soils	N_2O	2 463.3	2 236.3	15	200.6	80	400	81.39	447.47	3.54	0.77	1.48	2.78
3C6	Indirect N2O emissions from manure management	N_2O	408.9	469.3	23.5	115.5	80	400	83.39	416.35	0.13	0.04	0.18	0.03
3D1	Harvested wood products	CO_2	-290.4	-776.9	15	15	30	30	33.54	33.54	0.00	0.03	0.04	0.00
4A	Solid Waste Disposal	CH_4	10 533.9	17 366.0	50	50	40	40	64.03	64.03	4.37	0.40	2.86	8.37
4C2	Open Burning of Waste	CO_2	29.2	37.5	50	50	40	40	64.03	64.03	0.00	0.00	0.01	0.00
4C2	Open Burning of Waste	CH_4	187.5	240.7	50	50	100	100	111.80	111.80	0.00	0.00	0.04	0.00
4C2	Open Burning of Waste	N_2O	63.9	82.0	50	50	100	100	111.80	111.80	0.00	0.00	0.01	0.00
4D1	Wastewater Treatment and Discharge	CH_4	2 144.1	2 753.3	50	50	40	40	64.03	64.03	0.11	0.01	0.45	0.21
4D1	Wastewater Treatment and Discharge	N_2O	599.3	769.6	50	50	90	90	102.96	102.96	0.02	0.01	0.13	0.02
			428 652.9	532 173.3							96.13			67.71
										Uncertainty in total inventory	9.80		**Trend uncertainty**	8.23

C = Confidential

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Chapter 2: Trends in GHG emissions

2.1 Emission trends for aggregated greenhouse gas emissions

This chapter provides a description and interpretation of emission trends by sector and describes trends for the aggregated national emission totals. A complete table of emission estimates for 2017 are provided in Appendix 2.A.

2.1.1 National trends in emissions

Overall emissions (excluding FOLU)

Overall emissions (excluding FOLU) include those from *Energy*, *Industrial Processes and Product Uses*, *Livestock*, *Aggregated and non-CO_2 emissions from land*, and *Waste*. It does not include the removals from the *Land* and *Harvested wood products* category (which is termed FOLU in the Report).

2000 - 2017

South Africa's GHG emissions excluding FOLU were 449 181 Gg CO_2e in 2000 and these increased by 27.9% by 2017 (Table 2.1). Emissions (excl. FOLU) in 2017 were estimated at 574 697 Gg CO_2e. Emissions increased slowly between 2000 and 2013 when emissions reached their peak, after which there was a slight decline to 2015 and a stabilisation to 2017 (Figure 2.1). There were small declines in emissions in 2005, 2008 and 2011 (Table 2.2), but these dips have usually only lasted for one year. In 2014 there was a decline in two consecutive years. Between 2000 and 2017 the average annual growth was 1.5%, however the growth rate was 2.3% between 2000 and 2010 and this declined to 0.4% between 2010 and 2017. The *Energy* sector is the main contributor to the increasing emissions.

Table 2.1: Changes in South Africa's emissions excluding and including FOLU between 2000, 2015 and 2017.

	Emissions (Gg CO_2e)			Change between 2000 and 2017		Change between 2015 and 2017	
	2000	2015	2017	Gg CO_2e	%	Gg CO_2e	%
Emissions (excl. FOLU)	449 180.8	568 578.1	574 696.5	125 515.7	27.9	6 118.4	1.1
Emissions (incl. FOLU)	428 652.9	534 846.1	532 173.3	103 520.5	24.2	-2 672.8	-0.5

2015 - 2017

Emissions (excl. FOLU) increased by 1.1% between 2015 and 2017 (Table 2.1). The increase is due to a 1.5%, 3.2%, and 4.4% increase in the *Energy*, *IPPU*, and *Waste* sectors, respectively, over this period.

2017

The *Energy* sector was the largest contributor to South Africa's gross emissions (excl. FOLU) in 2017, comprising 79.8% of total emissions. This was followed by the *AFOLU* sector (excl. FOLU) (9.0%), *IPPU* sector (7.5%) and the *Waste* sector (3.7%).

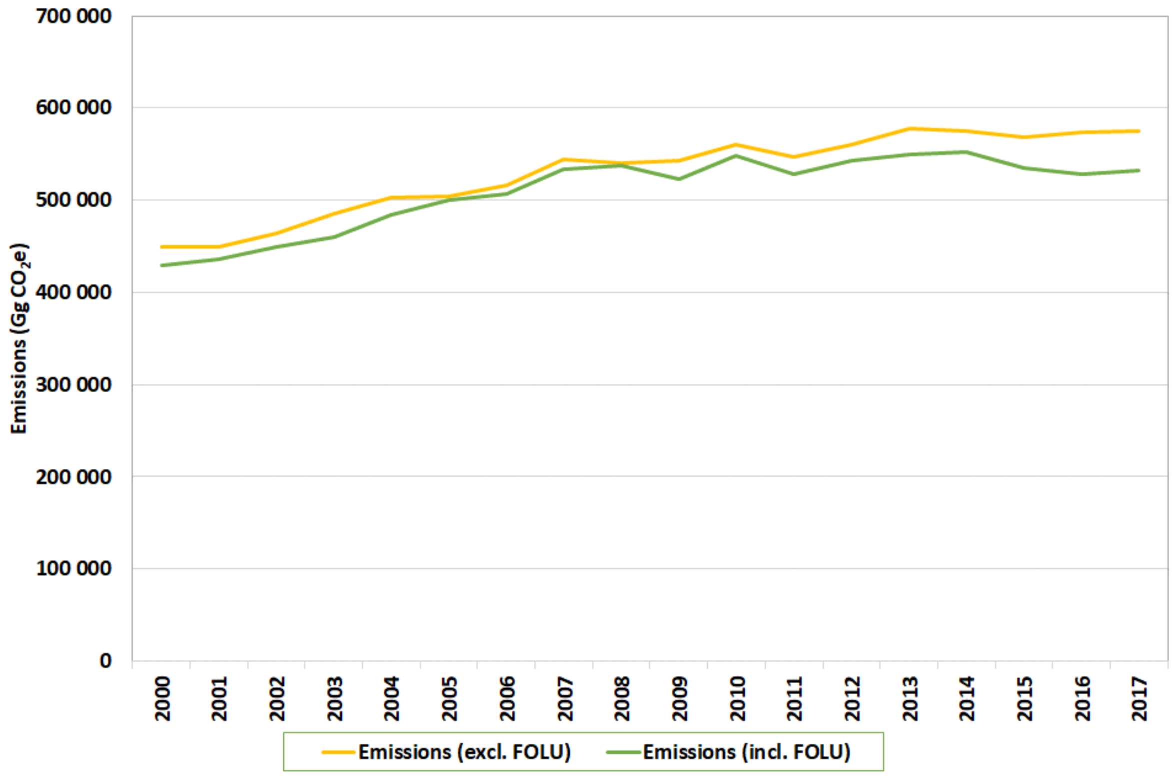


Figure 2.1: National GHG emissions (excluding and including FOLU) for South Africa, 2000 – 2017.

Table 2.2: Trends and annual change in emissions (excluding and including FOLU), 2000 – 2017.

	Emissions (excl. FOLU)		Emissions (incl. FOLU)	
	Gg CO_2e	Annual change (%)	Gg CO_2e	Annual change (%)
2000	449 180.8		428 652.9	
2001	448 796.9	-0.09	436 248.6	1.77
2002	464 021.1	3.39	448 800.7	2.88
2003	484 967.9	4.51	459 899.7	2.47
2004	503 189.6	3.76	484 491.3	5.35
2005	504 561.8	0.27	499 539.0	3.11
2006	515 702.9	2.21	506 393.6	1.37
2007	543 982.1	5.48	533 360.2	5.33
2008	540 463.5	-0.65	537 453.1	0.77

2009	543 008.8	0.47	523 137.2	-2.66
2010	560 530.4	3.23	547 809.6	4.72
2011	546 614.1	-2.48	527 589.1	-3.69
2012	560 322.1	2.51	542 520.3	2.83
2013	578 367.8	3.22	550 183.2	1.41
2014	575 463.6	-0.50	552 229.1	0.37
2015	568 578.1	-1.20	534 846.1	-3.15
2016	574 234.7	0.99	528 473.7	-1.19
2017	574 696.5	0.08	532 173.3	0.70

Net emissions (incl. FOLU)

Net emissions include all emissions (sources and sinks) from all sectors (i.e. *Energy*, *Industrial Processes and Product Uses*, *AFOLU* and *Waste*).

2000 – 2017

South Africa's GHG emissions (incl. FOLU) were 428 653 Gg CO_2e in 2000 and these increased by 24.2% by 2017 (Table 2.1). Emissions (incl. FOLU) in 2017 were estimated at 532 173 Gg CO_2e. The emissions (incl. FOLU) followed the same trend as the emissions (excl. FOLU) with a slightly lower emissions between 2010 and 2017 (Figure 2.1). This was due to the increased *Land* sink during this period. Emissions, therefore, increased slowly between 2000 and 2013 after which there was a decline to 2017 (Table 2.2). Between 2000 and 2017 the average annual growth was 1.3%. The *Energy* sector is the main contributor to this increase.

2015 – 2017

Emissions (incl. FOLU) decreased by 0.5% since the last inventory submission (Table 2.1). The reduction in the emissions relative to the growth in gross emissions was due to a decline in the *AFOLU* emissions and this was due to a 26.0% increase in removals from the *Land* sector.

2017

The *Energy* sector was the largest contributor to South Africa's net emissions in 2017, comprising 86.2% of total net emissions. This was followed by the *AFOLU* sector (9.7%), *IPPU* sector (8.1%) and *Waste* sector (4.0%).

2.2 Indicator trends

2.2.1 Total emission indicators

South Africa's carbon and energy intensity trends were determined from the GHG emissions, GDP data (Statistics SA, 2018), total primary energy supply data (DMRE Energy balance data) and population data (Statistics SA, 2018).

South Africa's per capita carbon[2] intensity was 9.74 t CO_2e in 2000 and this increased to a maximum of 11.05 t CO_2e between 2007 and 2010, after which it declined again to 9.42 by 2017 (Figure 2.2). The carbon intensity of the economy (i.e. emissions per million Rand of GDP) has declined by 22.7% since 2000. This is largely due to growth in the services and financial sectors, a decline in the manufacturing sector and stagnation in the mining sector.

[2] Carbon in this case refers to the total net emissions (i.e. emissions including FOLU).

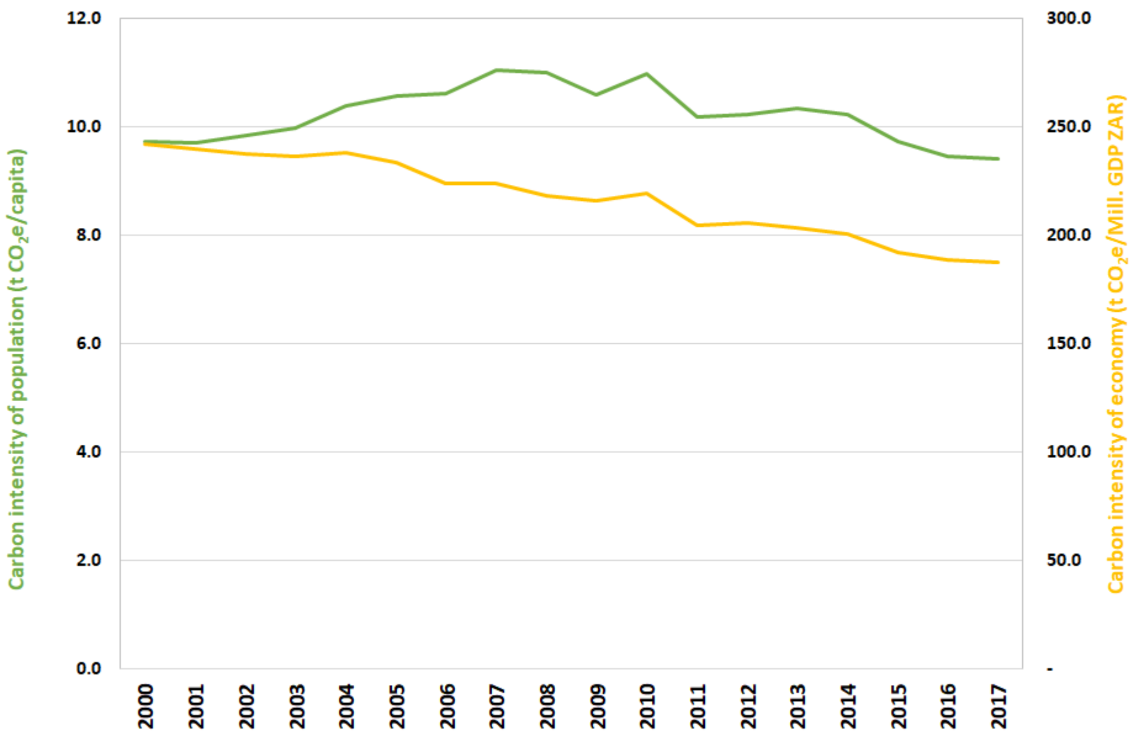


Figure 2.2: Trends in overall carbon intensity of the population and of the economy of South Africa between 2000 and 2017.

2.2.2 Energy emission indicators

The energy carbon intensity of the population (i.e. energy sector emissions per capita) increased significantly (15.3%) between 2001 and 2007, stabilised until 2010 and then showed a decline (10.4%) between 2010 and 2017 (Figure 2.3). Energy emissions per capita accounted for 80.6% of the total emissions (incl. FOLU) per capita in 2000 and this increased to 86.2% by 2017. The energy carbon intensity per capita trend is similar to that of the total carbon intensity of the population. This shows the large contribution to emissions from the energy sector.

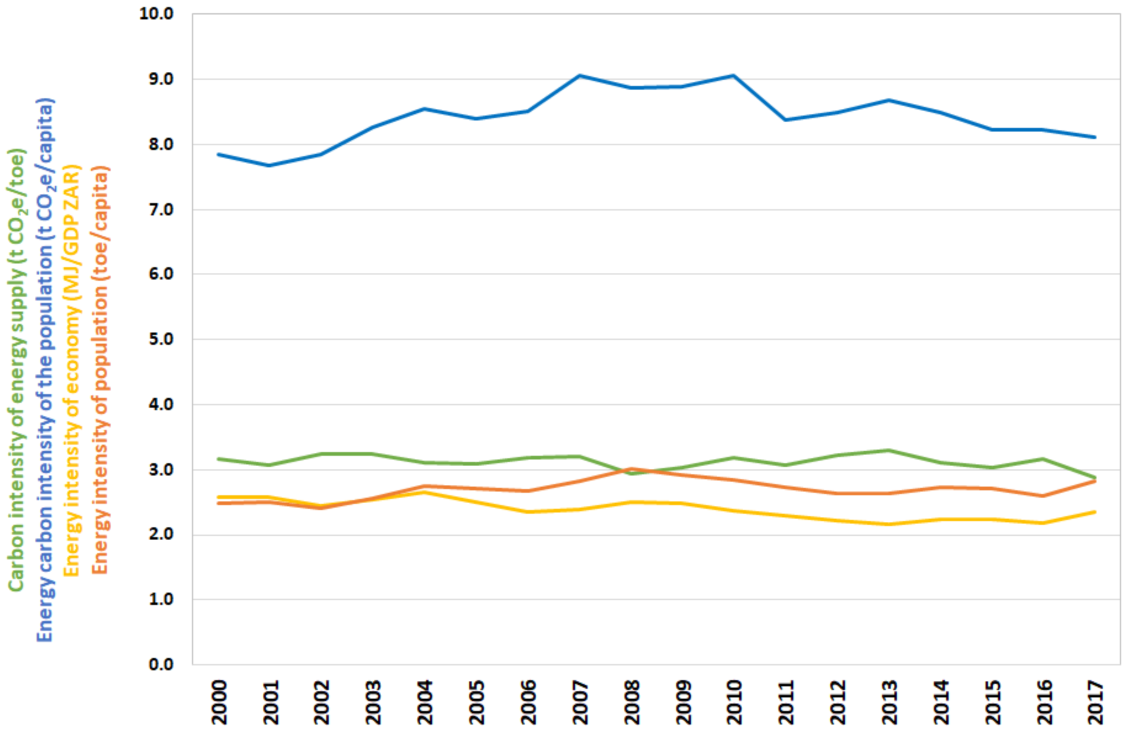


Figure 2.3: Trends in energy intensity indicators for South Africa between 2000 and 2017.

In terms of energy supply the Total Primary Energy Supply (TPES) data (Figure 2.4) from South Africa's annual Energy Balances are applied. The carbon intensity of the energy supply, which is the amount of GHG emissions produced by the energy sector per unit of TPES, remained fairly constant over the 17 year period with a small decline between 2016 and 2017 (Figure 2.3). The energy intensity of the population (TPES per person) has increased by 13.9% between 2000 and 2017, which is why the emissions per energy supply have remained fairly constant.

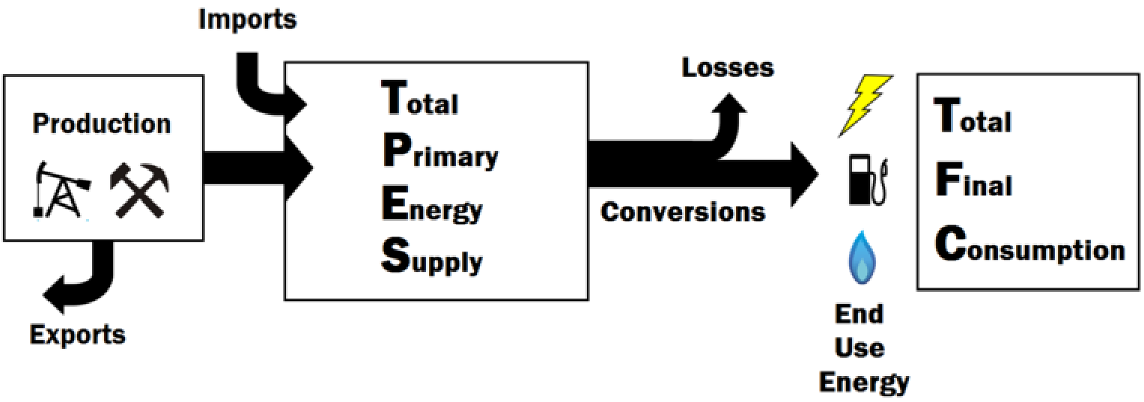
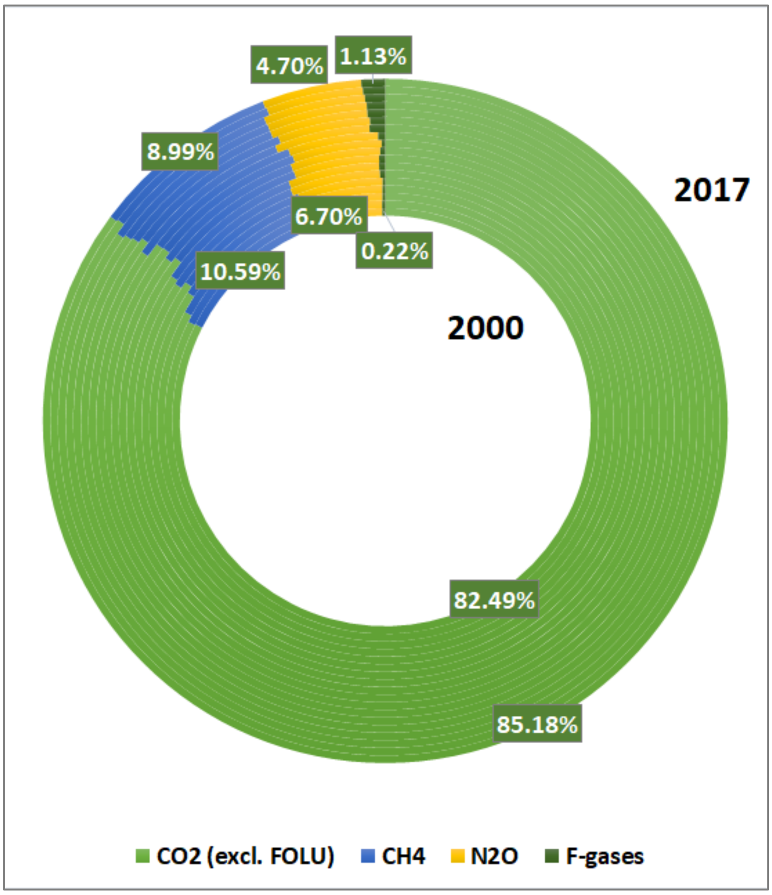


Figure 2.4: Energy flow diagram illustrating the difference between TPES and TFC.

The energy intensity of the economy, which is TPES MJ per unit GDP, has declined between 2000 and 2017 (8.9%), although there was a slight increase in 2017. As mentioned above the decline is likely due to the decline in the manufacturing and mining sectors and an increase in GDP in the service sectors in recent years.

2.3 Emission trends by gas

CO_2 gas is the largest contributor to South Africa's emissions (Figure 2.5). This is followed by CH_4 and then N_2O. The contribution from CH_4 and N_2O generally decline from 2000 to 2017 (Figure 2.5), while the contribution from CO_2 and F-gases increase. The F-gas contribution is, however, still below 1.5%.


4.70%
1.13%
8.99%
2017
6.70%
0.22%
10.59%
2000
82.49%
85.18%
CO2 (excl. FOLU)
CH4
N2O
F-gases

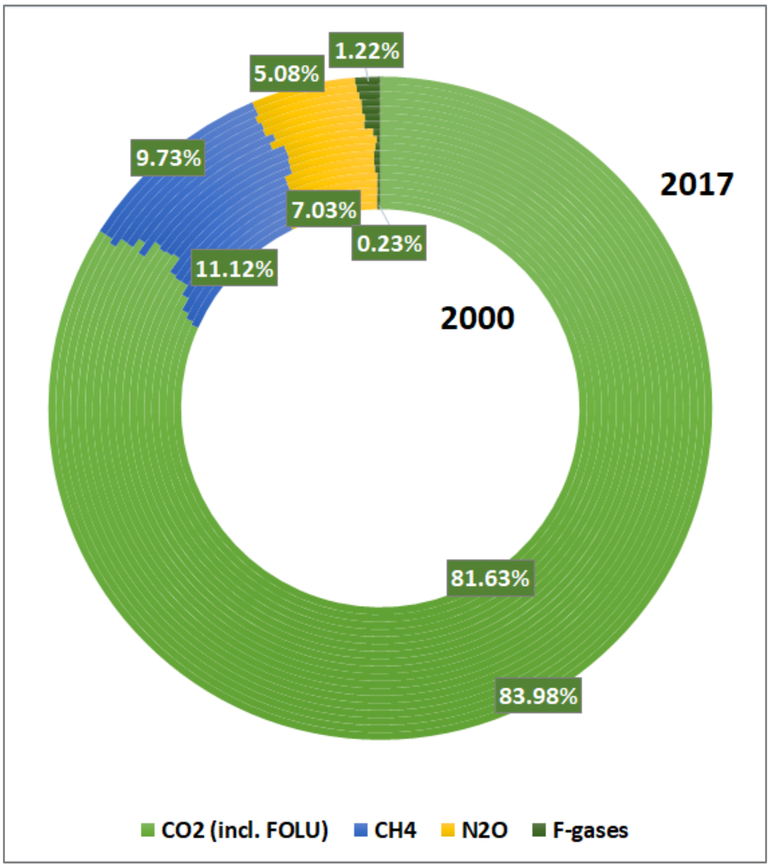


Figure 2.5: Percentage contributions from each of the gases to South Africa's emissions (excl. FOLU (top) and incl. FOLU (bottom)) between 2000 and 2017.

Carbon dioxide

The CO_2 emissions totalled 489 946 Gg CO_2 (excl. FOLU) and 446 356 Gg CO_2 (incl. FOLU) in 2017 (Table 2.3). Figure 2.6 presents the contribution of the main sectors to the trend in national CO_2 emissions (excl. FOLU). Since CO_2 is the largest contributor to national emissions the CO_2 emission trend follows that of the overall emission trend. The *Energy* sector is by far the largest contributor to CO_2 emissions in South Africa, contributing an average of 92.0% between 2000 and 2017, and 92.2% in 2017. The categories *1A1 energy industries* (56.9%), *1A3 Transport* (16.9%) and *1A4 Other sectors* (11.8%) were the major contributors to the *Energy* CO_2 emissions in 2017. The *IPPU* sector contribution an average of 7.7% between 2000 and 2017, while the AFOLU sector (excl. FOLU) contributed an average of 0.3%.

Methane

The sector contributions to the total CH_4 emissions in South Africa are shown in Figure 2.7. National CH_4 emissions increased from 47 573 Gg CO_2e in 2000 to 51 693 Gg CO_2e in 2017 (Table 2.3). The *AFOLU livestock* category and *Waste* sectors were the major contributors, providing 51.9% and 39.4%, respectively, to the total CH_4 emissions in 2017. The contribution from *livestock* declined by 11.0% (due to a decline in livestock populations), while the contribution from the *Waste* sector increased by 12.2% over the period 2000 to 2017.

Table 2.3: Trend in CO_2, CH_4, N_2O and F-gases between 2000 and 2017.

	Emissions						
	CO_2 (excl. FOLU)	CO_2 (incl. FOLU)	CH_4		N_2O		F-gases
	Gg CO_2		Gg CO_2e	Gg CH_4	Gg CO_2e	Gg N_2O	Gg CO_2e
2000	370 550.6	349 356.1	47 573.3	2 265.4	30 073.7	97.0	983.2
2001	369 945.4	356 730.5	48 043.6	2 287.8	29 800.2	96.1	1 007.7
2002	384 809.9	368 922.9	48 050.0	2 288.1	30 264.1	97.6	897.1
2003	408 203.7	382 468.8	47 499.6	2 261.9	28 368.4	91.5	896.2
2004	425 966.4	406 601.4	47 853.3	2 278.7	28 480.6	91.9	889.4
2005	424 858.7	419 169.4	48 578.1	2 313.2	29 411.6	94.9	1 713.4
2006	435 635.5	425 659.6	48 610.3	2 314.8	29 476.2	95.1	1 980.9
2007	465 200.6	453 912.1	48 406.8	2 305.1	28 340.6	91.4	2 034.1
2008	460 288.7	456 611.6	49 834.3	2 373.1	28 767.0	92.8	1 573.6
2009	464 493.6	443 955.4	49 480.3	2 356.2	27 934.7	90.1	1 100.3
2010	479 181.8	465 794.4	50 798.1	2 419.0	28 346.7	91.4	2 203.7
2011	462 803.2	443 111.6	50 760.9	2 417.2	28 364.7	91.5	4 685.2
2012	477 710.6	459 242.1	50 535.5	2 406.5	27 569.3	88.9	4 506.8
2013	491 494.0	462 642.8	52 098.4	2 480.9	29 477.0	95.1	5 298.4
2014	488 434.1	464 533.0	52 426.0	2 496.5	29 254.4	94.4	5 349.1
2015	481 680.5	447 281.9	52 491.4	2 499.6	28 738.0	92.7	5 668.2
2016	489 656.1	443 228.5	51 493.0	2 452.0	26 934.5	86.9	6 151.1
2017	489 546.1	446 356.3	51 693.3	2 461.6	26 989.2	87.1	6 467.9

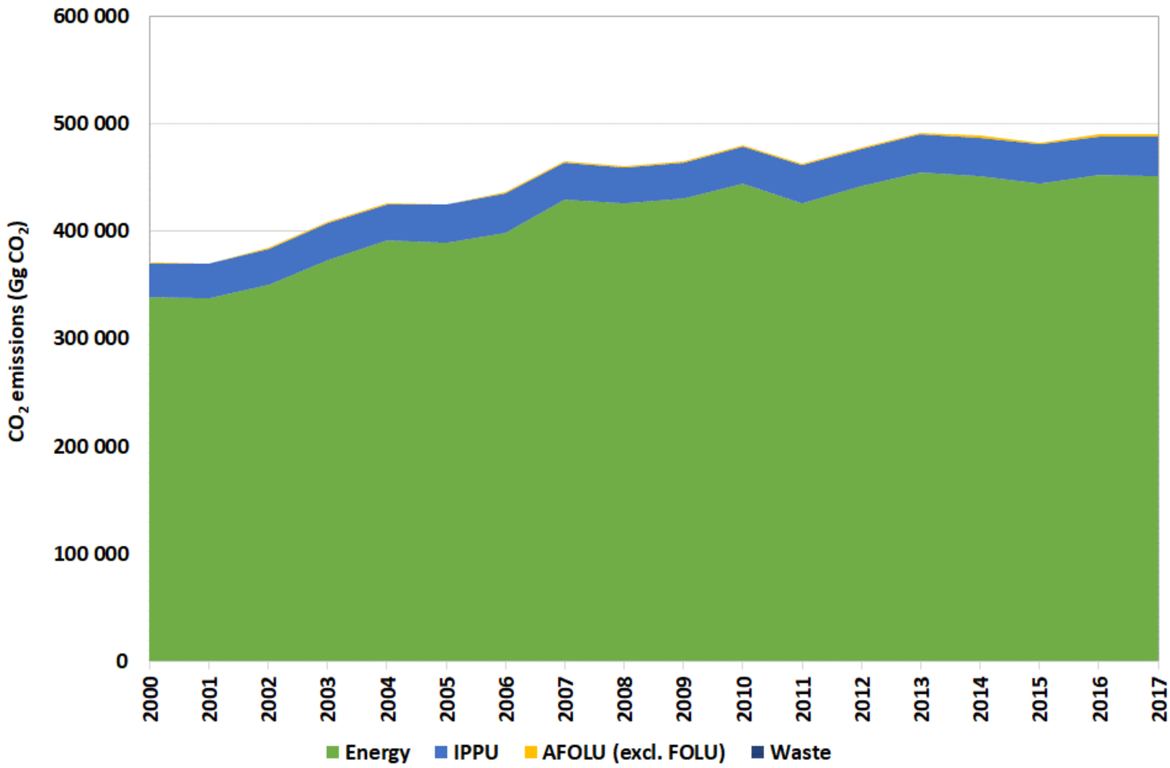


Figure 2.6: Trend and sectoral contribution to CO_2 emissions (excl. FOLU), 2000 – 2017.

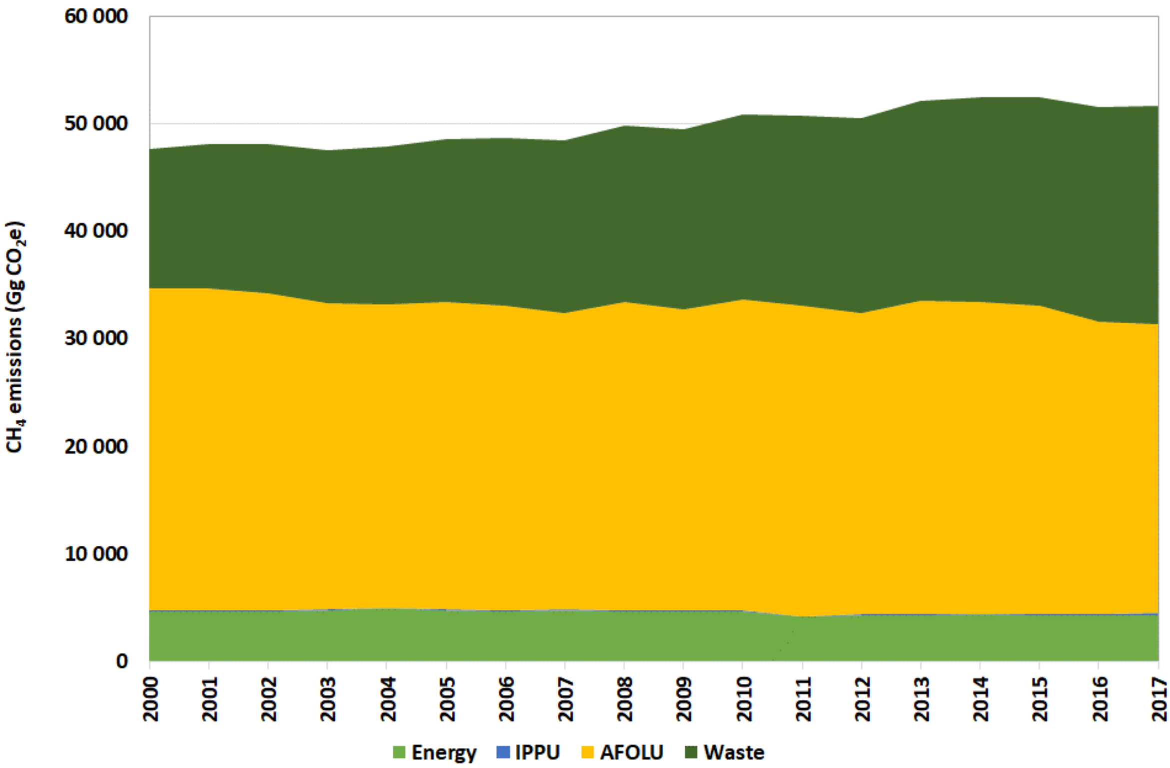


Figure 2.7: Trend and sectoral contribution to the CH_4 emissions, 2000 – 2017.

Nitrous oxide

Figure 2.8 shows the contribution from the major sectors to the national N_2O emissions in South Africa. The emissions declined by 10.3% over the 2000 to 2017 period from 30 074 Gg CO_2e to 26 989 Gg CO_2e (Table 2.3). The main contributors are the *AFOLU* (84.8%) and *Energy* (11.1%) sectors (Figure 2.8). The categories 3C *Aggregated and non-CO_2 sources on land* (which includes emissions from managed soils and biomass burning) and 1A *Fuel combustion activities* are the main contributors to N_2O. Livestock manure, urine and dung inputs to managed soils provided the largest N_2O contribution in the AFOLU sector therefore the trend follows a similar pattern to the livestock population. N_2O emissions from IPPU declined by 82.2% between 2000 and 2017. This is attributed to declines in N_2O emissions from *Nitric Acid production*. The Nitric Acid industry implemented Cleaner Development Mechanism (CDM) projects through the adoption of the latest N_2O emission reduction technologies.

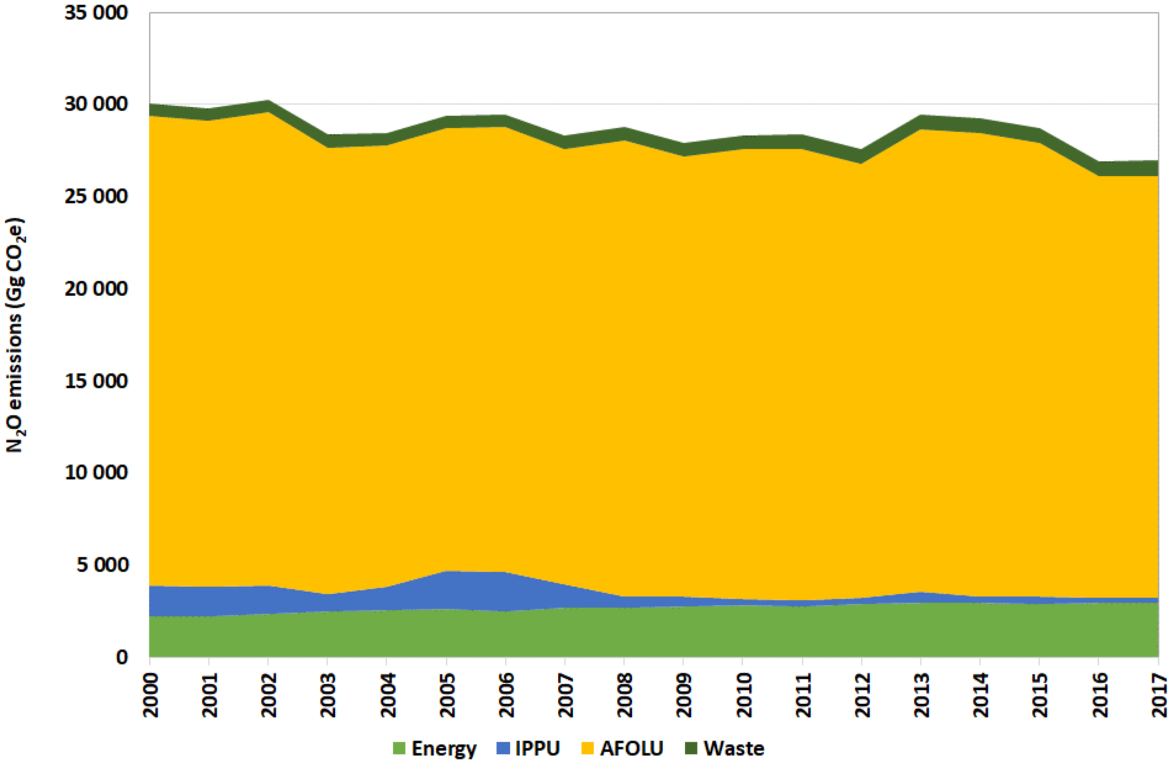


Figure 2.8: Trend and sectoral contribution to N_2O emissions in South Africa, 2000 – 2017.

F-gases

Estimates of hydrofluorocarbon (HFC) and perfluorocarbon (PFC) emissions were only estimated for the IPPU sector in South Africa. F-gas emission estimates varied annually (Table 2.3, Figure 2.9) an contributed 1.3% to overall emissions in 2017. Emissions increase from 2011 due to the addition of HFC emissions from *air conditioning*, *foam blowing agents*, *fire protection* and *aerosols* (Figure 2.9). There is no data prior to 2005 so this time-series is not consistent. The elevated F-gas emissions are therefore not necessarily due to an increase in emissions but rather due to the incorporation of new categories.

PFC emissions were estimated at 983 Gg CO_2e in 2000. This increased to 971 Gg CO_2e in 2007, then declined to 108 Gg CO_2e in 2009 and increased again to 2 453 Gg CO_2e in 2017. 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 assist with the rotational electricity load shedding in the country at the time and which necessitated switching on and off at short notice leading to large emissions of C_2F_4 and CF_4. CF4 emissions contribute the most to the PFC emissions (Table 2.4).

HFCs increased from 842 Gg CO_2e in 2005 to 4 015 Gg CO_2e in 2017, and the largest contributor is HFC-134a (Table 2.4).

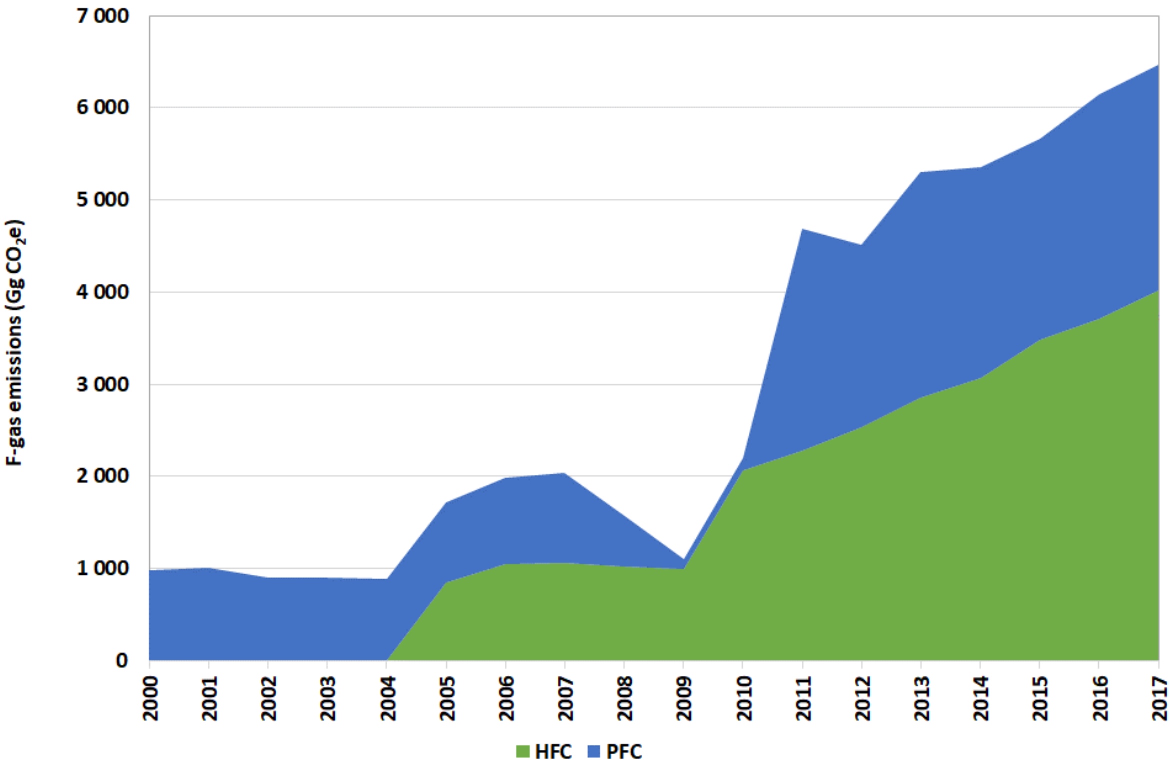


Figure 2.9: Trend in F-gas emissions in South Africa, 2000 – 2017.

Table 2.4: Trends in PFC and HFC emissions (Gg) by gas type.

	CF_4	C_2F_6	HFC-23	HFC-32	HFC-125	HFC-134a	HFC-152a	HFC-143a	HFC-227ea	HFC-365mfc
	(Gg)									
SAR GWP	6 500	9200	11 700	650	2 800	1 300	140	3 800	2 900	890

2000	0.133	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2001	0.136	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2002	0.122	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2003	0.122	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2004	0.121	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2005	0.118	0.011	0.001	0.000	0.000	0.643	0.000	0.000	0.000	0.000
2006	0.127	0.012	0.004	0.000	0.039	0.442	0.100	0.079	0.000	0.000
2007	0.132	0.013	0.000	0.000	0.012	0.750	0.000	0.014	0.000	0.000
2008	0.074	0.007	0.002	0.000	0.004	0.696	0.000	0.022	0.000	0.000
2009	0.014	0.002	0.000	0.000	0.001	0.744	0.000	0.006	0.000	0.000
2010	0.018	0.002	0.001	0.000	0.013	1.423	0.000	0.045	0.000	0.000
2011	0.325	0.033	0.000	0.007	0.038	1.465	0.000	0.061	0.008	0.002
2012	0.267	0.027	0.000	0.010	0.050	1.588	0.000	0.076	0.009	0.002
2013	0.330	0.033	0.000	0.014	0.066	1.730	0.000	0.099	0.011	0.001
2014	0.308	0.031	0.000	0.020	0.088	1.786	0.000	0.117	0.012	0.000
2015	0.295	0.029	0.000	0.027	0.111	1.935	0.000	0.156	0.015	0.001
2016	0.328	0.033	0.000	0.031	0.126	2.046	0.000	0.171	0.016	0.001
2017	0.331	0.033	0.000	0.036	0.145	2.161	0.000	0.194	0.017	0.001

2.4 Emission trends for indirect GHG

The trend in emissions of carbon monoxide (CO) and nitrogen oxides (NOx) is shown in Table 2.5. These emissions were estimated for biomass burning only.

Table 2.5: Trends in indirect GHG emissions between 2000 and 2017.

	NOx	CO	NMVOC
	(Gg)		
2000	65.8	1 395.5	62.2
2001	76.3	1 579.9	71.3
2002	75.9	1 610.5	72.4
2003	56.9	1 242.5	57.7
2004	53.3	1 143.1	53.8
2005	83.4	1 774.9	77.9
2006	75.2	1 618.8	70.9

2007	69.1	1 557.5	79.1
2008	71.0	1 573.1	82.0
2009	63.1	1 346.7	61.6
2010	63.3	1 383.6	66.2
2011	62.0	1 343.1	63.8
2012	53.2	1 183.0	61.2
2013	55.7	1 196.6	58.2
2014	54.9	1 176.2	55.1
2015	39.2	841.5	41.0
2016	22.0	511.5	29.1
2017	21.1	487.8	27.2

2.5 Emission trends by sector

Figure 2.10 and Table 2.6 shows the trend in the contribution from the four sectors to the total GHG emissions (excl. FOLU) in South Africa between 2000 and 2017, while Figure 2.11 shows the percentage contributed by each sector over this period.

Energy

The *Energy* sector is the largest contributor to South Africa's emissions (excl. FOLU), contributing 79.1% in 2017 (Figure 2.11). *Energy* sector emissions increased between 2000 and 2017 (Table 2.6). The main contributor to the increased *Energy* emission is increased demand for liquid fuels in road transportation, manufacturing industries and construction, civil aviation, residential and the commercial sector. This increased demand for fuels is largely driven by the increase in population and increasing economy.

IPPU

The *IPPU* sector contributed an average of 7.5% and 8.1% to the total emissions excluding and including FOLU, respectively, between 2000 and 2017 (Figure 2.11). In 2017 the IPPU contribution was 43 230 Gg CO_2e (Table 2.6). There has been an increasing trend in emissions from the *IPPU* sector, except for the reduced emissions during the recession. The main drivers in the *IPPU* sector are the metal industries, particularly *Iron and steel production* and *Ferroalloy production* which contributed 34.9% and 29.1% respectively to the total IPPU emissions in 2017. In addition, the HFC and PFC emissions should be monitored closely since HFC emissions have more than tripled since 2005, while PFC emissions have more than doubled since 2000. PFC emissions did increase from 2011 due to the addition of new categories (*Foam blowing agents*, *Fire protection* and *Aerosols*), but only 1.8% of the increase was accounted for by the new category emissions.

AFOLU

The *AFOLU* sector (excl. FOLU) contributed an average of 10.3% to the total emissions (excl. FOLU) between 2000 and 2017 (Figure 2.11). The contribution has declined by 3.5% since 2000. The main driver of change in the *AFOLU* emissions (excl. FOLU) is the livestock population. Livestock have input into the enteric fermentation, manure management, as well as direct and indirect N_2O emissions.

The *AFOLU* sector produced 51 608 Gg CO_2e (excl. FOLU) in 2017, while the emissions including FOLU were 9 085 Gg CO_2e (Table 2.6). This change is due to the increasing *Land* sink, which strengthened between 2009 and 2017. The sink increased declined between 2005 and 2008, after which there was some stabilisation until 2012. Between 2012 and 2017 there was a further increase in the sink. The largest contributor was the *Forest land* category. The increasing sink is due to increasing forest land area (particularly thickets and woodlands/open bush), and a decline in wood losses. There was a peak in burnt area in 2008, and then a fairly steep decline between 2014 and 2017, leading to reduction in disturbance losses. Furthermore, there was a decline is wood removals by households for lighting and cooking purposes, probably due to increased electrification, which also contributed to the reduced removals. Emissions and removals from *Grasslands* remained fairly constant, with *Land converted to grasslands* contributing the largest portion to this category. *Other lands* provide a fairly constant source of emissions as carbon is lost when land is converted to *Other lands*. The source from Other lands (16 044 Gg CO_2) is almost equal to the sink from Grasslands (18 173 Gg CO_2 in 2017).

Aggregated and non-CO_2 emissions on land contributed 45.4% to the AFOLU (excl. FOLU) emissions in 2017, and the largest contributor to this category (77.1%) is *Direct N_2O from managed soils*. Nitrogen inputs from urine and dung deposits contribute 63.3% to direct N_2O, followed by 11.9% from inorganic N inputs and 11.2% from organic N inputs.

Waste

The *Waste* sector emissions have increased from 13 558 Gg CO_2e in 2000 to 21 249 Gg CO_2e in 2017 (Table 2.6). The *Waste* sector contribution to overall emissions (excl. FOLU) has slowly increased from 3.0% in 2000 to 3.8% in 2017 (Figure 2.11). The emissions in this sector are driven mainly by population growth.

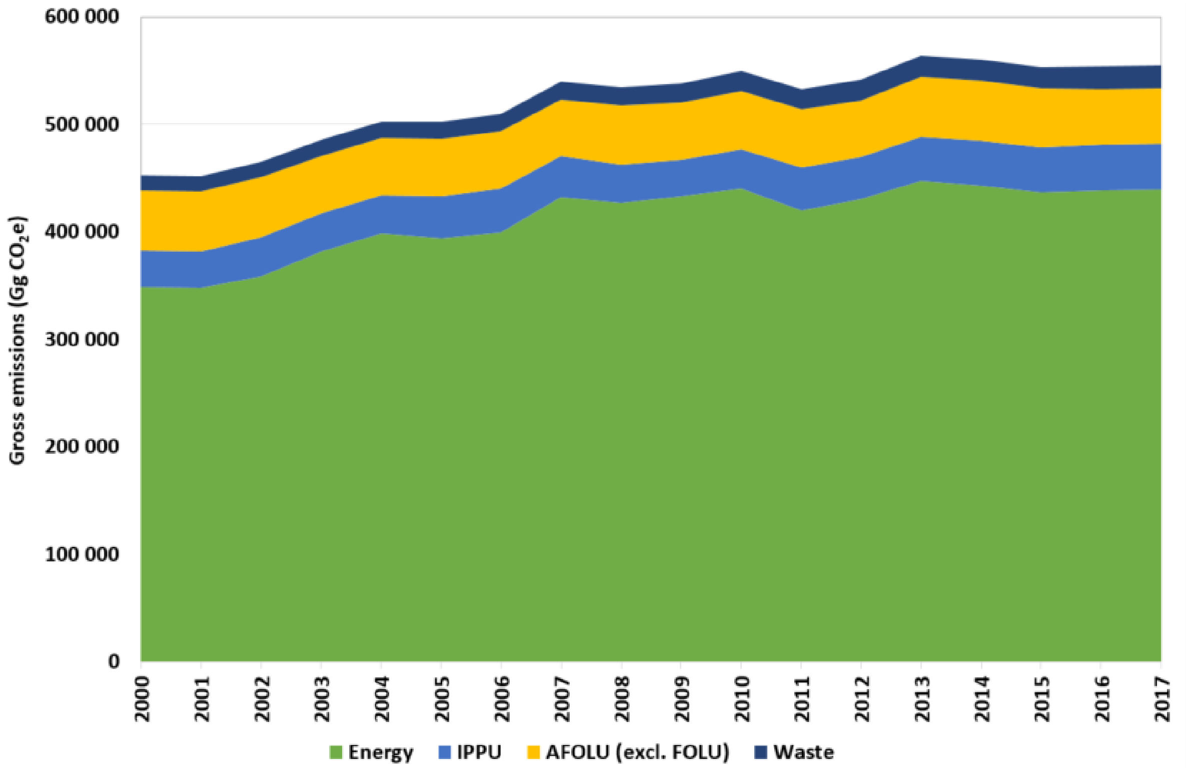
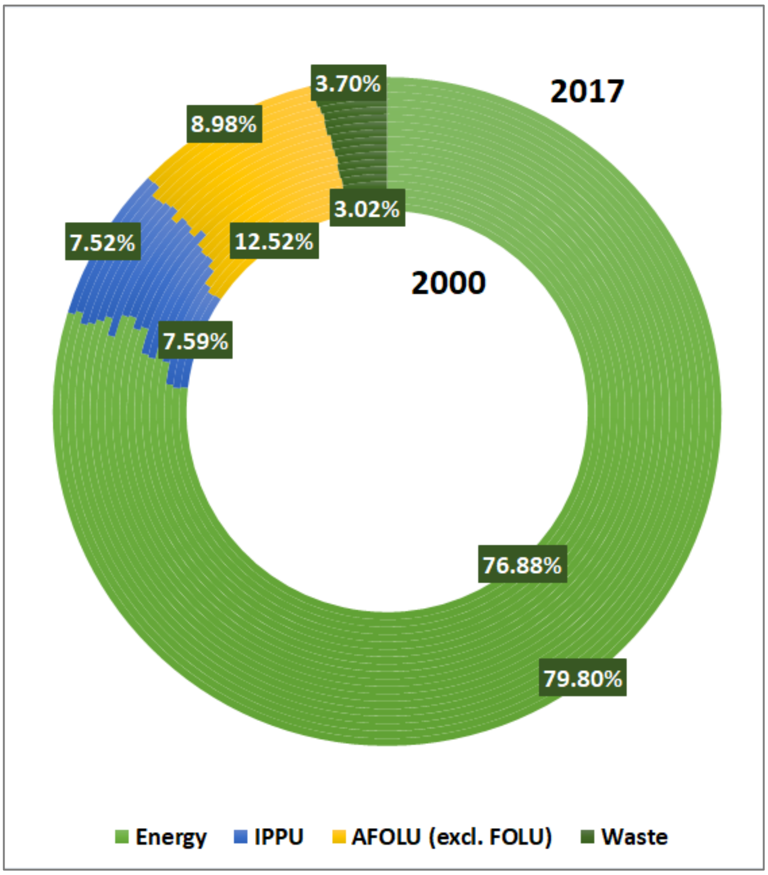


Figure 2.10: Sectoral contribution to the trend in the gross emissions for South Africa, 2000 – 2017.


2017
2000
3.70%
8.98%
7.52%
3.02%
12.52%
7.59%
76.88%
79.80%
Energy
IPPU
AFOLU (excl. FOLU)
Waste

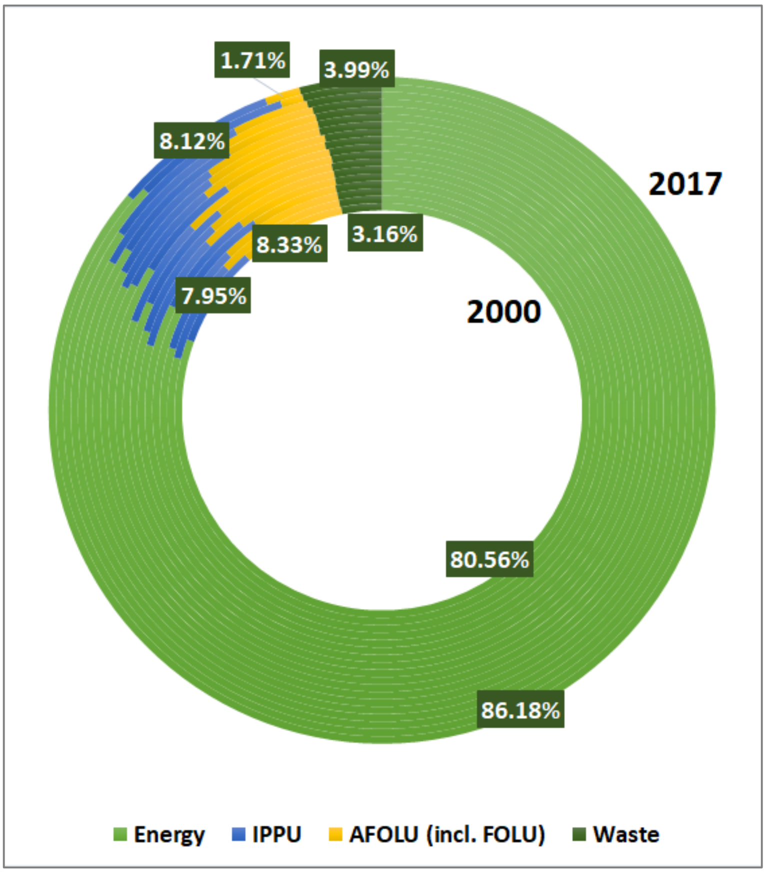


Figure 2.11: Percentage contributions from each of the sectors to South Africa's emissions (excluding (top) and including (bottom) FOLU) between 2000 and 2017.

Table 2.6: Trend in emissions and removals by sector for 2000 to 2017.

	Energy	IPPU	AFOLU (excl. FOLU)	AFOLU (incl. FOLU)	Waste
	Emissions (Gg CO_2e)				
2000	348 475,3	34 070.8	56 243.2	35 715.3	13 557.8
2001	347 361,5	34 057.4	56 123.6	43 575.3	14 051.4
2002	358 431,2	36 140.6	56 205.7	40 985.3	14 523.1
2003	381 676,1	35 606.5	53 603.5	28 535.2	14 984.9
2004	398 769,3	35 783.8	53 093.2	34 394.9	15 436.3
2005	394 591,1	39 118.2	53 211.1	48 188.3	15 879.1
2006	399 781,2	40 173.2	53 302.6	43 993.3	16 314.7
2007	432 985,7	38 222.5	52 259.4	41 637.5	16 743.3
2008	427 141,0	36 048.0	54 598.1	51 587.6	17 166.4

2009	433 106,4	34 352.0	52 996.0	33 124.4	17 582.3
2010	440 763,2	36 441.6	54 464.0	41 743.2	17 990.8
2011	419 562,5	40 227.7	54 678.2	35 653.2	18 493.2
2012	430 715,7	38 954.9	52 984.6	35 182.8	18 973.3
2013	447 748,9	41 348.8	55 559.1	27 374.5	19 393.6
2014	443 498,9	41 878.4	55 529.7	32 295.2	19 874.6
2015	437 203,5	41 882.3	54 514.1	20 782.2	20 350.2
2016	439 236,2	42 465.4	51 657.9	5 896.9	20 797.1
2017	439 576,3	43 229.5	51 608.4	9 085.2	21 249.0

Appendix 2.A Summary emission tables for 2017

Table 2A.1: Summary emission table for South Africa for 2017.

IPCC 2006 category	Emissions and removals								
	Net CO_2	CH_4	N_2O	HFCs	PFCs	NOx	CO	NMVOC	Total GHGs
	(Gg)[a]			(Gg CO_2e)[b]		(Gg)[a]			(Gg CO_2e)
Emissions (incl. FOLU)	**427 746,1**	**2 486,3**	**86,2**	**4 014.5**	**2 453.4**	**21.1**	**487.8**	**27.2**	**513 140,0**
Emissions (excl. FOLU)	**470 935,9**	**2 454,5**	**86,2**	**4 014.5**	**2 453.4**	**21.1**	**487.8**	**27.2**	**555 663,2**
1 - Energy	**432 698,0**	**199,1**	**8,7**						**439 576,3**
1.A - Fuel Combustion Activities	**406 288,9**	**19,5**	**8,7**			NE	NE	NE	**409 395,9**
1.A.1 - Energy Industries	256 724.5	2,9	3,9			NE	NE	NE	258 001,3
1.A.2 - Manufacturing Industries and Construction	37 264.4	0,5	0,5			NE	NE	NE	37 432,5
1.A.3 - Transport	57 865,9	12,2	2,8			NE	NE	NE	58 983,2
1.A.4 - Other Sectors	53 234.9	3,8	1,5			NE	NE	NE	53 775,3
1.A.5 - Non-Specified	1 199.3	0,1	0,0			NE	NE	NE	1 203,6
1.B - Fugitive emissions from fuels	**26 409.1**	**179.6**	NE			NE	NE	NE	**30 180.4**
1.B.1 - Solid Fuels	20.8	75.6	NE			NE	NE	NE	1 608.2
1.B.2 - Oil and Natural Gas	641.8	NE	NE			NE	NE	NE	641.8
1.B.3 - Other emissions from Energy Production	25 746.5	104.0	NE			NE	NE	NE	27 930.4
1.C - Carbon dioxide Transport and Storage	**NE**					**NE**	**NE**	**NE**	**0.0**
1.C.1 - Transport of CO2	NE					NE	NE	NE	0.0
1.C.2 - Injection and Storage	NE					NE	NE	NE	0.0
1.C.3 - Other	NA					NE	NE	NE	0.0
2 - Industrial Processes and Product Use	**36 298.7**	**8.1**	**0.9**	**4 014.5**	**2 453.4**				**43 229.5**
2.A - Mineral Industry	**6 462.1**	**NE**				**NE**	**NE**	**NE**	**6 462.1**
2.B - Chemical Industry	**523.9**	**8.0**	**0.9**			**NE**	**NE**	**NE**	**983.7**
2.C - Metal Industry	**29 037.2**	**0.1**	**NE**	**NE**	**2 453.4**	**NE**	**NE**	**NE**	**31 493.6**
2.D - Non-Energy Products from Fuels and Solvent Use	**275.6**	**NE**	**NE**			**NE**	**NE**	**NE**	**275.6**

2.E - Electronics Industry	**NE**		**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**0.0**
2.F - Product Uses as Substitutes for Ozone Depleting Substances	**NE**			**4 014.5**	**NE**	**NE**	**NE**	**NE**	**4 014.5**
2.G - Other Product Manufacture and Use			**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**0.0**
2.H - Other	**NA**	**NA**	**NA**			**NE**	**NE**	**NE**	**0.0**
3 - Agriculture, Forestry, and Other Land Use	**-41 288.1**	**1 309.6**	**73.8**			**21.1**	**487.8**	**27.2**	**9 085.2**
3.A - Livestock		**1 259.7**	**5.5**						**28 161.3**
3.A.1 - Enteric Fermentation		1 224.2							25 708.9
3.A.2 - Manure Management		35.5	5.5						2 452.4
3.B - Land	**-42 412.8**	**31.7**	**NE**						**-41 746.2**
3.B.1 - Forest land	-40 707.4	NE	NE						-40 707.4
3.B.2 - Cropland	528.3	NE	NE						528.3
3.B.3 - Grassland	-18 172.7	NE	NE						-18 172.7
3.B.4 - Wetlands	NE	31.7	NE						666.6
3.B.5 - Settlements	-105.8	NE	NE						-105.8
3.B.6 - Other Land	16 044.8	NE	NE						16 044.8
3.C - Aggregate sources and non-CO_2 emissions sources on land	**1 901.7**	**18.1**	**68.3**			**21.1**	**487.8**	**27.2**	**23 447.1**
3.C.1 - Emissions from biomass burning	IE	18.1	1.2			21.1	487.8	27.2	758.8
3.C.2 - Liming	1 222.1								1 222.1
3.C.3 - Urea application	679.6								679.6
3.C.4 - Direct N_2O Emissions from managed soils			58.3						18 081.0
3.C.5 - Indirect N_2O Emissions from managed soils			7.2						2 236.3
3.C.6 - Indirect N_2O Emissions from manure management			1.5						469.3
3.C.7 - Rice cultivations		NO	NO						0.0

3.C.8 - Other (please specify)	NO	NO	NO						0.0
3.D - Other	**-776.9**	**NA**	**NA**						**-776.9**
3.D.1 - Harvested Wood Products	-776.9								-776.9
3.D.2 - Other (please specify)	NO	NO	NO						0.0
4 - Waste	**37.5**	**969.5**	**2.7**						**21 249.0**
4.A - Solid Waste Disposal		**827.0**	**NE**			**NO/NA**	**NO/NA**	**NO/NA**	**17 366.0**
4.B - Biological Treatment of Solid Waste		**NE**	**NE**			**NO/NA**	**NO/NA**	**NO/NA**	
4.C - Incineration and Open Burning of Waste	**37.5**	**11.5**	**0.3**			**NA**	**NA**	**NA**	**360.2**
4.D - Wastewater Treatment and Discharge		**131.1**	**2.5**			**NO/NA**	**NO/NA**	**NO/NA**	**3 522.8**
4.E – Other	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	**NO**	
5 - Other									
5.A - Indirect N_2O emissions from the atmospheric deposition of nitrogen in NOx and NH_3			**NE**			**NE**	**NE**	**NE**	
5.B - Other			**NO**			**NO**	**NO**	**NO**	
Memo items									
International bunkers	**11 494.4**	**0.9**	**0.3**	**NA**	**NA**	**NA**	**NA**	**NA**	**11 603.2**
International aviation	2 242.3	0.1	0.0	NA	NA	NA	NA	NA	2 248.2
International water-borne transport	9 252.0	0.8	0.3	NA	NA	NA	NA	NA	9 354.9
Multilateral operations	NA	NA	NA	NA	NA	NA	NA	NA	

[a] *The emissions in Gg CO_2e for CH_4 and N_2O per category are provided in the next table.*

[b] *The emissions of PFC and HFCs are reported in Gg in Table 2.4.*

Table 2A.2: Summary emission table for South Africa for 2017 in Gg CO_2e.

IPCC 2006 category	Emissions					
	Net CO_2	CH_4	N_2O	HFCs	PFCs	Total
	Gg CO_2e					
Emissions (incl. FOLU)	**427 746,1**	**52 211,7**	**26 714,3**	**4 014,5**	**2 453,4**	**513 140,0**
Emissions (excl. FOLU)	**470 935,9**	**51 545,1**	**26 714,3**	**4 014,5**	**2 453,4**	**555 663,2**
1 - Energy	**432 698,0**	**4 180,5**	**2 697,8**			**439 576,3**
1.A - Fuel Combustion Activities	**406 288,9**	**409,2**	**2 697,8**			**409 395,9**
1.A.1 - Energy Industries	*256 724,5*	*61,3*	*1 215,6*			*258 001,3*
1.A.2 - Manufacturing Industries and Construction	*37 264,4*	*10,2*	*157,9*			*37 432,5*
1.A.3 - Transport	*57 865,9*	*256,9*	*860,4*			*58 983,2*
1.A.4 - Other Sectors	*53 234,9*	*79,7*	*460,8*			*53 775,3*
1.A.5 - Non-Specified	*1 199,3*	*1,1*	*3,2*			*1 203,6*
1.B - Fugitive emissions from fuels	**26 409.1**	**3 771.3**	NE			**30 180.4**
1.B.1 - Solid Fuels	*20.8*	*1 587.4*	*NE*			*1 608.2*
1.B.2 - Oil and Natural Gas	*641.8*	*NE*	*NE*			*641.8*
1.B.3 - Other emissions from Energy Production	*25 746.5*	*2 183.9*	*NE*			*27 930.4*
1.C - Carbon dioxide Transport and Storage	NE					
1.C.1 - Transport of CO_2	*NE*					
1.C.2 - Injection and Storage	*NE*					
1.C.3 - Other	*NA*					
2 - Industrial Processes and Product Use	**36 298.7**	**170.3**	**292.6**	**4 014.5**	**2 453.4**	**43 229.5**
2.A - Mineral Industry	**6 462.1**	**NE**				**6 462.1**
2.B - Chemical Industry	**523.9**	**167.3**	**292.6**			**983.7**
2.C - Metal Industry	**29 037.2**	**3.1**	**NE**	**NE**	**2 453.4**	**31 493.6**
2.D - Non-Energy Products from Fuels and Solvent Use	**275.6**	**NE**	**NE**			**275.6**
2.E - Electronics Industry	**NE**		**NE**	**NE**	**NE**	
2.F - Product Uses as Substitutes for Ozone Depleting Substances	**NE**			**4 014.5**	**NE**	**4 014.5**
2.G - Other Product Manufacture and Use			**NE**	**NE**	**NE**	
2.H - Other	**NA**	**NA**	**NA**			
3 - Agriculture, Forestry, and Other Land Use	**-41 288.1**	**27 501.0**	**22 872.3**			**9 085.2**
3.A - Livestock		**26 453.4**	**1 707.9**			**28 161.3**
3.A.1 - Enteric Fermentation		*25 708.9*				*25 708.9*
3.A.2 - Manure Management		*744.5*	*1 707.9*			*2 452.4*
3.B - Land	**-42 412.8**	**666.6**	**NE**			**-41 746.2**
3.B.1 - Forest land	*-40 707.4*	*NE*	*NE*			*-40 707.4*
3.B.2 - Cropland	*528.3*	*NE*	*NE*			*528.3*
3.B.3 - Grassland	*-18 172.7*	*NE*	*NE*			*-18 172.7*

3.B.4 - Wetlands	*NE*	*666.6*	*NE*			*666.6*
3.B.5 - Settlements	*-105.8*	*NE*	*NE*			*-105.8*
3.B.6 - Other Land	*16 044.8*	*NE*	*NE*			*16 044.8*
3.C - Aggregate sources and non-CO_2 emissions sources on land	**1 901.7**	**380.9**	**21 164.5**			**23 447.1**
3.C.1 - Emissions from biomass burning	*IE*	*380.9*	*377.8*			*758.8*
3.C.2 - Liming	*1 222.1*					*1 222.1*
3.C.3 - Urea application	*679.6*					*679.6*
3.C.4 - Direct N_2O Emissions from managed soils			*18 081.0*			*18 081.0*
3.C.5 - Indirect N_2O Emissions from managed soils			*2 236.3*			*2 236.3*
3.C.6 - Indirect N_2O Emissions from manure management			*469.3*			*469.3*
3.C.7 - Rice cultivations		*NO*	*NO*			
3.C.8 - Other (please specify)	*NO*	*NO*	*NO*			
3.D - Other	**-776.9**	NA	NA			**-776.9**
3.D.1 - Harvested Wood Products	*-776.9*					*-776.9*
3.D.2 - Other (please specify)	*NO*	*NO*	*NO*			
4 - Waste	**37.5**	**20 359.9**	**851.6**			**21 249.0**
4.A - Solid Waste Disposal		**17 366.0**	**NE**			**17 366.0**
4.B - Biological Treatment of Solid Waste		**NE**	**NE**			
4.C - Incineration and Open Burning of Waste	**37.5**	**240.7**	**82.0**			**360.2**
4.D - Wastewater Treatment and Discharge		**2 753.3**	**769.6**			**3 522.8**
4.E - Other	**NO**	**NO**	**NO**	**NO**	**NO**	
5 - Other						
5.A - Indirect N_2O emissions from the atmospheric deposition of nitrogen in NOx and NH3			**NE**			
5.B - Other			**NO**			
Memo items						
International bunkers	**11 494.4**	**16.5**	**92.3**	NA	NA	**11 603.2**
International aviation	*2 242.3*	*0.1*	*5.8*	*NA*	*NA*	*2 248.2*
International water-borne transport	*9 252.0*	*16.4*	*86.5*	*NA*	*NA*	*9 354.9*
Multilateral operations	*NA*	*NA*	*NA*	*NA*	*NA*	

Chapter 2: References

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environment, forestry & fisheries

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Environment, Forestry and Fisheries
REPUBLIC OF SOUTH AFRICA

Chapter 3: Energy

3.1 Sector overview

3.1.1 Introduction

South Africa's GDP is the 30th highest in the world, but in primary energy consumption South Africa is ranked 17th 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 2019, the Department of Mineral Resources and the Department of Energy were combined to form the Department of Mineral Resources and Energy (DMRE). The Energy division is responsible for the management, processing, exploration, utilisation and development of South Africa's energy resources.

The 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.

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. The primary energy supply in South Africa is dominated by coal (59 %), followed by crude oil (16%), renewable and waste (20%) and natural gas (3%) and Nuclear (2.0%) (DoE, 2018).

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.

The categories included in the energy sector for South Africa are *Fuel combustion activities* (1A), including international bunkers, and *Fugitive emissions from fuels* (1B).

3.1.2 Overview of shares and trends in emissions

2017

Total emissions from the *Energy* sector for 2017 were estimated to be 439 576 Gg CO_2e (Table 3.1). *Energy industries* were the main contributor, accounting for 58.7% of emissions from the *Energy* sector. This was followed by *transport* (13.4%) and *manufacturing industries and construction* (8.3%). The *residential* and *commercial* sectors are both heavily reliant on electricity for meeting energy needs.

A summary table of all emissions from the Energy sector by gas is provided in Appendix 3.A.

Table 3.1: Summary of emissions from the Energy sector in 2017.

Greenhouse gas source and sink categories	CO_2	CH_4		N_2O		Total
	Gg CO_2e	Gg	Gg CO_2e	Gg	Gg CO_2e	Gg CO_2e
1.ENERGY	**432 698.0**	**199.1**	**4 180,5**	**8.7**	**2 697,8**	**439 576.3**
1A Fuel combustion activities	406 289	19.48	409,2	8.7	2 697,8	409 395.9
1B Fugitive emissions from fuels	26 409.1	179.6	3 771.3	0.0	0.0	30 180.4
1C Carbon dioxide transport and storage	NE	NE	NE	NE	NE	NE

2000 - 2017

Energy sector emissions increased by 26.1% between 2000 and 2017 (Table 3.2). This growth in emissions is mainly from the 29.8% increase in *fuel combustion activities*. There was an increase of 34 736 Gg CO_2e increase in the *other sector* emissions, a 37 414 Gg CO_2e increase in *energy industry* emissions and a 16 829 Gg CO_2e increase in *transport* emissions (Table 3.2). On the other hand, *fugitive emissions from fuels* declined by 8.7%. Economic growth and development led to increased demand for electricity and fossil fuels. Economic growth also increased the amount people travelling, leading to higher rates of consumption of petroleum fuels. In addition, growing populations led to increased consumption of fuels in households, producing increased residential emissions.

Figure 3.1 shows the time-series for the *Energy* sector from 2000 to 2017, while Table 3.3 shows the actual emissions associated with this trend. It can be seen that emissions increase until 2007, after which there is still an increase but it is slower (Figure 3.2). A peak is reached in 2013, after which emissions appear to stabilize. Annual change (Figure 3.2) appears to be slowing, with more years where there is a decline in emissions.

Table 3.2: Summary of the change in emissions from the Energy sector between 2000 and 2017.

Greenhouse gas source and sink categories	Emissions ($Gg\ CO_2e$)		Difference ($Gg\ CO_2e$)	Change (%)
	2000	2017	2000-2017	2000-2017
1.ENERGY	**348 475.3**	**439 576.3**	**93295.5**	**32.8**
1.A Fuel combustion activities	**315 427.6**	**409 395,9**	**116 168.0**	**37.2**
1.A.1 Energy industries	*220 587.0*	*258 001.3*	*37 414.4*	*17.0*
1.A.1.a Electricity and heat production	*185 961.7*	*225 248.7*	*39 287.0*	*21.1*
1.A.1.b Petroleum refining	*4 049.5*	*3 333.0*	*-716.6*	*-17.7*
1.A.1.c Manufacture of solid fuels	*30 575.7*	*29 419.6*	*-1 156.1*	*-3.8*
1.A.2 Manufacturing industries and construction	*32 658.3*	*37 432.5*	*4 774.2*	*14.6*
1.A.3 Transport	*42 154.6*	*58 983,2*	*20 0005.2*	*51,3*
1.A.3.a Domestic aviation	*2 047.2*	*4 555.5*	*2 508.3*	*122.5*
1.A.3.b Road transportation	*34 787.3*	*71 351.8*	*36 564.4*	*105.1*
1.A.3.c Railways	*618.1*	*490.3*	*-127.8*	*-20.7*
1.A.3.d Water-borne navigation (domestic)	*1 525.4*	*1 619.0*	*93.6*	*6.1*
1.A.3.e Other transportation	*NE*	*NE*		
1.A.4 Other sectors	*19 048.9*	*53 775.3*	*34 726.4*	*182.3*
1.A.4.a Commercial/Institutional	*9 558.1*	*18 851.4*	*9 293.3*	*97.2*
1.A.4.b Residential	*7 103.0*	*30 612.1*	*23 509.1*	*331.0*
1.A.4.c Agriculture/Forestry/Fishing/Fish farms	*2 387.8*	*4 311.7*	*1 923.9*	*80.6*
1.A.5 Non-specified	*989.1*	*1 203.6*	*214.5*	*21.7*
1.B Fugitive emissions from fuels	**33 047.7**	**30 180.4**	**-2 867.3**	**-8.7**
1.B.1 Solid fuels	*1 830.5*	*1 608.2*	*-222.3*	*-12.1*
1.B.2 Oil and natural gas	*752.0*	*641.8*	*-110.2*	*-14.7*
1.B.3 Other emissions from energy production	*30 465.2*	*27 930.4*	*-2 534.8*	*-8.3*
1.C Carbon dioxide transport and storage	**NE**	**NE**		

Note: Columns may not add up exactly due to rounding off.

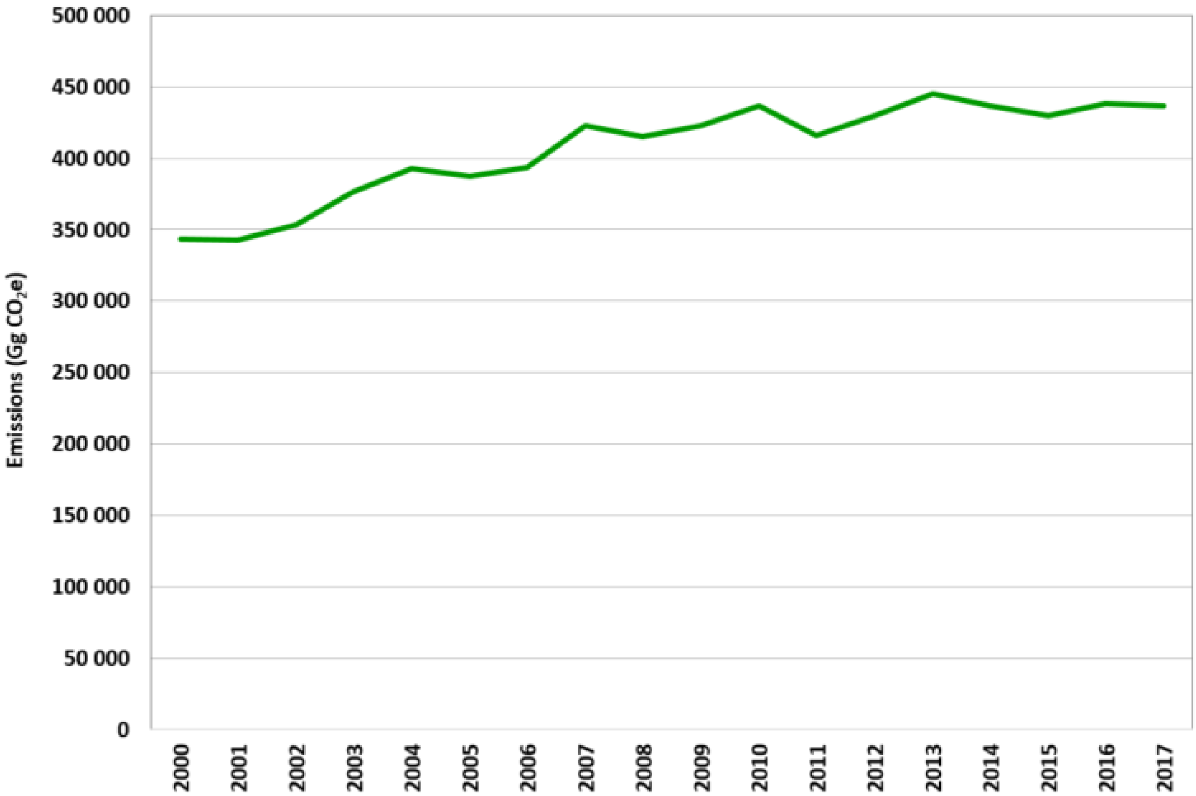

Figure 3.1: Trends in South Africa's energy sector emissions, 2000 – 2017.

Table 3.3: Trends in the energy sector emissions between 2000 and 2017.

	CO_2	CH_4	N_2O	Energy emissions
	Gg CO_2	Gg CH_4	Gg N_2O	Gg CO_2e
2000	*341 554,8*	*221,5*	*7,3*	*348 475,3*
2001	*340 439,0*	*221,0*	*7,4*	*347 361,5*
2002	*351 413,6*	*222,1*	*7,6*	*358 431,2*
2003	*374 453,2*	*225,4*	*8,0*	*381 676,1*
2004	*391 255,7*	*234,4*	*8,4*	*398 769,3*
2005	*387 242,8*	*225,0*	*8,5*	*394 591,1*
2006	*392 806,0*	*217,1*	*7,8*	*399 781,2*
2007	*425 684,5*	*221,9*	*8,5*	*432 985,7*
2008	*419 882,7*	*220,1*	*8,5*	*427 141,0*
2009	*425 845,7*	*219,2*	*8,6*	*433 106,4*
2010	*433 506,0*	*218,5*	*8,6*	*440 763,2*
2011	*412 958,0*	*193,0*	*8,2*	*419 562,5*

2012	*423 923,1*	*199,1*	*8,4*	*430 715,7*
2013	*440 789,0*	*201,3*	*8,8*	*447 748,9*
2014	*436 504,5*	*202,3*	*8,9*	*443 498,9*
2015	*430 275,2*	*200,9*	*8,7*	*437 203,5*
2016	*432 403,9*	*198,1*	*8,6*	*439 236,2*
2017	*432 698,0*	*199,1*	*8,7*	*439 576,3*

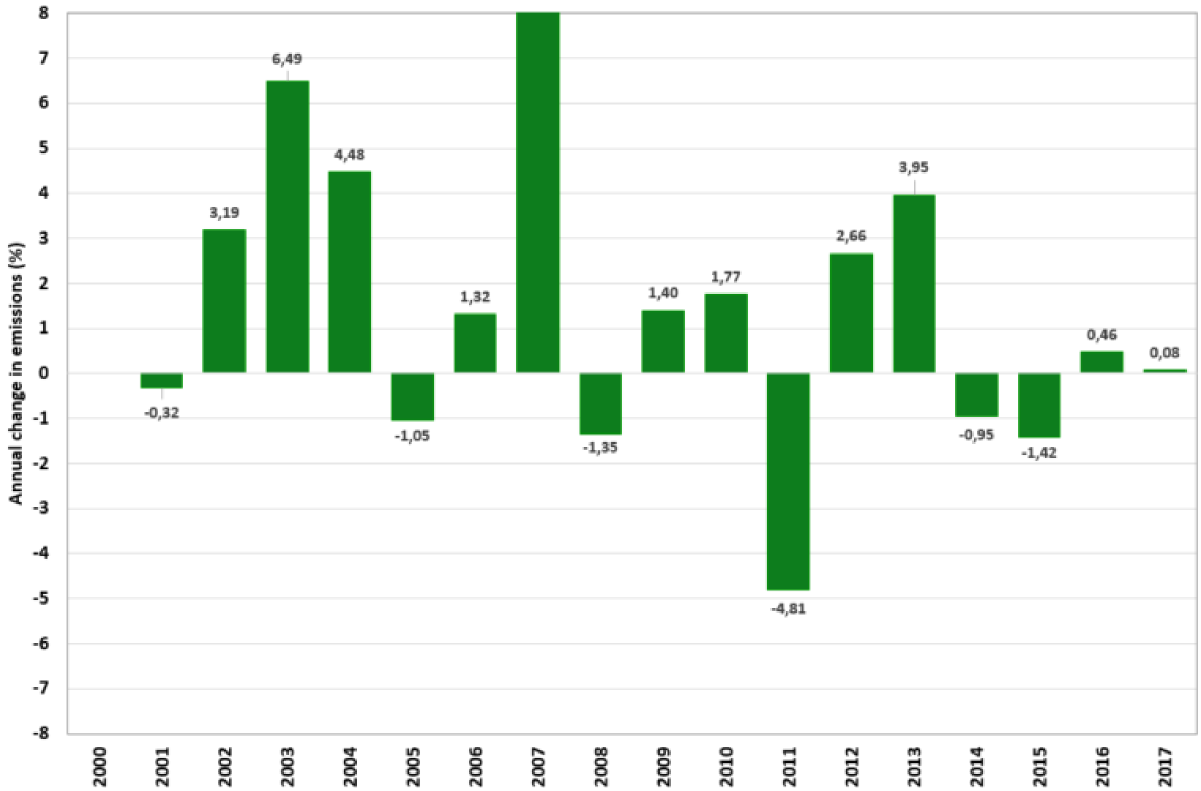

Figure 3.2: Trend in annual change in the total energy emissions in South Africa, 2000 – 2017.

2015 – 2017

Energy emissions increased by 0.5% (2 373 Gg CO_2e) since the previous 2015 submission. The main contributor to this increase was the *other sectors* which increased by 10.3% (5 014 Gg CO_2e). *Transport* decreased by 3.8% (2 354 Gg CO_2e). On the other hand, the *energy industries* emissions declined by 1 980 Gg CO_2 (0.8%) over this period.

3.1.3 Overview of methodology and completeness

Emissions for the *Energy* sector were estimated with a sectoral approach. In most cases a Tier 1 methodology was applied, but Table 3.4 provides a summary of the methods and emission factors applied to each subsector of energy.

Table 3.4: Summary of methods and emission factors for the energy sector and an assessment of the completeness of the energy sector emissions.

GHG Source and sink category		CO_2		CH_4		N_2O		Details
		Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	
A	**Fuel combustion activities**							
1	***Energy industries***							
	a. Main activity electricity and heat production	T1, T2	DF, CS	T1	DF	T1	DF	CS CO_2 EF for sub-bituminous coal (Technical Guidelines, 2016)
	b. Petroleum refining	T1	DF	T1	DF	T1	DF	
	c. Manufacture of solid fuels and other energy industries	T3	CS	T3	CS	T3	CS	No activity data; emissions supplied by Sasol and PetroSA - based on Mass Balance Approach
2	***Manufacturing industries and construction***	T1, T2	DF, CS	T1	DF	T1	DF	CS CO_2 EF for sub-bituminous coal (Technical Guidelines)
3	***Transport***							
	a. Civil aviation	T1	DF	T1	DF	T1	DF	
	b. Road transportation	T1	DF	T1	DF	T1	DF	
	c. Railways	T1	DF	T1, T2	DF, CS	T1	DF	CS CH_4 EF for gas/diesel oil (SAPIA)
	d. Water-borne navigation	T1	DF	T1	DF	T1	DF	
	e. Other transportation	NO		NO		NO		
4	***Other sectors***							
	a. Commercial/Institutional	T1, T2	DF, CS	T1	DF	T1	DF	CS CO_2 EF for sub-bituminous coal (Technical Guidelines)
	b. Residential	T1, T3	DF, CS	T1	DF	T1	DF	CS CO_2 EF for sub-bituminous coal (Technical Guidelines)

	c. Agriculture/Forestry/ Fishing/Fish farms	T1, T4	DF, CS	T1	DF	T1	DF	CS CO_2 EF for sub-bituminous coal (Technical Guidelines)
5	***Non-specified***							
	a. Stationary	T1, T2	DF, CS	T1	DF	T1	DF	CS CO_2 EF for sub-bituminous coal (Technical Guidelines)
	b. Mobile	IE		IE		IE		The fuels associated with this category are assumed to be included elsewhere in the energy balance.
B	**Fugitive emissions from fuels**							
1	***Solid fuels***							
	a. Coal mining and handling	T2	CS	T2	CS	NO		CS CO_2 and CH_4 EFs based on the study by Coaltech SA.
	b. Uncontrolled combustion and burning coal dumps	NE		NE		NO		
	c. Solid fuel transformation	IE		IE		NO		Fugitive emissions from coal-to-liquids is included under 1B3. Emissions from coke production are included under 2C
2	***Oil and natural gas***							
	a. Oil	T3	CS	T3	CS	NO		Based on measurements - PetroSA
	b. Natural gas	NE		NE				
3	***Other emissions from energy production***	T3	CS	T1, T3	DF, CS	NE		Industry specific CO_2 and CH_4 emissions supplied by Sasol and PetroSA - based on Mass Balance Approach. Charcoal CH_4 used approach T1
C	**Carbon dioxide transport and storage**							
1	***Transport of CO_2***							
	a. Pipelines	NE		NE		NE		
	b. Ships	NE		NE		NE		
	c. Other	NE		NE		NE		
2	***Injection and storage***							
	a. Injection	NE		NE		NE		
	b. Storage	NE		NE		NE		
3	***Other***	NE		NE		NE		

3.1.4 Recalculations since the 2015 submission

Recalculated emission estimates for the *Energy* sector were up to 5% higher than previous estimates for the *Energy* sector (Figure 3.3). These recalculations were necessary due to an update of consumption data in the *Road transport* and *Other emissions from energy production* categories.

A recent parc model study (DEFF, 2020) was completed for the transport sector which provided consumption data based on vehicle kilometres travelled (VKT). In this inventory the petrol, diesel and natural gas consumption data for *Road transport* was updated and this lead to a 3.8% decrease in the *Road transport* emission estimates between 2015 and 2017. In the *Other emissions from energy production* category the charcoal consumption data was corrected and this produced a 1% decline in emission estimates for 2008 to 2012 and a 12% reduction in the 2013 estimates.

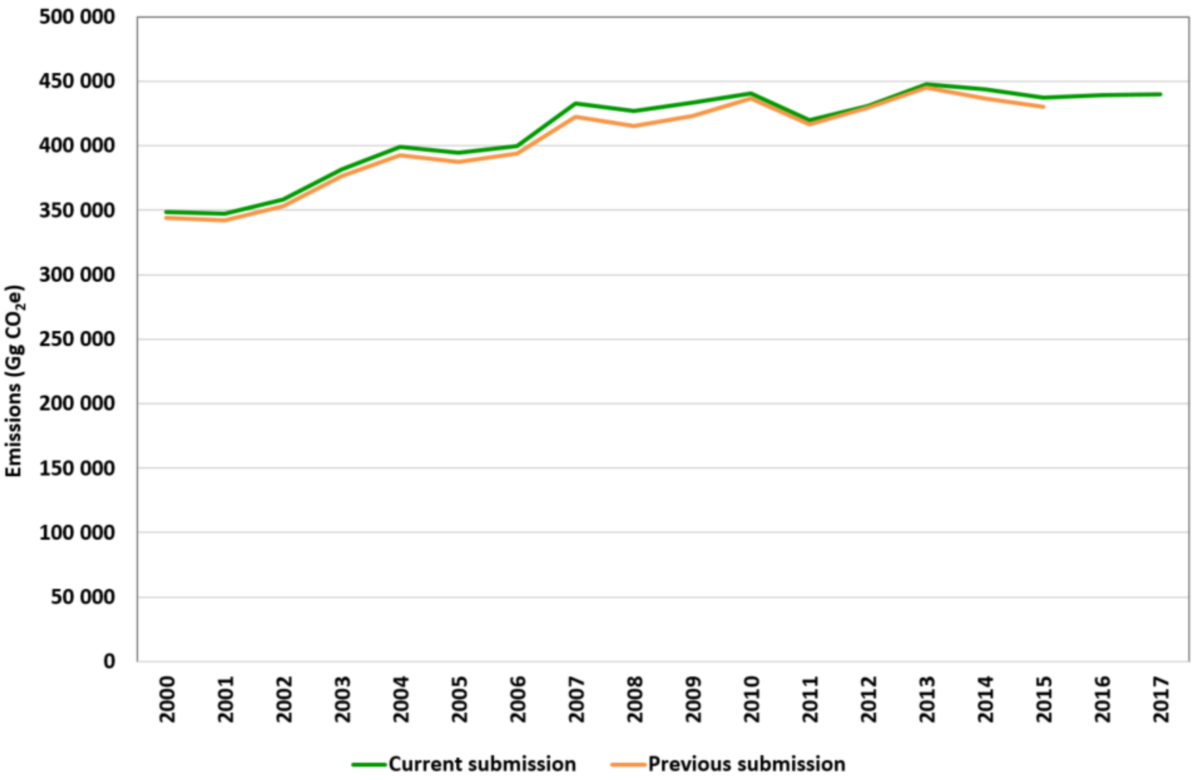

Figure 3.3: Recalculations for the Energy sector between 2000 and 2017.

3.1.5 Key categories in the energy sector

The key categories for the *Energy* sector as determined by the level (L) and trend (T) assessment are shown in Table 3.5.

Table 3.5: Key categories identified in the Energy sector.

IPCC Code	Category	GHG	Identification Criteria
1A1a	Electricity and heat production (solid fuels)	CO_2	L,T
1A1a	Electricity and heat production (liquid fuels)	CO_2	L
1A1b	Petroleum refining (gaseous fuels)	CO_2	L,T
1A1b	Petroleum refining (liquid fuels)	CO_2	T
1A1c	Manufacture of solid fuels and other energy industries (solid fuels)	CO_2	L,T
1A2	Manufacturing industries and construction (gaseous fuels)	CO_2	L,T
1A2	Manufacturing industries and construction (solid fuels)	CO_2	L,T
1A2	Manufacturing industries and construction (liquid fuels)	CO_2	T
1A3a	Civil aviation (liquid fuels)	CO_2	L,T
1A3b	Road transport (liquid fuels)	CO_2	L,T
1A4a	Commercial/institutional (liquid fuels)	CO_2	L,T
1A4a	Commercial/institutional (solid fuels)	CO_2	L
1A4b	Residential (solid fuels)	CO_2	L,T
1A4b	Residential (liquid fuels)	CO_2	T
1A4c	Agriculture/forestry/fishing/fish farms (liquid fuels)	CO_2	L,T
1B1a	Coal mining and handling	CH_4	T
1B3	Other emissions from energy production	CH_4	T

3.1.6 Planned improvements

Improvements planned for the next inventory are:

(i) There will be three instruments through which the data will be collected for the inventory in future. The first process will involve enhancement of the current direct communication between stakeholder and DEFF with memorandum of understandings which are being drafted to formalise the data collection process between significant industry players and government departments. For example, MoU will be finalised for government departments such as Department of Minerals Resources and Energy (DMRE), public entities such as Eskom (electricity production) and associations such as South African Petroleum Industry Association (SAPIA);

(ii) The other improvement will be data that will be generated through the South African Greenhouse Gas Emissions Reporting System (SAGERS). SAGERS was developed to improve the compilation of GHG emissions inventories by assisting DEFF and Category A[3] data providers to abide by the reporting regulations (National Greenhouse Gas Emissions Reporting Regulations of 2016, Notice No. 40762). Some selected data providers (Category A[4] data providers) SAGERS will be an online platform which allows users to register and submit their GHG emission reports. SAGERS will not only improve GHG reporting for the *Energy* sector, but will also improve the *IPPU* sector emission estimates which relied heavily on publicly available data. In the next inventory data gathered through the GHG regulation and SAGERS will be incorporated;

(iii) A fuel consumption study is currently underway. This study aims primarily to disaggregate the use of combustion fuels, including liquid fuels, solid fuels, biomass-based and gaseous fuel data according to the demand-side sectors and sub-sectors of the South African economy for each year in the period 2013 – 2018 and projections to 2035. Effectively this project will not only update the work done in the Phase I fuel disaggregation study conducted by GIZ in 2015, but also expand on its scope. The long-term forecasting will be based on final demand figures and event scenarios that are expected (might occur) in the next 15 years. This study is generating energy consumption data from all the demand sectors in South Africa and goes further to estimating vehicle kilometre travelled in the transport sector. The inventory will be updated with information from this study as it becomes available;

(iv) Fugitive emissions from coke production is currently accounted for under category 2C as part of process emissions, however it is planned that by the 2012 inventory these will be separated from process emissions and reported separately; and

(v) Time-series will be extended back to 1990 over the next few years, but this will likely only be available in the 6th BUR.

3.2 Source category 1.A Fuel combustion

[3] *Companies conducting IPCC activities and meet reporting thresholds as per the reporting regulations*

[4] *Data providers/companies that have thresholds (production quantity, usage quantity and installation capacity) defined in the NGERs to report on GHG emissions.*

3.2.1 Category information

Source category description

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
- 1A3 Transport sector
    - 1A3a Civil aviation
    - 1A3b Road transportation
    - 1A3c Railways
    - 1A3d Water-borne navigation
- 1A4 Other sectors
    - 1A4a Commercial/ institutional
    - 1A4b Residential
    - 1A4c Agriculture / forestry/ fishing/ fish farms
- 1A5 Non-specified
    - 1A5a Stationary

Emissions

2017

Total estimated emissions from *fuel combustion* were 409 396 Gg CO_2e in 2017, equal to 93.1% of the *energy* sector emissions. *Energy industries* contributed 58.7% to the total fuel combustion activity emissions in 2017. CO_2 emissions constitute 99.2% of fuel activity emissions. CH_4 and N_2O emissions contributed 0.1% and 0.6% respectively.

2000 - 2017

Emissions are seen to increase from 2000 to 2013, after which emissions stabilise to 2017. There is a slight decline to 2015 due to a decline in the *energy industries* emissions

(Figure 3.4, Table 3.6). There was a slight increase in 2016, but emissions decline again in 2017. Details of these declines, as well as further information about methodologies, emission factors, uncertainty, and quality control and assurance are provided in the various sub-category sections below.

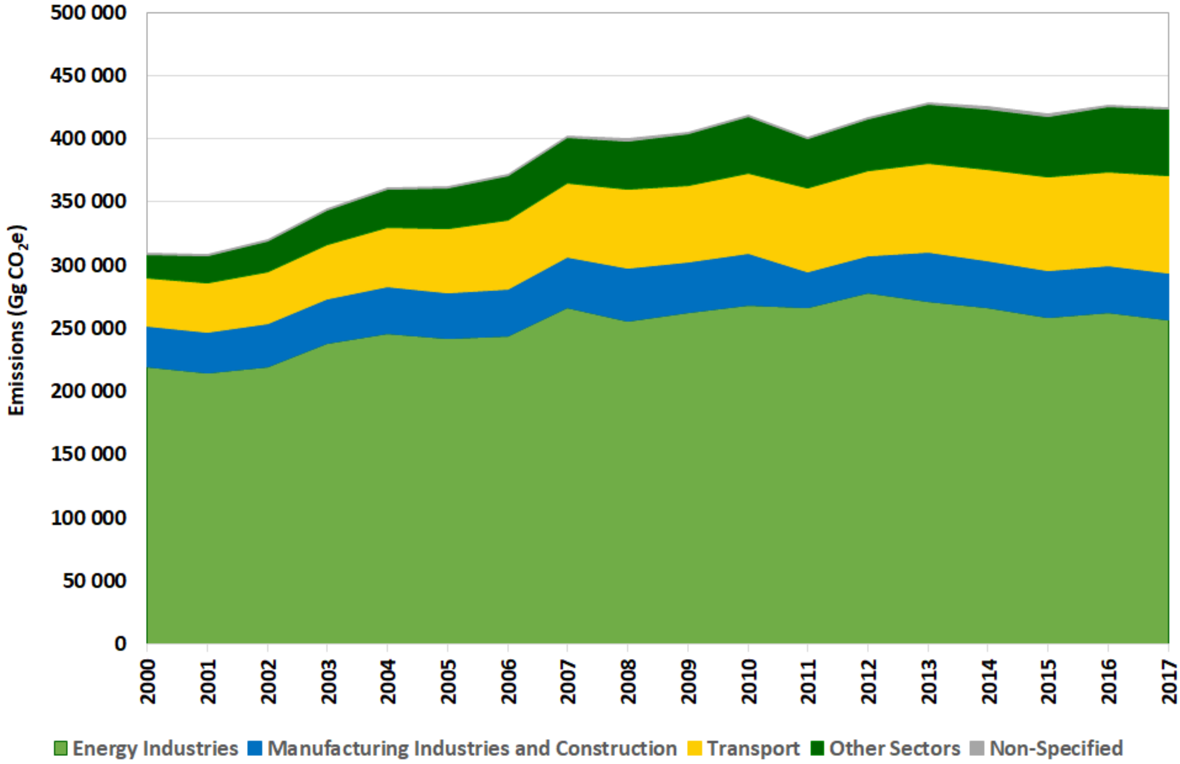

Figure 3.4: Trends and subcategory contributions to fuel combustion activity emissions in South Africa, 2000 – 2017.

Table 3.6: Trends in emissions from fuel combustion activities between 2000 and 2017.

	Energy Industries	Manufacturing Industries and Construction	Transport	Other Sectors	Non-Specified
	Gg CO_2e				
2000	220 587.0	32 658.3	42 155	19 048.9	989.1
2001	215 884.1	32 186.3	42 504	22 540.9	983.8
2002	221 177.2	33 395.4	43 294	25 662.5	983.3
2003	238 889.8	35 905.1	44 925	27 958.7	1 014.9

2004	246 680.0	37 884.3	47 379	31 034.4	1 045.1
2005	242 786.0	37 154.9	49 855	32 916.8	1 062.3
2006	244 834.0	38 078.3	49 594	35 551.3	1 073.1
2007	268 012.3	39 469.3	56 609	36 673.8	1 099.7
2008	257 213.4	42 284.6	58 097	38 692.7	1 053.1
2009	263 672.2	40 135.5	56 543	41 483.8	1 076.4
2010	269 930.7	41 124.5	53 589	45 240.1	1 139.0
2011	267 890.2	28 417.2	53 820	39 655.5	1 138.2
2012	279 356.4	29 217.0	50 797	40 682.0	1 114.5
2013	273 022.4	38 429.6	58 148	47 020.5	1 151.2
2014	267 531.9	37 011.2	59 949	48 269.9	1 164.3
2015	259 981.2	36 870.3	61 337	48 761.4	1 177.4
2016	263 428.4	37 309.5	56 302	51 736.6	1 190.5
2017	258 001.3	37 432.5	58 983	53 775.3	1 203.6

Methodology

Unless otherwise noted in the relevant section, estimates of emissions from the combustion of individual fuel types are determined by multiplying an activity data item (physical quantity of fuel combusted) by a fuel-specific energy content factor and a fuel-specific emission factor for each relevant greenhouse gas as follows:

$$(Emissions)_{ij} = Q_i \times EC_i \times EF_{ij} / 1000000 \qquad (Eq. 3.1)$$

Where:

E_{ij} = the emissions of gas type (j) in Gigagrams (Gg), being carbon dioxide, methane or nitrous oxide, released from the combustion of fuel type (i)
Q_i = quantity of fuel type in tonnes (i)
EC_i = calorific value of the type of fuel (conversion factor) in Terajoule/tonne (Table 3.8)
Ef_{ij} = emission factor for each gas type (j) released during the year measured in mass units (kg) per Terajoule (TJ) of fuel type (i) (Table 3.9)
A factor of 1000000 (to convert from kilograms to Gigagrams of greenhouse gas).

While small oxidation variations may be known for different types of fuel, a general oxidation factor of 1 was assumed.

Activity data

The required activity data and the main data providers for each subsector are provided in Table 3.7. The net calorific values for converting fuel quantities into energy units for solid, liquid and gaseous fuels are provided in Table 3.8 and are taken from DEA (2016).

Table 3.7: Data sources for the fuel combustion subcategory.

Sub-category	Activity data	Activity data sources
Electricity generation	Fuel consumption for public electricity generation	Eskom
	Fuel consumption for auto electricity producers	Energy balance (DoE)
	NCVs	Eskom
Petroleum refining	Fuel consumption	Refineries
Manufacture of solid fuels and other energy industries	No activity data, only emission data - based on Mass Balance Approach	PetroSA
		Sasol
Manufacturing industries and construction	Other kerosene, bitumen and natural gas consumption	Energy balance (DoE)
	Gas/Diesel consumption	SAPIA
	Residual fuel oil consumption	Energy digest
	LPG consumption	SAMI report (DMR)
Transport	Vehicle kilometres travelled for road transport	Fuel consumption study
	Domestic aviation gasoline consumption	SAPIA
	Domestic aviation jet kerosene consumption	Energy balance (DOE)
	Road transport fuel consumption	Energy balance (DoE)
	Road transportation other kerosene consumption	SAPIA
	Railway fuel oil consumption	Energy balance (DoE)
	Railway gas/diesel oil consumption	SAPIA
	Water-borne navigation fuel consumption	
	International aviation Jet Kerosene consumption	Energy balance (DoE); SAPIA
Commercial/institutional	Other kerosene, gas/diesel oil, gas works gas and natural gas consumption	Energy balance (DoE)
	Sub-bituminous coal consumption	Energy digest
	Residual fuel oil consumption	SAPIA
Residential	Coal consumption	SAMI report (DMR)
	LPG consumption	SAPIA
	Sub-bituminous coal consumption	Energy digest

	Other fuel consumption	Energy balance (DOE)
Agriculture/forestry/fishing/fish farms	Other kerosene consumption	SAPIA
	Gas/diesel oil consumption	Energy Digest
	Other fuel consumption	Energy balance (DOE)
Stationary non-specified	Fuel consumption	SAPIA

Table 3.8: Net calorific values for solid, liquid and gaseous fuels as provided by the South African Petroleum Industry Association.

Fuel		Net calorific value	Unit	Density (kg/l)
Solid fuels	Coal: Eskom Average	20.1	MJ/kg	
	Coal: General purpose	24.3	MJ/kg	
	Coal: Coking	30.1	MJ/kg	
	Coke	27.9	MJ/kg	
	Biomass (wood dry typical)	17	MJ/kg	
	Wood charcoal	31	MJ/kg	
Liquid fuels	Paraffin	37.5	MJ/l	0.790
	Diesel	38.1	MJ/l	0.845
	Heavy Fuel Oil	43	MJ/kg	0.958
	Fuel Oil 180	42	MJ/kg	0.99
	Petrol	34.2	MJ/l	0.75
	Avgas (100LL)	33.9	MJ/l	0.71
	Jet Fuel (Jet-A1)	37.5	MJ/l	0.79
Gaseous fuels	LPG	46.1	MJ/Nm^3	0.555
	Sasol gas (MRG)	33.6	MJ/Nm^3	
	Natural gas	38.1	MJ/Nm^3	
	Blast furnace gas	3.1	MJ/Nm^3	
	Refinery gas	20	MJ/Nm^3	
	Coke oven gas	17.3	MJ/Nm^3	

Emission factors

Table 3.9 provides the emission factors for stationary combustion. The default values are taken from 2006 IPCC Guidelines (Table 1.4 and 2.2 in volume 2). Country specific values are from the Technical Guidelines for Monitoring Reporting and Verification of GHG Emissions by Industry (DEA, 2016).

Table 3.9: Emission factors for stationary combustion (solid, liquid, gaseous and other fuels).

Fuel			CO_2		CH_4		N_2O	
			DF (Tier 1)	CS (Tier 2)	DF (Tier 1)	CS (Tier 2)	DF (Tier 1)	CS (Tier 2)
Liquid fuels		Crude oil	73 300		3		0.6	
		Orimulsion	77 000		3		0.6	
		Natural gas liquids	64 200		3		0.6	
	Gasoline	Motor gasoline	69 300		3		0.6	
		Aviation gasoline	70 000		3		0.6	
		Jet gasoline	70 000		3		0.6	
		Jet kerosene	71 500		3		0.6	
		Other kerosene	71 900		3		0.6	
		Shale oil	73 300		3		0.6	
		Gas/Diesel oil	74 100		3		0.6	
		Residual fuel oil	77 400		3		0.6	
		Liquified petroleum gases	63 100		1		0.1	
		Ethane	61 600		1		0.1	
		Naphtha	73 300		3		0.6	
		Bitumen	80 700		3		0.6	
		Lubricants	73 300		3		0.6	
		Petroleum coke	97 500		3		0.6	
		Refinery feedstocks	73 300		3		0.6	
	Other oil	Refinery gas	57 600		1		0.1	
		Paraffin waxes	73 300		3		0.6	
		White spirit and SBP	73 300		3		0.6	
		Other petroleum products	73 300		3		0.6	
Solid fuels		Anthracite	98 300		1		1.5	
		Coking coal	94 600		1		1.5	
		Other bituminous coal	94 600		1		1.5	
		Sub-bituminous coal	96 100	96 250	1		1.5	
		Lignite	101 000		1		1.5	
		Oil shale and Tar sands	107 000		1		1.5	
		Brown coal briquettes	97 500		1		1.5	
		Patent fuel	97 500		1		1.5	
	Coke	Coke oven coke and lignite coke	107 000		1		1.5	
		Gas coke	107 000		1		0.1	
		Coal tar	80 700		1		1.5	
	De	Gas works gas	44 400		1		0.1	
		Coke oven gas	44 400		1		0.1	

Fuel			CO_2 DF (Tier 1)	CO_2 CS (Tier 2)	CH_4 DF (Tier 1)	CH_4 CS (Tier 2)	N_2O DF (Tier 1)	N_2O CS (Tier 2)
		Blast furnace gas	260 000		1		0.1	
		Oxygen steel furnace gas	182 000		1		0.1	
Gaseous fuels	Natural gas		56 100	48 000	1		0.1	
Other fuels								
Other fossil fuels	Municipal wastes (non-biomass fraction)		91 700		30		4	
	Industrial wastes		143 000		30		4	
	Waste oils		73 300		30		4	
	Peat		106 000		1		1.5	
Solid biofuels	Wood/wood waste		112 000		30		4	
	Sulphite lyes (Black liquor)		95 300		3		2	
	Other primary solid biomass		100 000		30		4	
	Charcoal		112 000		200		4	
Liquid biofuels	Biogasoline		70 800		3		0.6	
	Biodiesels		70 800		3		0.6	
	Other liquid biofuels		79 600		3		0.6	
Gas biomass	Landfill gas		54 600		1		0.1	
	Sludge gas		54 600		1		0.1	
	Other biogas		54 600		1		0.1	
Other non-fossil fuels	Municipal wastes (biomass fraction)		100 000		30		4	

Uncertainty and time-series consistency

The time-series is complete for *Fuel combustion* activities. Uncertainties for this category are provided in Table 3.10.

Table 3.10: Uncertainty for South Africa's fuel combustion emission estimates.

Gas		Activity data uncertainty		Emission factor uncertainty	
		%	Source	%	Source
CO_2	1A1ai Electricity generation – liquid fuels	5	IPCC 2006	7	IPCC 2006
	1A1ai Electricity generation – solid fuels	5	IPCC 2006	7	IPCC 2006
	1A1b Petroleum refining – liquid fuels	5	IPCC 2006	7	IPCC 2006
	1A1ci Manufacture of solid fuels – liquid fuels	5	IPCC 2006	7	IPCC 2006
	1A1ci Manufacture of solid fuels – solid fuels	5	IPCC 2006	7	IPCC 2006
	1A1cii Other energy industries – liquid fuels	10	IPCC 2006	7	IPCC 2006
	1A2 Manufacturing industries and construction – liquid fuels	10	IPCC 2006	7	IPCC 2006
	1A2 Manufacturing industries and construction – solid fuels	10	IPCC 2006	7	IPCC 2006
	1A2 Manufacturing industries and construction – gaseous fuels	10	IPCC 2006	7	IPCC 2006
	1A3a Civil aviation – liquid fuels	5	IPCC 2006	1.5	IPCC 2006
	1A3b Railways liquid fuels	5	IPCC 2006	5	IPCC 2006
	1A4 Other sectors – liquid fuels	10	IPCC 2006	7	IPCC 2006
	1A4 Other sectors – solid fuels	10	IPCC 2006	7	IPCC 2006
	1A4 Other sectors – gaseous fuels	10	IPCC 2006	7	IPCC 2006
	1A4 Other sectors – biomass	40	IPCC 2006	7	IPCC 2006
	1A5 Non-specified – stationary liquid fuels	5	IPCC 2006	7	IPCC 2006
CH_4	1A1 Energy industries – liquid fuels	5	IPCC 2006	75	IPCC 2006
	1A1 Energy industries – solid fuels	5	IPCC 2006	75	IPCC 2006
	1A2 Manufacturing industries and construction – liquid fuels	10	IPCC 2006	75	IPCC 2006
	1A2 Manufacturing industries and construction – solid fuels	10	IPCC 2006	75	IPCC 2006
	1A2 Manufacturing industries and construction – gaseous fuels	10	IPCC 2006	75	IPCC 2006
	1A3a Civil aviation – liquid fuels	5	IPCC 2006	50	IPCC 2006
	1A3b Railways - liquid fuels	5	IPCC 2006	9	IPCC 2006
	1A4 Other sectors – liquid fuels	10	IPCC 2006	75	IPCC 2006
	1A4 Other sectors – solid fuels	10	IPCC 2006	75	IPCC 2006
	1A4 Other sectors – gaseous fuels	10	IPCC 2006	75	IPCC 2006
	1A4 Other sectors – biomass	40	IPCC 2006	75	IPCC 2006
	1A5 Non-specified – stationary liquid fuels	5	IPCC 2006	75	IPCC 2006
N_2O	1A1 Energy industries – liquid fuels	5	IPCC 2006	75	IPCC 2006
	1A1 Energy industries – solid fuels	5	IPCC 2006	75	IPCC 2006
	1A2 Manufacturing industries and construction – liquid fuels	10	IPCC 2006	75	IPCC 2006
	1A2 Manufacturing industries and construction – solid fuels	10	IPCC 2006	75	IPCC 2006

Gas		Activity data uncertainty		Emission factor uncertainty	
		%	Source	%	Source
	1A2 Manufacturing industries and construction – liquid fuels	10	IPCC 2006	75	IPCC 2006
	1A2 Manufacturing industries and construction – solid fuels	10	IPCC 2006	75	IPCC 2006
	1A2 Manufacturing industries and construction – gaseous fuels	10	IPCC 2006	75	IPCC 2006
	1A3a Civil aviation – liquid fuels	5	IPCC 2006	50	IPCC 2006
	1A3b Railways - liquid fuels	5	IPCC 2006	72	IPCC 2006
	1A4 Other sectors – liquid fuels	10	IPCC 2006	75	IPCC 2006
	1A4 Other sectors – solid fuels	10	IPCC 2006	75	IPCC 2006
	1A4 Other sectors – gaseous fuels	10	IPCC 2006	75	IPCC 2006
	1A4 Other sectors – biomass	40	IPCC 2006	75	IPCC 2006
	1A5 Non-specified – stationary liquid fuels	5	IPCC 2006	75	IPCC 2006

3.2.2 Comparison between sectoral and reference approach

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 reference approach outputs were compared to the sectoral emissions for the period 2000 to 2016 (energy balance data for 2017was not available) and the CO_2 emissions were always higher using the reference approach (Figure 3.5). The difference in CO_2 emissions using the reference and sectoral approach was 7.8% and 8.7% for the years 2015 and 2016, respectively. The largest differences were seen in the solid fuels, where consumption is consistently higher with the reference approach (Appendix 3.B, Figure 3.B.1). Allocation of solid fuels between energy use, non-energy use as well as use for synthetic fuels production remains one of the key drivers of the differences observed between the two datasets. The opposite is true for liquid fuels, with the sectoral approach showing higher values (Appendix 3.B, Figure 3.B.2), whereas for gaseous fuels the consumption data is higher with the reference approach (Appendix 3.B, Figure 3.B.3). Reasons for the differences between the emissions and fuel consumption data of the reference and sectoral approach are:

- 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 2000-2016 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;
- 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.

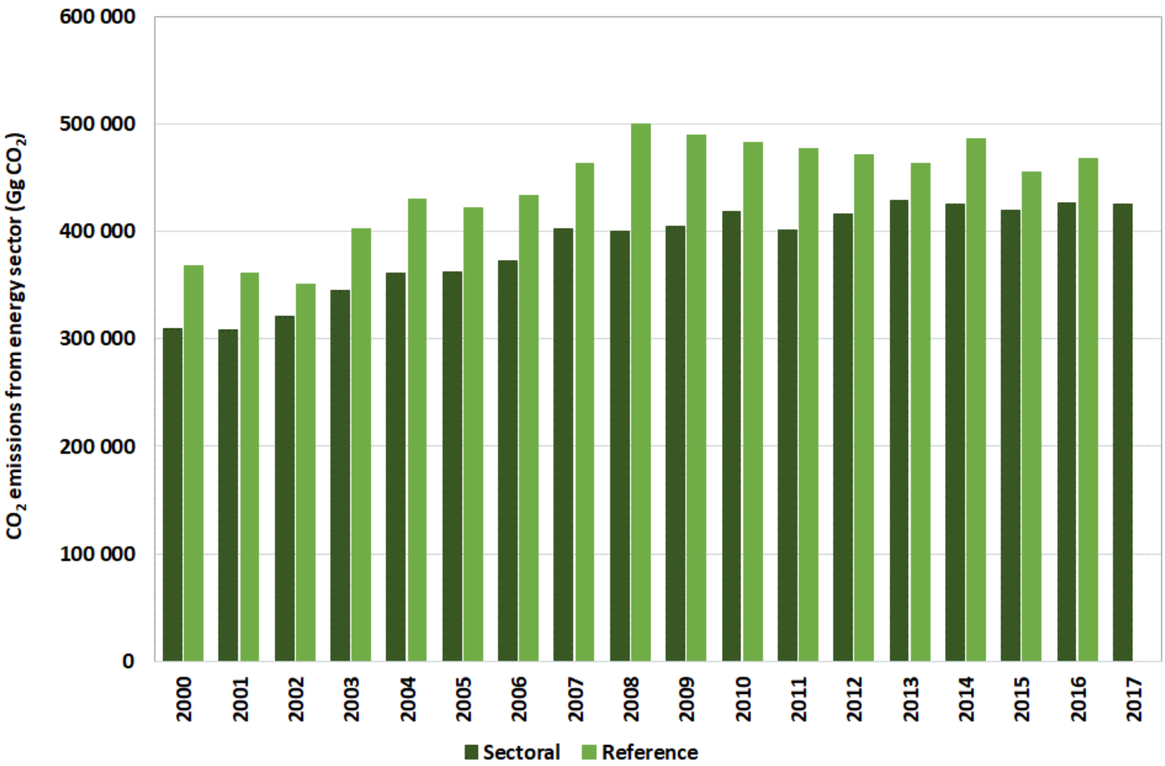

Figure 3.5: Comparisons between the reference and sectoral approach of determining the CO_2 emissions for the energy sector for South Africa, 2000 – 2017.

3.2.3 International bunker fuel

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*.

3.2.4 Feedstock 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.

3.2.5 Fuel combustion: Energy industries (1.A.1)

Source category description

The fuel combustion sub-category includes combustion for *main activity electricity and heat production*, *petroleum refining*, the *manufacture of solid fuels and other energy industries* and *non-specified sources*.

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. Eskom generates, transmits and distributes electricity to various sectors, such as the industrial, commercial, agricultural and residential sectors.

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.

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

In 2000 and 2015 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 & 2017). 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 DMRE is used to verify data reported by the petroleum industry.

The *manufacture of solid fuels and other energy industries* 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. The South African energy demand profile reveals that the industry/manufacturing sector utilizes the largest amount of electricity (36%), followed by the transport and residential sectors both at 27% (DoE, 2018).

Overview of shares and trends in emissions

2000 - 2017

The *energy industries* were estimated to produce 258 001 Gg CO_2e in 2017, which is 59.1% of the *Energy* sector emissions. Emissions were 38 020 Gg CO_2e (17.3%) above the 2000 level and this was due to an increase in the electricity consumption over this period.

1A1a Public electricity producer

Emissions from the public electricity producer were 87.0% of the energy industry emissions. Overall there has been an increasing trend in the emissions from the pubic electricity producer, however emissions have been showing a declining trend since 2012 (Table 3.11). Consumption increased by 29.3% over the 2000 - 2017 period, while emissions increased by 28.4%. The consumption of electricity and the associated emissions increased between 2000 and 2007 due to robust economic growth. 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. The manufacturing sector consumes approximately 45% of South Africa's electricity. Emissions from the public electricity producer increased thereafter to a peak in 2012 (Table 3.11). Since 2012 there has been a 7.9% decline in electricity consumption, leading to an 8.3% decline in emissions from the public electricity producer. At the same time a small percentage of electricity was generated using renewable energy resources such as wind, solar PV and concentrated solar power (CSP). In 2013, about 0.1 TWh of electricity was produced from renewables and by 2016, 6.9 TWh of electricity was produced from wind, solar PV and CSP resulting in avoided emissions (STATSA, 2016). Using a high level assumption that electricity from these sources replaced coal, 2384 Gg of CO_2 was avoided resulting in 1.03% emissions reductions.

Table 3.11: Emission trends for the public electricity producer, 2000 - 2017

	CO_2	CH_4	N_2O	Total
	Gg CO_2	Gg CH_4	Gg N_2O	Gg CO_2e
2000	173 858	1.8	2.7	174 736
2001	175 475	1.8	2.7	176 361
2002	181 307	1.9	2.8	182 222
2003	194 985	2.0	3.0	195 970
2004	204 690	2.1	3.2	205 724
2005	206 209	2.1	3.2	207 250
2006	207 465	2.2	3.2	208 512
2007	228 111	2.4	3.6	229 263
2008	218 543	2.3	3.4	219 645
2009	224 579	2.4	3.5	225 711
2010	231 405	2.4	3.6	232 572
2011	233 189	2.5	3.6	234 364
2012	243 497	2.6	3.8	244 723
2013	236 529	2.6	3.7	237 717
2014	231 203	2.5	3.6	232 363
2015	223 126	2.5	2.7	224 018
2016	227 761	2.5	3.5	228 902
2017	223 329	2.5	3.4	224 448

1A1a Auto electricity producers

Total emissions from auto electricity producers in South Africa fluctuated significantly from year to year, showing decreases in 2001, 2004, 2005, 2008, 2011, 2014, 2015 and 2016 (Table 3.12), 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. Overall there has been a declining trend in emissions with a decline of 92.9% (10 425 Gg CO_2e) since 2000, with 81.2% of this occurring since 2010.

Table 3.12: Trend in emissions from the auto electricity producers, 2000 – 2017.

	CO_2	CH_4	N_2O	Total
	Gg CO_2	Gg CH_4	Gg N_2O	Gg CO_2e
2000	11 169	0.12	0.17	11 226
2001	4 557	0.05	0.07	4 580
2002	4 939	0.05	0.08	4 964
2003	7 896	0.08	0.12	7 936
2004	6 192	0.06	0.10	6 223
2005	2 698	0.03	0.04	2 711
2006	3 814	0.04	0.06	3 833
2007	4 642	0.05	0.07	4 666
2008	3 856	0.04	0.06	3 876
2009	4 249	0.04	0.07	4 271
2010	4 251	0.04	0.07	4 273
2011	882	0.01	0.01	886
2012	1 184	0.01	0.02	1 190
2013	1 136	0.01	0.02	1 142
2014	993	0.01	0.02	998
2015	883	0.01	0.01	888
2016	797	0.01	0.01	801
2017	797	0.01	0.01	801

1A1b Petroleum refining

The total GHG emissions from *petroleum refining* was estimated at 4 050 Gg CO_2e in 2000, decreasing to 3 333 Gg CO_2 e in 2017 (Table 3.13). In 2000 refinery gas contributed 57.0% to the total GHG emissions in this subcategory and this increased to 66.5% in 2017. Emissions from residual fuel oil decreased from contributing 16.5% in 2000 to only 5.3% in 2017. A shift from residual fuel oil to refinery gas in most refineries is the main driver of emissions reduction in this source category.

Table 3.13: Trend in emissions from petroleum refining, 2000-2017.

	CO_2	CH_4	N_2O	Total
	Gg CO_2	Gg CH_4	Gg N_2O	Gg CO_2e
2000	4 043	0.10	0.02	4 050
2001	3 898	0.10	0.02	3 904
2002	3 385	0.08	0.01	3 390
2003	3 879	0.09	0.01	3 885
2004	3 563	0.08	0.01	3 569
2005	3 413	0.08	0.01	3 418
2006	3 669	0.09	0.01	3 675
2007	3 761	0.09	0.01	3 767
2008	3 868	0.09	0.01	3 874
2009	3 796	0.09	0.01	3 803
2010	3 546	0.08	0.01	3 551
2011	3 336	0.08	0.01	3 341
2012	3 379	0.08	0.01	3 384
2013	3 448	0.08	0.01	3 453
2014	3 418	0.08	0.01	3 423
2015	3 388	0.08	0.01	3 393
2016	3 358	0.08	0.01	3 363
2017	3 328	0.07	0.01	3 333

1A1c Manufacture of solid fuels and other energy industries

Emissions from *manufacture of solid fuels and other energy industries* totalled 29 420 Gg CO_2e in 2017, and these emissions have remained fairly stable over the 17 year period since 2000 (Table 3.14).

Table 3.14: Trend in emissions from manufacture of solid fuels and other energy industries, 2000 – 2017.

	CO_2	CH_4	N_2O	Total
	Gg CO_2	Gg CH_4	Gg N_2O	Gg CO_2e
2000	29 849	0.51	0.36	29 970
2001	30 444	0.51	0.36	30 567
2002	30 630	0.51	0.36	30 752
2003	31 518	0.54	0.38	31 646
2004	30 760	0.51	0.36	30 883
2005	28 500	0.48	0.34	28 616
2006	28 421	0.47	0.34	28 535
2007	29 740	0.51	0.36	29 862
2008	28 944	0.49	0.35	29 063
2009	29 109	0.49	0.36	29 230
2010	28 758	0.48	0.35	28 878
2011	28 846	0.46	0.35	28 966
2012	29 204	0.37	0.48	29 360
2013	30 555	0.37	0.48	30 710
2014	30 585	0.39	0.50	30 748
2015	31 367	0.38	0.49	31 525
2016	29 987	0.37	0.48	30 142
2017	29 271	0.36	0.46	29 420

Changes in emissions since 2015

Emissions in this subsector decreased by 0.8% (2 048 Gg CO_2e) since 2015. This is due to a 6.7% (2 105 Gg CO_2e) decline in emissions from *manufacture of solid fuels and other energy industries*. Emissions from *electricity and heat production* increased very slightly (118 Gg CO_2e) over this period, while *petroleum refining* emissions declined by 1.8% (60 Gg CO_2e).

Methodology

1A1a Electricity generation

A Tier 2 approach, with country-specific emission factors, was used to determine CO_2 emissions from coal combustion. For emissions from other fuels (e.g. other kerosene and diesel oil), and for all CH_4 and N_2O emission estimates a Tier 1 approach was applied.

1A1b Petrol refining

A Tier 1 approach was used to determine the emissions from petrol refining.

1A1c Manufacture of solid fuels and other energy industries

Emissions for this subcategory were determined by process balance analysis (tier 3). Combustion-related 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 fuel consumption for charcoal production is included under the category non-specified- stationary (1A5a).

Activity data

1A1a Electricity generation

Electricity generation is the largest key GHG emission source in South Africa, mainly because it mainly uses sub-bituminous coal which is abundantly available in the country. Data on fuel consumption for public electricity generation was obtained directly from the national power producer for the period 2000 to 2017. Eskom supplies more than 90% of South Africa's electricity needs (DoE, 2018). It generates, transmits and distributes electricity to various sectors, such as the industrial, commercial, agricultural and residential sectors. Total consumption in TJ is provided in Table 3.15. Auto electricity provider data was sourced from the DoE Energy balance spreadsheets (DoE, 2015).

To convert fuel quantities into energy units for public electricity generation, the net calorific values estimated by the national utility annually were applied (Table 3.8).

Table 3.15: Trend in fuel consumption for the various categories in the energy industry sector, 2000 – 2017.

	Public electricity producer	Auto electricity producer	Petroleum refining
	Fuel consumption (TJ)		
2000	1 806 317	116 046	59 638

2001	1 823 119	47 346	57 599
2002	1 883 709	51 311	50 680
2003	2 025 822	82 036	57 487
2004	2 126 649	64 333	53 292
2005	2 142 682	28 029	51 610
2006	2 155 477	39 627	55 121
2007	2 369 988	48 233	56 073
2008	2 271 791	40 066	57 870
2009	2 335 101	44 149	56 523
2010	2 406 936	44 171	52 520
2011	2 426 965	9 164	50 235
2012	2 537 365	12 305	51 049
2013	2 467 914	11 806	51 890
2014	2 414 256	10 317	51 504
2015	2 334 858	9 179	51 118
2016	2 382 448	8 280	50 731
2017	2 335 963	8 280	50 345

1A1b Petroleum refining

Activity data on the fuel consumed by refineries is sourced directly from refineries (Table 3.15). National energy balance data from the DoE is used to verify data reported by the petroleum industry. Some refineries did not record fuel consumption in the first four years of the time series (i.e. 2000-2003), therefore data splicing methodologies described in Chapter 5 of Volume 1 of the 2006 IPCC guidelines were applied for the filling of data gaps to ensure completeness and consistency in the data time series.

1A1c Manufacture of solid fuels and other energy industries

Emission estimates for this subcategory were supplied by the manufacturing plants PetroSA and Sasol.

Emission factors

Emission factors are provided in Table 3.9.

Uncertainty and time-series consistency

The time series is complete for this category.

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. A country-specific emission study to develop CO_2 emission factor for Energy Industries also produced uncertainty estimates that have been applied in this study. 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. Uncertainties are provided in Table 3.10.

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.

QA/QC and verification

All general QC checks listed in Table 1.2 were carried out, and consumption data from refineries was checked against the energy balance data.

Recalculations

No recalculations were conducted for this category.

Planned improvements and recommendations

1A1a Main activity electricity and heat production

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.

1A1b Petroleum refining

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 calorific and carbon content values, and also develop country-specific emission factors that can be used for the calculation of GHG emissions.

1A1c Manufacture of solid fuels and other energy industries

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.

3.2.6 Fuel combustion: Manufacturing industries and construction (1.A.2)

Source category description

Manufacturing industries and construction subsector 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 36% of the final energy supplied in South Africa (DoE, 2018). 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 19% of the total energy utilized by the industrial sector (DoE, 2018). 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.

Overview of shares and trends in emissions

2000 - 2017

The *manufacturing industries and construction* were estimated to produce 37 433 Gg CO_2e in 2017, which is 8.7% of the *Energy* sector emissions. Emissions were 4 774 Gg CO_2e (12.9%) above the 2000 level. 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. In 2011 emissions declined by 30.9% and remained low in 2012. In 2013 emissions increased to levels slightly below those of 2011 (Table 3.16). This was due to a decline in sub-bituminous coal and natural gas consumption (DoE, 2015). Emissions then increased again in 2013 to 38 430 Gg CO_2e and remained at these levels until 2017.

Changes in emissions since 2015

Emissions in this subsector increased by 562 GgCO_2e (1.5%) between 2015 and 2017.

Table 3.16: Trend in emissions from the manufacturing and construction sector, 2000 – 2017.

	CO_2	CH_4	N_2O	Total
	Gg CO_2	Gg CH_4	Gg N_2O	Gg CO_2e
2000	32 505	0.39	0.47	32 658
2001	32 036	0.39	0.46	32 186
2002	33 240	0.40	0.47	33 395
2003	35 738	0.43	0.51	35 905
2004	37 708	0.45	0.54	37 884
2005	36 983	0.45	0.52	37 155
2006	37 903	0.46	0.53	38 078
2007	39 288	0.48	0.55	39 469
2008	42 090	0.51	0.59	42 285
2009	39 952	0.49	0.56	40 135
2010	40 937	0.51	0.57	41 124
2011	28 290	0.37	0.39	28 417

2012	29 084	0.38	0.40	29 217
2013	38 255	0.48	0.53	38 430
2014	36 844	0.47	0.51	37 011
2015	36 704	0.47	0.50	36 870
2016	37 142	0.48	0.51	37 309
2017	37 264	0.49	0.51	37 432

Methodology

Emission estimates for 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.

Activity data

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 2012 the SAMI report (DMR, 2015) was used to extrapolate the fuel consumption. The activity data on liquid fuels for this category was sourced from SAPIA (SAPIA, 2016). Data from industries were also acquired and used to compare the figures in the energy digest and the SAMI report. To avoid double counting of fuel activity data, the fuel consumption associated with petroleum refining (1A1b) was subtracted from the fuel consumption activity data sourced for 1A2. Table 3.17 shows the total fuel consumption in this category for the period 2000 to 2015. NCV are provided in Table 3.8.

Table 3.17: Fuel consumption (TJ) in the manufacturing industries and construction category, 2000 – 2017.

Period	Other Kerosene	Gas/Diesel Oil	Residual Fuel Oil	LPG	Bitumen	Sub-Bituminous Coal	Natural Gas	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
2013	389	18 137	186	124	9 095	338 982	62 379	429 293
2014	365	18 824	186	126	9 384	322 743	63 799	415 427
2015	342	19 511	186	127	9 673	319 709	65 218	414 766
2016	318	20 198	186	128	9 963	322 672	66 637	420 102
2017	294	20 885	187	130	10 252	322 366	68 056	422 170

Emission factors

Emission factors are provided in Table 3.9. A country-specific emission factors for CO_2 for sub-bituminous coal was applied. For all other fuels the IPCC 2006 default emission factors were used to estimate emissions from the *manufacturing industries and construction* sector.

Uncertainty and time-series consistency

There are no time-series inconsistencies for this category.

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.

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.

Recalculations

No recalculations were performed for this category.

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. The industry reporting required by the new GHG regulation should assist in providing some of this more detailed data. Improved detail would also help to reduce the uncertainty associated with the activity data.

3.2.7 Fuel combustion: Transport (1.A.3)

Source category description

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.

Civil aviation emissions are produced from the combustion of jet fuel (jet kerosene and jet gasoline) and aviation gasoline. Aircraft engine emissions (ground emissions and cruise emissions) are roughly composed of 70% CO_2, less than 30% water and 1.0% of other components (NO_x, CO, SO_x, 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. Emissions from aircraft that returned from an international destination or were going to an international airport were included under *international* *bunkers*. The emissions from military aviation are reported separately under the *other* category or the memo item *multilateral operations*.

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.

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.

Water-borne navigation include emissions from use of heavy fuel oil/residual fuel oil as well as diesel. A fuel consumption study led by DEA in collaboration with DoE allowed for estimation of fuel consumption for water born navigation for the 2000-2012 time period. Data splicing techniques described in the 2006 IPCC Guidelines were used to extrapolate fuel consumption activity data to the period 2013-2015. Previously, emissions related to water-borne navigation as well as international navigation were assumed to be included under category *other sectors*.

Overview of shares and trends in emissions

2000 - 2017

In 2017 *transport* contributed 78 017 Gg CO_2e or 17.0% of the energy sector emissions. *Road transport* accounts for 91.5% of the transport emissions in 2017, while the contribution from *domestic aviation* and *railways* was small (5.8% and 0.6% respectively). Fuel used in *international aviation* and *international water-borne navigation* is, by international agreement, reported separately from the national net emissions. In 2017 the international bunker fuels generated 11 605 Gg CO_2e.

Emissions from *transport* increased from 38 978 Gg CO_2e in 2000 to 78 017 Gg CO_2e in 2017 (Table 3.18), which is a 51.4% increase. The major contributor to this subsector was *road transport* which doubled between 2000 and 2017. *Domestic aviation* more than doubled over the same period increasing by 2 508 Gg CO_2e. *Railway* emissions decreased by 128 Gg CO_2e (20.7%) between 2000 and 2017.

South Africa's contribution to international bunker emissions, from international aviation and international water-borne navigation, declined from 12 207 Gg CO_2e in 2000, but emissions have remained fairly stable over the 17 year period (Table 3.18).

Table 3.18: Trend in transport emissions, 2000 – 2017.

	Civil Aviation	Road Transport	Railways	Water-Borne Navigation	Total
	Gg CO_2e				
2000	2 047	34 787	618	1 525	38 978
2001	2 079	35 668	607	1 353	39 707
2002	2 204	37 986	592	1 233	42 014
2003	2 626	39 874	561	961	44 022
2004	2 837	42 952	585	1 111	47 486
2005	3 147	46 785	582	1 103	51 617
2006	3 118	51 190	537	880	55 725
2007	3 374	55 358	720	927	60 380
2008	3 425	57 882	779	1 520	63 607
2009	3 463	55 953	634	1 465	61 515
2010	3 662	58 479	792	1 527	64 460
2011	3 554	61 674	604	1 641	67 473
2012	3 479	63 877	515	1 620	69 490
2013	3 990	66 427	547	1 502	72 466
2014	4 132	68 331	637	1 531	74 631
2015	4 273	69 521	611	1 561	75 965
2016	4 414	69 872	504	1 590	76 380
2017	4 555	71 352	490	1 619	78 017

Table 3.19: Trend in the international bunker emissions, 2000 – 2017.

	Aviation			Water-borne navigation		
	Gg CO_2	Gg CH_4	Gg N_2O	Gg CO_2	Gg CH_4	Gg N_2O
2000	2 972	0.12	0.02	9 124	0.77	0.27

2001	2 708	0.11	0.02	8 975	0.77	0.26
2002	2 687	0.11	0.02	8 873	0.76	0.26
2003	2 584	0.11	0.02	8 640	0.75	0.25
2004	2 316	0.10	0.02	8 773	0.76	0.25
2005	2 267	0.10	0.02	8 768	0.75	0.25
2006	2 510	0.11	0.02	8 578	0.74	0.24
2007	2 557	0.11	0.02	8 627	0.75	0.25
2008	2 478	0.10	0.02	9 145	0.77	0.27
2009	2 423	0.10	0.02	9 091	0.77	0.27
2010	2 564	0.11	0.02	9 149	0.77	0.27
2011	2 482	0.10	0.02	9 255	0.78	0.28
2012	2 414	0.10	0.02	9 237	0.78	0.28
2013	2 349	0.10	0.02	9 139	0.77	0.27
2014	2 322	0.10	0.02	9 167	0.78	0.27
2015	2 296	0.10	0.02	9 196	0.78	0.28
2016	2 269	0.10	0.02	9 224	0.78	0.28
2017	2 242	0.09	0.02	9 252	0.78	0.28

Change in emissions since 2015

Transport emissions increased by 5.3% (2 051 Gg CO_2e) between 2015 and 2017 due to increase fuel consumption in the *road transport* subsector. *Road transport* increased by 5.3% (1 831 Gg CO_2e), and *domestic aviation* by 13.8% (283 Gg CO_2e). *Railway* emissions declined by 28 Gg CO_2e emissions.

Methodology

A Tier 1 approach was applied for this subsector.

Activity data

1A3a Civil aviation

Activity data on gasoline fuel consumption was sourced from SAPIA's annual reports (SAPIA, 2016), the DEA fuel consumption survey (DEA, 2015), while jet kerosene data was obtained from energy balance data and the DEA fuel consumption survey. It should however be noted that the SAPIA report indicates that data from 2009 are taken from the energy balance data anyway. The DEA fuel consumption survey was therefore used to calibrate the 2009 data contained in the DoE energy balances. 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. The DEA fuel consumption study is then used to quantify the actual fuel consumption for both international and domestic aviation. In the 2017 Inventory, DEA will implement the results of the updated DEA fuel consumption study to be completed in 2019. This will ensure that the energy balance data will be replaced by data sourced from the civil aviation industry.

According to the 2006 IPCC Guidelines, it is good practice to separate military aviation from domestic aviation. It was, however, not possible to estimate the amount of fuel used for military aviation activities as military aviation consumption is not separated out in the source data. 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.

1A3b Road transportation

Petrol, diesel and natural gas consumption data was determined from vehicle kilometre travelled for each class of vehicle. To determine the fuel consumed per technology class, the following equation was used:

$$Q_i = VKT_{vc} \; x \; FE_{vc} \; x \; N_{vc} \qquad (Eq. 3.2)$$

Where;
Q_i is the fuel (i) consumed in litres,
VKT_{vc} is the vehicle kilometre travelled per vehicle class,
FE_{vc} is the aggregate fuel economy of the vehicle class
N_{vc} is the number of vehicles per vehicle class

Activity data for these calculations were obtained from the fuel consumption study (Top Quartile, 2019).

The energy balance was the main source of data for residual fuel oil and LPG consumption, while SAPIA annual reports provided data on other kerosene consumption.

Road transport was responsible for the largest fuel consumed in the transport sector (73.8% in 2017). Motor gas contributed 60.2% of the *road transport* fuel consumption in

2017, followed by gas/diesel oil. Over the time series there has been an increase in the percentage contribution of gas/diesel oil to road transport consumption, and a corresponding decline in the contribution from motor gasoline (Figure 3.6). This can be attributed to the efficiency and affordability of diesel compared with motor gasoline.

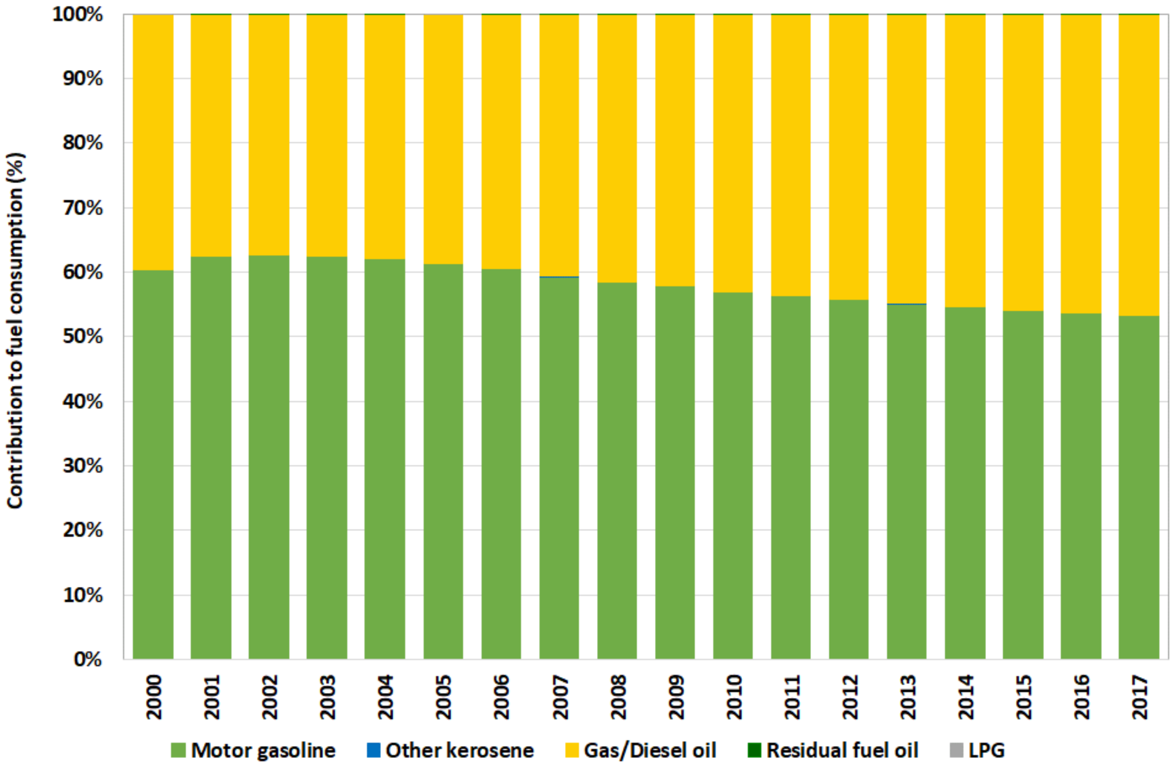

Figure 3.6: Percentage contribution of the various fuel types to fuel consumption in the road transport category (1A3b), 2000 – 2017.

1A3c Railways

The national railway operator, Transnet, provided activity data for railways for the period 2000-2017.

1A3d Water-borne navigation

A fuel consumption study led by DEFF in collaboration with DMRE allowed for estimation of fuel consumption for water born navigation for the 2000-2012 time period. Data splicing techniques described in the 2006 IPCC Guidelines were used to extrapolate fuel consumption activity data to the period 2013-2017. Default IPCC EFs for CO_2, CH_4 and N_2O were used to quantify emissions from this category using the IPCC default methodology.

Emission factors

IPCC default emission factors for road transport (Table 3.2.1 & Table 3.2.2, Chapter 3, IPCC 2006 Guidelines) were applied. Emission factors for railways were taken from the Technical Guidelines (DEA, 2016).

Uncertainty and time-series consistency

The time-series is complete for this subsector. All uncertainties are provided in Table 3.10.

1A3a Civil aviation

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).

1A3b Road transport

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 was 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.

1A3c Railways

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.

1A3d Water-borne navigation

In terms of the emission factors, default CO_2 uncertainty values for Diesel fuel are about +/- 1.5% and for residual fuel oil +/- 3% and are primarily dependent of carbon content of the fuel. The uncertainty values for non-CO_2 gases are much higher (CH_4 +/- 50% whilst for N_2O the uncertainty values ranges from 40% below or 140% above the default value)

For activity data the major uncertainty driver is the ability to separate between domestic and international fuel consumption. For a comprehensive data collection programme, the uncertainty in fuel consumption activity data is estimate at +/- 5%.

QA/QC and verification

All general QA/QC checks listed in Table 1.2 were undertaken. All activity data was compared to the energy balance data.

Recalculations

Recalculations were performed for this category for the full time series due to the updated *Road transport* fuel consumption data. In this inventory the petrol, diesel and natural gas consumption data for *Road transport* was updated and this led to a 40% increase in the *Road transport* emission estimates in 2015 (Figure 3.7).

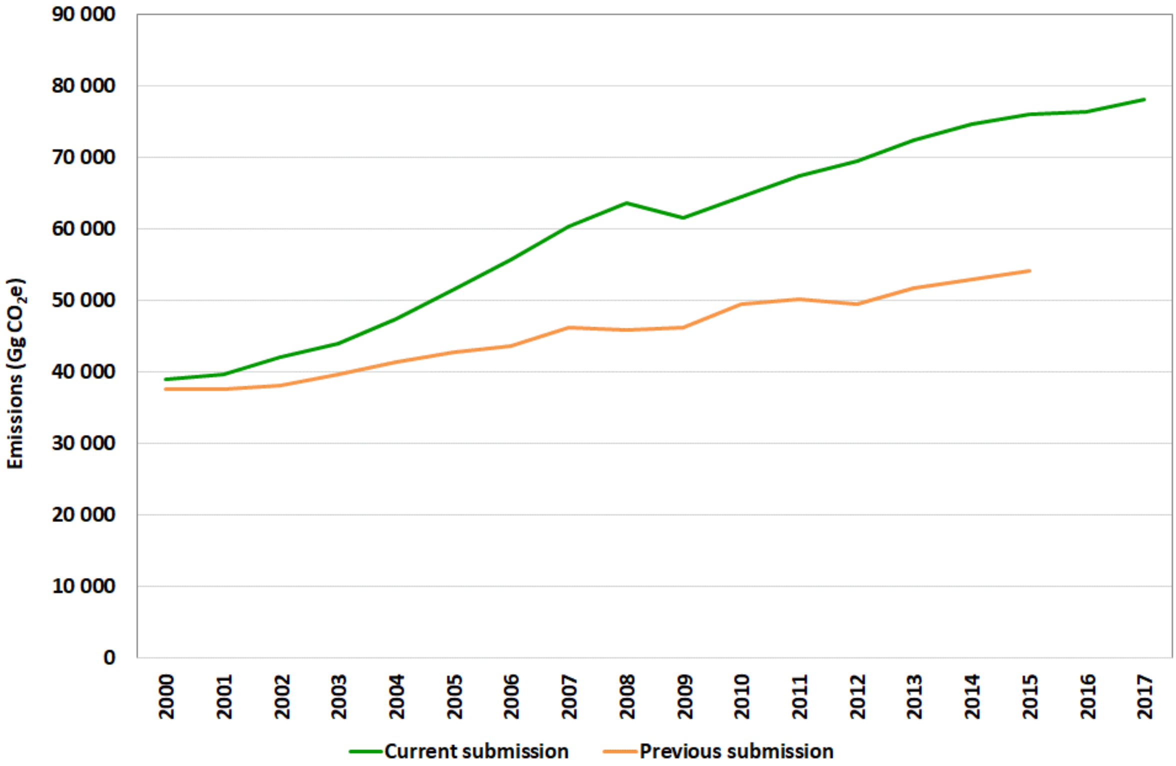

Figure 3.7: Recalculated transport emissions for 2000 to 2017, compared to 2015 submission estimates.

Planned improvements and recommendations

In this inventory *Road transport* consumption data for petrol, diesel and LPG was updated from the recently completed fuel consumption study (Top Quartile, 2019). Other disaggregated fuel consumption data from this study will be incorporated into the next inventory.

1A3a Civil aviation

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.

1A3b Road transport

The VKT data from the fuel consumption study will be considered for Tier 2 calculations of CH_4 and N_2O emissions. Furthermore, the development of local emission factors by fuel and vehicle-type will enhance the accuracy of the emission estimation.

1A3c Railways

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.

1A3d Water-borne navigation

No further improvements are planned for this subcategory.

3.2.8 Fuel combustion: Other sectors (1.A.4)

Source category description

This source category includes emissions from fuel combustion in commercial/ institutional buildings (as well as government, information technology, retail, tourism and services), residential households and agriculture (including large modern farms and small traditional subsistence farms), forestry, fishing and fish farms. Fuels included are residual fuel oil, other kerosene, gas/diesel oil, sub-bituminous coal, gas work gas, LPG and natural gas. In the residential sector there is also charcoal and other solid biomass.

Overview of shares and trends in emissions

2000 - 2017

The *other sectors* were estimated to produce 53 775 Gg CO_2e in 2017, which is 12.6% of the *energy* sector emissions. The largest contributor to this category was the *residential* emissions (56.9%) followed by 35.1% from commercial/institutional category (Table 3.2). Total *other sector* emissions were 34 726 Gg CO_2e above the 2000 level of 19 049 Gg CO_2e and this was due to a tripling of the residential emissions over this period (Table 3.20). There was also an 80.6% (1 923 Gg CO_2e) increase in emissions from *agriculture, forestry, fishing and fish farm* emissions. The drivers for emissions in this category are population and economic growth.

Change in emissions since 2015

Emissions in this subsector increased by 10.3% (5 014 Gg CO_2e) since 2015 due to a 16.4%, 6.1% and 2.4% increase in the *residential, agriculture/fishing/forestry/ fish farms* and *commercial/institutional* categories, respectively.

Table 3.20: Trend in emissions from other sectors, 2000 – 2017.

	Commercial/ Institutional	Residential	Agriculture/ Forestry/ Fishing/ Fish farms
	Gg CO_2e		
2000	9 558.1	7 103.0	2 387.8
2001	11 054.0	9 231.2	2 255.7
2002	12 221.0	11 114.1	2 327.4
2003	13 200.3	12 309.4	2 448.9
2004	14 462.6	13 990.5	2 581.3
2005	15 229.0	15 023.0	2 664.8
2006	16 519.5	16 222.2	2 809.5
2007	15 177.5	18 424.4	3 071.9
2008	15 410.8	20 260.9	3 021.0
2009	15 994.4	22 424.4	3 065.0
2010	17 139.2	24 792.9	3 308.0
2011	15 598.2	20 627.5	3 429.8
2012	16 214.1	21 035.9	3 431.9
2013	17 963.9	25 259.2	3 797.4
2014	18 185.4	26 165.3	3 919.2

2015	18 407.5	26 290.1	4 063.7
2016	18 629.3	28 948.2	4 159.1
2017	18 851.4	30 612.1	4 311.7

Methodology

A tier 1 approach was utilized for the estimation of emissions in this subsector.

Activity data

1A4a Commercial/Institutional

Data on fuel consumption in the commercial/institutional buildings category was sourced from the DDMRE's energy digest reports, the DMRE's SAMI report (solid fuels and natural gas) and SAPIA (liquid fuels) for 2000 to 2017. The DMRE energy reports were used to source solid fuels for the period 2000 to 2006, while for the period 2007 to 2017 the SAMI report was used to extrapolate the consumption of solid fuels for this category. NCV are provided in Table 3.8.

Fuels included are residual fuel oil, other kerosene, gas/diesel oil, sub-bituminous coal, gas work gas and natural gas (Figure 3.8). Liquid fuels contributed the most to the fuel consumption in this sector.

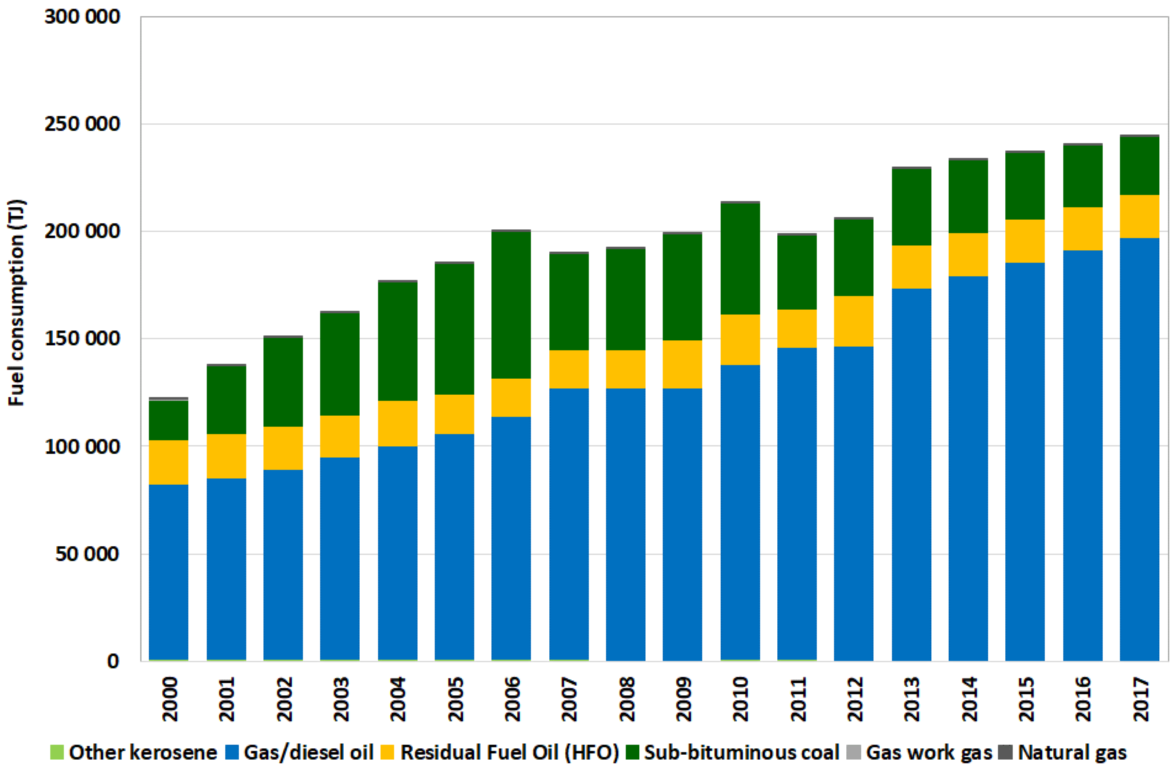

Figure 3.8: Fuel consumption in the commercial/institutional category, 2000 – 2017.

1A4b Residential

Data on fuel consumption in the residential sector was obtained from the DMRE's energy digest reports (sub-bituminous coal), the DMRE's SAMI report (coal consumption), FAO (charcoal), SAPIA (LPG) and DoE energy balance for all other fuels. The DMRE energy reports were used to source solid fuels for the period 2000 to 2006, for the period 2007 to 2017 the SAMI report was used to extrapolate the consumption of solid fuels for this category. NCV are given in Table 3.8.

The wood/wood product consumption, which is a Memo item, was assumed to be the same as the fuel wood consumption calculated as described in the *AFOLU* sector. Charcoal consumption data from 2010 was updated as in the previous inventory this data was not available and assumed values were applied.

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, however, from 2006 onwards there was no data reported for other primary solid biomass (Figure 3.9) therefore the biomass fuel source declined. Domestic coal consumption increases over the time-series, however the increase has slowed in the last 5 years.

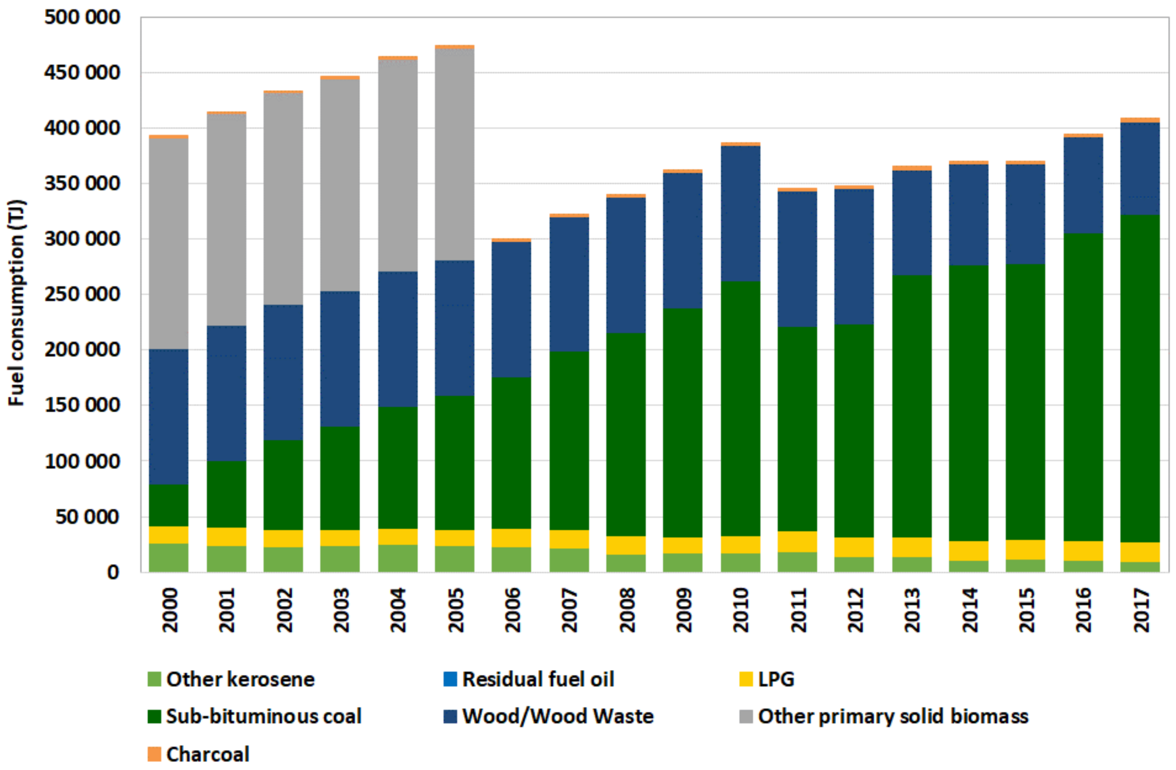

Figure 3.9: Trend in fuel consumption in the residential category, 2000 – 2017.

1A4c Agriculture/Forestry/Fishing/Fish farms

Data on fuel consumption in the agriculture, forestry, fishing and fish farms category was obtained from SAPIA (other kerosene), Energy digest (gas/diesel oil) and the energy balance for all other fuels. The consumption of fuels in this category has been increasing and decreasing throughout the period 2000 to 2017. NCV are provided in Table 3.8.

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 3.10).

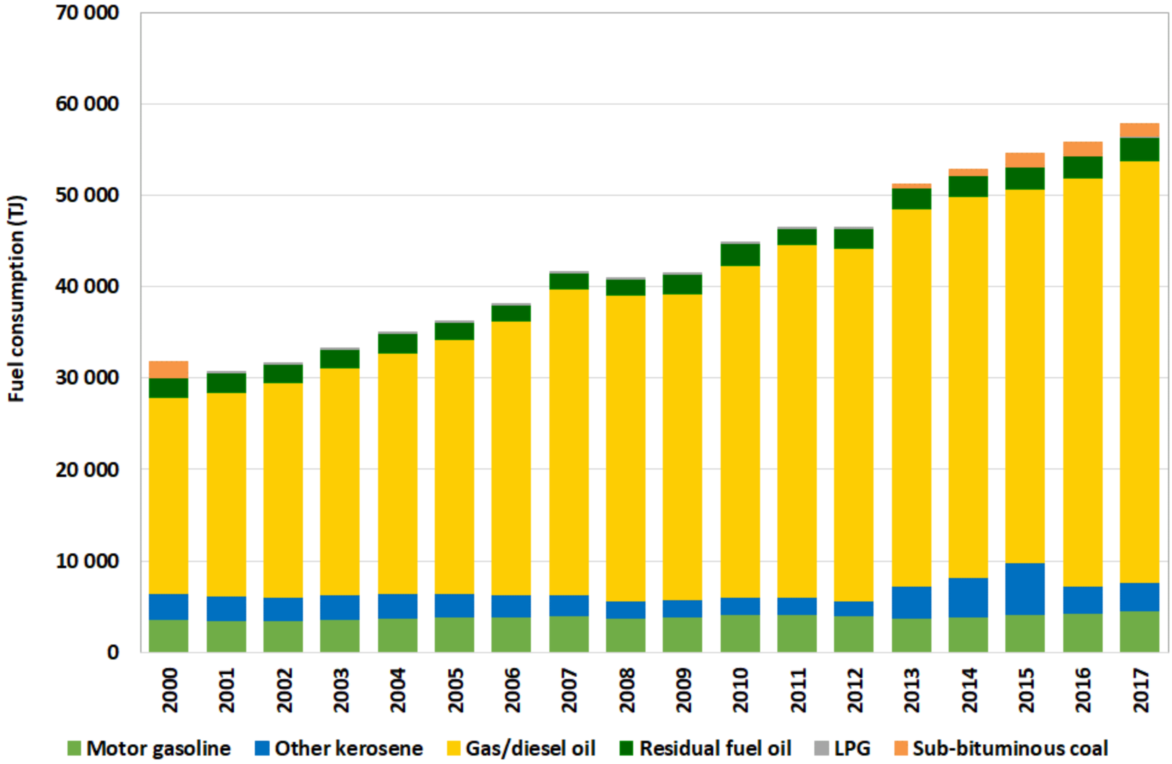

Figure 3.10: Trend in fuel consumption in the agriculture/forestry/fishing category, 2000 – 2017.

Emission factors

A country specific emission factor for CO_2 for sub-bituminous coal was applied (Table 3.9). For all other fuels the IPCC 2006 Guideline default emission factors were used.

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 higher. This high uncertainty is due to the lack of relevant and accurate measurements and/or insufficient understanding of the emission generating process.

QA/QC and verification

All general QC checks described in Table 1.2 were completed. Consumption data determined from SAMI and SAPIA reports were compared to the energy balance data.

Recalculations

Recalculations were performed for all years due to updated charcoal consumption data, however this change was very small and so did not have an overall impact on the sub-category emissions.

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.

1A4a Commercial/ institutional

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 recently implemented GHG regulation should assist in obtaining improved data from industries, and future inventories should draw on information gathered from industries.

1A4b Residential

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

1A4c Agriculture/ forestry/ fishing/ fish farms

As with the commercial/institutional sector, the GHG regulation should lead to more detailed data for this sector which should be explored in future inventories.

3.2.9 Fuel combustion: Non-specified (1.A.5)

Source category description

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.

Overview of shares and trends in emissions

2000 - 2017

The *non-specified* subsector was estimated to produce 1 204 Gg CO_2e in 2017, and these were 21.6% (215 Gg CO_2e) up from the 2000 level (989 Gg CO_2e). This category has shown a steady increase since 2000.

Change in emissions since 2015

Emissions in this subsector increased by 2.3% (26 Gg CO_2e) since 2015.

Methodology

The Tier 1 approach was utilized for the estimation of emissions in the *non-specified* subsector.

Activity data

Data on motor gasoline fuel consumption in the non-specified category were sourced from the SAPIA reports for the years 2007 to 2017, and from the DMRE's energy balance data for the rest of the years. Table 3.8 provides the NCV's.

Emission factors

IPCC 2006 default emission factor are shown in Table 3.9.

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.

QA/QC and verification

All general QC checks described in Table 1.2 were carried out. Data from SAPIA was compared to the energy balance data.

Recalculations

No recalculations were performed on this subsector.

Planned improvements and recommendations

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.

3.3 Source category 1.B Fugitive emissions from fuels

3.3.1 Category information

Source category description

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. CH_4 is the main gas produced during this process.

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)

Emissions

2017

Total estimated *fugitive emissions* for 2017 were 30 180 Gg CO_2e. Net *solid fuel* emissions contributed 5.3% (1 608 Gg CO_2e) of *fugitive emissions. Oil and natural gas account for 2.1% (642 Gg CO_2e), while other emissions from energy production accounted for 92.5%.*

2000 - 2017

Overall *fugitive emissions* decreased by 8.6% (2 867 Gg CO_2e) between 2000 and 2017 (Figure 3.11, Table 3.21). There was a peak of emissions in 2004 (32 360 Gg CO_2e) due to an increase in *other emissions from energy production*, with an 11.2% decrease in 2005 (Figure 3.11). Emissions declined slightly until 2011, after which they increased to 2017,

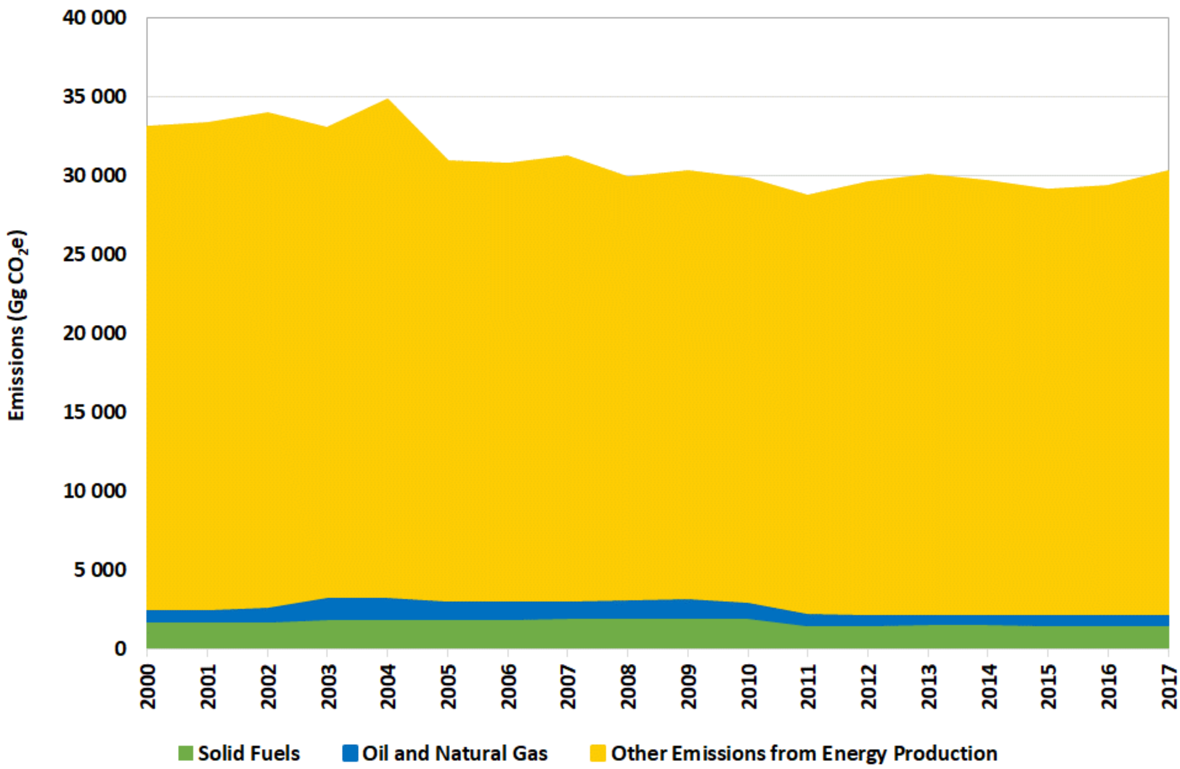

Figure 3.11: Trends in fugitive emissions from fuels, 2000 – 2017.

Table 3.21: Trends in emissions from fugitive emission categories, 2000 – 2017.

	Solid Fuels	Oil and Natural Gas	Other Emissions from Energy Production
	Gg CO_2e		
2000	1 830.5	752.0	30 465.2
2001	1 819.0	752.9	30 690.9
2002	1 792.7	955.1	30 690.9
2003	1 936.0	1 458.0	29 589.0
2004	1 980.8	1 378.9	31 387.2
2005	1 993.9	1 160.1	27 662.5
2006	1 992.6	1 133.2	27 524.7
2007	2 015.7	1 132.7	27 973.6
2008	2 052.7	1 138.2	26 609.5
2009	2 038.9	1 243.4	26 912.9
2010	2 071.5	964.2	26 704.5
2011	1 535.6	785.8	26 319.8
2012	1 608.7	641.8	27 298.7
2013	1 630.0	641.8	27 705.1
2014	1 663.7	641.8	27 266.8
2015	1 607.7	641.8	26 826.6
2016	1 595.0	641.8	27 032.6
2017	1 608.2	641.8	27 930.4

Methodology

Tier 2 and Tier 3 approaches were applied in this subsector and these are detailed in the relevant sections below.

Activity data

The required activity data and the main data providers for each subsector are provided in Table 3.22.

Table 3.22: Data sources for the fugitive emissions subsector.

Sub-category	Activity data	Data source
Coal mining and handling	Coal production	SAMI (2015) CoalTech
Oil and natural gas (flaring)	Production	Refineries Energy digests and energy balance (DoE)
Other emissions from energy production	Production	Sasol PetroSA

Emission factors

Country specific emission factors were utilized for coal mining and handling (see section 3.4.5). For oil and natural gas and other emissions from energy production the emissions were provided directly by the industry and activity data was not supplied so is therefore not reported in this submission.

3.3.2 Uncertainty and time-series consistency

The time-series is consistent for this category and uncertainties are provided in Table 3.23.

Table 3.23: Uncertainty for South Africa's fugitive emissions estimates.

Gas	Sub-category	Activity data uncertainty		Emission factor uncertainty	
		%	Source	%	Source
CO_2	1B1ai1 Mining	10	IPCC 2006	63	IPCC 2006
	1B1ai2 Post-mining seam gas emissions	10	IPCC 2006	50	IPCC 2006
	1B2aii Flaring	25	IPCC 2006	75	IPCC 2006
	1B3 Other emissions from energy production	25	IPCC 2006	75	IPCC 2006
CH_4	1B1ai1 Mining	10	IPCC 2006	63	IPCC 2006
	1B1ai2 Post-mining seam gas emissions	10	IPCC 2006	50	IPCC 2006
	1B3 Other emissions from energy production	25	IPCC 2006	75	IPCC 2006

3.3.3 Fugitive emissions: Solid fuels (1.B.1)

Source category description

This subsector includes emissions for *coal mining and handling* only. 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.

Overview of shares and trends in emissions

2000 - 2017

The *fugitive emissions from solid fuels* subsector was estimated to produce 1 608 Gg CO_2e in 2017, which is 0.4% of the energy sector emissions. Emissions were 222 Gg CO_2e (12.1%) below the 2000 level. Emissions increased by 13.1% between 2000 and 2010, then there was a 25.9% decrease in emissions in 2011 (Table 3.24). Emissions increased again from 2011 to 2014, after which levels remained fairly constant until 2017.

Table 3.24: Trends in fugitive emissions from solid fuels, 2000 – 2017.

	CO_2	CH_4	Total
	Gg CO_2	Gg CH_4	Gg CO_2e
2000	23.7	86.0	1 830.5
2001	23.5	85.5	1 819.0
2002	23.2	84.3	1 792.7
2003	25.0	91.0	1 936.0
2004	25.6	93.1	1 980.8
2005	25.8	93.7	1 993.9
2006	25.8	93.7	1 992.6
2007	26.1	94.7	2 015.7
2008	26.5	96.5	2 052.7
2009	26.4	95.8	2 038.9
2010	26.8	97.4	2 071.5
2011	19.9	72.2	1 535.6
2012	20.8	75.6	1 608.7
2013	21.1	76.6	1 630.0
2014	21.5	78.2	1 663.7
2015	20.8	75.6	1 607.7
2016	20.6	75.0	1 595.0
2017	20.8	75.6	1 608.2

Change in emissions since 2015

Emissions in this subsector increased by 1 Gg CO_2e since 2015.

Methodology

The tier 2 approach was used for the calculation of fugitive emissions from *coal mining and handling*. Fugitive emission estimates were based on coal production data. Coal waste dumps were also considered as another emission source. The methodology required coal production statistics by mining-type (above-ground and below-ground) and this split (61.80% surface mining and 38.2% underground mining) was based on the SAMI report for 2013. It was assumed that the split was constant for the entire time series.

Activity data

Data on coal production was obtained from the South Africa's Mineral Industry (SAMI), a report compiled by the Department of Mineral Resources and Energy (DMR, 2016) and Coaltech (Table 3.25).

Table 3.25: Amount of coal produced from opencast and underground mining, 2000 – 2017.

	Opencast	Underground
	Coal produced (tonne)	
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	201 600 000	113 400 000
2012	211 200 000	118 800 000
2013	135 733 000	120 367 000
2014	138 542 000	122 858 000
2015	133 666 000	118 722 000
2016	132 818 000	117 782 000
2017	134 699 500	118 761 000

Emission factors

Country specific emission factors were sourced from the study undertaken by the local coal research institute (DME, 2002). This study showed that emission factors for the South African coal mining industry are significantly lower than the IPCC default emission factors (Table 3.26).

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.

Table 3.26: Emission factors for coal mining and handling.

Mining method	Activity	GHG	Emission factor (m³ tonne⁻¹)	
			South African EF	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 (handling and transport)		0.018	NA
Surface mining	Coal mining		0	NA
	Post-mining (storage and transport)		0	NA

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 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. Uncertainties for fugitive emissions are provided in Table 3.23.

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.

Recalculations

No recalculations have been undertaken for this category.

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. Fugitive emissions from coke production is currently accounted for under category 2C as part of process emissions, however it is planned that by the 2012 inventory these will be separated from process emissions and reported separately.

3.3.4 Fugitive emissions: Oil and natural gas (1.B.2)

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.

Overview of shares and trends in emissions

2000 - 2017

The *fugitive emissions from oil and natural gas* subsector was estimated to produce 642 Gg CO_2e in 2017, which is 0.1% of the *energy* sector emissions. Emissions were 110 Gg CO_2e (14.7%) below the 2000 level (752 Gg CO_2e) (Table 3.27).

Table 3.27: Trends in fugitive emissions from oil and natural gas, 2000 – 2015.

	CO_2
	Gg CO_2
2000	752.0
2001	752.9

2002	955.1
2003	1 458.0
2004	1 378.9
2005	1 160.1
2006	1 133.2
2007	1 132.7
2008	1 138.2
2009	1 243.4
2010	964.2
2011	785.8
2012	641.8
2013	641.8
2014	641.8
2015	641.8
2016	641.8
2017	641.8

Change in emissions since 2015

Fugitive emissions show no change since 2015 as there was a lack of updated data so emissions between 2013 and 2017 were assumed to be the same as they were in 2012.

Methodology

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.

Activity data

Emissions data is supplied by refineries only, and not the activity data. Data on oil and natural gas emissions for 2000 to 2012 were obtained directly from refineries and, to a lesser extent, from the energy digest reports (DoE, 2009a). Data was not available for the years 2013 to 2017 therefore the 2012 estimates were carried through to 2017. This data will be updated in the next submission.

Emission factors

Emission data is supplied by the refineries so no emission factor data is supplied.

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%. Uncertainties are provided in Table 3.23.

QA/QC and verification

All general checks listed in Table 1.2 were completed and no category specific checks were undertaken.

Recalculations

No recalculations were conducted for this category.

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.

3.3.5 Fugitive emissions: Other emissions from energy production (1.B.3)

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. These GHG emissions are most specifically fugitive emissions related to the two mentioned processes (CTL and GTL) with the emphasis on CO_2 removal.

Overview of shares and trends in emissions

2000 - 2017

Other emissions from energy production was estimated to produce 27 930 Gg CO_2e in 2017, which is 6.1% of the energy sector emissions. Emissions were 2 535 Gg CO_2e (8.3%) below the 2000 level (30 465 Gg CO_2e) (Table 3.28).

Change in emissions since 2015

Emissions in this subsector increased by 4.1% (1 104 Gg CO_2e) since 2015.

Table 3.28: Trends in other emissions from energy production, 2000 – 2017.

	CO_2	CH_4	Total
	Gg CO_2	Gg CH_4	Gg CO_2e
2000	28 146.6	110.4	30 465.2
2001	28 370.9	110.5	30 690.9
2002	28 804.7	112.7	31 171.4
2003	27 308.8	108.6	29 589.0
2004	28 974.4	114.9	31 387.2
2005	25 465.0	104.6	27 662.5
2006	25 384.2	101.9	27 524.7
2007	25 775.7	104.7	27 973.6
2008	24 492.2	100.8	26 609.5
2009	24 806.5	100.3	26 912.9
2010	24 624.4	99.0	26 704.5
2011	24 242.9	98.9	26 319.8
2012	25 136.4	103.0	27 298.7
2013	25 536.6	103.3	27 705.1
2014	25 108.1	102.8	27 266.8
2015	24 657.5	103.3	26 826.6
2016	24 859.6	103.5	27 032.6
2017	25 746.5	104.0	27 930.4

Methodology

The use of facility-level production data and facility-level gas composition and vent flow rates enabled the use of Tier 3 methodology. Hence, CO_2 emissions from other emissions from energy production have been estimated using real continuous monitoring results and material balances.

Activity data

Data on *other emissions from energy production* were obtained from both Sasol and PetroSA. Emissions estimates were supplied but not the activity data.

Emission factors

Only emission estimates were supplied by industry so no emission factors are available.

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 15 years and other factors such as economic growth and fuel supply and demand.

QA/QC and verification

Quality checks highlighted in Table 1.2 were completed. 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.

Recalculations since the 2015 submission

Recalculations for the full time-series was undertaken due to the updated charcoal production data. Between 2000 and 2007 the recalculations resulted in very little change, while the rest of the years the recalculated data was slightly lower than the previous emission estimates. In 2013 the recalculated value was 96.2% lower. In the previous inventory it was mentioned that there was an anomaly in the charcoal production data from FAO, but this has now been corrected with data from Petro SA.

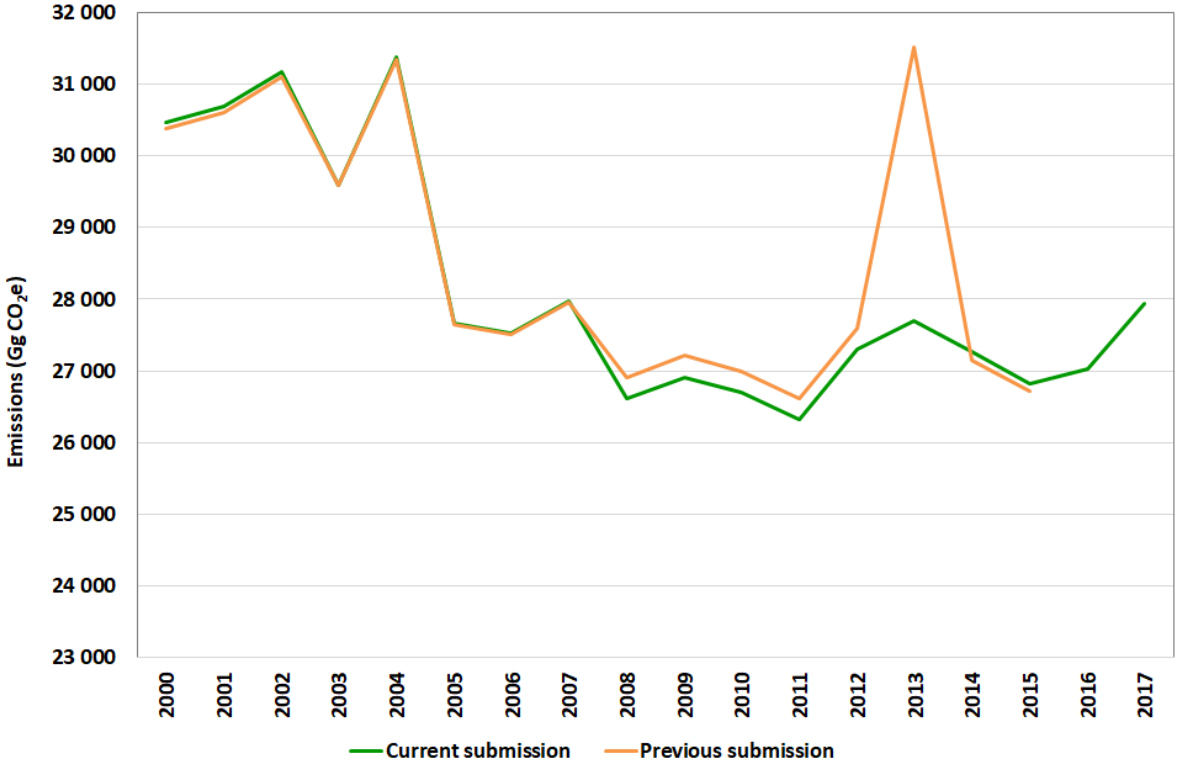

Figure 3.12: Recalculations for Other emissions from energy production for 2000 to 2017.

Planned improvements and recommendations

No improvements are planned for this section.

Appendix 3.A Summary table of Energy emissions in 2017

Categories	Emissions (Gg)							Emissions
	CO_2	CH_4	N_2O	NOx	CO	NMVOCs	SO_2	(Gg CO_2e)
1 - Energy	**432 698,0**	**199,1**	**8.7**	**0.0**	**0.0**	**0.0**	**0.0**	**439 576.3**
1.A - Fuel Combustion Activities	**406 289.0**	**19.5**	**8.7**	**0.0**	**0.0**	**0.0**	**0.0**	**409 395.9**
1.A.1 - Energy Industries	**256 724.5**	**2.9**	**3.9**	**0.0**	**0.0**	**0.0**	**0.0**	**258 001.3**
1.A.1.a - Main Activity Electricity and Heat Production	224 125.9	2.5	3.5	NE	NE	NE	NE	225 248.7
1.A.1.a.i - Electricity Generation	224 125.9	*2.5*	*3.5*	NE	NE	NE	NE	225 248.7
1.A.1.a.ii - Combined Heat and Power Generation (CHP)				NE	NE	NE	NE	0.0
1.A.1.a.iii - Heat Plants				NE	NE	NE	NE	0.0
1.A.1.b - Petroleum Refining	3 328.0	0.1	0.0	NE	NE	NE	NE	3 333.0
1.A.1.c - Manufacture of Solid Fuels and Other Energy Industries	29 270.6	0.4	0.5	NE	NE	NE	NE	29 419.6
1.A.1.c.i - Manufacture of Solid Fuels	*29 270.6*	*0.4*	*0.5*	NE	NE	NE	NE	29 419.6
1.A.1.c.ii - Other Energy Industries	*NE*	*NE*	*NE*	NE	NE	NE	NE	NE
1.A.2 - Manufacturing Industries and Construction	**37 264.4**	**0.5**	**0.5**	**0.0**	**0.0**	**0.0**	**0.0**	**37 432.5**
1.A.2.a - Iron and Steel				NE	NE	NE	NE	0.0
1.A.2.b - Non-Ferrous Metals				NE	NE	NE	NE	0.0
1.A.2.c - Chemicals				NE	NE	NE	NE	0.0
1.A.2.d - Pulp, Paper and Print				NE	NE	NE	NE	0.0
1.A.2.e - Food Processing, Beverages and Tobacco				NE	NE	NE	NE	0.0
1.A.2.f - Non-Metallic Minerals				NE	NE	NE	NE	0.0

1.A.2.g - Transport Equipment				NE	NE	NE	NE	0.0
1.A.2.h - Machinery				NE	NE	NE	NE	0.0
1.A.2.i - Mining (excluding fuels) and Quarrying				NE	NE	NE	NE	0.0
1.A.2.j - Wood and wood products				NE	NE	NE	NE	0.0
1.A.2.k - Construction				NE	NE	NE	NE	0.0
1.A.2.l - Textile and Leather				NE	NE	NE	NE	0.0
1.A.2.m - Non-specified Industry				NE	NE	NE	NE	0.0
1.A.3 - Transport	**57 865.9**	**12.2**	**2.8**	**0.0**	**0.0**	**0.0**	**0.0**	**58 983.2**
1.A.3.a - Civil Aviation	4 539.7	0.2	0.0	NE	NE	NE	NE	4 555.5
1.A.3.a.i - International Aviation (International Bunkers) (1)								*0.0*
1.A.3.a.ii - Domestic Aviation	*4 539.7*	*0.2*	*0.0*	*NE*	*NE*	*NE*	*NE*	*4 555.5*
1.A.3.b - Road Transportation	*51 277.1*	*11.9*	*2.6*	NE	NE	NE	NE	52 318.4
1.A.3.b.i - Cars				*NE*	*NE*	*NE*	*NE*	*0.0*
1.A.3.b.i.1 - Passenger cars with 3-way catalysts				*NE*	*NE*	*NE*	*NE*	*0.0*
1.A.3.b.i.2 - Passenger cars without 3-way catalysts				*NE*	*NE*	*NE*	*NE*	*0.0*
1.A.3.b.ii - Light-duty trucks				*NE*	*NE*	*NE*	*NE*	*0.0*
1.A.3.b.ii.1 - Light-duty trucks with 3-way catalysts				*NE*	*NE*	*NE*	*NE*	*0.0*
1.A.3.b.ii.2 - Light-duty trucks without 3-way catalysts				*NE*	*NE*	*NE*	*NE*	*0.0*
1.A.3.b.iii - Heavy-duty trucks and buses				*NE*	*NE*	*NE*	*NE*	*0.0*
1.A.3.b.iv - Motorcycles				*NE*	*NE*	*NE*	*NE*	*0.0*
1.A.3.b.v - Evaporative emissions from vehicles				*NE*	*NE*	*NE*	*NE*	*0.0*
1.A.3.b.vi - Urea-based catalysts				*NE*	*NE*	*NE*	*NE*	*0.0*
1.A.3.c - Railways	442.8	0.0	0.2	NE	NE	NE	NE	490.3

1.A.3.d - Water-borne Navigation	1 606.3	0.1	0.0	NE	NE	NE	NE	1 619.0
1.A.3.d.i - International water-borne navigation (International bunkers) (1)								*0.0*
1.A.3.d.ii - Domestic Water-borne Navigation	*1 606.3*	*0.1*	*0.0*	*NE*	*NE*	*NE*	*NE*	*1 619.0*
1.A.3.e - Other Transportation				*NE*	*NE*	*NE*	*NE*	*0.0*
1.A.3.e.i - Pipeline Transport	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*
1.A.3.e.ii - Off-road	*IE*	*IE*	*IE*	*NE*	*NE*	*NE*	*NE*	*NE*
1.A.4 - Other Sectors	**53 234.9**	**3.8**	**1.5**	**0.0**	**0.0**	**0.0**	**0.0**	**53 775.3**
1.A.4.a - Commercial/Institutional	18 771.9	0.7	0.2	NE	NE	NE	NE	18 851.4
1.A.4.b - Residential	30 166.6	2.9	1.2	NE	NE	NE	NE	30 612.1
1.A.4.c - Agriculture/Forestry/Fishing/Fish Farms	4 296.4	0.2	0.0	NE	NE	NE	NE	4 311.7
1.A.4.c.i - Stationary	*4 296.4*	*0.2*	*0.0*	NE	NE	NE	NE	4 311.7
1.A.4.c.ii - Off-road Vehicles and Other Machinery	*IE*	*IE*	*IE*	NE	NE	NE	NE	NE
1.A.4.c.iii - Fishing (mobile combustion)	*IE*	*IE*	*IE*	NE	NE	NE	NE	NE
1.A.5 - Non-Specified	**1 199.3**	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**1 203.6**
1.A.5.a - Stationary	1 199.3	0.1	0.0	NE	NE	NE	NE	1 203.6
1.A.5.b - Mobile				NE	NE	NE	NE	0.0
1.A.5.b.i - Mobile (aviation component)	*NE*	*NE*	*NE*	NE	NE	NE	NE	NE
1.A.5.b.ii - Mobile (water-borne component)	*NE*	*NE*	*NE*	NE	NE	NE	NE	NE
1.A.5.b.iii - Mobile (Other)	*NE*	*NE*	*NE*	NE	NE	NE	NE	NE
1.A.5.c - Multilateral Operations (1)(2)								0.0
1.B - Fugitive emissions from fuels	**26 409.1**	**179.6**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**30 180.4**
1.B.1 - Solid Fuels	**20.8**	**75.6**		**0.0**	**0.0**	**0.0**	**0.0**	**1 608.2**
1.B.1.a - Coal mining and handling	20.8	75.6		NE	NE	NE	NE	1 608.2

1.B.1.a.i - Underground mines	*20.8*	*75.6*		NE	NE	NE	NE	1 608.2
1.B.1.a.i.1 - Mining	*16.9*	*61.3*		NE	NE	NE	NE	1 303.5
1.B.1.a.i.2 - Post-mining seam gas emissions	*3.9*	*14.3*		NE	NE	NE	NE	304.7
1.B.1.a.i.3 - Abandoned underground mines	*NE*	*NE*		NE	NE	NE	NE	NE
1.B.1.a.i.4 - Flaring of drained methane or conversion of methane to CO_2	*NE*	*NE*		NE	NE	NE	NE	NE
1.B.1.a.ii - Surface mines	*0.0*	*0.0*		NE	NE	NE	NE	0.0
1.B.1.a.ii.1 - Mining	*0.0*	*0.0*		NE	NE	NE	NE	0.0
1.B.1.a.ii.2 - Post-mining seam gas emissions	*0.0*	*0.0*		NE	NE	NE	NE	0.0
1.B.1.b - Uncontrolled combustion and burning coal dumps	NE	NE	NE	NE	NE	NE	NE	NE
1.B.1.c - Solid fuel transformation	NE	NE	NE	NE	NE	NE	NE	NE
1.B.2 - Oil and Natural Gas	**641.8**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**641.8**
1.B.2.a - Oil	641.8	0.0	0.0	NE	NE	NE	NE	641.8
1.B.2.a.i - Venting	*NE*	*NE*		NE	NE	NE	NE	NE
1.B.2.a.ii - Flaring	*641.8*	*NE*		NE	NE	NE	NE	NE
1.B.2.a.iii - All Other				NE	NE	NE	NE	0.0
1.B.2.a.iii.1 - Exploration				NE	NE	NE	NE	0.0
1.B.2.a.iii.2 - Production and Upgrading				NE	NE	NE	NE	0.0
1.B.2.a.iii.3 - Transport				NE	NE	NE	NE	0.0
1.B.2.a.iii.4 - Refining				NE	NE	NE	NE	0.0
1.B.2.a.iii.5 - Distribution of oil products				NE	NE	NE	NE	0.0
1.B.2.a.iii.6 - Other				NE	NE	NE	NE	0.0
1.B.2.b - Natural Gas				NE	NE	NE	NE	0.0
1.B.2.b.i - Venting				NE	NE	NE	NE	0.0

1.B.2.b.ii - Flaring				NE	NE	NE	NE	0.0
1.B.2.b.iii - All Other				NE	NE	NE	NE	0.0
1.B.2.b.iii.1 - Exploration				NE	NE	NE	NE	0.0
1.B.2.b.iii.2 - Production				NE	NE	NE	NE	0.0
1.B.2.b.iii.3 - Processing				NE	NE	NE	NE	0.0
1.B.2.b.iii.4 - Transmission and Storage				NE	NE	NE	NE	0.0
1.B.2.b.iii.5 - Distribution				NE	NE	NE	NE	0.0
1.B.2.b.iii.6 - Other				NE	NE	NE	NE	0.0
1.B.3 - Other emissions from Energy Production	**25 746.5**	**104.0**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**
1.C - Carbon dioxide Transport and Storage	**0.0**			**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
1.C.1 - Transport of CO_2	**0.0**			**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
1.C.1.a - Pipelines	NE			NE	NE	NE	NE	NE
1.C.1.b - Ships	NE			NE	NE	NE	NE	NE
1.C.1.c - Other (please specify)	NE			NE	NE	NE	NE	NE
1.C.2 - Injection and Storage	**0.0**			**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
1.C.2.a - Injection	NE			NE	NE	NE	NE	NE
1.C.2.b - Storage	NE			NE	NE	NE	NE	NE
1.C.3 - Other	**0.0**			**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Appendix 3.B Reference and sectoral fuel consumption

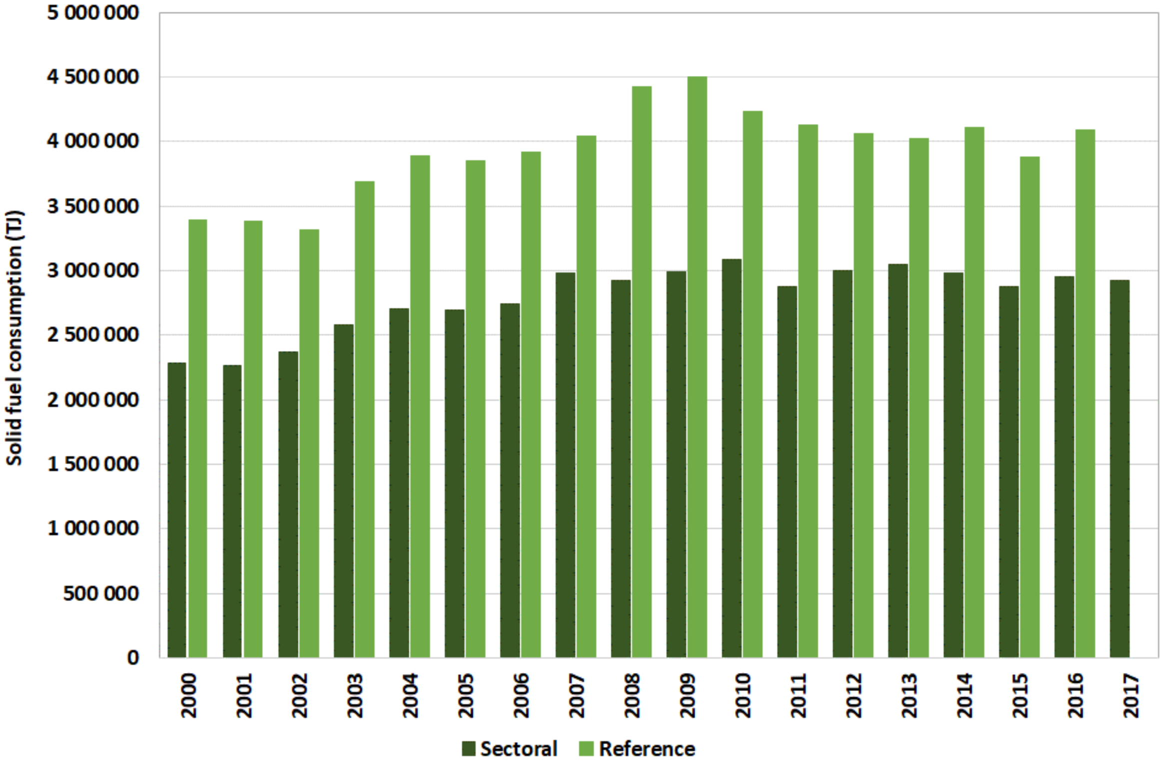

Figure 3.B.1: Comparisons between the solid fuel consumption determined by the reference and sectoral approaches, 2000 – 2017.

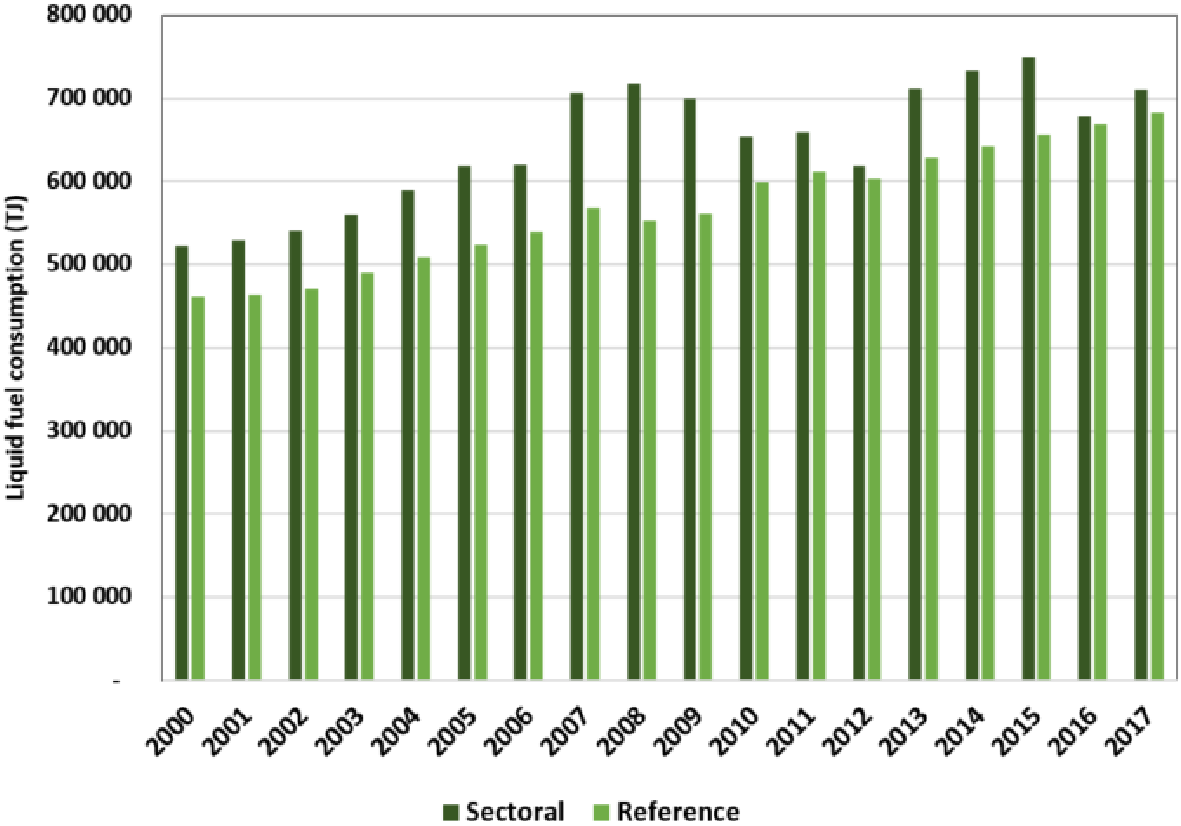

Figure 3.B.2: Comparisons between the liquid fuel consumption determined by the reference and sectoral approaches, 2000 – 2017.

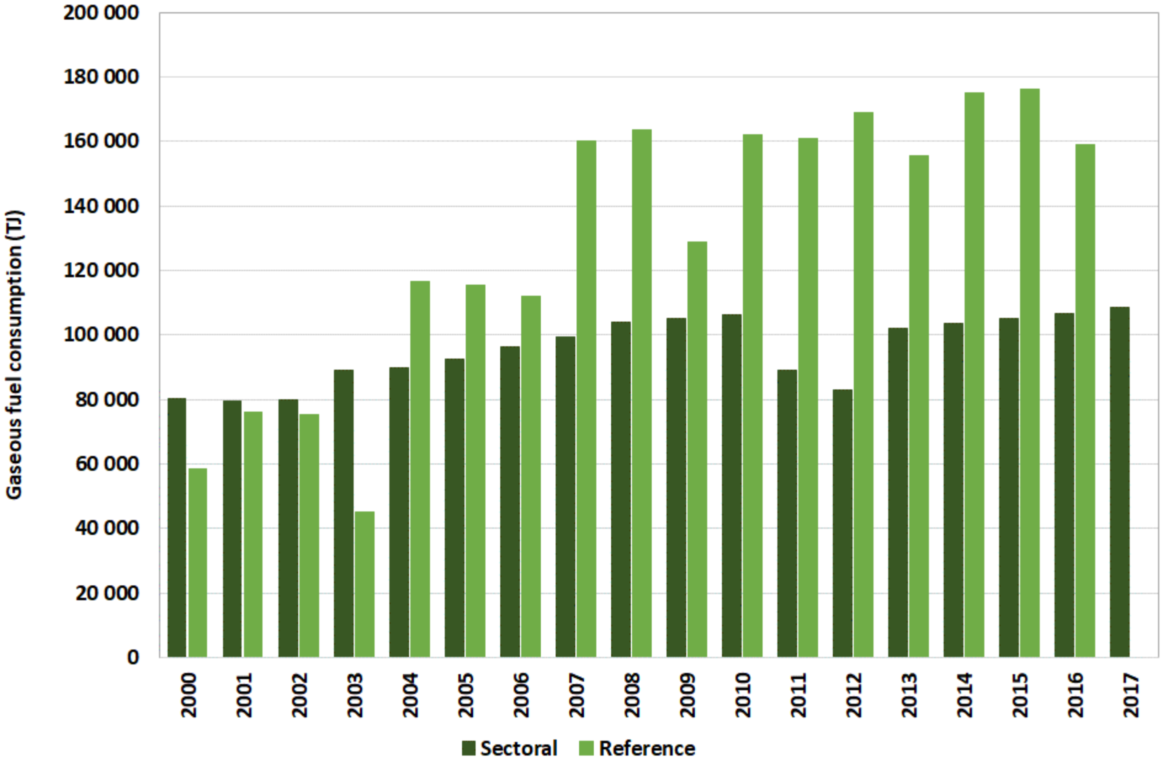

Figure 3.B.3: Comparisons between the gaseous fuel consumption determined by the reference and sectoral approaches, 2000 – 2016.

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Chapter 4: Industrial Processes and Product Use (IPPU)

4.1 Sector overview

4.1.1 South Africa's IPPU sector

The IPPU sector includes non-energy related emissions from industrial processing plants. 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 and PFCs. Also included in the IPPU sector are emissions used in products such as refrigerators, foams and aerosol cans. CO_2, CH_4 and N_2O emissions from the following industrial processes are included in South Africa's IPPU sector:

- Production of cement
- Production of lime
- Glass production
- Production of ammonia
- Nitric acid production
- Carbide production
- Production of titanium dioxide
- Petrochemical and carbon black production
- Production of steel from iron and scrap steel
- Ferroalloys production
- Aluminium production
- Production of lead
- Production of zinc
- Lubricant use
- Paraffin wax use

Hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) are used in a large number of products and in refrigeration and air conditioning equipment. PFCs are also emitted as a result of anode effects in aluminium smelting. Therefore, the IPPU sector includes estimates of PFCs from aluminium production, and HFCs from refrigeration and air conditioning.

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.

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. 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. Since the recession GDP annual growth has slowed compared to growth before the recession.

4.1.2 Overview of shares and trends in emissions

The *IPPU* sector produces CO_2 emissions (84.0%), fluorinated gases (15.0%) and smaller amounts of CH_4 and N_2O (Table 4.1). Carbon dioxide and any other emissions from combustion of fuels in these industries are reported under the *energy* sector.

2017

In 2015 the IPPU sector produced 43 230 Gg CO_2e, which is 7.5% of South Africa's emission (excluding FOLU). The largest source category is the *metal industry* category, which contributes 72.9% to the total IPPU sector emissions. *Iron and steel production* and *Ferroalloys production* are the biggest CO_2 contributors to the metal industry subsector, producing 15 074 Gg CO_2 (51.9%) and 12 572 Gg CO_2 (43.3%) respectively to the total metal industry CO_2 emissions. The *mineral industry* and the *product uses as substitute ODS* subsectors contribute 14.9% and 9.3%, respectively, to the IPPU sector emissions (Table 4.1), with all the emissions from the *product uses as substitute ODS* being HFCs. *Ferroalloy* *production* and *ammonia production* produce a small amount (170 Gg CO_2e) of CH_4, while chemical industries are estimated to produce 293 Gg CO_2e of N_2O.

A summary table of all emissions from the *IPPU* sector by gas is provided in Appendix 4.A.

Table 4.1: Summary of the estimated emissions from the IPPU sector in 2017 for South Africa.

GHG source categories	CO_2	CH_4	N_2O	HFCs	PFCs	Total
	Gg CO_2e					
2.IPPU	**36 298.7**	**170.3**	**292.6**	**4 014.5**	**2 453.4**	**43 229.5**
2.A Mineral industry	6 462.1	NE	NE	NE	NE	6 462.1
2.B Chemical industry	523.8	167.3	292.6	NE	NE	983.7
2.C Metal industry	29 037.2	3.1			2 453.4	31 493.6
2.D Non-energy products from fuels and solvents	275.6					275.6
2.E Electronic industry	NE			NE	NE	
2.F Product uses as substitute ODS				4 014.5	NE	4 014.5
2.G Other product manufacture and use	NE	NE	NE	NE	NE	
2.H Other	NE	NE	NE	NE	NE	

Numbers may not sum exactly due to rounding off.

2000 – 2017

Estimated emissions from the *IPPU* sector are 9 159 Gg CO_2e (26.9%) higher than the emissions in 2000 (Table 4.2). This was mainly due to the additional new categories under the *Product uses as substitute ODS* category, as there were no estimates in 2000. The overall increase in the IPPU sector emissions is also due to the 17.9% increase in the *metal industry* emissions and the 47.3% increase in the *mineral industry* emissions (Table 4.3). In the metal industry *Ferroalloy production* increased by 4 493 Gg CO_2e while *Iron and steel production* emissions declined by 1 336 Gg CO_2e.

Figure 4.1 shows that IPPU emissions increased by 17.9% between 2000 and 2006, after which there was a 14.5% decline to 2009. 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. 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. Emissions increased by 25.8% between 2009 and 2017.

Table 4.2: Summary of the change in emissions from the IPPU sector between 2000 and 2017.

GHG source categories	Emissions ($Gg CO_2e$)		Difference ($Gg CO_2e$)	Change (%)
	2000	2017	2000-2017	2000-2017
2.IPPU	**34 070.8**	**43 229.5**	**9 158.7**	**26.9**
2.A Mineral industry	4 386.3	6 462.1	2 075.7	47.3
2.B Chemical industry	2 773.6	983.7	-1 789.9	-64.5
2.C Metal industry	26 714.9	31 493.6	4 778.6	17.9
2.D Non-energy products from fuels and solvents	195.9	275.6	79.7	40.7
2.E Electronic industry	NE	NE		
2.F Product uses as substitute ODS	NE	4 015.5	4 015.5	
2.G Other product manufacture and use	NE	NE		
2.H Other	NE	NE		

Table 4.3: Trend in IPPU category emissions, 2000 – 2017.

	Mineral industry	Chemical industry	Metal industry	Non-energy products from fuels and solvent use	Electronics industry	Product uses as substitutes for ozone depleting substances	Other product manu-facture and use	Total
	$Gg CO_2e$							
2000	4 386.3	2 773.6	26 714.9	195.9	NE	0.0	NE	34 070.8
2001	4 303.7	2 715.1	26 812.7	226.0	NE	0.0	NE	34 057.4
2002	4 824.3	2 744.0	28 322.0	250.3	NE	0.0	NE	36 140.6
2003	5 095.6	2 169.1	28 093.2	248.6	NE	0.0	NE	35 606.5
2004	4 993.3	2 472.6	28 071.7	246.2	NE	0.0	NE	35 783.8
2005	5 736.1	2 973.6	29 098.9	467.9	NE	841.8	NE	39 118.2
2006	6 131.8	2 746.8	29 740.1	509.2	NE	1 045.4	NE	40 173.2
2007	6 064.0	1 969.0	28 892.1	234.1	NE	1 063.4	NE	38 222.5
2008	6 320.7	1 226.4	27 253.9	221.1	NE	1 026.0	NE	36 048.0
2009	6 590.8	1 068.2	25 467.2	233.8	NE	992.0	NE	34 352.0
2010	5 916.7	1 021.2	27 204.0	233.9	NE	2 065.8	NE	36 441.6
2011	5 719.8	1 070.9	30 966.2	196.4	NE	2 274.4	NE	40 227.7
2012	5 457.2	931.3	29 784.9	253.9	NE	2 527.6	NE	38 954.9

2013	5 688.4	1 152.2	31 384.1	271.7	NE	2 852.5	NE	41 348.8
2014	5 770.1	927.6	31 842.3	272.8	NE	3 065.6	NE	41 878.4
2015	6 178.5	1 001.5	30 946.4	273.8	NE	3 482.1	NE	41 882.3
2016	6 396.8	968.9	31 109.8	274.7	NE	3 715.1	NE	42 465.4
2017	6 462.1	983.7	31 493.6	275.6	NE	4 014.5	NE	43 229.5

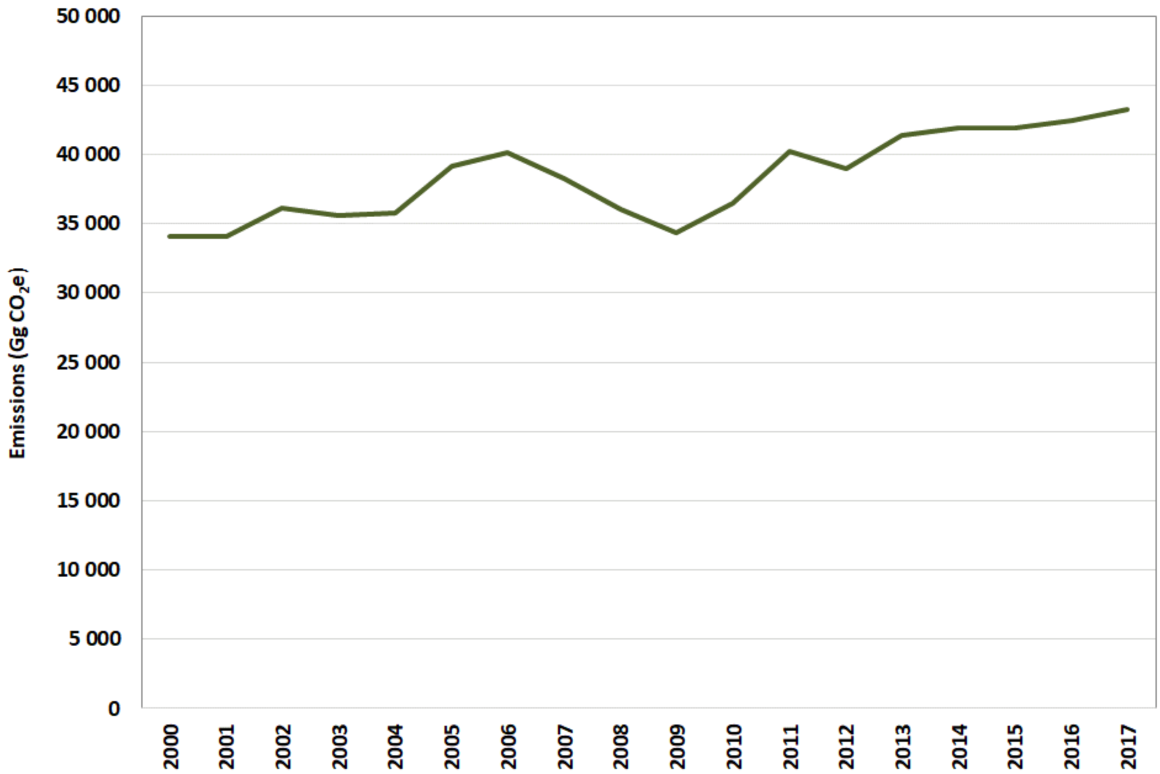

Figure 4.1: Trend in South Africa's IPPU sector emissions, 2000 – 2017.

2015 – 2017

IPPU emissions showed an increase of 3.2% (1 347 Gg CO_2e) between 2015 and 2017. The main contributors to this increase were the *iron and steel production* and *product uses as substitute ODS* categories which increased by 7.0% (981 Gg CO_2e) and 15.3% (532 Gg CO_2e) respectively, over this period. The *mineral industry* emissions increased by 4.6%

(283 Gg CO_2e) between 2015 and 2017, and the *metal industry* showed a smaller 1.8% (547 Gg CO_2e) increase.

4.1.3 Overview of methodology and completeness

Table 4.4 provides a summary of the methods and emission factors applied to each subsector of IPPU.

Table 4.4: Summary of methods and emission factors (EF) for the IPPU sector and an assessment of the completeness of the IPPU sector emissions.

GHG Source and sink category		CO_2		CH_4		N_2O		HFCs		PFCs	
		Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor
A	**Mineral industry**										
1	*Cement production*	T1	DF	NO		NO		NO		NO	
2	*Lime production*	T1	DF	NO		NO		NO		NO	
3	*Glass production*	T1	DF	NO		NO		NO		NO	
4	*Other process uses of carbonates*	NE		NO		NO		NO		NO	
B	**Chemical industry**										
1	*Ammonia production*	T3	CS	T3	CS						
2	*Nitric acid production*	NO		NO		T3	CS	NO		NO	
3	*Adipic acid production*	NO		NE		NE		NO		NO	
4	*Caprolactam, glyoxal and glyoxylic acid production*	NO		NE		NE		NO		NO	
5	*Carbide production*	T3	CS	NE		NE		NO		NO	
6	*Titanium dioxide production*	T2	CS	NE		NE		NO		NO	
7	*Soda Ash production*	NO		NE		NE		NO		NO	
8	*Petrochemical and carbon black production*	T1	DF	NE		NE		NO		NO	
9	*Fluorochemical production*			NE		NE		NO		NO	
C	**Metal industry**										

1	*Iron and steel production*	T1, T2	DF, CS	NE		NE		NO		NO	
2	*Ferroalloy production*	T1, T3	DF, CS	T1, T3	DF, CS	NE		NO		NO	
3	*Aluminium production*	T1	DF	NE		NE		NO		T3	CS
4	*Magnesium production*	NO		NE		NE		NO		NO	
5	*Lead production*	T1	DF	NE		NE		NO		NO	
6	*Zinc production*	T1	DF	NE		NE		NO		NO	
D	**Non-energy products from fuels and solvents**										
1	*Lubricant use*	T1	DF	NE		NE		NO		NO	
2	*Paraffin wax use*	T1	DF	NE		NE		NO		NO	
3	*Solvent use*	NE		NE		NE		NO		NO	
E	**Electronics industry**										
1	*Integrated circuit or semiconductor*	NE		NE		NE		NO		NO	
2	*TFT flat panel display*	NE		NE		NE		NO		NO	
3	*Photovoltaics*	NE		NE		NE		NO		NO	
4	*Heat transfer fluid*	NE		NE		NE		NO		NO	
F	**Product uses as substitute ODS**										
1	*Refrigeration and air conditioning*	NO		NO		NO		T1	DF	NE	
2	*Foam blowing agents*	NO		NO		NO		T1	DF	NE	
3	*Fire protection*	NO		NO		NO		T1	DF	NE	
4	*Aerosols*	NO		NO		NO		T1	DF	NE	
5	*Solvents*	NO		NO		NO		NE		NE	
G	**Other product manufacture and use**										
1	*Electrical equipment*	NE		NE		NE		NO		NO	
2	*SF6 and PFCs from other product uses*	NE		NA		NA		NE		NE	
3	*N_2O from product uses*	NO		NE		NE		NO		NO	
H	**Other**										
1	*Pulp and paper industry*	NE		NE		NE		NE		NE	
2	*Food and beverage industry*	NE		NE		NE		NE		NE	

4.1.4 Recalculations since 2015 submission

There were no recalculations for this category.

4.1.5 Key categories in the IPPU sector

The key categories identified in the *IPPU* sector by the level (L) and trend (T) analysis are shown in Table 4.5.

Table 4.5: Key categories identified in the IPPU sector.

IPCC Code	Category	GHG	Identification Criteria
2A1	Cement production	CO_2	L
2B	Chemical industry	C	T
2C1	Iron and steel production	CO_2	L,T
2C2	Ferroalloys production	CO_2	L,T
2C3	Aluminium production	PFCs	L,T
2F1	Refrigeration and air conditioning	HFCs	L

4.1.6 Planned improvements

Due to the recent introduction of the GHG Regulation companies will be reporting data and emissions through the SAGERS system. In the next inventory updated and improved information from this reporting will be included.

4.2 Source Category 2.A Mineral industry

4.2.1 Category information

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 (2A1), lime production (2A2) and glass production (2A3).

Emissions

2017

In 2017 the *mineral industries* produced 6 462 Gg CO_2, which is 14.9% of the IPPU sector emissions. *Cement production* accounted for 82.0% of these emissions. All the emissions in this category were CO_2 emissions.

2000 – 2017

The emissions were 47.3% (2 075 Gg CO_2) higher than the 4 386 Gg CO_2 in 2000. There was a 50.3% increase in the *mineral industry* emissions between 2000 and 2009, after which emissions declined by 17.2% to 5 457 Gg CO_2 in 2012 (Figure 4.2). The increase between 2000 and 2009 was due to increased emissions from *cement production* as a result of economic growth during this period. 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, 2010). Between 2012 and 2017 emissions increased again by 1 004 Gg CO_2 (18.4%) due mainly to increasing *cement production*.

Cement production is the largest contributor to the emissions from this category (Table 4.6).

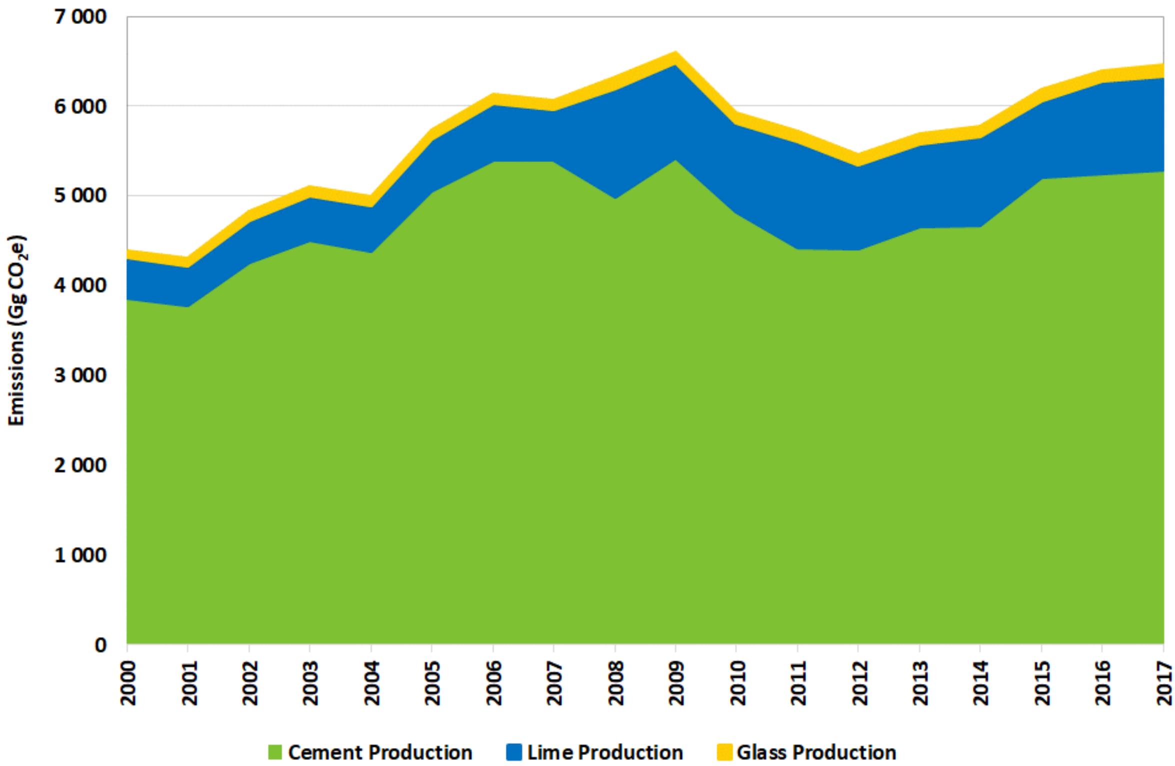

Figure 4.2: Category contribution and trend for the mineral subsector, 2000 – 2017.

Table 4.6: Trend in emissions from the mineral industries, 2000 – 2017.

	Cement production	Lime production	Glass production
	Gg CO_2e		
2000	3 870.6	441.4	74.4
2001	3 783.0	436.3	84.4
2002	4 258.4	477.6	88.3
2003	4 514.6	489.7	91.3
2004	4 390.1	507.3	95.9
2005	5 061.5	572.2	102.4
2006	5 399.8	630.2	101.8
2007	5 407.7	551.3	105.0
2008	4 988.6	1 214.7	117.4
2009	5 432.1	1 048.9	109.8
2010	4 819.0	993.9	103.9
2011	4 432.8	1 181.0	106.1

2012	4 414.5	928.8	113.9
2013	4 659.2	915.3	113.9
2014	4 678.2	978.0	113.9
2015	5 204.8	859.8	113.9
2016	5 255.3	1 022.4	119.2
2017	5 295.9	1 045.3	120.9

Methodology

Emissions were estimated using a Tier 1 approach for *cement* and *glass production*, while a Tier 2 was applied for *lime production*. Methodologies are discussed in the relevant sections below.

Activity data

The required activity data and the main data providers for each subsector are provided in Table 4.7.

Table 4.7: Data sources for the mineral industry.

Sub-category	Activity data	Data source
Cement production	Cement produced	SAMI Report from DMR (2015)
	Clinker fraction	Cement industries
Lime production	Mass of lime produced	SAMI Report from DMR (2015)
Glass production	Glass production	Glass production industries (PG Group, Consol Glass and Nampak)

Emission factors

Emission factors applied in this subsector are provided in Table 4.8.

Table 4.8: Emission factors applied in the mineral industry emission estimates.

Sub-category	Emission factor	Source

	(tonnes CO_2/tonne product)	
Cement production	0.52	IPCC 2006
Lime production: High-calcium lime	0.75	IPCC 2006
Hydraulic lime	0.59	IPCC 2006
Glass production	0.2	IPCC 2006

Uncertainty and time-series consistency

The uncertainty on the activity data and emission factors in the mineral industry subsector are provided in Table 4.9. These are discussed further in the relevant sections below.

Table 4.9: Uncertainty for South Africa's mineral industry emission estimates.

Gas	Sub-category	Activity data uncertainty		Emission factor uncertainty	
		%	Source	%	Source
CO_2	2A1 Cement production	30	IPCC 2006	4.5	IPCC 2006
	2A2 Lime production	30	IPCC 2006	6	IPCC 2006
	2A3 Glass production	5	IPCC 2006	60	IPCC 2006

4.2.2 Mineral industry: Cement production (2.A.1)

Source category description

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.

Overview of shares and trends in emissions

2000 - 2017

Cement production was estimated to produce 5 296 Gg CO_2e in 2017, which is 12.3% of the *IPPU* sector emissions. Emissions were 1 425 Gg CO_2e (36.8%) above the 2000 level (3 871 Gg CO_2e).

Change in emissions since 2015

Emissions in this subsector showed a 17.5% increase (91 Gg CO_2e) since 2015.

Methodology

A Tier 1 approach was used to determine the amount of clinker produced and the emissions from *cement production*. From 2008 exports of clinker were included in the calculations.

Activity data

Data on cement production in South Africa was obtained from the SAMI Reports (DMR, 2010 – 2017) produced by DMR (Table 4.10). Clinker fraction for the years 2000 to 2012 were obtained from cement industries, but was not available for this submission so the

2012 ratio was assumed to remain unchanged between 2012 and 2017. This will be updated once new data becomes available.

Table 4.10: Production data for the mineral industries, 2000 – 2017.

	Cement production	Quick lime production	Hydrated lime production	Glass production
	Production (tonne)			
2000	9 794 000	532 100	46 270	561 754
2001	9 700 000	522 910	45 470	624 156
2002	11 218 000	572 369	49 771	667 110
2003	11 893 000	586 969	51 041	702 008
2004	11 565 000	608 056	52 874	726 644
2005	13 519 000	685 860	59 640	775 839
2006	14 225 000	755 302	65 678	808 328
2007	14 647 000	660 772	57 458	858 382
2008	14 252 000	1 436 000	142 000	978 488
2009	14 860 000	1 264 000	104 000	993 784
2010	13 458 000	1 179 000	113 000	1 009 043
2011	12 373 000	1 422 000	118 000	1 019 755
2012	12 358 000	1 113 000	97 000	1 095 264
2013	13 037 000	1 091 000	100 000	1 095 264
2014	13 099 000	1 111 579	148 760	1 095 264
2015	14 522 000	1 026 591	92 623	1 095 264
2016	14 646 757	1 214 530	114 910	1 146 296
2017	14 759 961	1 241 397	117 774	1 162 436

Emission factors

For the calculation of GHG emissions in cement production, CO_2 emission factors were sourced from the 2006 IPCC Guidelines (Table 4.8). It was assumed that the CaO composition (one tonne of clinker) contains 0.65 tonnes of CaO from $CaCO_3$. This carbonate is 56.03% of CaO and 43.97% of CO_2 by weight (IPCC, 2006, p. 2.11). The emission factor for CO_2, provided by IPCC 2006 Guidelines, is 0.52 tonnes 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 2015 ranged between 69% - 76%.

Uncertainty and time-series consistency

Since this submission moved back to a Tier 1 method uncertainty has increased. According to the 2006 IPCC Guidelines, uncertainty with a Tier 1 approach could be as much as 35%. The largest uncertainty in this sub-category is the production and import/export data. According to IPCC 2006 the uncertainties are: 1% for chemical analysis of clinker to determine CaO; 10% for country production data; 30% for the CKD correction factor default assumption; and 10% on the trade data. Uncertainty data is provided in Table 4.9.

QA/QC

All general QC listed in Table 1.2 were completed for this category and no specific QC checks were completed for this sub-category.

Verification

For cement production, the facility-level activity data submitted by facilities for the previous inventory submission was compared with data published by the cement association as well as data reported in the SAMI reports. The production data in the SAMI report follows the same trend as the facility level production data, but it produces clinker production amounts which are 10-20% higher than what is reported by industry. The cementitious sales statistics (CI, 2015) are slightly lower than the production numbers provided by DMRE, but sales values are expected to be lower than production figures. The numbers in the DMR report are actually the total amount of lime and dolomite sold to the cement industry so may produce slightly overestimated values if not all lime is converted to cement in that year. In addition, the estimates of clinker production from the DMRE data do not include clinker exports due to a lack of data. It is not clear if the industry level clinker data takes imports and exports into account. These differences lead to increased uncertainty and the reasons for the discrepancies need to be further investigated.

Recalculations

No recalculations were performed for this category.

Planned improvements and recommendations

In the next inventory updated information from SAGERS will be included. The activity data should 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, however further data collected by SAGERS could assist in reducing this uncertainty and aid in more consistent reporting in future.

4.2.3 Mineral industry: Lime production (2.A.2)

Source category description

Lime is the most widely used chemical alkali in the world. Calcium oxide (CaO or quicklime or slaked lime) is sourced from calcium carbonate ($CaCO_3$), which occurs naturally as limestone ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$). 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, 2015). 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).

Overview of shares and trends in emissions

2000 - 2017

Lime production was estimated to produce 1 045 Gg CO_2 in 2017, which is 2.4% of the *IPPU* sector emissions. Emissions were 604 Gg CO_2 (136.8%) above the 2000 level (441

Gg CO_2). The fluctuations in *lime production* were directly linked to developments and investments in the steel and metallurgical industries. It should however be noted that there is an inconsistency in the time series with the data prior to 2008 only included pyrometallurgical quicklime and hydrated lime only included lime for water purification. The production data prior to 2008 is therefore much lower than the data for the later years. This means that the change from 2000 to 2017 is not only an increase do to emissions but also due to a change in the activity data.

Change in emissions since 2015

Emissions in this subsector increased by 21.6% (185 Gg CO_2e) since 2015.

Methodology

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 2 approach was used for the calculation of GHG emissions from lime production (Equation 2.6, IPCC 2006 Guidelines). This report estimated the total lime production based on the quantity of quicklime and hydrated lime produced (DMR, 2017).

Activity data

The DMRE publishes data on lime product that is divided into quicklime which includes pyrometallurgical and chemical components; and hydrated lime that includes water purification, chemical and other (DMR, 2017). In the previous submission only pyrometallurgical quicklime and water purification hydrated lime was incorporated, so in this submission the total values from the SAMI Reports (DMR, 2017) were used (Table 4.10). It was assumed that all quicklime is high calcium lime. No dolomitic lime is indicated.

Emission factors

Quicklime is indicated to be high-calcium lime. The 2006 IPCC default emission factor for high-calcium lime (0.75 tonnes CO_2 per tonne lime) was applied (Table 4.8). An IPCC (IPCC, 2006) default LKD correction factor (1.02) was applied, along with a default hydrated lime correction factor (0.97) for the hydrated lime component.

Uncertainty and time-series consistency

According to the IPCC 2006 Guidelines, the uncertainty on lime production emissions are: 6% for assuming an average CaO in lime; 2% for high-calcium EF; 5% for correction for hydrated lime; and 30% for LKD correction. Uncertainty data is provided in Table 4.9.

QA/QC

All general QC listed in Table 1.2 were completed for this category and no specific QC checks were completed for this sub-category.

Verification

The only available data for *lime production* was sourced from the SAMI report; therefore, there was no comparison of data across different plants.

Recalculations

No recalculations were completed for this category.

Planned improvements

There are no subcategory specific planned improvements, but any updated information from SAGERS will be included.

4.2.4 Mineral industry: Glass production (2.A.3)

Source category description

There are many types of glass and compositions used commercially, however the glass industry is divided into four categories: containers, flat (window) glass, fibre glass and speciality glass. When other materials (including metal) solidify, they become crystalline, whereas glass (a super cool liquid) is non-crystalline. The raw materials used in glass production are sand, limestone, soda ash, dolomite, feldspar and saltcake. The major glass raw materials which emit CO_2 during the melting process are limestone ($CaCO_3$), dolomite $CaMg(CO_3)_2$ and soda ash (Na_2CO_3). Glass makers do not produce glass only from raw materials, 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).

Overview of shares and trends in emissions

2000 - 2017

Glass production was estimated to produce 121 Gg CO_2 in 2017, which is 0.3% of the IPPU sector emissions. Emissions were 47 Gg CO_2e (62.6%) above the 2000 level (74 Gg CO_2).

Change in emissions since 2015

Emissions increased by 7 Gg CO_2e (6.1%) since 2015.

Methodology

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.

Activity data

Production data was obtained from glass production industries (PG Group, Consol Glass and Nampak) (Table 4.10).

Emission factors

The 2006 IPCC default emission factor (Table 4.8) was applied. This was 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).

Uncertainty and time-series consistency

The uncertainty associated with use of the Tier 1 emission factor and cullet ratio is significantly high at +/- 60% (IPCC, 2006, Vol 3).

QA/QC

All general QC listed in Table 1.2 were completed for this category and no specific QC checks were completed for this sub-category.

Recalculations

No recalculations were performed for this category.

Planned improvements

In the next inventory updated information from SAGERS will be included. 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.

4.2.5 Mineral industry: Other process uses of carbonates (2.A.4)

Emissions in this category were not estimated due to a lack of data. A survey will be conducted to obtain data; however, the data is only likely to be available for the 2021 inventory.

4.3 Source Category 2.B Chemical industry

4.3.1 Category information

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 3.0% to the GDP and 23% of its manufacturing. 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.

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.

Emissions

2017

The *chemical industries* were estimated to produce 984 Gg CO_2e in 2017, which is 2.3% of the IPPU sector emissions. The largest contributions are from *ammonia production* and *nitric acid production*.

2000 – 2017

Emissions from the *chemical industries* declined by 1 789 Gg CO_2e (64.5%) since 2000 (2 774 Gg CO_2e). Emissions from this subsector fluctuated considerably over the 17 year period (Figure 4.3). Between 2000 and 2006 emissions fluctuated between 2 169 Gg CO_2e and 2 974 Gg CO_2e (Table 4.3), then there was a decline of 55.4% between 2006 and 2008, largely due to N_2O emission reductions in *nitric acid production*. Thereafter the emissions remained at the lower level.

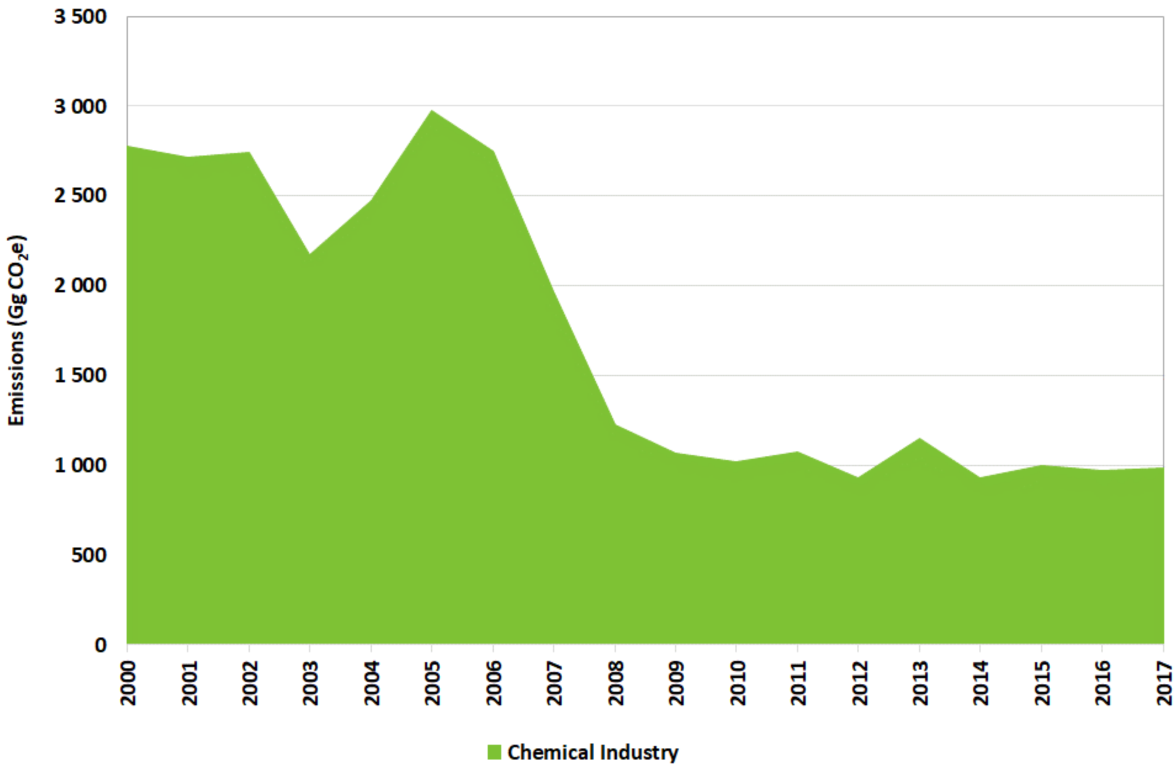

Figure 4.3: Trend in chemical industry emissions in South Africa, 2000 – 2017.

Methodology

Many of the *chemical industries* determine their own emissions and provide these emission estimates to DEFF. In most cases the activity data and emission factors used are not supplied due to confidentiality issues. Emissions are determined by a Tier 3 process balance analysis unless otherwise stated. There was a mix of Tier 1, Tier 2 and Tier 3 approaches to calculating emissions in this category and these are discussed in the sections below.

Activity data

The required activity data and the main data providers for each subsector are provided in Table 4.11. Activity data is only provided for carbide production and carbon black production, while the other industries provide emissions data.

Table 4.11: Data sources for the chemical industry.

Sub-category	Activity data	Data source
Ammonia production	Emissions from ammonia production	Sasol
Nitric acid production	Emissions from nitric acid production	Sasol
		Nitric acid production plants
Carbide production	Raw material (petroleum coke) consumption	SAMI report – DMR (2015)
Titanium dioxide production	Emissions from titanium dioxide production	SAMI report – DMR (2015)
Carbon black production	Amount of carbon black produced	Orion Engineered Carbons (Pty) Ltd

Emission factors

Emission factors applied in the *ammonia production*, *nitric acid production*, and *titanium dioxide production* are provided by the various industries and are not supplied. Table 4.12 provides the default emission factors used in *carbide production* and *carbon black production* emission calculations.

Table 4.12: Emission factors applied in the chemical industry emission estimates.

Sub-category	CO_2 EF (tonnes CO_2/tonne product)	CH_4 EF (kg CH_4/tonne product)	Source
Carbide production	1.09		IPCC 2006
Carbon black production	2.62	0.06	IPCC 2006

Uncertainty and time-series consistency

Uncertainty on activity data and emission factors in the *chemical industry* are shown in Table 4.13.

Table 4.13: Uncertainty for South Africa's chemical industry emission estimates.

Gas	Subcategory	Activity data uncertainty		Emission factor uncertainty	
		%	Source	%	Source
CO_2	2B1 Ammonia production	5	IPCC 2006	6	IPCC 2006
	2B5 Carbide production	5	IPCC 2006	10	IPCC 2006
	2B6 Titanium dioxide production	5	IPCC 2006	10	IPCC 2006
	2B8f Carbon black	10	IPCC 2006	85	IPCC 2006
CH_4	2B1 Ammonia production	5	IPCC 2006	6	IPCC 2006
	2B5 Carbide production	5	IPCC 2006	10	IPCC 2006
	2B8f Carbon black	10	IPCC 2006	85	IPCC 2006
N_2O	2B2 Nitric acid production	2	IPCC 2006	10	IPCC 2006

4.3.2 Chemical industry: Ammonia production (2.B.1)

Source category description

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.

Methodology

Emission estimates from *ammonia production* were obtained through the Tier 3 approach. Emissions were calculated based on actual process balance analysis. Total emission estimates were obtained from the ammonia production plants.

Activity data

Consumption data was not provided as the information is confidential.

Emission factors

The emission factors are not provided as the information is confidential.

Uncertainty and time-series consistency

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. Uncertainties on activity data and emission factors are provided in Table 4.13.

QA/QC

All general QC listed in Table 1.2 were completed for this category and no specific QC checks were completed for this sub-category.

Recalculations

No recalculations were performed for this category.

Planned improvements

There are no subcategory specific planned improvements, but any updated information from SAGERS will be included.

4.3.3 Chemical industry: Nitric acid production (2.B.2)

Source category description

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.

Methodology

The emissions from *nitric acid production* were calculated based on continuous monitoring (Tier 3 approach). Sasol emissions were also included.

Activity data

Consumption data was not provided by industry as the information is confidential, only emission data was provided.

Emission factors

The emission factors are not provided as the information is confidential.

Uncertainty and time-series consistency

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 NO_x control and the NO_x abatement system may or may not reduce the N_2O concentration of the treated gas. The uncertainty measures of default emission factors are +/- 2%. 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, pg 3.23, Table 3.3). Since a tier 3 approach was applied in this inventory the lower uncertainty value of 10% was assumed. Uncertainty data for the chemical industries is provided in Table 4.13.

QA/QC

All general QC listed in Table 1.2 were completed for this category and no specific QC checks were completed for this sub-category.

Recalculations

No recalculations were performed on this category.

Planned improvements and recommendations

There are no subcategory specific planned improvements, but any updated information from SAGERS will be included.

4.3.4 Chemical industry: Adipic acid production (2.B.3)

There is no *adipic acid production* occurring in South Africa.

4.3.5 Chemical industry: Caprolactuam, glyoxal and glyoxylic acid production (2.B.4)

There is no *caprolactuam, glyoxal and glyoxylic acid production* occurring in South Africa.

4.3.6 Chemical industry: Carbide production (2.B.5)

Source category description

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).

Methodology

Emissions from *carbide production* were calculated based on a Tier 1 approach.

Activity data

Calcium carbide consumption values were sourced from the carbide production plants but are not shown due to confidentiality issues.

Emission factors

An IPCC 2006 default emission factor was applied and is shown in Table 4.12.

Uncertainty and time-series consistency

The emissions from *carbide production* 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%. Uncertainties for the chemical industries are given in Table 4.13.

QA/QC

All general QC listed in Table 1.2 were completed for this category and no specific QC checks were completed for this sub-category.

Recalculations

No recalculations were performed for this subcategory.

Planned improvements

There are no subcategory specific planned improvements, but any updated information from SAGERS will be included.

4.3.7 Chemical industry: Titanium dioxide production (2.B.6)

Source category description

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.

Methodology

A Tier 1 approach was used for calculating GHG emissions from titanium dioxide production.

Activity data

The *titanium dioxide production* emissions data were sourced from the titanium dioxide production plants and activity data was not supplied due to confidentiality issues.

Emission factors

The emission factors are not provided as the information is confidential.

Uncertainty and time-series consistency

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%. Table 4.13 provides the uncertainties for the chemical industries.

QA/QC

All general QC listed in Table 1.2 were completed for this category and no specific QC checks were completed for this sub-category.

Recalculations

No recalculations were performed for this category.

Planned improvements

There are no subcategory specific planned improvements, but any updated information from SAGERS will be included.

4.3.8 Chemical industry: Soda ash production (2.B.7)

There is no *soda ash production* occurring in South Africa.

4.3.9 Chemical industry: Petrochemical and carbon black production (2.B.8)

Source category description

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 emissions 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.

Methodology

Tier 1 was the main approach used in estimating emissions from *carbon black production*, using production data and relevant emission factors.

Activity data

Carbon black activity data was sourced directly from industry, but is not shown due to confidentiality issues.

Emission factors

For the calculation of emissions from *carbon black production*, the IPCC 2006 default CO_2 and CH_4 emission factors were applied (Table 4.12). It was assumed that carbon black is produced through the furnace black process.

Uncertainty and time-series consistency

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.

QA/QC

All general QC listed in Table 1.2 were completed for this category and no specific QC checks were completed for this sub-category.

Recalculations

No recalculations were performed for this subcategory.

Planned improvements

There are no subcategory specific planned improvements, but any updated information from SAGERS will be included.

4.3.10 Chemical industry: Flourochemical production (2.B.9)

There is no *flourochemical production* occurring in South Africa.

4.4 Source Category 2.C Metal industry

4.4.1 Category information

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.

Emissions

2017

The *metal industry* was estimated to produce 31 494 Gg CO_2e in 2017, which is 72.9% of the IPPU sector emissions. The largest contribution comes from *iron and steel production* (15 074 Gg CO_2e or 47.9%), followed by *ferroalloy production* (12 575 Gg CO_2e or 39.9%).

2000 – 2017

Emissions from the *metal industry* increased 4 779 g CO_2e (17.9%) above the 2000 emissions of 26 715 Gg CO_2e. Figure 4.4 shows that emissions from the *metal industries* increased slowly (11.3%) between 2000 and 2006, after which there was a 14.4% decline to 25 467 Gg CO_2e in 2009. This decrease was evident in the *iron and steel production* emissions (25.7%), *aluminium production* emissions (40.7%) and *zinc production* emissions (17.6%).

Aluminium production emissions more than doubled between 2010 and 2011 due to increased PFC emissions (Figure 4.4; Table 4.14). In 2000 almost half (47.4%) of the *aluminium production* emissions 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. In 2017 the contribution from PFCs to emissions from aluminium production emissions was 65.0%.

Ferroalloy industry emissions increased steadily by 66.0% (5 338 GgCO_2e) between 2000 and 2015, with a slight decline of 6.3% (845 Gg CO_2e) between 2015 and 2017. Overall though there is still an increase of 4 492 Gg CO_2e (55.6%) since 2000.

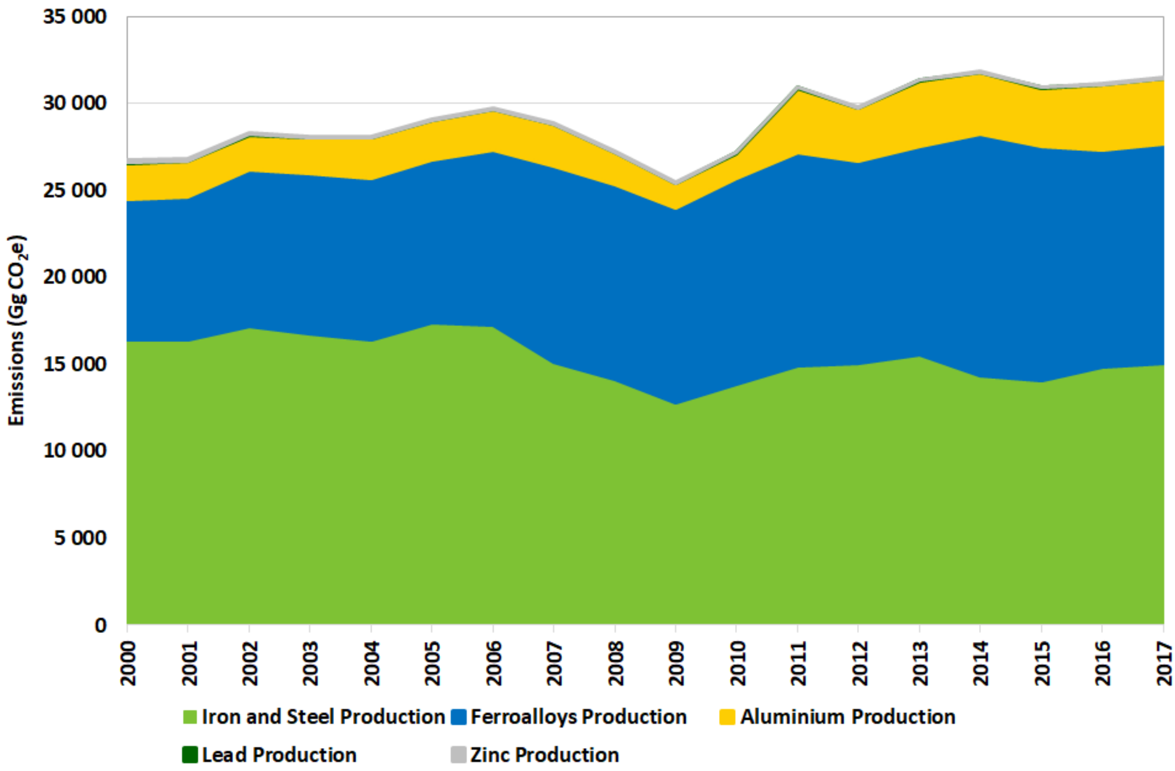

Figure 4.4: Trend and category contribution to emissions from the metal industries, 2000 – 2017.

Table 4.14: Trend in emissions from metal industries, 2000 – 2017.

	Iron and Steel Production	Ferroalloys Production	Aluminium Production	Lead Production	Zinc Production
	Emissions (Gg CO_2e)				
2000	16 410.5	8 082.4	2 074.4	39.2	108.4
2001	16 410.5	8 199.2	2 071.1	26.9	104.9
2002	17 176.1	8 974.3	2 035.8	25.7	110.1
2003	16 786.4	9 160.5	2 055.0	20.7	70.5
2004	16 425.3	9 286.9	2 285.0	19.5	55.0
2005	17 359.7	9 388.0	2 274.1	21.9	55.0
2006	17 218.5	10 068.3	2 369.7	25.1	58.5
2007	15 147.1	11 250.1	2 419.7	21.8	53.3
2008	14 152.0	11 179.5	1 848.4	24.1	49.9
2009	12 794.5	11 192.7	1 406.3	25.5	48.2

2010	13 861.7	11 822.1	1 432.0	26.3	61.9
2011	14 922.6	12 241.2	3 710.4	28.3	63.6
2012	15 020.7	11 627.2	3 046.1	27.3	63.6
2013	15 582.1	11 964.3	3 764.2	21.8	51.6
2014	14 363.5	13 897.4	3 514.3	22.1	45.0
2015	14 093.5	13 420.2	3 364.5	18.2	49.9
2016	14 829.1	12 462.6	3 749.1	21.9	47.2
2017	15 074.3	12 575.4	3 775.8	21.7	46.3

Methodology

A Tier 1 approach was used for all subcategories, except for iron and steel production where a combination of Tier 1 and 2 were used. Also the Ferrochromium emissions were determined by industry using a Tier 3 approach. Further details are discussed in the relevant sections below.

Activity data

The required activity data and the main data providers for each subsector are provided in Table 4.15.

Table 4.15: Data sources for the metal industry.

Sub-category	Activity data	Data source
Iron and steel production	Production data	South African Iron and Steel Institute (SAISI)
Ferroalloys production	Production data	South African Minerals Industry (SAMI) Report produced by DMR (2017)
Aluminium production	Production data	Aluminium industry (2000 – 2017)
		SAMI Report produced by DMR (2017)
Lead production	Production data	SAMI Report produced by DMR (2017)

Emission factors

The emission factors applied in this subsector are shown in Table 4.16. The Ferrochromium emission factors utilised by industry were not supplied and are therefore not shown in Table 4.16.

Table 4.16: Emission factors applied in the metal industry emission estimates.

Sub-category	CO_2 EF (tonnes CO_2/tonne product)	CH_4 EF (kg CH_4/tonne product)	Source
Iron and steel production			
Basic oxygen furnace	*1.46*		IPCC 2006
Electric arc furnace	*0.08*		IPCC 2006
Pig iron production	*1.35*		IPCC 2006
Direct reduced iron	*1.525*		CS (Iron and steel companies)
Sinter	*0.34*		CS (Iron and steel companies)
*Other**	*0.77*		Weighted avg of IPCC defaults
Ferroalloy production			
Ferromanganese (7% C)	*1.3*		IPCC 2006
Ferromanganese (1% C)	*1.5*		IPCC 2006
Ferrosilicon 65% Si	*3.6*	*1*	IPCC 2006
Silicon metal	*5*	*1.2*	IPCC 2006
Aluminium production			
Prebake	*1.6*		
Soderberg	*1.7*		
Lead production	0.52		IPCC 2006
Zinc production	1.72		IPCC 2006

**The Corex process is the only process included under this sub-category*

Uncertainty and time-series consistency

Activity data and emission factor uncertainties are provided in Table 4.17.

Table 4.17: Uncertainty for South Africa's metal industry emission estimates.

Gas	Sub-category	Activity data uncertainty		Emission factor uncertainty	
		%	Source	%	Source
CO_2	2C1 Iron and steel	10	IPCC 2006	25	IPCC 2006
	2C2 Ferroalloys production	5	IPCC 2006	25	IPCC 2006
	2C3 Aluminium production	5	IPCC 2006	10	IPCC 2006
	2C5 Lead production	10	IPCC 2006	50	IPCC 2006
	2C6 Zinc production	10	IPCC 2006	50	IPCC 2006

CH_4	2C2 Ferroalloys production	5	IPCC 2006	25	IPCC 2006
PFCs	2C3 Aluminium production	5	IPCC 2006	15	IPCC 2006

4.4.2 Metal industry: Iron and steel production (2.C.1)

Source category description

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.

Overview of shares and trends in emissions

2000 - 2017

Iron and steel production was estimated to produce 15 074 Gg CO_2e in 2017, which is 34.9% of the IPPU sector emissions. Emissions were 1 336 Gg CO_2e (8.1%) below the 2000 level (16 411 Gg CO_2e) (Table 4.14).

Change in emissions since 2015

Emissions in this subsector increased by 7.0% (981 Gg CO_2e) since 2015.

Methodology

A combination of the Tier 1 and Tier 2 approaches (country-specific emission factors) was applied to calculate the emissions from *iron and steel production* 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 emissions from direct reduced iron production and sinter. 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.

Activity data

The SAISI provided data for *iron and steel production* (Table 4.18).

Table 4.18: Production data for the iron and steel industry, 2000 – 2015.

	Basic oxygen furnace	Electric arc	Pig iron	Direct reduced iron	Other
	Production (tonne)				
2000	4 674 511	4 549 828	4 674 511	1 552 553	705 872
2001	4 849 655	4 716 954	4 849 655	1 220 890	706 225
2002	5 051 936	4 888 870	5 051 936	1 340 976	706 578
2003	5 083 168	5 353 456	4 474 699	1 542 008	706 931
2004	4 949 693	5 508 488	4 224 487	1 632 767	733 761
2005	5 255 831	5 089 818	4 441 904	1 781 108	735 378
2006	5 173 676	5 413 204	4 435 551	1 753 585	739 818
2007	4 521 461	5 473 908	3 642 520	1 735 914	705 428
2008	4 504 275	4 581 523	3 746 786	1 177 925	460 746
2009	3 953 709	4 359 556	3 184 566	1 339 720	429 916
2010	4 366 727	4 235 993	3 695 327	1 120 452	584 452
2011	3 991 686	3 554 803	4 603 558	1 414 164	570 129
2012	3 904 276	3 904 276	4 599 015	1 493 420	677 891
2013	4 271 948	3 292 870	4 927 550	1 295 000	590 356
2014	3 622 909	2 789 291	4 401 734	1 611 530	585 728
2015	3 907 513	2 490 587	4 463 759	1 124 971	581 399
2016	3 498 862	3 039 702	4 650 922	1 806 067	577 332
2017	3 426 153	2 920 514	4 924 688	1 802 354	573 498

Emission factors

A combination of country-specific emission factors and IPCC default emission factors were applied for the calculation of emissions from *iron and steel production*. Country-specific emission factors were sourced from one of the iron and steel companies in South Africa (Table 4.16) 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 it was based on a small sample and needs further investigation before it can be applied. The country-specific emission factor for Direct reduced iron production is more than twice the default factor. This country specific factor was used for estimating 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 solely on production by the Corex process. This process is 50% Basic Oxygen Furnace and 50% Electric Arc Furnace, therefore, a weighted emission factor (0.77 t CO_2/ t production) accounting for these two processes was applied to the *Other* category.

Uncertainty and time-series consistency

Data was consistent throughout the time series as the data was provided by the same source. The Tier 1 approach for metal production emission estimates generates a number of uncertainties. The IPCC 2006 Guidelines indicate 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, page 4.40, Table 4.9). For this inventory the maximum default uncertainty for T1 of 25% was assumed for the EF. There is a default 10% uncertainty on the activity data (IPCC 2006, Table 4.4). Uncertainty details are provided in Table 4.17.

QA/QC

All general QC listed in Table 1.2 were completed for this category and no specific QC checks were completed for this sub-category.

Recalculations

No recalculations were performed on the emissions from this subcategory.

Planned improvements

There are no subcategory specific planned improvements, but any updated information from SAGERS will be included. An improvement to consider in the future is the estimation of CH_4 emissions.

4.4.3 Metal industry: Ferroalloys production (2.C.2)

Source category description

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 CO_2 emissions (IPCC, 2006, p. 4.32). South Africa is the world's largest producer of chromium and vanadium ores, and the leading supplier of these alloys (DMR, 2015). South Africa is also the largest producer of iron and manganese ores, and an important supplier of ferromanganese, ferrosilicon and silicon metal (DMR, 2013).

Overview of shares and trends in emissions

2000 - 2017

Ferroalloys production was estimated to produce 12 575 Gg CO_2e in 2017 (Table 4.14), which is 29.1% of the IPPU sector emissions. Emissions were 4 493 Gg CO_2e (55.6%) above the 2000 level (8 082 Gg CO_2e). In this subcategory 3 Gg CO_2e of the *ferroalloys production* total was from CH_4.

Change in emissions since 2015

Emissions in this subcategory declined by 6.3% (845 Gg CO_2e) since 2015.

Methodology

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

Activity data

Ferrochromium production data for 2000 to 2017 were obtained from the SAMI annual reports (DMR, 2015) and are provided in Table 4.19. 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, 2013, 2015). For 2014 and 2017 the split between 7% and 1% was not provided (only a total manganese value) therefore the split from 2013 was applied. This will be investigated further in the next inventory.

Table 4.19: Production data for the ferroalloy industry, 2000 – 2017.

	Ferro-chromium	Ferro-manganese (7% C)	Ferro-manganese (1% C)	Ferro-silicon (65% Si)	Silicon metal
	Production (tonne)				
2000	2 574 000	596 873	310 400	108 500	40 600
2001	2 141 000	523 844	259 176	107 600	39 400
2002	2 351 000	618 954	315 802	141 700	42 500
2003	2 813 000	607 362	313 152	135 300	48 500
2004	3 032 000	611 914	373 928	140 600	50 500
2005	2 802 000	570 574	275 324	127 000	53 500
2006	3 030 000	656 235	277 703	148 900	53 300
2007	3 561 000	698 654	327 794	139 600	50 300
2008	3 269 000	502 631	259 014	134 500	51 800
2009	2 346 000	274 923	117 683	110 400	38 600
2010	3 607 000	473 000	317 000	127 700	46 400
2011	3 422 000	714 000	350 000	126 200	58 800
2012	3 063 000	706 000	177 000	83 100	53 000
2013	3 219 000	681 000	163 000	78 400	34 000
2014	3 719 000	814 263	194 737	87 700	47 200
2015	3 685 000	492 000	123 000	138 000	42 600
2016	3 334 706	684 017	163 139	105 948	38 252
2017	3 370 941	707 123	155 494	104 183	35 014

Emission factors

Ferrochromium production emission factors were not supplied by industry between 2000 and 2012, only emissions. For the period 2013 to 2017 industry emissions were not supplied so an implied emission factor (i.e., emissions divided by production) based on 2012 data was applied to activity data. These values will be updated and corrected in the next inventory. IPCC 2006 default values were applied to the other processes (Table 4.16).

Uncertainty and time-series consistency

IPCC 2006 Guidelines indicates that for Tier 1 the default emission factors may have an uncertainty of ± 25% (IPCC 2006, Vol 3, Chpt 4, page 4.40, Table 4.9). 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). Details of uncertainties are provided in Table 4.17.

QA/QC

All general QC listed in Table 1.2 were completed for this category and no specific QC checks were completed for this sub-category.

Recalculations

No recalculations were performed for this subcategory.

Planned improvements

There are no subcategory specific planned improvements, but any updated information from SAGERS will be included.

4.4.4 Metal industry: Aluminium production (2.C.3)

Source category description

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 CF_4 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.

Overview of shares and trends in emissions

2000 - 2017

Aluminium production was estimated to produce 3 776 Gg CO_2e in 2017, which is 8.7% of the IPPU sector emissions. Emissions were 1 701 Gg CO_2e (82.0%) above the 2000 level (2 074 Gg CO_2e) (Table 4.14). In 2017 CO_2 emissions accounted for 35.0% of the total aluminium production emissions, with the rest being PFCs (CF_4 and C_2F_6).

Change in emissions since 2015

Emissions in this subsector increased by 12.2% (411 Gg CO_2e) since 2015.

Methodology

A Tier 1 approach was used for CO_2 emission estimation, while a Tier 3 methodology was applied to the PFCs between 2000 and 2012. In the Tier 3 approach the amount of CF_4 and C_2F_6 produced were tracked and used to determine emissions in this category. The tier 3 method was then extrapolated for the 2013-15 period (using activity data and an implied emission factor). It is considered that the extrapolation of a tier 3 method might overestimate or underestimate the emissions. Therefore, in the 2000-2017 inventory, this will be corrected so that actual plant-performance data is used to quantify emissions for the 2013-2017 period.

Activity data

The source of activity data for *aluminium production* was the SAMI report (DMR, 2015). For PFCs the industry provided emission data for 2000 to 2017, therefore activity and emission factor data was used for these emissions.

Emission factors

Emission factors are provided in Table 4.16. For PFCs between 2013 and 2017 an implied emission factor was determined from activity and emission data in previous years. This will be corrected an updated in the next inventory.

Uncertainty and time-series consistency

The uncertainty on the Tier 1 CO_2 emission factors for aluminium production is +/-10% (IPCC 2006). Even though a tier 3 approach was used for *aluminium production* PFC emission, no data was collected on uncertainty. The Tier 3 default uncertainty for CF_4 and C_2F_6 are indicated to be +/-15% (IPCC 2006, Vol 3, Chpt 4, page 4.56). Uncertainties are provided in Table 4.17.

QA/QC

All general QC listed in Table 1.2 were completed for this category and no specific QC checks were completed for this sub-category.

Recalculations

No recalculations were performed for this category.

Planned improvements

There are no subcategory specific planned improvements, but any updated information from SAGERS will be included.

4.4.5 Metal industry: Magnesium production (2.C.4)

There is no *magnesium production* occurring in South Africa.

4.4.6 Metal industry: Lead production (2.C.5), zinc production (2.C.6), other (2.C.7)

Source category description

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.

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.

Overview of shares and trends in emissions

2000 - 2017

Lead production was estimated to produce 22 Gg CO_2e in 2017, which is 0.05% of the IPPU sector emissions. Emissions were 17 Gg CO_2e (44.4%) below the 2000 level (39 Gg CO_2e). *Zinc production* was estimated to produce 46 Gg CO_2e in 2017, which is 0.1% of the IPPU sector emissions. Emissions were 62 Gg CO_2e (57.3%) below the 2000 level (108 Gg CO_2e).

During 2003/04 South Africa's lead mine production declined by 6.2%, as did the emissions (Table 4.14), 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 2009/2010, 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). Emissions from zinc production have remained very low since 2004.

Change in emissions since 2015

Emissions from *lead production* increased by 4 Gg CO_2e (19.5%) since 2015. *Zinc production* emissions declined by 4 Gg CO_2e (7.2%) over the same period.

Methodology

Emissions from *lead* and *zinc production* were estimated using a Tier 1 approach.

Activity data

In the previous submission the *zinc production* data was supplied by industry, however this was not available for this submission. Data was therefore sourced from the SAMI report (DMR, 2015). This was also the source for the *lead production* data (Table 4.20).

Emission factors

IPCC 2006 default emission factors were applied (Table 4.16). It was assumed that for *lead production* 80% Imperial Smelting Furnace and 20% direct smelting was used, and for *zinc production* it was 60% imperial smelting and 40% Waelz Kiln (IPCC 2006 default values).

Table 4.20: Production data for the lead and zinc industries, 2000 – 2017.

	Lead	Zinc

	Production (tonne)	
2000	75 300	63 000
2001	51 800	61 000
2002	49 400	64 000
2003	39 900	41 000
2004	37 500	32 000
2005	42 200	32 000
2006	48 300	34 000
2007	41 900	31 000
2008	46 400	29 000
2009	49 100	28 000
2010	50 600	36 000
2011	54 460	37 000
2012	52 489	37 000
2013	42 000	30 000
2014	42 446	26 141
2015	35 000	29 000
2016	42 119	27 414
2017	41 814	26 928

Uncertainty and time-series consistency

For both *lead* and *zinc production* emissions there is a +/-10% uncertainty on the activity data and a +/-50% uncertainty on the IPCC default emission factor (IPCC, 2006, vol 3, Table 4.23). Uncertainties are provided in Table 4.17.

QA/QC

All general QC listed in Table 1.2 were completed for this category and no specific QC checks were completed for this sub-category.

Recalculations

No recalculations were performed for this category.

Planned improvements

There are no subcategory specific planned improvements, however for *lead* and *zinc production* it is recommended that data be collected to determine the relative amounts of lead and zinc produced from primary and from secondary materials. This would allow for the selection of more appropriate emission factors.

4.5 Source Category 2.D Non-Energy Products from Fuels and Solvent Use

4.5.1 Category information

Non-energy use of fuels and solvents includes lubricants, paraffin wax and solvents. 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). 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. Emissions from solvents are not estimated due to a lack of data.

Emissions

2017

The *non-energy products from fuels and solvent use* was estimated to produce 276 Gg CO_2e in 2017, which is 0.6% of the IPPU sector emissions. The largest contribution comes from lubricant use (273 Gg CO_2e or 99.0%).

2000 – 2017

Emissions from the *non-energy products from fuels and solvent use* category were 80 Gg CO_2e (40.7%) higher than the 2000 level of 196 Gg CO_2e. Emissions fluctuated between

196 Gg CO_2e and 250 Gg CO_2e between 2000 and 2004, and hovered around 230 Gg CO_2e between 2007 and 2010, with a peak in emissions (509 Gg CO_2e) occurring in 2006 (Figure 4.5). In 2011 there was a declines in emissions to 196 Gg CO_2e. Between 2013 and 2017 emissions remained around 270 Gg CO_2e.

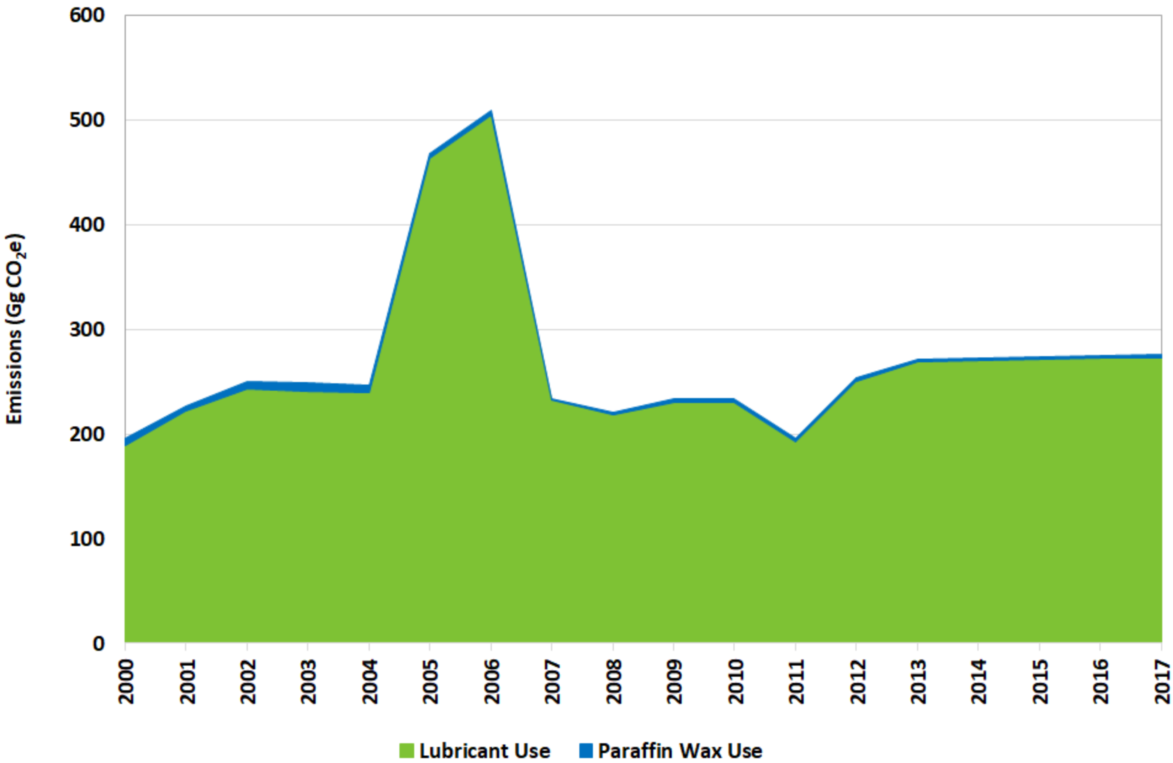

Figure 4.5: Trend and category contribution in the emissions from non-energy products from fuels and solvents, 2000 – 2017.

Methodology

A Tier 1 approach was used to determine emissions from *non-energy products from fuels and solvents*.

Activity data

The activity data was obtained from the energy balances (DoE, 2017) as indicated in Table 4.21 and provided in Table 4.22.

Table 4.21: Data sources for the non-energy products from fuels and solvents.

Sub-category	Activity data	Data source
Lubricant use	Lubricant consumption	Energy balance data from DoE
Paraffin wax use	Paraffin wax consumption	Energy balance data from DoE

Table 4.22: Lubricant and paraffin wax consumption, 2000 – 2017.

	Lubricant	Paraffin wax
	Consumption (tonne)	
2000	12 851	507
2001	15 093	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	225
2013	18 310	215
2014	18 392	207
2015	18 469	199
2016	18 541	191
2017	18 610	184

Emission factors

The IPCC 2006 default ODU 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. The carbon content was 20 t C per TJ.

Uncertainty and time-series consistency

Uncertainties for the activity data and emission factors are given in Table 4.23 and discussed in more detail in the relevant sections below.

Table 4.23: Uncertainty for South Africa's non-energy products from fuels and solvents emission estimates.

Subcategory	Activity data uncertainty		Emission factor uncertainty	
	%	Source	%	Source
2D1 Lubricant use	10	IPCC 2006	50	IPCC 2006
2D2 Paraffin wax use	10	IPCC 2006	50	IPCC 2006

4.5.2 Non-energy products from fuels and solvent use: Lubricant use (2.D.1)

Overview of shares and trends in emissions

2000 - 2017

Lubricant use was estimated to produce 273 Gg CO_2e in 2017, which is 0.6% of the IPPU sector emissions. Emissions were 85 Gg CO_2e (44.8%) below the 2000 level (188 Gg CO_2e).

Change in emissions since 2015

Emissions in this subsector increased by 0.7% (2 Gg CO_2e) since 2015.

Methodology

A Tier 1 method was applied to this subcategory.

Activity data

The source of activity data for solvents was the energy balance tables published annually by the DMRE (Table 4.22).

Emission factors

IPCC 2006 default emission factors (Section 4.5.1) were applied to this subsector.

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. Uncertainties are provided in Table 4.23.

QA/QC

All general QC listed in Table 1.2 were completed for this category and no specific QC checks were completed for this sub-category.

Recalculations

No recalculations were performed for this category.

Planned improvements

There are no subcategory specific planned improvements, but any updated information from SAGERS will be included.

4.5.3 Non-energy products from fuels and solvent use: Paraffin wax use (2.D.2)

Overview of shares and trends in emissions

2000 - 2017

Paraffin wax use was estimated to produce 2.7 Gg CO_2e in 2017. Emissions were 5 Gg CO_2e (63.7%) below the 2000 level (7 Gg CO_2e).

Change in emissions since 2015

Emissions in this subsector decreased by 7.5% since 2015.

Methodology

A Tier 1 method was applied to this subcategory.

Activity data

The source of activity data for solvents was the energy balance tables published annually by the DoE (Table 4.22).

Emission factors

IPCC 2006 default emission factors (Section 4.5.1) were applied to this subsector.

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. Uncertainties are provided in Table 4.23.

QA/QC

All general QC listed in Table 1.2 were completed for this category and no specific QC checks were completed for this sub-category.

Recalculations

No recalculations were performed for this category.

Planned improvements

There are no subcategory specific planned improvements, but any updated information from SAGERS will be included.

4.6 Source Category 2.E Electronics industry

Emissions from the *electronics industry* in South Africa are not estimated due to a lack of data. DEFF will undertake a survey to estimate greenhouse gas emissions for this category and report progress in its future GHG inventory submissions.

4.7 Source Category 2.F Product Uses as Substitutes for Ozone Depleting Substances (ODS)

4.7.1 Category information

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 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).

Emissions were only estimated from 2005 onwards due to a lack of data prior to that. The 2012 inventory only estimated emissions from refrigeration, but due to recent studies, this inventory includes emissions from *air conditioning*, *foam blowing agents*, *fire protection* and *aerosols*. Emissions from solvents are not estimated due to a lack of data.

Emissions

2017

Production uses as substitutes for ODSs category was estimated to produce 4 015 Gg CO_2e in 2017, which is 9.3% of the IPPU sector emissions. The largest contribution comes from *refrigeration and air conditioning* (3 964 Gg CO_2e or 98.7%).

2000 – 2017

Emissions were only estimated from 2005 when emissions were estimated at 842 Gg CO_2e in 2005. In 2010 there was a doubling of emissions (Figure 4.6) due to an increase in the mobile air conditioning emissions (Table 4.24). In 2013 emissions from *air conditioning*, *foam blowing agents*, *fire protection* and *aerosols* were added, therefore the emissions for this subcategory increased to 2 929 Gg CO_2e in 2013. There was then a 40.7% increase in emissions between 2013 and 2017. The increase was seen throughout the subcategories.

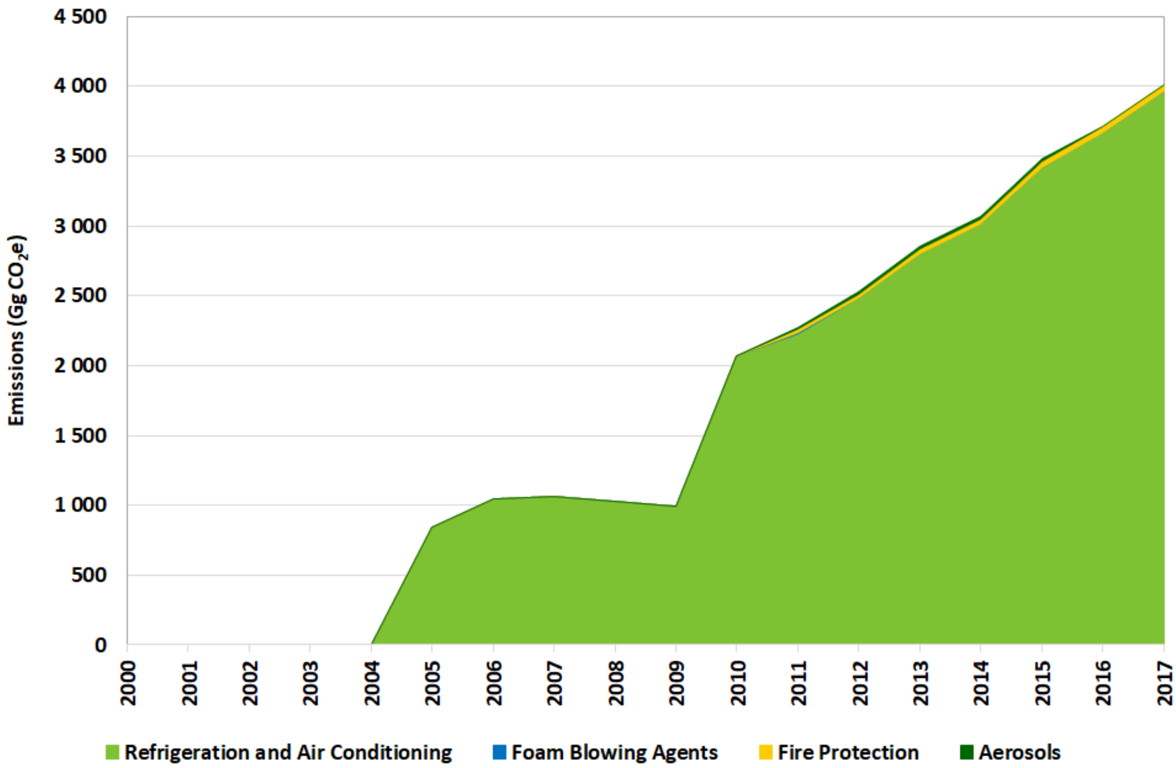

Figure 4.6: Trend and category contribution to the product uses as substitutes for ODS emissions, 2000 – 2017.

Table 4.24: Trends in emissions from product uses as substitutes for ODS categories, 2000 – 2017.

	Refrigeration and air conditioning	Foam blowing agents	Fire protection	Aerosols
	Emissions (Gg CO_2e)			
2000	0.0	0.0	0.0	0.0
2001	0.0	0.0	0.0	0.0
2002	0.0	0.0	0.0	0.0
2003	0.0	0.0	0.0	0.0
2004	0.0	0.0	0.0	0.0
2005	841.8	0.0	0.0	0.0
2006	1 045.4	0.0	0.0	0.0
2007	1 063.4	0.0	0.0	0.0
2008	1 026.0	0.0	0.0	0.0

2009	992.0	0.0	0.0	0.0
2010	2 065.8	0.0	0.0	0.0
2011	2 232.5	3.8	23.0	15.1
2012	2 482.8	3.5	25.3	16.0
2013	2 802.4	2.0	30.5	17.6
2014	3 011.3	1.7	35.9	16.6
2015	3 419.7	2.1	42.1	18.2
2016	3 669.0	0.0	46.1	0.0
2017	3 963.5	0.0	51.1	0.0

Methodology

The Tier 1 approach was used to estimate emissions from *refrigeration and air conditioning*, while a Tier 2 approach was applied to *foam blowing agents*, *fire protection* and *aerosols*.

Activity data

The required activity data and the main data providers for each subsector are provided in Table 4.25.

Table 4.25: Data sources for the product uses as substitutes for ODS category.

Sub-category	Activity data	Data source
Refrigeration and air conditioning	Estimated the yearly data on existing, new and retired domestic refrigerators in South Africa based on data from Stats SA. Yearly data on existing, new and retired refrigerated trucks based on previous studies (GIZ, 2014) and expert knowledge (South African Refrigeration Distribution Association) Yearly data on existing, new and retired vehicles from eNaTIS and NAAMSA.	HFC Survey DEFF
Foam blowing agents	Total HFC used in foam manufacturing in a year	HFC Survey DEFF

Fire protection	Bank of agent in fire protection equipment in a year	HFC Survey DEFF
Aerosols		HFC Survey DEFF

Emission factors

The Tier 1 defaults and emission factors applied in this subsector are shown in Table 4.26.

Table 4.26: Emission factors and defaults applied in the product uses as substitutes for ODS emission estimates.

Sub-category	Value	Units	Source
Refrigeration and air conditioning ***Assumed equipment lifetime Emission factor from installed base*** ***% of HFC destroyed at End-of-Life***	*10* *15* *25*	*Years* *%* *%*	IPCC 2006 IPCC 2006 IPCC 2006
Foam blowing agents ***Product life*** ***First year loss*** ***Annual loss*** ***Landfilling loss*** ***Landfill annual loss***	*34* *14* *0.66* *16* *0.75*	*Years* *%* *%* *%* *%*	(UNEP, 2005, IPCC, 2006)
Fire protection	4	%	IPCC 2006
Aerosols (HFC-134a)	0,50	Fraction	IPCC 2006

Uncertainty and time-series consistency

Uncertainties in the activity data and emission factors for *product uses as substitutes for ODS* are given in Table 4.27. Further details are provided in the relevant sections below.

Table 4.27: Uncertainty for South Africa's product uses as substitutes as ODS emission estimates.

Gas	Category	Activity data uncertainty		Emission factor uncertainty	
		%	Source	%	Source
HFCs	2F Product uses as substitutes for ODS	25	IPCC 2006	25	IPCC 2006

4.7.2 Product uses as substitute ODS: Refrigeration and air conditioning (2.F.1)

Overview of shares and trends in emissions

2000 - 2017

Refrigeration and air conditioning was estimated to produce 3 964 Gg CO_2e of HFCs in 2017, which is 98.7% of the *product uses as substitute ODS emissions*. *Refrigeration and stationary air conditioning* contributed 48.4% to this subcategory, while the rest was from *mobile air conditioning*. Since the addition of the *mobile air conditioning* estimates in 2011 the emissions for this subcategory have more than doubled (Table 4.24).

Change in emissions since 2015

Emissions from *refrigeration and air conditioning* have increased by 544 Gg CO_2e (15.9%) since 2015.

Methodology

The IPCC guidelines (IPCC, 2006) propose either an emissions factor approach at the sub-application level (Tier 2a) or a mass balance approach at the sub-application level (Tier 2b) to calculate emissions from RAC applications.

In the HFC Emissions Database the emissions factor approach (Tier 2a) is primarily applied, with the mass balance approach applied for uncertainty purposes/checking. There was insufficient data to follow this approach for Commercial Refrigeration and Industrial Processes. Thus a hybrid approach is applied for these sub-applications, which were combined into one application. Table 4.28 summarises the approach used for each sub-application in the RAC sector:

Table 4.28: Methodology and data sources used for each RAC sub-application

Sub-application	Method	Motivation
Domestic Refrigeration	Tier 2a (2b)	Estimated the yearly data on existing, new and retired domestic refrigerators in South Africa based on data from Stats SA. Emission factors based on IPCC (2006) and other international studies. Estimated yearly sales of R134a for servicing and/or new equipment into domestic refrigeration from survey for cross checking
Commercial Refrigeration and Industrial Processes	Tier 2b	Estimated early sales of refrigerants into commercial refrigeration. Assumed share of refrigerant taken up into charging of new equipment. Emission factors based on IPCC (2006) and other international studies.
Stationary Air Conditioning	Tier 2a	Yearly data on stationary air conditioning units (BSRIA) Emission factors based on IPCC (2006) and other international studies. Estimated yearly sales of refrigerants into stationary air conditioning for servicing and/or new equipment from survey for cross checking
Transport Refrigeration	Tier 2a (2b)	Yearly data on existing, new and retired refrigerated trucks based on previous studies (GIZ, 2014) and expert knowledge (SARDA). Emission factors based on IPCC (2006) and other international studies. Estimated yearly sales of R134a and R404a into transport refrigeration for servicing and/or new equipment from survey for cross checking.
Mobile Air Conditioning	Tier 2a (2b)	Yearly data on existing, new and retired vehicles from eNaTIS and NAAMSA. Emission factors based on IPCC (2006) and other international studies. Estimated yearly sales of R-134a into mobile air conditioning for servicing and/or new equipment from survey for cross checking.

Activity data

Stakeholders in the refrigeration and air conditioning sector in South Africa were identified by means of desktop research and the membership lists of the various industry associates in the refrigeration and air conditioning sector, such as the South African Institute of Refrigeration and Air Conditioning (SAIRAC), the South African Refrigeration & Air Conditioning Contractors' Association (SARACCA) and the South African Refrigeration Distribution Association (SARDA). Other sources included the members of the DEFF's Chemical Management HCFC working group, and importers and exporters listed in the International Trade Centre (ITC) website (Market Analysis and Research). Other literature and statistical data sources provided the activity data for other sub-applications, e.g. eNaTIS for vehicle data for mobile air conditioning and transport refrigeration and Stats SA for data on the number of households with refrigerators.

Emission factors

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.

Uncertainty and time-series consistency

An uncertainty of +/-25% was assumed for both activity data and emission factors (IPCC, 2006). Time series is not consistent over the full 17 year time period as emission data is only available from 2005, with an enhanced data set (including mobile air conditioning) from 2011. Discussions with the ODS management unit to retrieve data for the 1990-2004 period are on-going and a progress report will be added in the next inventory.

QA/QC

All general QC listed in Table 1.2 were completed for this category and no specific QC checks were completed for this sub-category.

Recalculations

No recalculations were performed for this category.

Planned improvements

It is planned that the HFC survey will be updated and will focus mostly on the refrigeration and air conditioning sector in order to improve emissions estimates form this category. In addition, if data becomes available through discussions with ODS unit a full time-series will be considered in the next inventory

4.7.3 Product uses as substitute ODS: Foam blowing agents (2.F.2)

Overview of shares and trends in emissions

2000 - 2017

Emissions from *foam blowing agents* was estimated to produce 2 Gg CO_2e in 2017.

Change in emissions since 2015

Emissions in this subcategory were added since the 2012 inventory, but recalculations were not done for years prior to 2011 due to a lack of data. This sub-category added 4 Gg CO_2e each year to the 2011 and 2012 emission estimates for *refrigeration and air conditioning*.

Methodology

HFC emissions from foam blowing applications are calculated in the HFC Emissions Database following the approach in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Chapter 7: Emissions of Fluorinated Substitutes for Ozone Depleting Substances), as given in Equation 3 (IPCC, 2006, Ashford et al., 2005). This formula calculates the emissions based on the amount of HFC lost during manufacture and the first year of foam use, the annual amount lost from HFC-containing foams in use (banks), and the amount lost at the end of the foams' life when products are decommissioned, less the amount of HFC recovered or destroyed from decommissioned foam products.

Activity data

Where data is difficult to obtain in the country the IPCC guidelines suggest obtaining historic regional usage to account for HFC banks and emissions factors from the UNEP Foams Technical Options Committee (FTOC). The latest UNEP FTOC report suggests that in 2008 only 0.15% of the foam bank within developing nations contained HFCs and that sub-Saharan Africa had not utilised any HFC for foam manufacture at this time (UNEP, 2010). This suggests that the HFC-containing foam bank in South Africa is limited and the foam bank in the HFC Emissions are therefore estimated by simply extrapolating the annual net consumption data for 2010-2016 back to the date HFC blowing agent was introduced into South Africa (2005).

Emission factors

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. Emission factors used are presented in table 4.25.

Uncertainty and time-series consistency

An uncertainty of +/-25% was assumed for both activity data and emission factors (IPCC, 2006). Time series is not consistent over the full 17 year time period as emission data for this sub-category is only available from 2011. Extrapolation of a full time-series will be considered in the next inventory.

QA/QC

All general QC listed in Table 1.2 were completed for this category and no specific QC checks were completed for this sub-category.

Recalculations

No recalculations were performed for this category.

Planned improvements and recommendations

Extrapolation of HFCs across the full time-series will be considered in the next inventory.

4.7.4 Product uses as substitute ODS: Fire protection (2.F.3)

Overview of shares and trends in emissions

2000 - 2017

Emissions from *fire protection* was estimated to produce 51 Gg CO_2e in 2017.

Change in emissions since 2015

Emissions in this subcategory increased by 9 Gg CO_2e (21.4%) since 2015.

Methodology

Emissions from fire protection applications are expected to be small because their use is non-emissive, that is, they are used in the provision of stand-by fire protection equipment. However, this does result in an accumulating bank of gas that has the potential to be released in the future when equipment is decommissioned (IPCC, 2006). The emissions from the fire protection sector are calculated in accordance with the approach suggested by the IPCC guidelines, Equation 12 and Equation 13.

Activity data

Emissions from fire protection equipment are estimated using local sales data from eight importers/distributors of fire protection equipment and gases. This yielded very similar results to those calculated from net consumption (imports minus exports) of ten companies importing fire suppression agents.

Emission factors

Emissions from Fire Protection were calculated in accordance with the IPCC guidelines and an emission factor was calculated based on the fraction of agent in equipment emitted each year (excluding emissions from retired equipment or otherwise removed from service), dimensionless. However, none of the contractors or wholesalers of the agents interviewed could provide an estimation of the fraction of agent emitted each year (EF) or the emissions of agent during recovery, recycling or disposal at the time of removal from service (RRL). However, experience gained with the emissions patterns of halon substances has yielded valuable lessons in terms of emissions factors for fire suppression agents. A proposed emissions factor of 4% of in-use quantities is assumed, as proposed by the IPCC (IPCC, 2006).

Uncertainty and time-series consistency

An uncertainty of +/-25% was assumed for both activity data and emission factors (IPCC, 2006). Activity data and emission factor uncertainties are provided in Table 4.29. Time series is not consistent over the full 17 year time period as emission data for this sub-category is only available from 2011. Extrapolation of HFCs across the full time-series will be considered in the next inventory.

Table 4.29: Uncertainty for South Africa's Product uses as substitute ODS: Fire Protection emission estimates.

Gas	Sub-category	Activity data uncertainty		Emission factor uncertainty	
		%	Source	%	Source
HFCs	2F3 Fire Protection	25	IPCC 2006	25	IPCC 2006

QA/QC

All general QC listed in Table 1.2 were completed for this category and no specific QC checks were completed for this sub-category.

Recalculations

No recalculations were undertaken for this category as they were not previously estimated.

Planned improvements

No further improvements are planned for this sub-category.

4.7.5 Product uses as substitute ODS: Aerosols (2.F.4)

Overview of shares and trends in emissions

2000 - 2017

Emissions from *aerosols* was estimated to produce 18 Gg CO_2e in 2017.

Change in emissions since 2015

Emissions in this subcategory were added since the 2012 inventory, but recalculations were not done for years prior to 2011 due to a lack of data. This sub-category contributed an additional 15 Gg CO_2e and 16 Gg CO_2e to the emissions in 2011 and 2012 respectively.

Methodology

An emission factor approach on a sub-application level (Tier 2a) was applied to calculate emissions from aerosols. However, data from gas suppliers could not be disaggregated into sub-applications, resulting in a Tier 1a approach being applied in addition to the Tier 2a approach.

Activity data

Data on the number of aerosol products sold locally at the sub-application level (e.g. number of individual metered dose inhalers, hair care products, and tyre inflators, etc.), as well as the average charge of propellant per container, is required. In the HFC emissions database aerosols are grouped into the following sub-applications:

- Metered Dose Inhalers (MDIs)
- Personal Care Products
- Household Products
- Industrial Products
- Other General Products

Data on aerosol imports and exports had to be obtained directly from the companies/distributors, as trade data could not be used because official import statistics for aerosol products do not differentiate HFC-containing aerosols from other alternatives. Furthermore, import/export figures are typically reported in million units with no indication of the mass of the product or the type or loading of propellant, rendering them unusable for HFC emissions estimation.

Emission factors

The simplified default approach in Equation 2 assumes that all emissions associated with aerosols and metered dose inhalers occur during the use phase, that there are zero losses on the initial charge of the product during manufacture, zero leakages during the life of the product and zero emissions from the disposal of the product. A product life span of two years translates to a default emission factor (EF) of 50% of the initial charge per year (Commonwealth of Australia, 2015).

Uncertainty and time-series consistency

Time series is not consistent over the full 17 year time period as emission data for this sub-category is only available from 2011. Extrapolation of HFCs across the full time-series will be considered in the next inventory. An uncertainty of +/-25% was assumed for both activity data and emission factors (IPCC, 2006). Activity data and emission factor uncertainties are provided in Table 4.30.

Table 4.30: Uncertainty for South Africa's Product uses as substitute ODS: Aerosols emission estimates.

Gas	Sub-category	Activity data uncertainty		Emission factor uncertainty	
		%	Source	%	Source
HFCs	2F4 Aerosols	25	IPCC 2006	25	IPCC 2006

QA/QC

All general QC listed in Table 1.2 were completed for this category and no specific QC checks were completed for this sub-category.

Recalculations

No recalculations were performed for this category as they were not previously estimated.

Planned improvements

Extrapolation of HFCs across the full time-series will be considered in the next inventory.

4.8 Source Category 2.G Other product manufacture and use

Emissions from *other product manufacture and use* were not estimated for South Africa due to a lack of data.

4.9 Source Category 2.H Other

Emissions from this category were not estimated for South Africa due to a lack of data.

environment, forestry & fisheries

Department:
Environment, Forestry and Fisheries
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Appendix 4.A Summary table of IPPU emissions in 2017

Categories	(Gg)			CO_2 Equivalents(Gg)							Emissions
	CO_2	CH_4	N_2O	HFCs	PFCs	SF6	NOx	CO	NMVOCs	SO_2	(Gg CO_2e)
2 - Industrial Processes and Product Use	**36 298.7**	**8.1**	**0.9**	**4 014.5**	**2 453.4**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**43 229.5**
2.A - Mineral Industry	**6 462.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**6 462.1**
2.A.1 - Cement production	**5 295.9**						**NE**	**NE**	**NE**	**NE**	**5 295.9**
2.A.2 - Lime production	**1 045.3**						**NE**	**NE**	**NE**	**NE**	**1 045.3**
2.A.3 - Glass Production	**120.9**						**NE**	**NE**	**NE**	**NE**	**120.9**
2.A.4 - Other Process Uses of Carbonates	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**
2.A.4.a - Ceramics	*NE*						*NE*	*NE*	*NE*	*NE*	*NE*
2.A.4.b - Other Uses of Soda Ash	*NE*						*NE*	*NE*	*NE*	*NE*	*NE*
2.A.4.c - Non Metallurgical Magnesia Production	*NE*						*NE*	*NE*	*NE*	*NE*	*NE*
2.A.4.d - Other (please specify) (3)	*NE*						*NE*	*NE*	*NE*	*NE*	*NE*
2.A.5 - Other (please specify) (3)							**NE**	**NE**	**NE**	**NE**	**NE**
2.B - Chemical Industry	**523.9**	**8.0**	**0.9**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**983.7**
2.B.1 - Ammonia Production	**C**	**C**					**NE**	**NE**	**NE**	**NE**	**C**
2.B.2 - Nitric Acid Production			**C**				**NE**	**NE**	**NE**	**NE**	**C**
2.B.3 - Adipic Acid Production			**NE**				**NE**	**NE**	**NE**	**NE**	**NE**
2.B.4 - Caprolactam, Glyoxal and Glyoxylic Acid Production			**NE**				**NE**	**NE**	**NE**	**NE**	**NE**
2.B.5 - Carbide Production	**C**	**NE**					**NE**	**NE**	**NE**	**NE**	**C**
2.B.6 - Titanium Dioxide Production	**C**						**NE**	**NE**	**NE**	**NE**	**C**

2.B.7 - Soda Ash Production	**NE**						**NE**	**NE**	**NE**	**NE**	**NE**
2.B.8 - Petrochemical and Carbon Black Production	**C**	**C**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**C**
2.B.8.a - Methanol	*NO*	*NO*					NO	NO	NO	NO	NO
2.B.8.b - Ethylene	*NO*	*NO*					NO	NO	NO	NO	NO
2.B.8.c - Ethylene Dichloride and Vinyl Chloride Monomer	*NO*	*NO*					NO	NO	NO	NO	NO
2.B.8.d - Ethylene Oxide	*NO*	*NO*					NO	NO	NO	NO	NO
2.B.8.e - Acrylonitrile	*NO*	*NO*					NO	NO	NO	NO	NO
2.B.8.f - Carbon Black	*C*	*C*					NE	NE	NE	NE	*C*
2.B.9 - Fluorochemical Production	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**
2.B.9.a - By-product emissions (4)				*NE*			NE	NE	NE	NE	*NE*
2.B.9.b - Fugitive Emissions (4)							NE	NE	NE	NE	*0.0*
2.B.10 - Other (Please specify) (3)							**NE**	**NE**	**NE**	**NE**	**0.0**
2.C - Metal Industry	**29 037.2**	**0.1**	**0.0**	**0.0**	**2 453.4**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**31 493.6**
2.C.1 - Iron and Steel Production	**15 074.3**	**0.0**					**NE**	**NE**	**NE**	**NE**	**15 074.3**
2.C.2 - Ferroalloys Production	**12 572.3**	**0.1**					**NE**	**NE**	**NE**	**NE**	**12 575.4**
2.C.3 - Aluminium production	**1 322.5**				**2 453.4**		**NE**	**NE**	**NE**	**NE**	**3 775.8**
2.C.4 - Magnesium production (5)	**NO**					**NO**	**NO**	**NO**	**NO**	**NO**	**NO**
2.C.5 - Lead Production	**21.7**						**NE**	**NE**	**NE**	**NE**	**21.7**
2.C.6 - Zinc Production	**46.3**						**NE**	**NE**	**NE**	**NE**	**46.3**
2.C.7 - Other (please specify) (3)	**0.0**						**NE**	**NE**	**NE**	**NE**	**0.0**
2.D - Non-Energy Products from Fuels and Solvent Use (6)	**275.6**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**275.6**

2.D.1 - Lubricant Use	**272.9**						**NE**	**NE**	**NE**	**NE**	**272.9**
2.D.2 - Paraffin Wax Use	**2.7**						**NE**	**NE**	**NE**	**NE**	**2.7**
2.D.3 - Solvent Use (7)							**NE**	**NE**	**NE**	**NE**	**0.0**
2.D.4 - Other (please specify) (3), (8)							**NE**	**NE**	**NE**	**NE**	**0.0**
2.E - Electronics Industry	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
2.E.1 - Integrated Circuit or Semiconductor (9)				**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**
2.E.2 - TFT Flat Panel Display (9)					**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**
2.E.3 - Photovoltaics (9)					**NE**		**NE**	**NE**	**NE**	**NE**	**NE**
2.E.4 - Heat Transfer Fluid (10)					**NE**		**NE**	**NE**	**NE**	**NE**	**NE**
2.E.5 - Other (please specify) (3)							**NE**	**NE**	**NE**	**NE**	**NE**
2.F - Product Uses as Substitutes for Ozone Depleting Substances	**0.0**	**0.0**	**0.0**	**4 014.5**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**4 014.5**
2.F.1 - Refrigeration and Air Conditioning	**0.0**	**0.0**	**0.0**	**3 963.5**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	***3 963.5***
2.F.1.a - Refrigeration and Stationary Air Conditioning				*1 919.7*			NE	NE	NE	NE	*1 919.7*
2.F.1.b - Mobile Air Conditioning				*2 043.7*			NE	NE	NE	NE	*NE*
2.F.2 - Foam Blowing Agents				**0.0**			**NE**	**NE**	**NE**	**NE**	**0.0**
2.F.3 - Fire Protection				**51.1**	**NE**		**NE**	**NE**	**NE**	**NE**	**51.1**
2.F.4 - Aerosols				**0.0**			**NE**	**NE**	**NE**	**NE**	**0.0**
2.F.5 - Solvents				**NE**	**NE**		**NE**	**NE**	**NE**	**NE**	**NE**
2.F.6 - Other Applications (please specify) (3)				**NO**	**NO**		**NO**	**NO**	**NO**	**NO**	**NO**
2.G - Other Product Manufacture and Use	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
2.G.1 - Electrical Equipment	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**
2.G.1.a - Manufacture of Electrical Equipment					NE	NE	NE	NE	NE	NE	NE

2.G.1.b - Use of Electrical Equipment					NE	NE	NE	NE	NE	NE	NE
2.G.1.c - Disposal of Electrical Equipment					NE	NE	NE	NE	NE	NE	NE
2.G.2 - SF6 and PFCs from Other Product Uses	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**
2.G.2.a - Military Applications					NE	NE	NE	NE	NE	NE	NE
2.G.2.b - Accelerators					NE	NE	NE	NE	NE	NE	NE
2.G.2.c - Other (please specify) (3)					NE	NE	NE	NE	NE	NE	NE
2.G.3 - N_2O from Product Uses	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**
2.G.3.a - Medical Applications			NE				NE	NE	NE	NE	NE
2.G.3.b - Propellant for pressure and aerosol products			NE				NE	NE	NE	NE	NE
2.G.3.c - Other (Please specify) (3)			NE				NE	NE	NE	NE	NE
2.G.4 - Other (Please specify) (3)							**NE**	**NE**	**NE**	**NE**	**NE**
2.H - Other	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
2.H.1 - Pulp and Paper Industry							**NE**	**NE**	**NE**	**NE**	**0.0**
2.H.2 - Food and Beverages Industry							**NE**	**NE**	**NE**	**NE**	**0.0**
2.H.3 - Other (please specify) (3)							**NE**	**NE**	**NE**	**NE**	**0.0**

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Chapter 5: Agriculture, Forestry and Other Land Use (AFOLU)

5.1 Sector overview

5.1.1 South Africa's AFOLU sector

This section includes GHG emissions and removals from agriculture as well as land use and forestry. Based on the IPCC 2006 Guidelines, the main categories included in the emission estimates for the AFOLU sector are shown in Table 5.1.

Table 5.1: Main IPCC categories included in the AFOLU sector emission estimates.

IPCC Category	Category name	Included
3A1	Enteric fermentation	√
3A2	Manure management	√
3B1	Forest lands	√
3B2	Croplands	√
3B3	Grasslands	√
3B4	Wetlands	√
3B5	Settlements	√
3B6	Other lands	√
3C1	Biomass burning	√
3C2	Liming	√
3C3	Urea application	√
3C4	Direct N_2O emissions from managed soils	√
3C5	Indirect N_2O from managed soils	√
3C6	Indirect N_2O from manure management	√
3C7	Rice cultivation	NO
3C8	Other	NO
3D1	Harvested wood products	√
3D2	Other	NO

Emissions from fuel combustion in this sector are not included here as these fall under the *agriculture/forestry/fisheries* subsector (see Section 3.2.8) in the energy sector. 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 (Formulation B) 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. DEFF recently completed a project on organic and humic soils, but this data only became available late in the inventory preparation process so was unable to be included. Similarly, with the update to the National Terrestrial Carbon Sinks Assessment (NTCSA), which was completed early 2020. These data sets will be assessed in the next inventory round and all available data will be incorporated.

Emissions from ruminants in privately owned game parks was included in the previous inventory, however, due to discussions during the UNFCCC in-country review, these were excluded from this inventory as they are considered not to be managed. Similarly, for Buffalo emissions. In addition, in the previous inventory the dairy cattle included all dairy cattle (both lactating and non-lactating cattle); however, in this inventory only lactating cows and heifers are included under Dairy cattle. The emissions from non-lactating dairy cattle are included under the Other cattle sub-category. Further details are provided in the relevant sections below.

Emissions

2017

The *AFOLU* sector in South Africa was a source of 9 085 Gg CO_2e in 2017 (Table 5.2). A detailed summary table for the AFOLU emissions in 2017 are provided in Appendix 5A. In 2017 CH_4 emissions contributed the most (53.3%) to the AFOLU (excl. FOLU) emissions, with N_2O contributing 44.3%. *Enteric fermentation* contributed 96.2% of the CH_4 emissions. *Direct N_2O emissions from managed soils* was the largest contributor (77.1%) to the N_2O emission in this sector. Indirect emissions of NOx, CO and NMVOCs were estimated for biomass burning.

Table 5.2: Summary of the estimated emissions from South Africa's AFOLU sector in 2017.

GHG source categories	CO_2	CH_4	N_2O	NOx	CO	NMVOCs	Total*

	(Gg)						(Gg CO_2e)
3. AFOLU (incl. FOLU)	**-41 288.1**	**1 309.6**	**73.8**	**487.8**	**20.3**	**27.2**	**9 085.2**
3. AFOLU (excl. FOLU)	**1 901.7**	**1 277.8**	**73.8**	**487.8**	**20.3**	**27.2**	**51 608.4**
3.A Livestock	NA	1 259.7	5.5	NA	NA	NA	28 161.3
3.B Land	-42 412.8	31.7	NE	NA	NA	NA	-41 746.2
3.C Aggregated and non-CO_2 sources	1 901.7	18.1	68.3	487.8	20.3	27.2	23 447.1
3.D Other	-776.9	NA	NA	NA	NA	NA	-776.9

**Totals may not sum exactly due to rounding off.*

2000 – 2017

The AFOLU (excl. FOLU) emissions declined by 820% (4 635 Gg CO_2e) between 2000 and 2017, while AFOLU (incl. FOLU) declined by 74.6% (26 630 Gg CO_2e) (Table 5.3). This large decline is due to a 23 911 Gg CO_2 (79.2%) increase in the *Land* sink over this period. There were, however fluctuations in the *Land* sink throughout the 17 year period (Figure 5.1**Error! Reference source not found.**).

Total GHG emissions from *Livestock* declined due mainly to the decreasing cattle, sheep and goat populations. The other cattle[5] population has declined by 4.7% since 2000, leading to a decline in other cattle emissions which is the largest contributor to *Enteric fermentation*. *Livestock* contributed 54.6% to the total AFOLU (excl. FOLU) emissions.

The *Land* component is estimated to be an overall sink with the *Forest land* category being the main contributor to this sink. The increasing sink is due to increasing forest land area (particularly thickets and woodlands/open bush), and a decline in wood losses. There was a peak in burnt area in 2008, and then a fairly steep decline between 2014 and 2017, leading to reduction in disturbance losses. Furthermore, there was a decline is wood removals by households for lighting and cooking purposes, probably due to increased electrification, which also contributed to the reduced removals.

The *Grasslands* sink remained fairly constant over the 17-year period with a reduction in the sink between 2010 and 2012. This was due to an increase in fire disturbance losses from low shrublands (which are included within the *Grassland* category) during these years. *Land converted to grasslands* contributing the largest portion (95.4%) to the *Grassland* category. *Croplands* were a small, fairly constant sink which remained below 860 Gg CO_2 over the time-series. *Croplands remaining croplands* contributed to the sink,

[5] All cattle except dairy cows and lactating heifers.

while *Land converted to croplands* produced emissions of 2 321 Gg CO_2e in 2017, and the annual variation was not more than 60 Gg CO_2e. The majority of the emissions were from the conversion of forest land to cropland.

Other lands provide a constant source of emissions (16 045 Gg CO_2) as carbon is lost when land is converted to *Other lands*. Since it is assumed there is no vegetation in *Other lands* and no changes in soil carbon, there are no emissions or removals from *Other lands remaining other land* category. In *Land converted to other land* only changes due to initial biomass loss and soil carbon losses are relevant. These rates of change are constant due to the constant change area.

Emissions from *Aggregated and non-CO_2 emission sources* declined by 8.9% between 2000 and 2017. The fluctuations in this category are driven mainly by changes in *Liming* and *Direct N_2O from managed soils*. *Aggregated and non-CO_2 emissions on land* contributed 45.4% to the AFOLU (excl. FOLU) emissions in 2017.

HWP estimates indicate that this subsector is a small sink of CO_2 and this sink increased from 290 Gg CO_2e in 2000 to 776 Gg CO_2e in 2017, however there were annual fluctuations (Table 5.3).

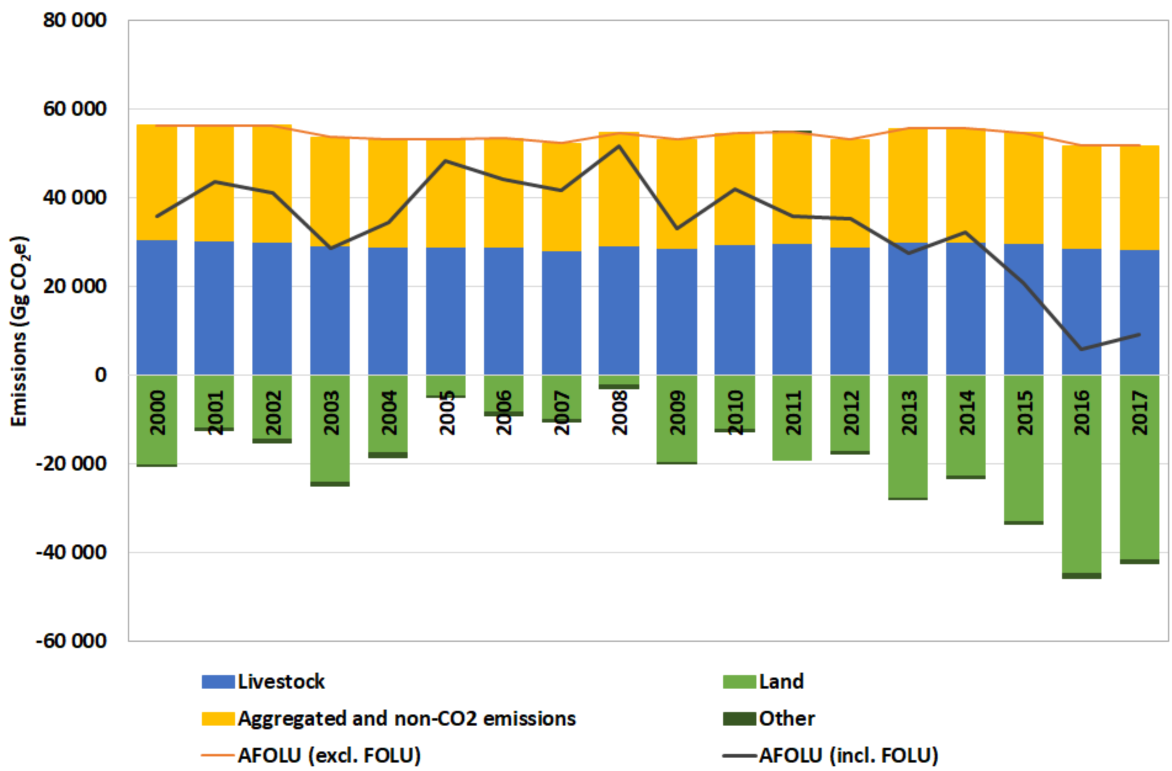

Figure 5.1: Emission trends for South Africa's AFOLU sector, 2000 – 2017.

Table 5.3: Trends in category emission within the AFOLU sector between 2000 and 2017.

	Livestock	Land	Aggregated & non-CO_2 sources	Other (HWP)	AFOLU (incl. FOLU)	AFOLU (excl. FOLU)
	Gg CO_2e					
2000	30 515.5	-20 237.4	25 727.8	-290.4	35 715.3	56 243.2
2001	30 340.1	-11 991.3	25 783.5	-557.0	43 575.3	56 123.6
2002	29 862.3	-14 484.9	26 343.3	-735.5	40 985.3	56 205.7
2003	28 988.5	-24 175.2	24 615.0	-893.1	28 535.2	53 603.5
2004	28 771.7	-17 547.3	24 321.5	-1 151.0	34 394.9	53 093.2
2005	28 806.7	-4 771.0	24 404.4	-251.7	48 188.3	53 211.1
2006	28 710.7	-8 440.2	24 591.9	-869.1	43 993.3	53 302.6
2007	27 953.8	-9 992.9	24 305.6	-629.0	41 637.5	52 259.4
2008	29 128.5	-2 218.2	25 469.6	-792.3	51 587.6	54 598.1
2009	28 566.8	-19 752.5	24 429.2	-119.1	33 124.4	52 996.0
2010	29 466.3	-12 207.7	24 997.7	-513.1	41 743.2	54 464.0
2011	29 540.4	-19 082.3	25 137.8	57.2	35 653.2	54 678.2
2012	28 765.7	-17 360.4	24 218.9	-441.4	35 182.8	52 984.6
2013	29 976.2	-27 901.6	25 583.0	-282.9	27 374.5	55 559.1
2014	29 854.3	-22 699.1	25 675.5	-535.4	32 295.2	55 529.7
2015	29 764.8	-33 123.6	24 749.3	-608.3	20 782.2	54 514.1
2016	28 493.5	-44 669.9	23 164.5	-1 091.1	5 896.9	51 657.9
2017	28 161.3	-41 746.2	23 447.1	-776.9	9 085.2	51 608.4

2015 – 2017

There was a 5.4% (2 906 Gg CO_2e) decrease in the AFOLU (excl. FOLU) emissions since 2015. This can be attributed to a slight decline in livestock population during this period. The AFOLU (incl. FOLU) emissions declined by 56.3% (11 697 Gg CO_2e) over the same period due to a large increase in the *Land* sink. *Aggregated and non-CO_2 emissions on land* decreased by 1 302 Gg CO_2e (5.3%), while the *HWP* sink increased by 169 Gg CO_2e since 2015.

5.1.2 Overview of methodology and completeness

Table 5.4 provides a summary of the methods and types of emission factors used during the compilation of the 2017 inventory.

Table 5.4: Summary of methods and emission factors for the AFOLU sector and an assessment of the completeness of the AFOLU sector emissions.

GHG Source and sink category		CO_2		CH_4		N_2O		Details
		Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	
3A LIVESTOCK	***1 Enteric fermentation***							
	a.i. Dairy cattle	NA		T2	CS	NA		CS EF for CH_4 and N_2O from Du Toit et al. (2013a - d) were applied for all indicated livestock.
	a.ii. Other cattle	NA		T2	CS	NA		
	b. Buffalo	NA		NO		NO		
	c. Sheep	NA		T2	CS	NA		
	d. Goats	NA		T2	CS	NA		
	e. Camels	NA		NO		NO		
	f. Horses	NA		T1	DF	NA		
	g. Mules and asses	NA		T1	DF	NA		
	h. Swine	NA		T2	CS	NA		
	j. Other	NA		NO		NO		
	2 Manure management							
	a.i. Dairy cattle	NA		T2	CS	T2	DF	CS EF for CH_4 and N_2O from Du Toit et al. (2013a) were applied.
	a.ii. Other cattle	NA		T2	CS	T2	DF	
	b. Buffalo	NA		NO		NO		
	c. Sheep	NA		T2	CS	NO		CS EF for CH_4 from Du Toit et al. (2013b) were applied.
	d. Goats	NA		T2	CS	NO		
	e. Camels	NA		NO		NO		

	f. Horses	NA		T1	DF	NO		
	g. Mules and asses	NA		T1	DF	NO		
	h. Swine	NA		T2	CS	T2	DF	CS EF for CH_4 from Du Toit et al. (2013b - d) were applied.
	i. Poultry	NA		T2	CS	T2	DF	
	j. Other	NA		NO		NO		
3B LAND	***1 Forest land***							
	a. Forest land remaining forest land	Biomass: T2	Biomass: CS	NE		NE		CS activity data and EF are applied (see data sources table)
		Litter: T2	Litter: CS					CS DOM (litter) stocks are utilized from NTCSA (DEA, 2014)
		Soil: T1	Soil: DF					Mineral soils only, Organic soils NE
	b. Land converted to forest land	Biomass: T2	Biomass: CS	NE		NE		CS activity data and EF are applied (see data sources table)
		Litter: T2	Litter: CS					CS DOM (litter) stocks are utilized from NTCSA (DEA, 2014)
		Soil: T1	Soil: DF					Mineral soils only, Organic soils NE
	2 Cropland							
	a. Cropland remaining cropland	Biomass: T1	Biomass: DF	NE		NE		CS activity data and EF are applied (see data sources table)
		Litter: T1	Litter: DF					CS DOM (litter) stocks are utilized from NTCSA (DEA, 2014)
		Soil: T1	Soil: DF					Mineral soils only, Organic soils NE
	b. Land converted to cropland	Biomass: T2	Biomass: CS	NE		NE		CS activity data and EF are applied (see data sources table)
		Litter: T2	Litter: CS					CS DOM (litter) stocks are utilized from NTCSA (DEA, 2014)
		Soil: T2	Soil: DF, CS					CS stock change factors were applied. Mineral soils only, Organic soils NE
	3 Grassland							

a. Grassland remaining grassland	Biomass: T1	Biomass: DF	NE		NE		CS activity data and EF are applied (see data sources table)
	Litter: T2	Litter: CS					CS DOM (litter) stocks are utilized from NTCSA (DEA, 2014)
	Soil: T1	Soil: DF					Mineral soils only, Organic soils NE
b. Land converted to grassland	Biomass: T2	Biomass: CS	NE		NE		CS activity data and EF are applied (see data sources table)
	Litter: T2	Litter: CS					CS DOM (litter) stocks are utilized from NTCSA (DEA, 2014)
	Soil: T1	Soil: DF					Mineral soils only, Organic soils NE
4 Wetland							
a. Wetland remaining wetland	NE		T1	DF	NE		
b. Land converted to wetland	NE		NE		NE		
5 Settlements							
a. Settlements remaining settlements	Biomass: T2	Biomass: CS	NE		NE		CS activity data and EF are applied (see data sources table)
	Litter: T2	Litter: CS					CS DOM(litter) stocks are utilized from NTCSA (DEA, 2014)
	Soil: T1	Soil: DF					Mineral soils only, Organic soils NE
b. Land converted to settlements	Biomass: T2	Biomass: CS	NE		NE		CS activity data and EF are applied (see data sources table)
	DOM: T2	DOM: CS					CS DOM (litter) stocks are utilized from NTCSA (DEA, 2014)
	Soil: T1	Soil: DF					Mineral soils only, Organic soils NE
6 Other land							
a. Other land remaining other land	Biomass: NE		NE		NE		
	Soil: T1	Soil: DF					

	b. Land converted to other land	Biomass: T2 Soil: T1	Biomass: CS Soil: DF	NE		NE		CS activity data and EF are applied (see data sources table) Mineral soils only, Organic soils NE
3C AGGREGATED SOURCES AND NON-CO_2 EMISSIONS ON LAND	***1 Biomass burning***	T2	DF, CS	T2	DF, CS	T2	DF, CS	CS Mb, Cf and EF for savannas and croplands were applied (DEA, 2009; DAFF, 2010)
	2 Liming	T1	DF	NA		NA		
	3 Urea application	T1	DF	NA		NA		
	4 Direct emissions from managed soils							
	Synthetic fertilizers	NA		NA		T1	DF	
	Animal waste added to soils	NA		NA		T1, T2	DF	CS manure management data was applied (Du Toit et al., 2013a - d; Moeletsi et al., 2015)
	Other organic fertilizers	NA		NA		T1	DF	Compost included; sewage sludge is included in Waste sector (IE)
	Urine and dung deposited by grazing livestock	NA		NA		T1, T2	DF	
	Crop residues	NA		NA		T1	DF	
	5 Indirect emissions from managed soils							
	Atmospheric deposition	NA		NA		T1	DF	
	Nitrogen leaching and runoff	NA		NA		T1	DF	
	6 Indirect emissions from manure management							
	Volatilization	NA		NA		T1	DF	
	Nitrogen leaching and runoff	NA		NA		T1	DF	
	7 Rice cultivation	NO		NO		NO		
3D OTHER	***1 Harvested wood products***	T2	DF	NA		NA		
	2 Other	NO		NA		NA		

Data sources

The main activity data for the calculation of emissions from the AFOLU sector are shown in Table 5.5.

Table 5.5: Data sources for AFOLU sector.

Category	Sub-category	Activity data	Data source
3A LIVESTOCK	**Enteric fermentation**	Population data	DAFF (2016)
			SA Poultry Association (SAPA) (2016)
			Du Toit et al. (2013)
		Herd composition	Du Toit et al. (2013a-c)
		Livestock activity data (weights, intake, DMD, etc)	Du Toit et al. (2013a-c)
			Moeletsi et al. (2015); Moeletsi & Tongwane (2015)
	Manure management	Manure management data	Du Toit et al. (2013a-c)
			Moeletsi et al. (2015); Moeletsi & Tongwane (2015)
		N excretion rates	IPCC 2006 Guidelines
			Du Toit et al. (2013b,c)
3B LAND	**General land data**	Land cover and change maps (1990 – 2013/14)	GTI (2015)
		Climate map	Moeletsi et al. (2015)
		Soil map	Moeletsi et al. (2015)
		Litter carbon stock data	National Terrestrial Carbon Sinks Assessment (DEA, 2014)
		Burnt area data	MODIS burnt area product – collection 5 and 6 (2019)
	Forest land	Plantation data	Forestry South Africa Industry facts (2016)
			Du Toit et al. (2016)
			Alembong (2015)
			Timber Statistics reports (DAFF, 2018)
		Natural forests and woodland carbon stock data	National Terrestrial Carbon Sinks Assessment (DEA, 2014)
		Natural forest wood removals	Statistics SA, 2017, P0318; General household survey 2017
	Cropland	Planted/harvested areas	DAFF Agricultural Abstracts (2018);
			DAFF – Crop estimates committee (2014)
			Statistics SA (2007)

			FAOStat (2018)
		Yield	DAFF Agricultural Abstracts (2018)
			Moeletsi et al. (2015)
			FAOStat (2018)
		Crop management data	Moeletsi et al. (2015)
			Tongwane et al. (2016)
		Perennial crop carbon stock data	Citrus Growers Association Statistics Book (2016)
			National Terrestrial Carbon Sinks Assessment (DEA, 2014)
	Grassland	Biomass carbon stock data and growth rates	National Terrestrial Carbon Sinks Assessment (DEA, 2014)
		Grassland management data	Fairbanks et al. (2000)
			Matsika (2007)
	Settlements	Management data	Fairbanks et al. (2000)
			GTI (2015)
	Other lands	Soil carbon stock data	IPCC (2006)
3C AGGREGATED AND NON-CO_2 EMISSIONS ON LAND	**Biomass burning**	Burnt area data	MODIS burnt area product – collection 5 and 6 (2019)
		Mass of fuel available, combustion factors	2000 NIR (DEA, 2009)
			Van Leeuwen et al. (2014)
			The South African Agricultural GHG inventory for 2004 (DAFF, 2010)
			Hely et al. (2003)
	Liming	Lime consumption	Fertilizer Association SA (2019); SAMI Reports (DMRE, 2018)
	Urea application	Urea import data	SARS (2018)
	Synthetic fertilizers	Total N fertilizer consumption	Fertilizer Association of SA (2019)
		N content of fertilizers	Grain SA Report
	Organic fertilizers	Compost estimates	The South African Agricultural GHG inventory for 2004 (DAFF, 2010)
	Crop residues	Crop area planted	DAFF Agricultural Abstracts (2018)
			Crop Estimates Committee
			Statistics SA (2007)
			FAOStat (2019)
		Crop yield data	Moeletsi et al. (2015)
			Tongwane et al. (2016)
			FAOStats (2019)
		C:N ratios	Moeletsi et al. (2015)
			Tongwane et al. (2016)

		Crop residue management	Tongwane et al. (2016)
			Moeletsi et al. (2015)
3D HARVESTED WOOD PRODUCTS	**Harvested wood products**	Production, import and export data for HWP	FAOStat (2019)

Uncertainty and time-series consistency

The time-series is complete between 2000 and 2017 for the AFOLU sector. Uncertainties are discussed under the various category sections below.

5.1.3 Recalculations and improvements since 2015 submission

The AFOLU sector is under continual improvement which leads to recalculations As in the previous 2015 inventory, significant changes have been made to this sector and these are provided in Table 5.6 along with their contribution to the overall change in the 2015 recalculated values. Further details of improvements are provided in the various category sections below.

The recalculations led to a 7.5% and a 16.7% increase in the 2015 estimates for *Livestock* and *Aggregated and non-CO_2 emissions on land*. The *Land* category showed a 29.5% increase in the sink in 2015, however in some years the estimates showed a decrease in the sink (Figure 5.2). Recalculations for *HWP* produced a 7.8% decrease in the sink estimate for 2015, but similar to the *Land* category, there were annual fluctuations. Overall the recalculations for the AFOLU sector excluding FOLU showed a 10.1% increase in emission estimates for 2015, while the AFOLU sector including FOLU decreased by 1.3%.

Table 5.6: AFOLU improvements and their contribution to the total change since the previous submission.

Sub-category	Improvement/ update	Change ($Gg\ CO_2e$)
Enteric fermentation	Adjusted herd composition for cattle; Removal of game emissions	1351.9
Manure management (CH_4)	Adjusted herd composition for cattle; Updated manure management data	70.4
Manure management (N_2O)	Adjusted herd composition for cattle; Updated manure management data; Country specific N excretion rates for poultry and swine	654.1
Forest land	Area adjustment for 20 year transition period; Updated biomass, litter and soil ref data; Updated wood removal data	1055.0
Cropland	Area adjustment for 20 year transition period; Updated biomass, litter and soil ref data; Improved disturbance data	-3028.4
Grassland	Area adjustment for 20 year transition period; Updated biomass, litter and soil ref data; Improved disturbance data	-14819.6
Wetland	Updated CH_4 emission factor	31.6
Settlements	Area adjustment for 20 year transition period; Updated biomass, litter and soil ref data; Improved disturbance data	-2860.3
Other lands	Area adjustment for 20 year transition period; Include Tier 1 assumption that soil carbon becomes zero after 20 years	13674.0
Biomass burning	Improved burnt area data; Updated fuel load and combustion factor data	-279.2
Liming	New lime consumption data source	323.1
Direct N_2O from managed soils	Adjusted herd composition data for cattle; Updated manure management data; Improved crop residue calculations; Excluded sewage sludge N input due to double counting	3507.3
Indirect N_2O from managed soils	Adjusted herd composition data for cattle; Updated manure management data; Improved crop residue calculations	161.8
Indirect N_2O from manure management	Adjusted herd composition for cattle; Updated manure management data; Country specific N excretion rates for poultry, swine, horses, mules and asses	-171.4
Harvested wood products	Updated import and export data from FAOStat	51.8
Total change (incl. FOLU)		**-277.7**

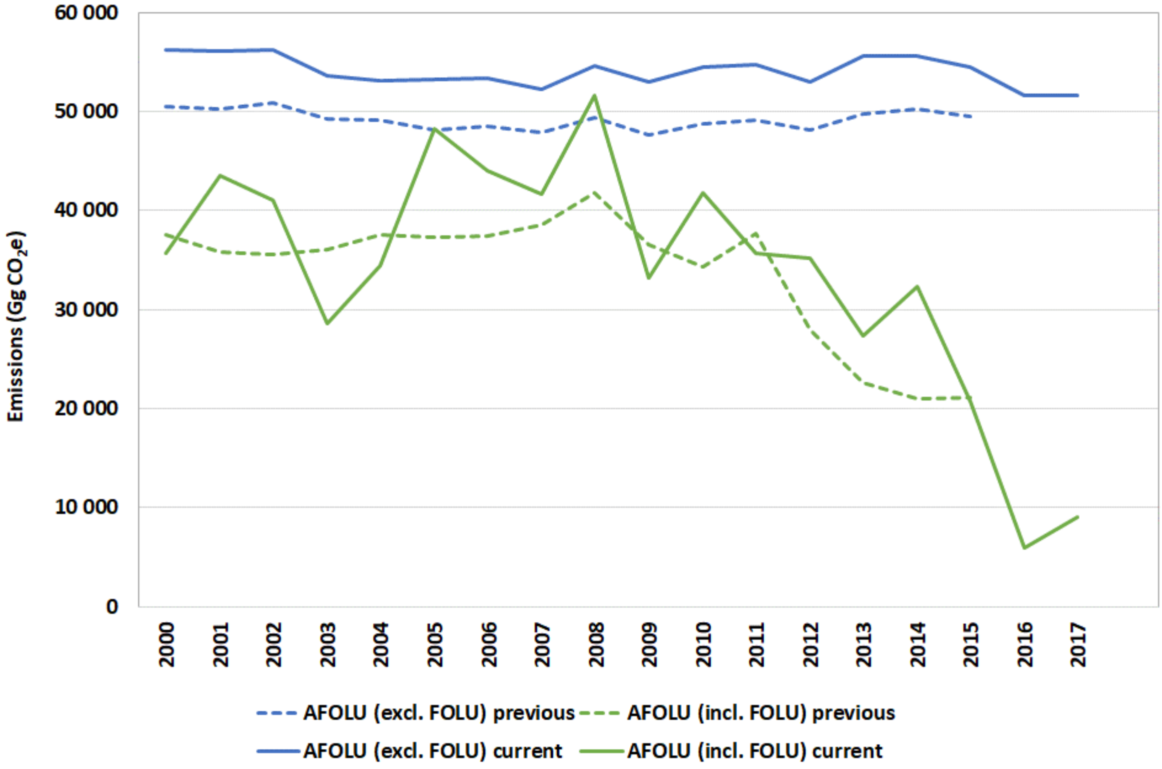

Figure 5.2: Change in AFOLU emission estimates due to recalculations since 2015 submission.

5.1.4 Key categories in the AFOLU sector

The key categories for the AFOLU sector are shown in Table 5.7 with the detailed key category results presented in Appendix 1.B.

Table 5.7: Key categories in the AFOLU sector in 2017.

IPCC Code	Category	GHG	Identification Criteria

3B1a	Forest land remaining forest land	CO_2	L, T
3B1b	Land converted to forest land	CO_2	L, T
3A1a	Enteric fermentation - cattle	CH_4	L, T
3C4	Direct N_2O from managed soil	N_2O	L, T
3B6b	Land converted to other land	CO_2	L, T
3B3b	Land converted to grassland	CO_2	L, T
3a1c	Enteric fermentation - sheep	CH_4	L, T
3C5	Indirect N_2O from managed soils	N_2O	L, T
3C2	Liming	CO_2	T
3C1c	Biomass burning in grasslands	N_2O	T
3D1	Harvested wood products	CO_2	T
3B2a	Grassland remaining grassland	CO_2	T

5.2 Source Category 3.A.1 Enteric Fermentation

5.2.1 Category information

Methane is produced in herbivores as a by-product of enteric fermentation, a digestive process by which plant material consumed by an animal is broken down by bacteria in the gut under anaerobic conditions. A portion of the plant material is fermented in the rumen to simple fatty acids, CO_2 and CH_4. The fatty acids are absorbed into the bloodstream, and the gases vented by eructation and exhalation by the animal. Unfermented feed and microbial cells pass to the intestines.

South Africa identified, through tier 1 level and trend assessments, enteric fermentation as a key source category. In accordance with IPCC good practice requirements tier 2 methods are therefore used, to estimate enteric fermentation emissions from the major livestock sub-categories.

Emissions

2000 - 2017

Enteric fermentation emissions declined very slowly from 2000 to 2007 after which emissions showed a slight increase to 2013. This trend follows the same pattern as the livestock population data. Emissions stabilised between 2013 and 2014 (Figure 5.3), after which emissions declined to 2017 (Table 5.8). The main reason for the declining livestock numbers in recent years is the consecutive droughts that occurred in 2015 and 2016 (BFAP, 2018) and livestock owners are struggling to rebuild their herds to pre-2014 levels. In addition there have been stock losses due to disease.

The other cattle[6] population has declined by 4.6% since 2000, leading to a decline in other cattle emissions. In comparison to other cattle, the total number of dairy cattle[7] (less than 10% of the cattle population) declined slightly between 2000 and 2009, but returned to similar levels by 2017. Dairy cattle contribution to the overall *Enteric fermentation* emissions therefore increased by 1.7% between 2000 and 2017. Poultry numbers have also increased, mainly due to chicken being a cheaper meat and in higher demand. Poultry do not use enteric fermentation to break down food, therefore do not contribute to the *Enteric fermentation* emissions.

In 2017 the *Enteric fermentation* category contributed 25 709 Gg CO_2e (Table 5.9). Other cattle and sheep were the largest contributors to the *Enteric fermentation* category (Table 5.9). Emissions from horses and dairy cattle increased between 2000 and 2017, while emissions from all other livestock declined during this time.

[6] All cattle except dairy cows and lactating heifers.
[7] Only dairy cows and lactating heifers.

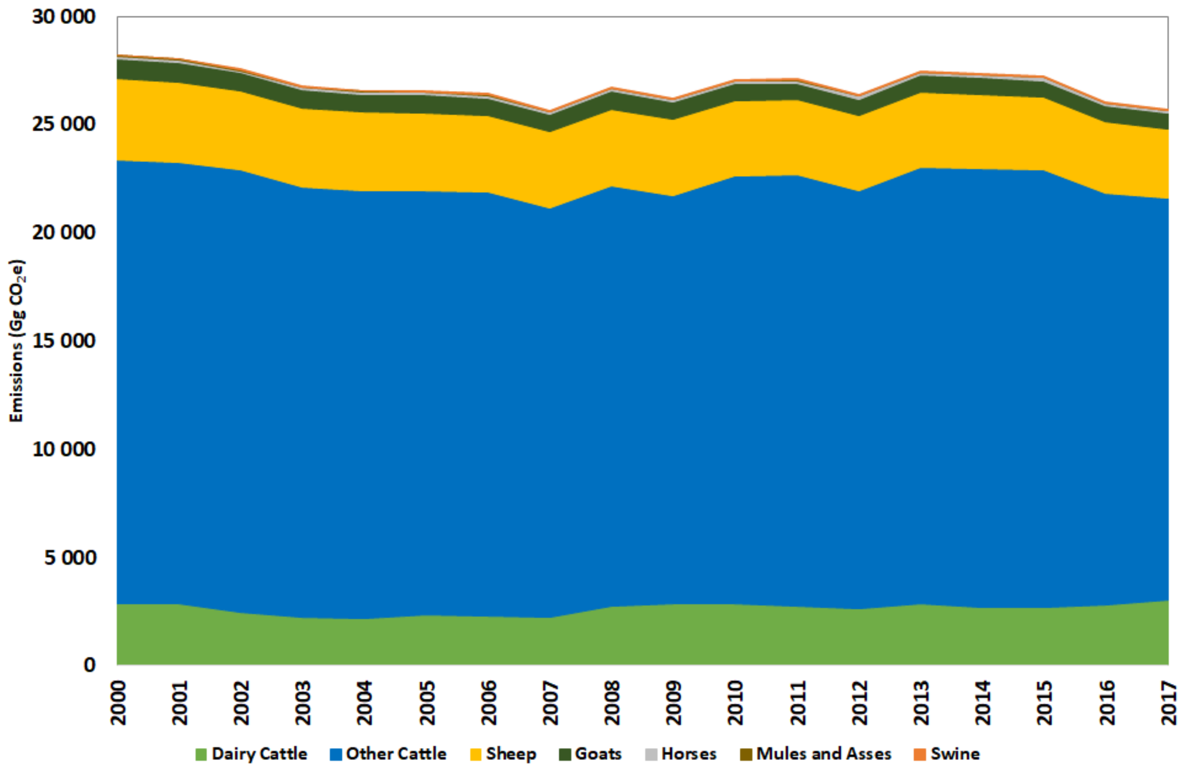

Figure 5.3: *Enteric fermentation* emission trends, 2000 – 2017.

Table 5.8: *Enteric fermentation* emission trends between 2000 and 2017.

	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017
	Gg CO_2e									
Dairy cattle[7]	2 848.6	2 327.7	2 837.4	2 734.2	2 633.1	2 839.5	2 683.6	2 715.9	2 817.0	3 030.4
Other cattle	20 496.1	19 641.2	19 794.5	19 961.9	19 319.3	20 195.5	20 290.3	20 177.0	19 013.6	18 559.3
Buffalo	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Sheep	3 800.5	3 581.8	3 465.1	3 438.1	3 453.4	3 480.3	3 417.9	3 390.6	3 294.6	3 214.6
Goats	906.2	822.0	789.6	782.3	780.4	771.6	764.6	754.2	731.5	709.2
Camels	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Horses	102.1	102.1	113.4	115.3	116.4	117.2	117.9	119.0	121.3	122.0
Mules & asses	34.4	34.4	34.9	35.1	35.1	35.8	35.9	35.5	34.0	34.2
Swine	43.5	43.6	42.1	41.9	41.7	41.6	41.3	40.3	40.0	39.1
Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Total	28 231.5	26 552.9	27 077.1	27 108.8	26 379.4	27 481.4	27 351.6	27 232.5	26 052.0	25 708.9

Note: Numbers may not add exactly due to rounding off.

Table 5.9: Change in *Enteric fermentation* emissions (2000 – 2017) and relative contribution of the various livestock categories to the total emissions.

	Emissions ($Gg\ CO_2e$)		Change (2000-2017)		Share of enteric fermentation (%)	
	2000	2017	Diff	%	2000	2017
Dairy cattle Error! ookmark not defined.4	2 848.6	3 030.4	181.8	6	10.09	11.79
Other cattle	20 496.1	18 559.3	-1 936.8	-9	72.60	72.19
Buffalo	IE	IE				
Sheep	3 800.5	3 214.6	-585.9	-15	13.46	12.50
Goats	906.2	709.2	-197.0	-22	3.21	2.76
Camels	NO	NO				
Horses	102.1	122.0	19.9	20	0.36	0.47
Mules & asses	34.4	34.2	-0.2	-1	0.12	0.13
Swine	43.5	39.1	-4.4	-10	0.15	0.15
Other	NO	NO				
Total	**28 231.5**	**25 708.9**	**-2 522.6**	**-9**	**100**	**100**

Note: Numbers may not add exactly due to rounding off.

5.2.2 Methodology

For *Enteric fermentation* the equation 10.20 from the IPCC 2006 guidelines (IPCC, 2006, vol 4, chapter 10, pg 10.28) was applied. For horses, mules and asses a tier 1 approach with IPCC 2006 default emission factors was applied. For cattle, sheep, goats and swine emission factors were taken from Du Toit et al. (2013a-c) where a tier 2 approach was used. Moeletsi et al. (2015) also reported livestock emission factors (see comparison in section 5.3.4) and in some cases these differed from those of Du Toit et al. (2013). The emission factors of Du Toit et al. (2013) were selected for use in the inventory as:

(a) the calculations incorporated more country specific data,

(b) there were more detailed categories and herd compositions,

(c) methodologies were clearly described and

(d) all the background supporting data was supplied.

Some of the Moeletsi et al (2015) information could not be followed through to the source making it difficult to determine the reason for the discrepancies. This inventory, however, does highlight that there are differences in the data and this should be discussed with both the data providers to determine the reason for the differences and therefore the most appropriate emission factor to apply in future.

The methods, as described below (and in Du Toit et al., 2013a-c), are based on the Australian National Inventory Report (ANIR, 2016) methods because these methods allow the heterogeneity (spatial and seasonal) of available feed types within South Africa to be incorporated. Furthermore, the methodology was developed in Australia which has similar conditions to South Africa. The methodology incorporates detail on animal productivity, diet quality and management circumstances in South Africa into feed intake estimates which are then used to determine methane production.

Emissions from *Enteric fermentation* are calculated from activity data on animal numbers and the appropriate emission factor (IPCC 2006, V4, Ch10, Equation 10.19 and 10.20).

South Africa does not have any managed camels or llamas 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). In the previous inventory estimates of emissions from game in private parks was included, however in this inventory game (including buffalo) have been excluded due to a discussion with experts during the in-country UNFCCC review. It was discussed that the game and buffalo in South Africa are not considered to be farmed or managed, and therefore should be excluded from the overall emissions.

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 2006 Guidelines as there is insufficient data to determine a default value. This exclusion of poultry from *Enteric fermentation* emissions is in line with the IPCC 2006 Guidelines, as well as the upcoming IPCC 2006 Guideline update.

Cattle (3A1a)

Dairy Cattle (3A1ai and 3A1aii)

Dairy cattle are split between the Dairy cattle (3A1ai) and Other cattle (3A1aii) sub-categories. According to IPCC 2006 (Chapter 10, page 10.10) the Dairy cattle category does not include cows kept principally to produce calves for meat or to provide draft power. It indicates that low producing cows and heifers should be considered Other cattle. Therefore, even though the methodology for all dairy cattle is discussed in this section, it is important to note that only cows (lactating and dry) and lactating heifers are included under Dairy cattle, while the emissions from the rest are included under Other cattle (non-lactating producing dairy cattle).

Population data

The total number of dairy cattle was sourced from the Abstracts of Agricultural Statistics (DAFF, 2018), and herd composition provided in Du Toit et al. (2013a) were applied. It was noted that the statistics data showed a different cow and heifer composition to what was suggested in Du Toit et al. (2013a), however until there is further investigation and documentation on this difference the data from the Agricultural Abstracts is applied. There are two major dairy production systems in South Africa, namely a total mixed ration (TMR)-based system and a pasture-based system. The total dairy cattle were therefore divided into these two categories using the ratio from Du Toit et al. (2013a). The herd composition and emission factors for both was determined in the same manner. Figure 5.4 shows how the total population data was split into the more detailed categories based on sex and age. Population and herd composition data for 2010 to 2017 are shown in Table 5.10.

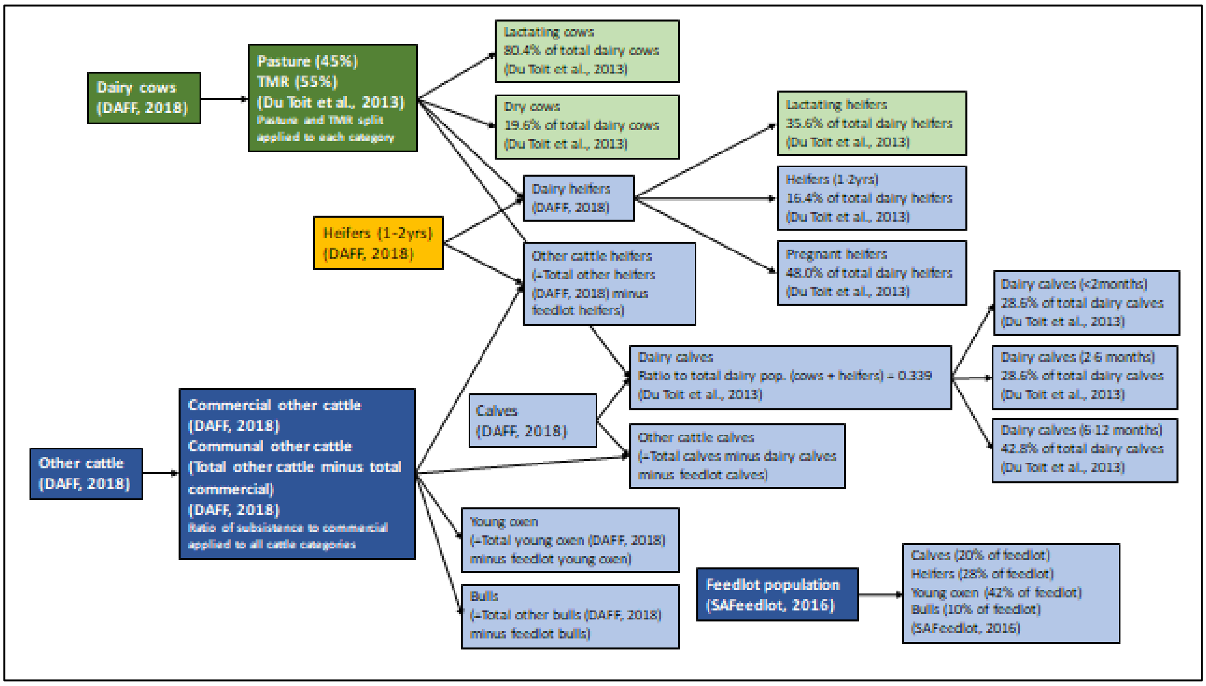

Figure 5.4: Diagram illustrating how the cattle population data was split into the more detailed sex and age classes. Green blocks reflect what is included under Dairy cattle, while blue shows the Other cattle category.

Emission factors

Emission factors applied in this inventory (Table 5.10) were taken from Du Toit et al. (2013a) and the methodology is described below.

Emissions from dairy cattle are based on commercial production systems. Data on average daily milk production (10.5 kg/day) were sourced from the commercial dairy industry and calculated from the number of dairy producers and the number of cows per producer (LACTO data, 2010). The live weights of all classes of animals was calculated according to a 60% Holstein and 40% Jersey ratio reported by Banga (2009). This ratio was utilized to calculate the live weight of animals used in the emission calculations.

Live weights of animals per age group were determined by using a prediction equation according to the Von Bertalanffy growth function given by Bakker & Koops (1978):

$$LW = M \times [1-\{1-(W0/M)^{1/3}\}e^{-kt}]^3$$

Where:

LW = live weight (kg)
M = mature weight (kg)

W_0 = birth weight (kg)
k = growth rate parameter
t = age (months).

Variables used in the above equation were sourced from Banga (2009) and dairy breed societies in South Africa. The animal weight, weight gain, diet characteristics and management data used in the algorithms to calculate emissions are provided in Du Toit et al. (2013a).

Daily methane production was calculated from dry matter intake (I) and this was calculated for each cattle class according to Minson & McDonald (1987):

$$I = (1.185 + 0.00454W - 0.0000026W^2 + 0.315LWG)^2 \times MR + MI$$

Where:

I = intake (kg DM/head/day)
W = weight in kg (Du Toit et al., 2013a)
LWG = live weight gain in kg/day (Du Toit et al., 2013a)
MR = metabolic rate when producing milk - 1.1 for cows in milk and 1 for all other classes (SCA, 1990).

Additional intake for milk production from lactating animals (MI) was included as:

$$MI = MP \times NE / k_l / q_m / 18.4$$

Where:

MP = milk production (kg/head/day) (LACTO data, 2010)
NE = 3.054 MJ NE/kg milk (SCA, 1990)
k_l = 0.60 efficiency of use of ME for milk production (SCA, 1990)
q_m = metabolizability of the diet (i.e. ME/GE). Calculated using the equation of Minson & McDonald (1987)
q_m = 0.00795 DMD – 0.0014 (where DMD is expressed as a %) (Du Toit et al., 2013a).
18.4 = gross energy content of DM (MJ/kg) (SCA, 1990)

Gross energy intake (GEI) of all dairy cattle classes was calculated as the sum of intake (I) multiplied by 18.4 MJ/kg DM. Intake of animals relative to that needed for maintenance (L) was calculated as:

$$L = I / (1.185 + 0.00454W - 0.0000026W^2 + (0.315 \times 0))^2$$

Blaxter & Clapperton's (1965) equation was used to calculate the percentage of GEI that is yielded as methane (Y):

$$Y = 1.3 + 0.112DMD + L(2.37 - 0.050DMD)$$

Where:

DMD = dry matter digestibility (%) (Du Toit et al., 2013a)
L = intake relative to that needed for maintenance.

The total daily production of methane (M), (kg CH_4/ head/ day) was calculated as:

$$M = Y / 100 \times GEI / F$$

Where:

M = total daily production of methane (kg CH_4/head/day)
F = 55.22 MJ/kg CH_4 (Brouwer, 1965)
GEI = Gross energy intake (MJ/day)

Table 5.10: Dairy cattle population data for 2010 to 2017 and enteric fermentation emission factors.

Livestock category			Population								Enteric fermentation EF
			2010	2011	2012	2013	2014	2015	2016	2017	(kg CH_4/head)
Pasture	*3Aai Dairy cattle*	*Lactating cows*	362 133	351 269	336 784	358 512	344 027	351 269	365 755	391 104	127.0
		Dry cows	88 281	85 633	82 102	87 398	83 867	85 633	89 164	95 344	83.4
		Lactating heifers	54 518	49 708	49 708	59 329	49 708	46 501	46 501	52 915	116.0
	3Aaii Other cattle	*Calves <6months*	58 517	55 897	54 150	59 391	55 024	55 024	56 770	61 574	20.0
		Heifers 2-6 months	58 517	55 897	54 150	59 391	55 024	55 024	56 770	61 574	24.5
		Heifers 6-12 months	87 776	83 845	81 225	89 086	82 535	82 535	85 155	92 361	37.1
		Heifers >1year	25 115	22 899	22 899	27 331	22 899	21 422	21 422	24 376	52.6
		Pregnant heifers	73 508	67 022	67 022	79 994	67 022	62 698	62 698	71 346	61.8
TMR	*3Aai Dairy cattle*	*Lactating cows*	441 867	428 611	410 936	437 448	419 773	428 611	446 285	477 216	132.0
		Dry cows	107 719	104 487	100 178	106 642	102 333	104 487	108 796	116 336	80.4
		Lactating heifers	66 522	60 652	60 652	72 391	60 652	56 739	56 739	64 565	127.0
	3Aaii Other cattle	*Calves <6months*	71 401	68 204	66 073	72 467	67 138	67 138	69 270	75 131	21.5
		Heifers 2-6 months	71 401	68 204	66 073	72 467	67 138	67 138	69 270	75 131	62.6
		Heifers 6-12 months	107 102	102 306	99 109	108 700	100 708	100 708	103 905	112 697	42.1
		Heifers >1year	30 645	27 941	27 941	33 349	27 941	26 138	26 138	29 744	22.5
		Pregnant heifers	89 692	81 778	81 778	97 606	81 778	76 502	76 502	87 054	67.7

Other Cattle (3A1aii)

Population data

The total number of commercial other cattle and the herd composition were taken from Table 59 in Abstracts of Agricultural Statistics (DAFF, 2018). To determine the communal population, the total number of cattle was obtained from Table 58 of Abstracts of Agricultural Statistics (DAFF, 2018) and the total cattle number from Table 59 was subtracted. In Table 58 the numbers are indicated to be from July one year to June the next year (e.g. 2000/01) while in Table 59 it shows just one year (e.g. 2001). However, both tables indicate the numbers are as they were on the 31st August each year, therefore the numbers were considered to be for the same periods. In the inventory the 2000/01 data in Table 58, for example, was considered to be the 2001 data, to match with the 2001 data in Table 59. This data corresponded well with the figures reported in the FAO database.

DAFF indicated that feedlot numbers were included however there was not a separate category for feedlot cattle. To include a feedlot category, the feedlot population numbers were obtained from SA Feedlot Association. SA Feedlot indicated that the feedlot population is around 10% young bulls, 28% heifers and the rest steers or young oxen (8-14 months). Therefore, the number for each category was calculated and subtracted from the associated DAFF numbers and allocated to the feedlot category. In this inventory this feedlot herd ratio required adjustment as subtracting the young oxen from the numbers provided by DAFF (2017) led to negative numbers. The feedlot young oxen were indicated to be 8-14 months, so many of them could be considered calves since calves are <1 year. It was therefore assumed that 10% were young bulls, 28% heifers, 20% calves and the remainder steers (young oxen). These population numbers need to be investigated further in the next inventory.

Communal populations were assumed to have the same herd composition as commercial cattle without feedlot cattle. Figure 5.4 illustrates how the other cattle and feedlot cattle populations were determined for each of the various age and sex classes. Table 5.11 provides the other cattle population and herd composition data for 2010 to 2017.

Emission factors: Other Cattle on Pasture

The enteric fermentation emission factors for other cattle categories (Table 5.11) were taken from Du Toit et al. (2013a) and the methodology is described below.

South African beef cattle production systems are mainly extensive and based on rangelands or pastures. In Du Toit et al. (2013a) the veld types were divided into sweetveld, sourveld and mixed veld and the percentage of each veld type in each province was estimated according to a map produced by Tainton (1999). The seasonal variation in veld quality and digestibly was sourced from the literature (Dugmore & Du Toit, 1988; De Waal, 1990; O'Reagain & Owen-Smith, 1996).

The commercial beef herd is composed of approximately 70% medium frame cattle, 15% large frame and 15% small frame (Du toit et al., 2013a). Live weights for each frame type were calculated from weight data published by Meissner *et al*. (1983). The average live weight per beef cattle age group or class was estimated according to the ratio of medium, large and small frame breed types. Communal cattle live weights were calculated from the commercial cattle weights with a 20% reduction[8], since communal cattle are more Sanga and Zebu types, fed on lower-quality diets and with lower intakes. Live weight, live weight gain, feed characteristics and management data used in the algorithms are presented in Du Toit et al. (2013a).

Dry matter intake for each beef cattle class was calculated using the same equation as for dairy cattle. It was assumed that the intake of all breeding cows increased by 30% during the season in which calving occurs and by 10% in the following season (SCA, 1990) as energy requirement for milk production declines during the second half of lactation.

Additional intake for milk production (MA) was calculated as:

$$MA = (LC \times FA) + ((1 - LC) \times 1)$$

Where:

MA = milk production
LC = proportion of cows > 2 years lactating
FA = feed adjustment (1.3 during the season of calving and 1.1 during the following season).

Calving percentage of 62% for commercial cattle and 35% for communal cattle (Scholtz *et al.*, 2012) were used to calculate MA. A single calving season was used for commercial cattle and it was assumed that communal cattle would calve throughout the year. As feed

[8] Moeletsi & Tongwane. (2015) provides subsistence cattle typical animal masses which are in a similar range to what is provided by Du Toit et al. (2013). In this inventory the Du Toit et al. (2013a) estimates were applied in order to be consistent with the calculation of the emission factors. In the next inventory, when data for T2 calculations of emission factors are incorporated into the inventory calculation files then the Moeletsi et al. (2015) animal masses and emission factors will be considered.

dry matter has a gross energy concentration of 18.4 MJ/ kg (SCA, 1990), the DMI was converted to GEI (MJ/ day) by:

$$GEI = I \times 18.4$$

The intake of cattle relative to that needed for maintenance (L) was calculated using Eq.3.4 and the percentage of GEI that is yielded as methane (Y) was calculated according to Eq.3.5. The total daily methane production (M) was calculated using the equation of Kurihara *et al*. (1999) which was developed for animals grazing in tropical pastures:

$$M = (34.9 \times I - 30.8)/1000$$

Where:

M = methane emissions (kg/CH_4/head/ day)
I = intake (kg DM/head/day).

Emission factor: Beef Cattle on Feedlots

The feedlot enteric fermentation emission factor (Table 5.11) was taken from Du Toit et al. (2013a) and the methodology is detailed below.

The feedlot enteric methane emission (Y), (MJ CH_4/head/day) calculations are based on intake of specific diet components using an equation developed by Moe & Tyrrell (1979):

$$Y = 3.406 + 0.510SR + 1.736H + 2.648C$$

Where:
SR = intake of soluble residue (kg/day)
H = intake of hemicellulose (kg/day)
C = intake of cellulose (kg/day).

Soluble residue intake, hemicellulose intake and cellulose intake were calculated from feedlot diet analysis (ANIR, 2010) and average DM intake taken as 8.5 kg DM/day (SAFA, 2012 and industry experts) (Du Toit et al., 2013a). Total daily methane production (M), (kg CH_4/head/day) was calculated as:

$$M = Y / F$$

Where:
F = 55.22 MJ/ kg CH_4 (Brouwer, 1965).

Table 5.11: Beef cattle population data for 2010 to 2017 and enteric fermentation emission factors.

Livestock category		Population								Enteric fermentation EF
		2010	2011	2012	2013	2014	2015	2016	2017	(kg CH_4/head)
Commercial cattle	***Bulls***	160 018	163 820	111 573	139 735	127 898	136 060	153 186	130 842	113
	Calves	1 455 776	1 563 720	2 132 785	1 108 430	1 188 655	1 024 980	1 855 673	1 713 693	51.6
	Cows	2 980 000	2 800 000	2 420 000	2 720 000	2 660 000	2 730 000	2 720 000	2 600 000	92.6
	Feedlot	399 822	461 800	484 274	502 649	521 025	539 400	568 136	591 585	58.9
	Heifers	798 050	820 696	1 584 403	679 258	704 113	678 968	700 922	494 356	75.9
	Oxen	170 000	450 000	240 000	570 000	780 000	750 000	110 000	260 000	89.4
	Young oxen	462 075	206 044	616 605	678 887	571 170	573 452	71 383	21 534	51.6
Subsistence cattle	***Bulls***	181 105	185 530	92 488	166 839	146 730	157 912	185 096	168 175	83.8
	Calves	1 647 614	1 770 953	1 767 974	1 323 429	1 363 680	1 189 601	2 242 220	2 202 671	40.9
	Cows	3 372 698	3 171 071	2 006 061	3 247 590	3 051 675	3 168 461	3 286 591	3 341 874	73.1
	Heifers	903 215	929 459	1 313 393	811 012	807 791	788 016	846 928	635 414	62.5
	Oxen	192 402	509 636	198 948	680 561	894 852	870 456	132 914	334 187	72.6
	Young oxen	522 966	233 350	511 135	810 569	655 272	665 553	86 252	27 679	41.6

Sheep (3A1c)

Population data

The total number of commercial sheep were sourced from Table 63 in Abstracts of Agricultural Statistics (DAFF, 2018). The flock composition provided by Du Toit et al. (2013b), which were based on an average South African flock structure (NWGA, 2011), was applied to the data. It was assumed that the commercial and emerging/communal sectors would have similar flock structures. The flock structure consisted of older breeding rams (1%), breeding ewes (45%), young breeding rams (2%), young ewes (12%), weaned lambs (16%) and lambs (23%). The total communal population numbers for sheep was obtained by using the ratio of communal to commercial population from the quarterly census numbers which have been recorded by DAFF from 1996 onwards. The ratio for sheep was 0.14. It was assumed this ratio remained constant over the years as there is insufficient data to show otherwise. The communal population was assumed to have the same flock structure as the commercial sheep and the composition remained constant over the time series due to a lack of data. Population data is provided in Table 5.12.

Emission factors

The enteric fermentation emission factors applied in this inventory (Table 5.12) were taken from Du Toit et al. (2013b) and the methodology is described below.

The South African sheep industry consists of a well-defined commercial sector and an emerging and communal sector (subsistence farmers). The emerging and communal small stock sectors were grouped under communal production systems.

Sheep live weight per age group and breed type are reported in Du Toit et al. (2013b). Communal animals are smaller, within a similar breed type, than commercial animals and a 20% weight reduction was assumed for emerging/communal animals compared with commercial animals across all age groups and breed types.

The South African small stock industry is based predominantly on extensive grazing systems. The natural rangeland in South Africa was divided into sweetveld, sourveld and mixed veld (as done for cattle) as the quality of veld will vary according to veld type and season of use. The intake and methane production of animals will vary as the quality of veld changes through the seasons. The digestibility of veld between and within veld types and between seasons was sourced from literature (Dugmore & Du Toit, 1988; De Waal, 1990; O'Reagain & Owen-Smith, 1996) and is reported in Du Toit et al. (2013b).

Sheep are selective grazers and browsers and will select for a higher quality diet. Commercial production systems employ supplemental feeding strategies that will improve the overall quality and utilization of the diet on offer. A 5% increase in the dry matter digestibility (DMD) was assumed for commercial small stock production systems to account for selective grazing and supplementation practices in the methane emissions calculations.

Sheep methane emissions estimates are based on Howden & Reyenga (1987), who reported a close relationship between dry matter intake (DMI) and methane production. The potential intake of sheep is dependent on body size and the metabolizability (ME/GE) of the diets received by the animals (ANIR, 2009). The potential intake of sheep (PI), (kg DM/head/day) is given by AFRC (1990) as:

$$PI = (104.7q_m + 0.307W - 15.0)\, W_{0.75}/1000$$

Where:

W = live weight (kg) (Du Toit et al., 2013b)
q_m = metabolizability of the diet (ME/GE) = 0.00795 DMD – 0.0014 (Minson & McDonald, 1987). Dry matter digestibility is expressed as a percentage.

Feed intake increases during lactation (ARC, 1980). It was assumed that 80% of commercial ewes and 50% of emerging/communal ewes will lamb during the year. Commercial production systems will employ two breeding seasons with 80% of the national flock lambing in autumn and 20% lambing in spring (Du Toit et al., 2013b). It was assumed that communal production systems would lamb throughout the year. The intake of lactating animals was increased by 30% during the season in which lambing occurs (ANIR, 2009). Based on relationships presented by the SCA (1990) the additional intake for milk production (MA) was calculated as:

$$MA = (LE \times FA) + ((1 - LE) \times 1)$$

Where:

LE = portion of breeding ewes lactating, calculated as the annual lambing rates x proportion of lambs receiving milk in each season (Du Toit et al., 2013b);
FA = feed adjustment (assumed to be 1.3).

The daily methane production (M), (kg/head/day) was then calculated using potential intake in the following equation published by Howden & Reyenga (1987):

$$M = PI \times 0.0188 + 0.00158$$

Where:

PI = intake (kg DM/head/day).

Table 5.12: Sheep population data for 2010 to 2017 and enteric fermentation emission factors.

Livestock category		Population								Enteric fermentation EF
		2010	2011	2012	2013	2014	2015	2016	2017	(kg CH_4/head)
Commercial sheep	*Karakul breeding ewes*	11 250	10 800	11 250	10 800	10 800	10 800	10 350	10 350	7.28
	Karakul breeding rams	250	240	250	240	240	240	230	230	10.5
	Karakul lambs	6 000	5 760	6 000	5 760	5 760	5 760	5 520	5 520	3.62
	Karakul weaners	4 000	3 840	4 000	3 840	3 840	3 840	3 680	3 680	5.02
	Karakul young ewes	3 000	2 880	3 000	2 880	2 880	2 880	2 760	2 760	5.94
	Karakul young rams	500	480	500	480	480	480	460	460	7.64
	Merino breeding ewes	5 062 950	5 023 350	5 065 200	5 098 050	5 006 250	4 966 650	4 824 900	4 709 700	8.07
	Merino breeding rams	112 510	111 630	112 560	113 290	111 250	110 370	107 220	104 660	14.7
	Merino lambs	2 700 240	2 679 120	2 701 440	2 718 960	2 670 000	2 648 880	2 573 280	2 511 840	3.62
	Merino weaners	1 800 160	1 786 080	1 800 960	1 812 640	1 780 000	1 765 920	1 715 520	1 674 560	5.54
	Merino young ewes	1 350 120	1 339 560	1 350 720	1 359 480	1 335 000	1 324 440	1 286 640	1 255 920	6.21
	Merino young rams	225 020	223 260	225 120	226 580	222 500	220 740	214 440	209 320	11.5
	Non-wool breeding ewes	2 725 650	2 704 500	2 716 200	2 722 050	2 673 450	2 651 850	2 582 550	2 518 200	9.66
	Non-wool breeding rams	60 570	60 100	60 360	60 490	59 410	58 930	57 390	55 960	14.7
	Non-wool lambs	1 453 680	1 442 400	1 448 640	1 451 760	1 425 840	1 414 320	1 377 360	1 343 040	3.62
	Non-wool weaners	969 120	961 600	965 760	967 840	950 560	942 880	918 240	895 360	5.54
	Non-wool young ewes	726 840	721 200	724 320	725 880	712 920	707 160	688 680	671 520	6.88
	Non-wool young rams	121 140	120 200	120 720	120 980	118 820	117 860	114 780	111 920	9.88
	Other wool breeding ewes	1 872 000	1 857 600	1 849 500	1 884 150	1 850 400	1 835 550	1 779 300	1 735 650	10.4
	Other wool breeding rams	41 600	41 280	41 100	41 870	41 120	40 790	39 540	38 570	22.2

Livestock category		Population 2010	2011	2012	2013	2014	2015	2016	2017	Enteric fermentation EF (kg CH_4/head)
	Other wool lambs	998 400	990 720	986 400	1 004 880	986 880	978 960	948 960	925 680	3.62
	Other wool weaners	665 600	660 480	657 600	669 920	657 920	652 640	632 640	617 120	4.77
	Other wool young ewes	499 200	495 360	493 200	502 440	493 440	489 480	474 480	462 840	8.01
	Other wool young rams	83 200	82 560	82 200	83 740	82 240	81 580	79 080	77 140	14.8
Subsistence sheep	***Karakul breeding ewes***	1 570	1 507	1 570	1 507	1 507	1 507	1 444	1 444	5.27
	Karakul breeding rams	35	33	35	33	33	33	32	32	7.62
	Karakul lambs	837	804	837	804	804	804	770	770	2.76
	Karakul weaners	558	536	558	536	536	536	514	514	3.76
	Karakul young ewes	419	402	419	402	402	402	385	385	4.4
	Karakul young rams	70	67	70	67	67	67	64	64	5.6
	Merino breeding ewes	706 584	701 058	706 898	711 483	698 671	693 145	673 362	657 285	5.79
	Merino breeding rams	15 702	15 579	15 709	15 811	15 526	15 403	14 964	14 606	10.5
	Merino lambs	376 845	373 897	377 012	379 457	372 625	369 677	359 126	350 552	2.76
	Merino weaners	251 230	249 265	251 342	252 972	248 416	246 451	239 418	233 701	4.12
	Merino young ewes	188 422	186 949	188 506	189 729	186 312	184 839	179 563	175 276	4.59
	Merino young rams	31 404	31 158	31 418	31 621	31 052	30 806	29 927	29 213	8.25
	Non-wool breeding ewes	380 391	377 439	379 072	379 889	373 106	370 092	360 420	351 439	6.83
	Non-wool breeding rams	8 453	8 388	8 424	8 442	8 291	8 224	8 009	7 810	10.5
	Non-wool lambs	202 875	201 301	202 172	202 607	198 990	197 382	192 224	187 434	2.76
	Non-wool weaners	135 250	134 201	134 781	135 072	132 660	131 588	128 149	124 956	4.12
	Non-wool young ewes	101 438	100 651	101 086	101 304	99 495	98 691	96 112	93 717	5.07

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Livestock category		Population								Enteric fermentation EF
		2010	2011	2012	2013	2014	2015	2016	2017	(kg CH_4/head)
	Non-wool young rams	16 906	16 775	16 848	16 884	16 582	16 449	16 019	15 620	6.94
	Other wool breeding ewes	261 256	259 246	258 116	262 952	258 241	256 169	248 319	242 227	7.4
	Other wool breeding rams	5 806	5 761	5 736	5 843	5 739	5 693	5 518	5 383	15
	Other wool lambs	139 336	138 265	137 662	140 241	137 729	136 623	132 437	129 188	2.76
	Other wool weaners	92 891	92 176	91 775	93 494	91 819	91 082	88 291	86 125	3.55
	Other wool young ewes	69 668	69 132	68 831	70 120	68 864	68 312	66 218	64 594	5.8
	Other wool young rams	11 611	11 522	11 472	11 687	11 477	11 385	11 036	10 766	10.5

Goats (3A1d)

Population data

Total number of commercial goats were taken from Table 63 in Abstracts of Agricultural Statistics (DAFF, 2018). The goat industry consists of a meat goat sector (commercial and communal), a milk goat sector and an Angora goat sector. Flock structures were assumed to be similar to the sheep flock structures and were verified by industry as reported in Du Toit et al. (2013). The flock composition data was taken from Du Toit et al. (2013b). It was assumed that the commercial and emerging/communal sectors would have similar flock structures. The total communal population numbers for goats 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 ratio for goats was 1.975. It was assumed this ratio remained constant over the years as there is insufficient data to show otherwise. The communal population (Table 5.13) was assumed to have the same flock structure as the commercial goats and the composition remained constant over the time series due to a lack of data.

Emission factors

Emission factors for goats (Table 5.13) were taken from Du Toit et al. (2013b) and were determined using the same calculations as for sheep. Live weight of commercial goats was taken from Du Toit et al. (2013b) which sourced the data from industry and experts. The emerging/communal sector goats are assumed to be smaller and less productive than meat goats in the commercial sector and their live weights were based on commercial goat weights less 20%. It was assumed that Milk and Angora goats are only farmed commercially. Goats that are milked in the communal sector are mainly dual purpose and have a comparative low milk yield compared with commercial dairy goats. These goats were therefore incorporated into the emerging/communal meat goat class for the purpose of this inventory.

Dietary quality parameters used in the goat emission calculations were assumed to be similar to sheep diet quality for commercial and communal goat production systems across all seasons. Meat goat emission calculations were split into commercial and communal goats based on the population data and it was assumed that lactating milk goats would receive a higher quality diet with a DMD of 70% throughout the year. Two kidding seasons, autumn and spring, were assumed for commercial meat goats with 80% of does kidding during the year. Communal meat goats are bred throughout the year with

50% of does kidding during the year. Milk and Angora goat producers employ only a single autumn breeding season with 95% and 70% of does kidding, respectively (Muller, 2005). The lactation feed adjustment was taken as 1.3 during the season of kidding and 1.1 during the season after kidding for milk goats.

Table 5.13: Goat population data for 2010 to 2017 and enteric fermentation emission factors.

Livestock category		Population								Enteric fermentation EF
		2010	2011	2012	2013	2014	2015	2016	2017	(kg CH_4/head)
Commercial goats	*Angora - Breeding buck*	7 464	7 394	7 376	7 293	7 227	7 129	6 914	6 703	6.01
	Angora - Breeding does	339 590	336 445	335 618	331 811	328 833	324 364	314 600	305 002	4.76
	Angora - Kids	173 153	171 550	171 128	169 187	167 668	165 390	160 412	155 517	2.63
	Angora - Weaners	120 909	119 789	119 495	118 139	117 079	115 488	112 012	108 594	3.39
	Angora - Young buck	14 927	14 789	14 752	14 585	14 454	14 258	13 829	13 407	4.51
	Angora - Young does	90 308	89 472	89 252	88 240	87 448	86 260	83 663	81 110	3.64
	Commercial goats - Breeding buck	110 948	109 921	109 651	108 407	107 434	105 974	102 784	99 648	18.3
	Commercial goats - Breeding does	457 985	453 744	452 629	447 495	443 478	437 452	424 283	411 338	12.1
	Commercial goats - Kids	202 546	200 670	200 177	197 906	196 130	193 465	187 641	181 916	3.62
	Commercial goats - Weaners	336 716	333 598	332 778	329 003	326 050	321 619	311 938	302 421	5.54
	Commercial goats - Young buck	69 665	69 020	68 851	68 070	67 459	66 542	64 539	62 570	13.1
	Commercial goats - Young does	112 239	111 199	110 926	109 668	108 683	107 206	103 979	100 807	8.01
	Milk goats - Breeding buck	156	154	154	152	151	149	144	140	10.5
	Milk goats - Breeding does	7 075	7 010	6 993	6 913	6 851	6 758	6 555	6 355	8.48
	Milk goats - Kids	3 608	3 574	3 566	3 525	3 493	3 446	3 342	3 240	3.62
	Milk goats - Weaners	2 519	2 496	2 490	2 461	2 439	2 406	2 334	2 263	5.02
	Milk goats - Young buck	311	308	307	304	301	297	288	279	7.65
	Milk goats - Young does	1 882	1 864	1 860	1 839	1 822	1 797	1 743	1 690	5.94
Sub sist	*Breeding bucks*	44 585	44 172	44 063	43 564	43 173	42 586	41 304	40 044	11.1
	Breeding does	1 921 202	1 903 414	1 898 732	1 877 198	1 860 346	1 835 067	1 779 827	1 725 524	7.4

	Kids	806 581	799 112	797 147	788 106	781 031	770 418	747 227	724 429	2.54
	Weaners	684 986	678 643	676 974	669 296	663 288	654 275	634 580	615 219	3.66
	Young buck	81 063	80 313	80 115	79 207	78 496	77 429	75 098	72 807	8.11
	Young does	514 753	509 986	508 732	502 962	498 447	491 674	476 874	462 324	5.19

Horses (3A1f)

Population data

In country population data was not continuous and numbers are variable therefore the FAO population data was used so as to have a consistent time series (Table 5.14).

Table 5.14: Horse population data for 2010 to 2017.

	2010	2011	2012	2013	2014	2015	2016	2017
Horses	300 000	305 000	308 000	310 000	312 000	314 689	320 787	320 787

Emission factor

A default IPCC 2006 emission factor of 18 kg CH_4/head/year was applied.

Mules and Asses (3A1g)

Data sources and calculations for this category are the same as for horses. Population data are shown in Table 5.15.

Table 5.15: Mule and ass population data for 2010 to 2017.

	2010	2011	2012	2013	2014	2015	2016	2017
Mules & asses	166 300	167 000	167 000	170 500	171 000	169 010	162 226	162 226

Emission factor

The IPCC 2006 default emission factor of 10 kg CH_4/head/year was applied.

Swine (3A1h)

Population data

The total number of commercial pigs were sourced from Table 62 in Abstracts of Agricultural Statistics (DAFF, 2018). The population numbers for commercial and communal (emerging and subsistence) pigs were calculated from the number of sows per province according to the average composition of a 100-sow unit provided by SAPPO (Du Toit et al., 2013c). To accommodate the use of artificial insemination in commercial pig production systems the number of breeding boars was reduced from 6 to 3 per 100 sow unit. It was assumed that the commercial and emerging/communal sectors would have similar flock structures. The total communal population numbers for pigs 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 ratio for pigs was 0.131. It was assumed this ratio remained constant over the years as there is insufficient data to show otherwise. The communal population was assumed to have the same flock structure as the commercial goats and the composition remained constant over the time series due to a lack of data. Table 5.16 shows the population data for pigs.

Emission factors

Enteric fermentation emission factors for pigs (Table 5.16) were obtained from Du Toit et al. (2013c) and the methodology is described below.

Pigs are typically fed concentrate-based diets, especially in the commercial sector, and convert approximately 1% of gross energy intake (GEI) into methane compared with 6% - 7% for cattle and sheep (OECD, 1991). Methane conversion values for pigs are reported to be between 0.4% and 1.2% (Kirchgessner *et al.*, 1991; Moss, 1993). A methane conversion factor of 0.7% was used in the calculation for pigs based on the ANIR (2009). Daily intake and diet data for all classes of commercial and communal pigs were sourced from SAPPO (2011).

The total daily methane production (M), (kg CH_4/head/day) from enteric fermentation in pigs was calculated based on the ANIR (2009) as:

$$M = I \times 18.6 \times 0.007 / F$$

Where:

I = intake (kg DM/day) (Du Toit et al., 2013c)
F = 55.22 MJ/kg CH_4 (Brouwer, 1965)
18.6 = MJ GE/kg feed dry matter (DM).

Table 5.16: Swine population data for 2010 to 2017 and enteric fermentation emission factors.

Livestock category		Population								Enteric fermentation EF
		2010	2011	2012	2013	2014	2015	2016	2017	(kg CH_4/head)
Commercial swine	*Baconers*	78 106	77 616	77 371	77 126	76 538	74 627	74 088	72 569	0.99
	Boars	9 564	9 504	9 474	9 444	9 372	9 138	9 072	8 886	1.89
	Cull boars	9 564	9 504	9 474	9 444	9 372	9 138	9 072	8 886	1.89
	Cull sows	82 888	82 368	82 108	81 848	81 224	79 196	78 624	77 012	1.55
	Dry gestating sows	296 484	294 624	293 694	292 764	290 532	283 278	281 232	275 466	2.15
	Lactating sows	52 602	52 272	52 107	51 942	51 546	50 259	49 896	48 873	4.09
	Porkers	446 320	443 520	442 120	440 720	437 360	426 440	423 360	414 680	0.51
	Pre-wean piglets	526 020	522 720	521 070	519 420	515 460	502 590	498 960	488 730	0.43
	Replacement boars	9 564	9 504	9 474	9 444	9 372	9 138	9 072	8 886	2.41
	Replacement sows	82 888	82 368	82 108	81 848	81 224	79 196	78 624	77 012	2.41
Subsistence swine	*Baconers*	7 702	7 653	7 629	7 605	7 547	7 359	7 305	7 156	0.79
	Boars	3 747	3 723	3 711	3 700	3 671	3 580	3 554	3 481	1.55
	Cull boars	1 873	1 862	1 856	1 850	1 836	1 790	1 777	1 741	1.55
	Cull sows	15 819	15 720	15 671	15 621	15 502	15 115	15 006	14 698	1.24
	Dry gestating sows	57 033	56 676	56 497	56 318	55 888	54 493	54 099	52 990	1.72
	Lactating sows	10 199	10 135	10 103	10 071	9 995	9 745	9 675	9 476	3.27
	Porkers	43 087	42 817	42 682	42 547	42 222	41 168	40 871	40 033	0.41
	Pre-wean piglets	50 997	50 677	50 517	50 357	49 973	48 725	48 374	47 382	0.34

	Replacement boars	1 873	1 862	1 856	1 850	1 836	1 790	1 777	1 741	1.93
	Replacement sows	15 819	15 720	15 671	15 621	15 502	15 115	15 006	14 698	1.93

5.2.3 Uncertainties and time series consistency

Time series consistency is ensured by the use of consistent methods and full recalculations in the event of any refinement to methodology or data sources. The same source of activity data is used for the entire time period.

Activity data uncertainty

Uncertainty on cattle and swine population data and feeding situation is based the data provided in the Moeletsi et al. (2015) report. For the rest of the livestock uncertainty was not provided in this report so it was assumed that there is a 10 % uncertainty on the commercial livestock populations (expert opinion - H. Meissner) and 20% on the subsistence populations (as suggested by the external review of the 2012 inventory). Uncertainty on feeding situation was estimated at 5% based on the information from Moeletsi et al (2015).

Emission factor uncertainty

Uncertainty values were not provided with the country specific emission factors therefore a 20% uncertainty was applied as suggested by IPCC 2006 for a tier 2 methodology (Chapter 10, page 10.33). IPCC default uncertainty values of ±30-50% (IPCC 2006, Chapter 10, Table 10.10) were applied to EF for horses, mules and asses.

5.2.4 Source specific QA/QC

Activity data

Livestock population data were compared to the data in the FAO database and these were found to be very similar for all livestock. A comparison was also made with the population data for 2010 reported by Meissner et al. (2013) and the cattle numbers were within 4% of these numbers. It was noted that the ratio of subsistence to commercial cattle reported in the inventory was higher (0.8-1.2) than the 0.729 reported in Meissner et al. (2013) and this is due to lower commercial cattle numbers in the inventory. The sheep and goat numbers were within 10% and 2% of the Meissner et al. (2013) numbers, and the ratio of subsistence to commercial sheep were the same. The goat ratios were lower (1.9) in the inventory compared to the 2.5 reported in Meissner et al. (2013), however the difference could be because the inventory considers all goats and not just meat goats. There were some differences in the pig and poultry numbers with the inventory data being about 40% higher for pigs and 20% lower for poultry. The ratio of subsistence to commercial swine was, however, found to be very similar to that reported in Meissner et al. (2013). The data suggests that, although there is a lot of similarity, there are also some difference between national reporting and data from livestock associations. There is therefore still a need to develop a Livestock Estimates Committee as discussed in the previous inventory, where government and private associations come together to reach consensus of livestock population data. Since the last inventory there has not been any further developments with this committee and this will be revisited during the next inventory to further encourage the development of such a committee.

Average daily milk production data were verified against the total annual milk production. Live weights were verified with breed societies and were also compared to data in Moeletsi & Tongwane (2015) where possible.

Finally, all estimates and calculations were reviewed by a second person to ensure that the correct methodology was used, and determine that all calculations were correct.

Emission factors

The calculated emission factors (Du Toit et al., 2013a-c) were compared to those provided in Moeletsi et al. (2015) (Table 5.17).

Table 5.17: Enteric fermentation emission factor comparison between two SA studies.

Livestock category	Du Toit et al. (2013)#	Moeletsi et al. (2015)
Dairy cattle		
Lactating cow (pasture)	127	112.36
Lactating cow (TMR)	132	83.7
Other cattle (commercial)		
Calves	51.6	31.61
Feedlot	58.9	44.35
Heifer	75.9	58.47
Bulls	113	73.5
Mature cows	92.6	77.67
Mature oxen	89.4	80.03
Young oxen	51.6	85.71

Livestock category	Du Toit et al. (2013)[#]	Moeletsi et al. (2015)
Other cattle (subsistence)		
Calves	40.9	32.41
Heifers	62.5	75.43
Mature bulls	83.8	98.4
Mature cows	73.1	106.98
Oxen	72.6	98.4
Young oxen	41.6	76.94
Sheep (commercial)	6.76[a]	8.48[b]
Wool – mature ram	10.5 – 22.2	13.29
Wool – mature ewe	7.28 – 10.4	10.23
Wool – replacement ram	7.67 – 14.8	11.93
Wool – replacement ewe	5.94 – 8.01	8.8
Wool – lamb	3.62	3.96
Non-wool – mature ram	14.7	15.04
Non-wool – mature ewe	9.66	12.5
Non-wool – replacement ram	9.88	11.93
Non-wool – replacement ewe	6.88	8.32
Non-wool – lamb	3.62	5.42
Sheep (subsistence)		
Mature ram	7.62 – 15	6.46
Mature ewe	5.27 – 7.4	5.61
Replacement ram	5.6 – 10.5	4.77
Replacement ewe	4.4 – 5.8	3.08
Lamb	2.76	3.59
Goats	2.54 – 18.3	5
Swine	1.11[a]	1

[#] EF used in this 2017 inventory

In addition implied emission factors (IEFs)[9] have been compared to the IPCC defaults as well as those reported in the Australian NIR (ANIR, 2016) (Table 5.18). Dairy cattle IEF is higher than Africa default and is slightly higher than the default values for Oceania and Western Europe. The weight and milk production of SA dairy cattle are closer to those in Oceania and Western Europe than those in Africa, hence the closer alignment of the emission factors with these regions. Similarly for non-dairy cattle. The sheep, goat and

[9] An implied emission factor is defined as emissions divided by the relevant measure of activity: IEF = Emissions / Activity data

swine IEFs are generally consistent with the IPCC defaults and the values provided for Australia.

Table 5.18: Comparison between SA implied emission factors (2017) and IPCC default factors for enteric fermentation.

Livestock category	SA IEF (2017)	IPCC			Australia (2016 NIR)
		Africa	Oceania	Western Europe	
	EF (kg CH_4/head/year)				
Dairy cattle	127.75	46	90	117	92
Other cattle	66.39	31	60	57	51-67
Sheep	6.74	5	5	8	6.7
Goats	6.16	5	5	5	
Swine	1.11	1	1	1.5	1.6

5.2.5 Recalculations since the 2015 Inventory

Recalculations were completed for all years between 2000 and 2017 due to:

a) movement of non-lactating dairy cattle from sub-category *3Aai Dairy cattle* to the sub-category *3Aaii Other cattle* to be in alignment with IPCC 2006 guidelines. This was just a re-allocation of emissions and did not lead to any changes in the overall emissions.
b) an adjustment in the other cattle population numbers. The total cattle population from the Agricultural Abstracts (DAFF, 2018) was, in previous inventories, assumed to be the total dairy and other cattle population, however during verification it was found that the total number was only for other cattle. Numbers were corrected to reflect this. The change meant an increase in the number of subsistence cattle. The recalculated emissions due to the adjustments made (a) and (b) were 11.6% higher than the 2015 emissions.
c) removal of game emissions. This change led to a 3.6% and 4.3% decline in the *Enteric fermentation* emissions in 2000 and 2017, respectively.

Overall the recalculated enteric fermentation emissions were 5.2% higher than reported in the 2015 inventory.

5.2.6 Source specific planned improvements

It is planned that over the next two inventory cycles the background data and calculations of the Enteric fermentation emission factors will be incorporated into the calculation files. Initially the cattle data will be included (since this is a key category), followed by the other livestock. This will enable adjustments to the various components of the calculations to be made as new data becomes available.

5.3 Source Category 3.A.2 Manure Management

5.3.1 Category information

Livestock manure is composed principally of organic material. When the manure decomposes in the absence of oxygen, methanogenic bacteria produce CH_4. The amount of CH_4 emissions is related to the amount of manure produced and the amount that decomposes anaerobically. The *Manure management* category also includes N_2O emissions related to manure handling before it is added to agricultural soil. The amount of N_2O emissions depends on the system of waste management and the duration of storage.

Emissions

2000 - 2017

Emissions from manure management increased by 7.4% between 2000 and 2017 (Table 5.19). CH_4 emissions declined (Table 5.20), while N_2O emissions increased (Table 5.21).

Table 5.19: Trends and changes in manure management emissions (2000 to 2017).

	Emissions ($Gg\ CO_2e$)		Change (2000 – 2017)		Share of manure management	
	2000	2017	Diff	%	2000	2017
					%	%
Methane	763.3	744.5	-18.8	-2.5	33.4	30.4
Nitrous oxide	1 520.7	1 707.9	187.2	12.3	66.6	69.6
Total manure management	**2 284.0**	**2 452.4**	168.4	7.4	100	100

Most of South Africa's livestock (cattle, sheep, goats, horses, mules and asses) are kept on pasture, range and paddock (Table 5.22), therefore the *Manure management* category emissions were relatively small in 2017. Methane from *Manure management* declines slowly over the years (Figure 5.5), while the N_2O emissions show greater variation. The N_2O emissions have been increasing from 2000 to 2015, after which there is a slight decline going to 2017 (Figure 5.6). This increase is mainly due to the increase in poultry population. The manure managed in dairy farms and piggeries contributed the most to the CH_4 emissions (29.6% and 58.9% respectively); while the largest contributors to the N_2O emissions were non-dairy cattle (45.0%) and poultry (38.0%).

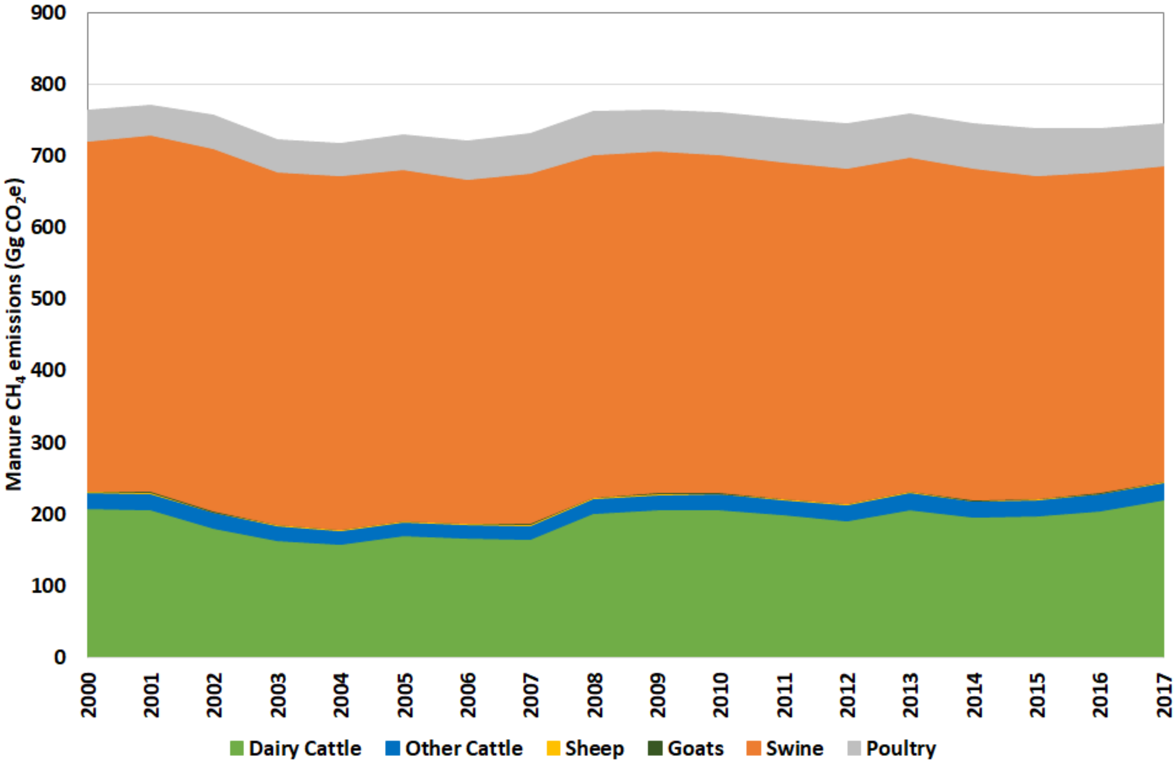


Figure 5.5: Trend in manure management CH_4 emissions from livestock, 2000 – 2017.

Table 5.20: *Manure management* CH_4 emission trends between 2000 and 2017.

	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017
	Gg CO_2e									
Dairy cattle[7]	207.9	169.5	206.6	198.9	191.7	207.1	195.3	197.4	204.6	220.3
Other cattle[6]	22.4	19.8	21.3	21.8	22.0	23.7	22.9	22.9	23.4	24.7
Buffalo	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Sheep	1.0	1.0	0.9	0.9	0.9	1.0	0.9	0.9	0.9	0.9
Goats	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.8
Camels	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Horses	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Mules & asses	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Swine	487.7	488.9	472.1	469.1	467.6	466.1	462.6	451.0	447.8	438.6
Poultry	43.1	49.0	57.3	59.5	61.0	59.4	61.5	63.7	60.1	59.2
Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017
	Gg CO_2e									
Total	763.3	729.3	759.3	751.2	744.1	758.3	744.1	736.9	737.7	744.5

Note: Numbers may not add exactly due to rounding off.

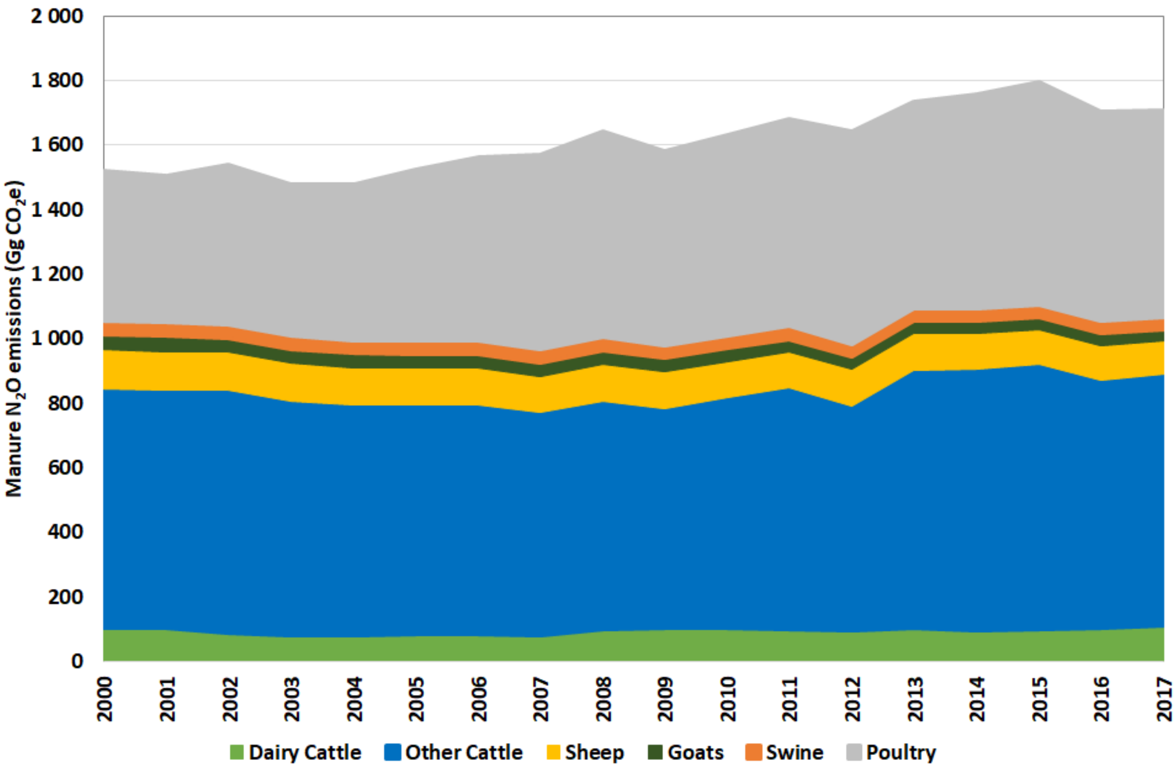


Figure 5.6: Trend in manure management N_2O emissions from livestock, 2000 – 2017.

Table 5.21: *Manure management* N_2O emission trends between 2000 and 2017.

	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017
	Gg CO_2e									
Dairy cattle[7]	102.8	84.2	102.6	99.0	95.3	102.5	97.1	98.5	102.2	109.8
Other cattle[6]	741.3	709.4	715.0	748.1	697.5	800.7	807.6	820.8	770.7	779.7
Buffalo	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Sheep	122.5	115.4	111.7	110.8	111.3	112.2	110.2	109.3	106.2	103.6
Goats	46.4	42.1	40.4	40.0	39.9	39.5	39.1	38.6	37.4	36.3

	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017
	Gg CO_2e									
Camels	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Horses	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mules & asses	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Swine	41.3	41.4	40.0	39.7	39.6	39.5	39.2	38.2	37.9	37.1
Poultry	466.5	531.9	620.3	642.7	658.6	642.1	665.4	690.1	649.3	641.3
Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Total	1 520.7	1 524.4	1 630.0	1 680.5	1 642.2	1 736.5	1 758.5	1 795.4	1 703.8	1 707.9

Note: Numbers may not add exactly due to rounding off.

5.3.2 Methodology

For CH_4 from manure the equation 10.22 from the IPCC 2006 guidelines (IPCC, 2006, vol 4, chapter 10, pg. 10.37) was applied. Methane production from the managed manure of livestock was calculated based on the volatile solids entering the manure management systems, and country specific or default methane conversion factors. Integrated MCFs were determined taking into account the proportion of manure managed in each system, the MCF of each system and the volatile solid losses. Methodology for the various livestock is detailed below.

Methanogenesis occurs in anaerobic conditions. The high temperatures, high solar radiation and low humidity environments in South Africa dry manure rapidly leaving little chance for the formation of anaerobic conditions (ANIR, 2016). Methane production from manure of livestock kept on rangelands is assumed to be negligible. For these livestock the manure emission factor for temperate environments (1.4 x 10^{-5} kg CH_4/kg DM manure) provided in the ANIR (2016) was applied.

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. Nitrogen excretion rates (N_{rate}) for horses, mules/asses, swine and poultry were determined from data utilised in Du Toit et al. (2013c). For the other livestock the Africa default values (IPCC, 2006, Table 10.19) were applied. The typical animal mass (TAM) for the various livestock categories is provided in the livestock category sections below. Manure management data (Table 5.22) 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). Weighted average N_2O emission factors for each livestock type were determined from the manure management usage data and the N_2O emission factors. Results are report in the livestock sections below.

Direct manure N_2O was only determined for managed manure (Table 5.22), therefore there were no emissions for horses, mules and asses as their manure is all deposited on pasture, range and paddock. Manure management data was obtained from Du Toit et al. (2013a – c), and Moeletsi and Tongwane (2015).

For selection of emission factors a mean annual temperature of 21°C (Du Toit et al, 2013; DEA, 2015) was applied.

Table 5.22: Livestock manure management (%).

		Lagoon	Liquid/slurry	Drylot	Solid storage	Daily spread	Compost	Manure with bedding	Poultry manure without litter	Poultry manure with litter	PRP
Dairy cattle	Pasture	11.0	0.0	8.0	10.0	3.0	0.0	8.0	0.0	0.0	60.0
	TMR	95.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0
Other cattle	Non-lactating dairy cattle	0.0	0.0	0.0	2.0	1.0	0.0	2.0	0.0	0.0	95.0
	Commercial beef cattle	0.0	0.0	2.5	0.0	0.0	2.5	0.0	0.0	0.0	95.0
	Beef feedlot	3.0	3.0	86.0	0.0	3.0	5.0	0.0	0.0	0.0	0.0
	Subsistence	0.0	0.0	5.0	0.0	0.0	0.0	5.0	0.0	0.0	90.0
Sheep	Commercial	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	99.0
	Subsistence	0.0	0.0	2.0	0.0	0.0	0.0	5.0	0.0	0.0	93.0
Goats	Commercial	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	99.0
	Subsistence	0.0	0.0	2.0	0.0	0.0	0.0	5.0	0.0	0.0	93.0
Horses, mules, asses		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0

Swine	Commercial	71.0	11.0	13.0	0.0	3.0	2.0	0.0	0.0	0.0	0.0
	Subsistence	25.0	10.0	35.0	0.0	28.0	2.0	0.0	0.0	0.0	0.0
Poultry	Broilers	0.0	0.0	80.0	0.0	0.0	5.0	0.0	0.0	15.0	0.0
	Layers	0.0	5.0	70.0	0.0	5.0	10.0	0.0	10.0	0.0	0.0

Dairy cattle (3A2ai and 3A2aii)

Methane

Methane emissions from dairy cattle manure were calculated by applying IPCC (2006) equation 10.22 and multiplying population data by an emission factor. Emission factors were calculated as described below with further details given in Du Toit et al. (2013a).

Methane emissions from manure originate from the organic fraction of the manure (volatile solids). Volatile solids (VS), (kg/head/day) for South African dairy cattle were calculated according to ANIR (2010) as:

$$VS = I \times (1 - DMD) \times (1 - A)$$

Where:

I = dry matter intake (calculated as described in 5.2.2 above)
DMD = dry matter digestibility expressed as a fraction (Du Toit et al., 2013a)
A = ash content of manure expressed as a fraction (assumed to be 8% of faecal DM – Du Toit et al., 2013a).

The percentage of manure managed in different manure management systems in South Africa and the manure methane conversion factors (ANIR, 2009) for these systems are reported in (Du Toit et al., 2013a). Methane production from manure (M) (kg/head/day) was calculated as:

$$M = VS \times Bo \times MCF \times p$$

Where:

B_o = emissions potential (0.24 m^3 CH_4/ kg VS) (IPCC, 2006)

MCF = integrated methane conversion factor – based on the proportion of the different manure management systems and the MCF for warm regions
p = density of methane (0.662 kg/m^3).

The integrated MCF for lactating dairy cattle in TMR-based production systems was calculated as 10.07% and 1% for all other classes of dairy cattle. In pasture-based production systems the integrated MCF for lactating cattle was calculated as 3.64% and 1% for all other classes of cattle.

Dairy cattle emission factors are provided in Table 5.23.

Direct nitrous oxide emissions

Direct N_2O emissions from manure management were calculated from cattle population data, annual N excretion rate (Table 5.23), fraction of manure in manure system (Table 5.22) and an emission factor using Equation 10.25 (IPCC 2006 Guidelines, vol 4, Chpt 10, page 10.54). IPCC 2006 default emission factors (IPCC, 2006; Table 10.21, pg. 10.62-10.64) for the various manure management systems and daily excretion rates (IPCC, 2006; Table 10.19, pg. 10.59) were applied. The N excretion rates and weighted N_2O emission factors for dairy cattle are shown in Table 5.23.

Table 5.23: Typical animal mass (TAM), N excretion rates and manure emission factors for dairy cattle.

Livestock subcategory			Typical animal mass	Manure CH_4 emission factor	Annual N excretion rate	Weighted N_2O emission factor
			(kg)	(kg CH_4 $head^{-1}$ yr^{-1})	(kg N (animal mass)$^{-1}$ yr^{-1})	(kg N_2O-N (kg Nex)$^{-1}$)
Pasture	3Aai Dairy cattle	Lactating cows	540	5.0	118.3	0.0029
		Dry cows	540	1.1	124.2	
		Lactating heifers	438	4.8	95.9	
	3Aaii Other cattle	Calves <6months	36	0.3	8.3	0.0003
		Heifers 2-6 months	54	0.4	12.4	
		Heifers 6-12 months	142	0.6	32.7	
		Heifers >1year	254	0.8	58.4	
		Pregnant heifers	333	0.9	76.6	

TMR	3Aai Dairy cattle	Lactating cows	590	14.8	129.2	0.0005
		Dry cows	590	1.5	135.7	
		Lactating heifers	503	14.7	110.2	
	3Aaii Other cattle	Calves <6months	35	0.2	8.1	0.0003
		Heifers 2-6 months	55	1.2	12.7	
		Heifers 6-12 months	172	0.8	39.6	
		Heifers >1year	322	0.4	74.0	
		Pregnant heifers	394	1.2	90.6	

Other cattle (3A2aii)

Methane

Other cattle on pastures

South African beef production systems are mainly extensive and manure is deposited directly onto pastures and not actively managed (Table 5.22). Methane emissions from manure of beef cattle were calculated as described in Du Toit et al. (2013a), with calculations shown below.

Methane emissions from manure (M), (kg/head/day) of beef cattle were calculated according to the ANIR (2010) as:

$$M = I \times (1 - DMD) \times MEF$$

Where:

I = intake (as calculated in section 5.2.2)
DMD = dry matter digestibility across seasons (Du Toit et al., 2013a)
MEF = emissions factor (kg CH_4/kg DM manure). The factor of 1.4×10^{-5} based on the work of Gonzalez-Avalos & Ruiz-Suarez (2001) was used.

Emission factors are provided in Table 5.24.

Beef cattle in feedlots

The high stocking density of animals in feedlots results in a build-up of manure, which may lead to the production of methane, especially when the manure is wet. The method of manure management at a feedlot influences the amount of methane that is emitted from it. South African feedlots manage manure mainly by dry packing, which results in only a small fraction of potential methane emissions being generated (IPCC, 1997). The Australian national inventory (ANIR, 2010) reported default values for drylot methane conversion factors (MCF) of 1.5% based on the IPCC (1997). The volatile solid production for feedlot cattle was estimated based on data developed under the enteric methane emission calculations reported earlier.

The volatile solid production was calculated as for dairy cattle, assuming a DMD of 80% for feedlot diets. The daily methane production from feedlot manure was calculated using the same equation as for dairy cattle, assuming an emissions potential (B_0) of 0.17 m^3 CH_4/kg VS (IPCC, 2006) and a MCF of 1.5% as stated above. Emission factors are provided in Table 5.24.

Direct nitrous oxide emissions

Direct N_2O emissions from manure management were calculated from cattle population data, annual N excretion rate (Table 5.24), fraction of manure in manure system and an emission factor using Equation 10.25 (IPCC 2006 Guidelines, vol 4, Chpt 10, page 10.54). IPCC 2006 default emission factors (IPCC, 2006; Table 10.21, pg. 10.62-10.64) and daily N excretion rates (IPCC, 2006; Table 10.19, pg 10.59) were applied. Data is provided in Table 5.24.

Table 5.24: Typical animal mass (TAM), N excretion rates and manure emission factors for beef cattle.

Livestock subcategory		Typical animal mass	Manure CH_4 emission factor	Annual N excretion rate	Weighted N_2O emission factor
		(kg)	(kg CH_4 $head^{-1}$ yr^{-1})	(kg N (animal $mass)^{-1}$ yr^{-1})	(kg N_2O-N (kg $Nex)^{-1}$)
Co	Bulls	733	0.022	168.6	0.0007

	Calves	190	0.012	43.7	
	Cows	475	0.018	109.2	
	Feedlot	286	0.87	65.8	0.0164
	Heifers	365	0.016	83.9	0.0007
	Oxen	430	0.018	98.9	
	Young oxen	193	0.012	44.4	
Subsistence cattle	**Bulls**	462	0.017	106.2	0.0015
	Calves	152	0.01	35.0	
	Cows	360	0.015	82.8	
	Heifers	292	0.013	67.2	
	Oxen	344	0.015	79.1	
	Young oxen	154	0.01	35.4	

Sheep (3A2c)

Methane

South African small stock production systems are mainly extensive, and most manure is deposited directly onto pastures and veld/rangeland with very little active manure management occurring. The loss of animals owing to predators and stock theft is one of the major challenges for South African small stock producers. Some producers' overnight sheep and goats in enclosures where manure deposition will be concentrated and be managed in a drylot or compost system.

Methane emissions from manure for all categories of sheep were calculated using IPCC (2006) equation 10.22, with the method for determining the emission factor being described below and in detail in Du Toit et al. (2013b).

Methane emissions from manure (M), (kg/head/day) of all categories of sheep were calculated as:

$$M = I \times (1 - DMD) \times MEF$$

Where:

I = intake (kg DM/head/day) as calculated under enteric emissions
MEF = emissions factor (kg CH_4/kg DM manure). The factor of 1.4×10^{-5} based on the work of Gonzalez-Avalos & Ruiz-Suarez (2001) was used.

Table 5.25 shows the manure CH_4 emission factors for sheep.

Direct nitrous oxide emissions

Direct N_2O emissions from manure management were calculated from sheep population data, annual N excretion rate (Table 5.25), fraction of manure in manure system (Table 5.22) and an emission factor using Equation 10.25 (IPCC 2006 Guidelines, vol 4, Chpt 10, page 10.54). IPCC 2006 default emission factors (IPCC, 2006; Table 10.21, pg. 10.62-10.64) and daily N excretion rates (IPCC, 2006; Table 10.19, pg 10.59) were applied. Data is provided in Table 5.25.

Table 5.25: Typical animal mass (TAM), N excretion rates (per animal) and manure emission factors for sheep.

Livestock subcategory		Typical animal mass	Manure CH_4 emission factor	Annual N excretion rate	Weighted N_2O emission factor
		(kg)	(kg CH_4 head^{-1} yr^{-1})	(kg N (animal mass)$^{-1}$ yr^{-1})	(kg N_2O-N (kg Nex)$^{-1}$)
Commercial sheep	Karakul breeding ewes	48	0.002	20.5	0.0002
	Karakul breeding rams	72.5	0.003	31.0	
	Karakul lambs	22.5	0.001	9.6	
	Karakul weaners	33.5	0.0013	14.3	
	Karakul young ewes	40.5	0.0016	17.3	
	Karakul young rams	53	0.002	22.6	
	Merino breeding ewes	53	0.0022	22.6	
	Merino breeding rams	97.5	0.0042	41.6	
	Merino lambs	22.5	0.001	9.6	
	Merino weaners	37.5	0.0014	16.0	
	Merino young ewes	42.5	0.0016	18.1	
	Merino young rams	78.3	0.0032	33.4	
	Non-wool breeding ewes	63.5	0.0027	27.1	
	Non-wool breeding rams	97.5	0.0041	41.6	
	Non-wool lambs	22.5	0.001	9.6	
	Non-wool weaners	37.5	0.0014	16.0	
	Non-wool young ewes	47.5	0.0018	20.3	
	Non-wool young rams	68.3	0.0027	29.2	

	Other wool breeding ewes	68	0.0029	29.0	
	Other wool breeding rams	138	0.0064	58.9	
	Other wool lambs	22.5	0.001	9.6	
	Other wool weaners	31.5	0.0012	13.5	
	Other wool young ewes	55.5	0.0022	23.7	
	Other wool young rams	98.3	0.0042	42.0	
Subsistence sheep	Karakul breeding ewes	38.4	0.0015	16.4	0.0031
	Karakul breeding rams	58	0.0022	24.8	
	Karakul lambs	18	0.0007	7.7	
	Karakul weaners	26.8	0.001	11.4	
	Karakul young ewes	32.4	0.0012	13.8	
	Karakul young rams	42.4	0.0016	18.1	
	Merino breeding ewes	42.1	0.0017	18.0	
	Merino breeding rams	78	0.0032	33.3	
	Merino lambs	18	0.0007	7.7	
	Merino weaners	30	0.0011	12.8	
	Merino young ewes	34	0.0013	14.5	
	Merino young rams	62.6	0.0025	26.7	
	Non-wool breeding ewes	50.3	0.002	21.5	
	Non-wool breeding rams	78.1	0.0032	33.4	
	Non-wool lambs	18	0.0007	7.7	
	Non-wool weaners	30	0.0011	12.8	
	Non-wool young ewes	38	0.0014	16.2	
	Non-wool young rams	54.3	0.0021	23.2	
	Other wool breeding ewes	54.5	0.0022	23.3	
	Other wool breeding rams	110	0.005	47.0	
	Other wool lambs	18	0.0007	7.7	
	Other wool weaners	25	0.001	10.7	
	Other wool young ewes	44	0.002	18.8	
	Other wool young rams	59.5	0.0032	25.4	

Goats (3A2d)

Methane

Methodology is the same as that described above for sheep and the calculated emission factors are shown in Table 5.26.

Table 5.26: Manure CH_4 emission factors and typical animal mass data for goats.

Livestock subcategory		Typical animal mass	Manure CH_4 emission factor	Annual N excretion rate	Weighted N_2O emission factor
		(kg)	(kg CH_4 $head^{-1}$ yr^{-1})	(kg N (animal mass)$^{-1}$ yr^{-1})	(kg N_2O-N (kg Nex)$^{-1}$)
Commercial goats	Angora - Breeding buck	41.5	0.0062	20.8	0.0002
	Angora - Breeding does	30	0.005	15.0	
	Angora – Kids	14.5	0.002	7.3	
	Angora - Weaners	20.5	0.003	10.3	
	Angora - Young buck	29.5	0.004	14.8	
	Angora - Young does	22.5	0.003	11.3	
	Commercial goats - Breeding buck	118	0.02	59.0	
	Commercial goats - Breeding does	78	0.013	39.0	
	Commercial goats - Kids	22.5	0.0034	11.3	
	Commercial goats - Weaners	33.5	0.006	16.8	
	Commercial goats - Young buck	53	0.014	26.5	
	Commercial goats - Young does	40.5	0.0084	20.3	
	Milk goats - Breeding buck	72.5	0.009	36.3	
	Milk goats - Breeding does	48	0.007	24.0	
	Milk goats - Kids	22.5	0.003	11.3	
	Milk goats - Weaners	33.5	0.004	16.8	
	Milk goats - Young buck	53	0.006	26.5	
	Milk goats - Young does	40.5	0.005	20.3	
Subsistence goats	Breeding bucks	82	0.013	41.0	0.0009
	Breeding does	54.4	0.009	27.2	
	Kids	16	0.003	8.0	
	Weaners	26	0.004	13.0	
	Young buck	61.6	0.009	30.8	
	Young does	39	0.006	19.5	

Direct nitrous oxide emissions

Methodology is the same as that described above for sheep and the calculated emission factors are shown in Table 5.26.

Horses (3A2f) and Mules/asses (3A2g)

Methane

Horses, donkeys and mules are kept on the veld in extensive systems with a relatively small amount of methane being produced from manure. Methane production from manure (M) (kg/head/day) originating from these sources was calculated as (following Du Toit et al (2013c)):

$$M = DMM \times MEF$$

Where:

DMM = dry matter in manure (Du Toit et al., 2013c)
MEF = manure emission factor (kg CH_4/kg DM manure) taken as 1.4 x 10^{-5} kg CH_4/kg DMM (Gonzalez-Avalos & Ruiz-Suarez, 2001).

Annual emission factors are provided in Table 5.27.

Table 5.27: Manure CH_4 emission factors and typical animal mass for horses, mules and asses.

Livestock subcategory	Typical animal mass (kg)	Manure CH_4 emission factor (kg CH_4 $head^{-1}$ yr^{-1})
Horses	595	0.013
Mules and asses	250	0.0045

Direct nitrous oxide emissions

No manure was managed for horses, mules and asses, therefore there was no N_2O emissions. All the manure is deposited on pasture, range and paddock and so the N_2O emissions are accounted for under *Direct N_2O from managed soils*.

Swine (3A2h)

Methane

The management of livestock manure can produce anthropogenic methane and nitrous oxide emissions (EPA, 2013). Commercial pig production systems in South Africa are housed systems, and a large proportion of manure and waste is managed in lagoon systems. These lagoon systems create anaerobic conditions, resulting in a high proportion of the volatile solids being fermented, which leads to the production of methane (ANIR, 2009). Methodology for the calculation of the emission factor for swine is provided in Du Toit et al. (2013c) and summarised below.

The volatile solid production (VS), (kg/head/day) from pig manure was calculated according to the IPCC (2006) as:

$$VS = [GE \times (1 - (DE\%/100)) + (UE \times GE)] \times [(1 - Ash)/18.45]$$

Where:

GE = gross energy intake (MJ/day)
DE% = digestibility of feed (%) (Du Toit et al., 2013c)
(UE x GE) = urinary energy expressed as a fraction of GE. (Typically 0.02GE for pigs, IPCC, 2006)
Ash = ash concentration of manure (17%), (F.K. Siebrits, 2012, Pers. Comm., Dept. Animal Science, Tshwane University of Technology, Private Bag X680, Pretoria, 0001)
18.45 = conversion factor for dietary GE per kg of DM (MJ/kg).

Methane produced from manure (M), (kg/head/day) and wasted feed was calculated according to the ANIR (2009) as:

$$M = VS \times Bo \times MCF \times p$$

Where:

VS = volatile solid production (kg/head/day)
B_o = emissions potential (0.45 m^3 CH_4/kg VS) (IPCC 2006)
MCF = integrated methane conversion factor. Based on the different manure management systems
p = density of methane (0.662 kg/m^3).

Table 5.28 provides the manure CH_4 emission factors.

Direct nitrous oxide emissions

Direct N_2O emissions from manure management were calculated from pig population data, annual N excretion rate, fraction of manure in manure system (Table 5.28 and Table 5.23) and an emission factor using Equation 10.25 (IPCC 2006 Guidelines, vol 4, Chpt 10, page 10.54). N excretion rate data was obtained from Du Toit et al. (2013c). Default emission factors for the various manure management systems, and their uncertainties, are provided in (IPCC 2006 Guidelines, vol 4, Chpt 10, Table 10.21). N excretion rates and N_2O emission factors are provided in Table 5.28.

Table 5.28: Manure CH_4 emission factors and activity data for manure N_2O emissions for swine.

Livestock subcategory		Typical animal mass	Manure CH_4 emission factor	Annual N excretion rate	Weighted N_2O emission factor
		(kg)	(kg CH_4 head^{-1} yr^{-1})	(kg N (animal mass)$^{-1}$ yr^{-1})	(kg N_2O-N (kg Nex)$^{-1}$)
Commercial swine	Baconers	90	20.96	11.0	0.0027
	Boars	300	16.47	14.6	
	Cull boars	325	16.47	14.6	
	Cull sows	325	13.47	20.7	
	Dry gestating sows	350	18.71	20.7	
	Lactating sows	300	35.55	20.7	
	Porkers	70	17.96	11.0	
	Pre-wean piglets	9	3.74	11.0	
	Replacement boars	135	20.96	12.3	
	Replacement sows	135	20.96	12.2	
Subsistence swine	Baconers	70	0.46	11.0	0.0071
	Boars	240	0.37	14.6	
	Cull boars	260	0.37	14.6	
	Cull sows	260	0.3	20.7	
	Dry gestating sows	280	0.42	20.7	
	Lactating sows	240	0.79	20.7	
	Porkers	56	0.4	11.0	
	Pre-wean piglets	7	0.08	11.0	
	Replacement boars	108	0.46	12.3	
	Replacement sows	108	0.46	12.2	

Poultry (3.A.2.i)

Methane

Volatile solid production from poultry production systems was calculated following Du Toit et al. (2013c), which was based on the ANIR (2009), utilizing intake data and diet dry matter digestibility's as follows:

$$VS = I \times (1 - DMD) \times (1 - Ash)$$

Where:

VS = volatile solid production (kg/head/day)
I = dry matter intake (assumed to be 0.11 kg/day), (ANIR, 2009)
DMD = dry matter digestibility (assumed to be 80%), (ANIR, 2009)
Ash = ash concentration (assumed to be 8% of faecal DM), (ANIR, 2009).

Methane production from poultry manure (M) (kg/head/day) was calculated from the equation provided for swine, but using a MCF of 1.5% according to the IPCC (2006). The manure CH_4 emission factor for poultry was determined to be 0.0235 kg CH4/head/year (Du Toit et al., 2013c).

Direct nitrous oxide emissions

Direct N_2O emissions from manure management were calculated from population data, annual N excretion rate, fraction of manure in manure system and an emission factor using Equation 10.25 (IPCC 2006 Guidelines, vol 4, Chpt 10, page 10.54). The N excretion values of 07 kg N (animal mass)$^{-1}$ yr^{-1} for layers and 0.6 kg N (animal mass)$^{-1}$ yr^{-1} for broilers was provided by Du Toit et al. (2013c). IPCC 2006 default emission factors for the various manure management systems is provide in vol 4, chapter 10, Table 10.21 of the IPCC 2006 Guidelines. The weighted N_2O emission factors for broilers and layers were calculated to be 0.0165 kg N_2O-N (kg Nex)$^{-1}$ and 0.0147 kg N_2O-N (kg Nex)$^{-1}$, respectively.

5.3.3 Uncertainties and time series consistency

Time series consistency is ensured by the use of consistent methods and data sources, with full recalculations in the event of any refinement to methodology or data.

Activity data uncertainty

For uncertainties on livestock populations see section 5.2.3. Uncertainty on manure management data was taken from Moeletsi et al. (2015) and varies between ±2% to ±25% for the various livestock. IPCC default N excretion data has a ±50% uncertainty, with a ±30% uncertainty on the country specific N excretion rates. TAM uncertainty was derived from Du Toit et al. (2015a-c) and Moeletsi et al. (2015).

Emission factor uncertainty

Uncertainty values were not provided with the country specific emission factors therefore a ±20% uncertainty was applied to the CH_4 emission factor as suggested by IPCC 2006 for a tier 2 methodology. There are large uncertainties associated with the N_2O manure emission factors, even if they are country specific. The default values have an uncertainty of -50% to 100% (IPCC 2006, Chapter 10, pg 10.66), therefore for country specific factors an uncertainty of -25% to 50% was assumed.

5.3.4 Source specific QA/QC

Activity data

Du Toit et al. (2013c) indicated poultry N excretion values to be 0.6-0.7 kg N/bird/year which is in the same range as that provided by IPCC. Excretion rates for pigs were determined to be in the range of 11.0 to 20.7 kg N/head/year which is well within the range provided by IPCC and other countries (IPCC, 2006; ANIR, 2016; NZNIR, 2016). Annual N excretion rates and TAM (Table 5.29) are similar to those reported in Moeletsi & Tongwane (2015).

Emission factors

Comparison with other studies

Emission factors were compared to data reported in Moeletsi & Tongwane (2015) and to the IPCC default values. For dairy cattle the CH_4 EF applied in this inventory are within the range of the between the Africa and Oceania IPCC default values, whereas the value reported in Moeletsi & Tongwane (2015) was much higher than all the IPCC default values and double the current emission factors. For other cattle, sheep and goats the EF in the current inventory are much lower than the IPCC default values. On the other hand the Moeletsi & Tongwane (2015) data for other cattle are much higher than the default values (Table 5.29). Emission factors for swine and poultry in all studies are within a similar range.

The emission factors applied in this inventory (and based on Du Toit et al, 2013) utilise country specific data on feed digestibility, whereas Moeletsi & Tongwane (2015) applied the IPCC Oceania default values for VS and B_0, and this could be causing the differences in the emission factors. In addition, the two studies have different data for manure management for the various livestock and this could also be contributing to the differences. Reducing the uncertainty on this data will improve the emission estimates. In the next inventory the two studies will be investigated in more detail to determine the overall best emission factors to apply.

Incorporating the background emission factor calculations into the spreadsheets may resolve some of the differences, and even highlight where the main inconsistencies exist. There are some inconsistencies in the data in that the emission factors are reported in the studies (Du Toit et al., 2013a-c; Moeletsi & Tongwane, 2015), and these utilise a MCF determined from the manure management data in each study. However, in the current inventory the manure management data is based on a combination of the two data sets yet the MCF in the EF calculations were not adjusted. Thus, by incorporating the calculations into the spreadsheets these small discrepancies can be corrected.

Table 5.29: Manure management CH_4 emission factor, N excretion rate and TAM comparisons with other studies.

Livestock category	CH_4 emission factor ($kg\ CH_4\ head^{-1}\ yr^{-1}$)				Annual N excretion ($kg\ N\ (animal\ mass)^{-1}\ yr^{-1}$)		Typical animal (kg)	
	Du Toit et al. (2013)#	Moeletsi & Tongwane (2015)	IPCC Africa default	IPCC Oceania default	Current inventory	Moeletsi & Tongwane (2015)	Current inventory	Moeletsi & Tongwane (2015)
Dairy cattle								
Lactating cow (pasture)	5.0	40.98	1	29	118.3	80.0	540	498
Lactating cow (TMR)	14.8				129.2		590	
Lactating heifer (pasture)	4.8	1.85			95.9	63.9	438	355

Livestock category	CH_4 emission factor ($kg\ CH_4\ head^{-1}\ yr^{-1}$)				Annual N excretion ($kg\ N\ (animal\ mass)^{-1}\ yr^{-1}$)		Typical animal (kg)	
	Du Toit et al. (2013)#	Moeletsi & Tongwane (2015)	IPCC Africa default	IPCC Oceania default	Current inventory	Moeletsi & Tongwane (2015)	Current inventory	Moeletsi & Tongwane (2015)
Lactating heifer (TMR)	14.7				110.2		503	
Other cattle (commercial)								
Feedlot	0.87	8.48			65.8	54.8	286	300
Calves	0.012	1.81	1	2	43.7	40.0	190	124
Heifer	0.016				83.9	60.4	365	331
Bulls	0.022				168.6	181.2	733	993
Mature cows	0.018				109.2	93.4	475	512
Mature oxen	0.018				98.9	100.4	430	550
Young oxen	0.012				44.4	84.32	193	462
Other cattle (subsistence)								
Calves	0.01	3.56	1	2	35.0	19.6	152	85
Heifers	0.013				67.2	49.0	292	213
Mature bulls	0.017				106.2	134.5	462	585
Mature cows	0.015				82.8	84.9	360	369
Oxen	0.015				79.1	92.2	344	401
Young oxen	0.01				35.4	69.0	154	300
Sheep								
Commercial	0.002 – 0.004	0.28	0.15	0.28	9.6 – 58.9	28.5	22.5 – 98.3	69
Subsistence	0.0007 – 0.0032				7.7 – 47.0	17.1	18 – 78.1	40
Goats								
Commercial	0.003 – 0.014	0.2-0.54	0.17	0.2	7.3 – 59.0	25.9	14.5 – 118	50
Subsistence	0.003 – 0.013				8.0 – 41.0	18.0	16 - 82	36
Swine								
Market	17.96 – 20.96	14.13 – 25.23	1	13	11.0	15.5 – 45.3	70 – 90	80 – 270
Breeding	3.74 – 35.55		1	23	11.0 – 20.7		9 – 350	
Subsistence	0.08 – 0.79				11.0 – 20.7		7 – 280	

Livestock category	CH_4 emission factor ($kg\ CH_4\ head^{-1}\ yr^{-1}$)				Annual N excretion (kg N (animal mass)$^{-1}$ yr^{-1})		Typical animal (kg)	
	Du Toit et al. (2013)#	Moeletsi & Tongwane (2015)	IPCC Africa default	IPCC Oceania default	Current inventory	Moeletsi & Tongwane (2015)	Current inventory	Moeletsi & Tongwane (2015)
Poultry	0.0235	0.01 – 0.06	0.02	0.02 – 1.4	0.6 – 0.7	0.6 – 0.7	1.6 - 2	1.8 – 2

EF used in the current inventory

Implied emission factors

Implied emission factors were compared to the IPCC defaults as well as those reported in the Australian NIR (ANIR, 2016) (Table 5.30) since the methodology was adopted from the equations in this report. The dairy cattle IEF is higher than Africa default but is lower than the emission factor for Oceania and Western Europe. It is, however similar to the value reported in the Australian inventory. The differences are due to the different manure management systems in these regions which impacts the MCF. The situation is similar for the IEF for swine. The Other cattle IEF is much lower than that in other countries and is even lower than the Africa default value and this needs to be investigated further in the next inventory. Sheep and goat IEF are lower than IPCC default values but are in line with those from the Australian inventory. Poultry IEFs are consistent with IPCC 2006 default values.

Table 5.30: Comparison between implied emission factors for manure CH_4 (2017) and IPCC default emission factors.

Livestock category	SA IEF (2017)	IPCC			Australia (2016 NIR)
		Africa	Oceania	Western Europe	
	Emission factor (kg CH_4/head/year)				
Dairy cattle	10.35	1	29	55	15
Other cattle	0.10	1	2	16	0.5 – 3.6
Sheep	0.002	0.15	0.15	0.28	0.002
Goats	0.01	0.17	0.17	0.2	

Swine	12.47	1	13 – 24	13 – 20	23
Poultry	0.02	0.02	0.02	0.2	0.03

5.3.5 Recalculations since the 2015 Inventory

Manure emissions were recalculated for all years between 2000 and 2017 due to the following improvements:

a) movement of non-lactating dairy cattle from sub-category *3Aai Dairy cattle* to the sub-category *3Aaii Other cattle* to be in alignment with IPCC 2006 guidelines. This was just a re-allocation of emissions and did not lead to any significant changes in the overall emissions;
b) an adjustment in the other cattle population numbers. The total cattle population from the Agricultural Abstracts (DAFF, 2018) was, in previous inventories, assumed to be the total dairy and other cattle population, however during verification it was found that the total number was only for other cattle. Numbers were corrected to reflect this. The change meant an increase in the number of subsistence cattle. The recalculated emissions due to the adjustments made (a) and (b) were 11.6% higher than the 2015 emissions;
c) Emissions from game manure were removed as, per UNFCCC in-country review, it is not considered to be managed. Again this did not lead to any changes as game manure was not managed and all went to PRP;
d) Adjustments were made to the manure management data for cattle, sheep, goats, swine and poultry based on new data from Moeletsi & Tongwane (2015). Also with the separation of lactating and non-lactating dairy cattle, the manure management data for these categories were also adjusted based on data from Moeletsi & Tongwane (2015);
e) Lastly daily spread manure was moved to the managed soils section and was not included here. This is to bring the methodology in line with recommended IPCC 2006 methodology.

These population and manure management changes led to a 10.6% increase in the manure CH_4 emissions and a 57.3% increase in the manure N_2O emissions for 2015 (Table 5.31).

Table 5.31: Changes in manure management emissions due to recalculations.

Year		Manure management emissions (Gg CO_2e)		Difference	
		2015 submission	2017 submission	(Gg CO_2e)	(%)
2000	Manure CH_4	692.6	763.3	70.7	10.2
	Manure N_2O	975.6	1 520.7	545.1	55.9
2010	Manure CH_4	687.2	759.3	72.0	10.5
	Manure N_2O	1 015.2	1 630.0	614.7	60.6
2015	Manure CH_4	666.5	736.9	70.4	10.6
	Manure N_2O	1 141.3	1 795.4	654.1	57.3

5.3.6 Source specific planned improvements

Currently the two studies available provide fairly varying results, so these data sets will be interrogated further to determine the reason for discrepancies. In addition, the background data and calculations for the Tier 2 calculations of the EF's will be incorporated into the calculation files over the next two inventory cycles. The University of Pretoria is conducting several studies to determine manure emission rates, so these could be incorporated in future once the studies have been published.

5.4 Source Category 3.B Land

5.4.1 Category information

The land component of the AFOLU sector includes CO_2 emissions and sinks of the carbon pools above-ground and below-ground biomass, litter 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 and CH_4 emissions from biomass burning were estimated but are included in the *aggregated and non-CO_2 emission sources on land* section, while CH_4 emissions from wetlands were included here following the methodology in the previous inventories (DEAT, 2009; DEA, 2014).

Organic soils were assumed to be negligible (Moeletsi et al., 2015) and therefore not included, however the distribution of organic soils is currently under investigation and new data will be incorporated into the next inventory. All other emissions in the land category were assumed to be negligible.

National circumstances

South Africa has an area of 124 929 820 ha and has a warm, temperate and dry climate. Low shrublands dominate the land covering approximately a third of the land area, followed by grasslands which covers approximately one fifth (Table 5.32). Indigenous forests and plantations cover around 2% of the area, while woodlands and thickets cover 10% and 7%, respectively. The largest change between 1990 and 2014 was seen in the cultivated area, with a 220% increase in the irrigated annual crop area. Plantations and grasslands show a decline in area (Table 5.32).

Table 5.32: Land cover change between 1990 and 2014 (Source: GTI, 2015).

Land class	1990		2014		% change
	1000 ha	% of total area	1000 ha	% of total area	
Indigenous forest	376.65	0.30	428.44	0.34	13.75
Thicket/dense bush	6 645.98	5.32	8 291.67	6.64	24.76
Woodland/open bush	11 007.79	8.81	12 434.93	9.95	12.96
Low shrubland	41 139.86	32.93	41 827.26	33.48	1.67
Plantations/woodlots	1 922.82	1.54	1 873.70	1.50	-2.55
Cultivated commercial annual crops (non-pivot)	11 486.58	9.19	10 610.84	8.49	-7.62
Cultivated commercial annual crops (pivot)	244.27	0.20	782.05	0.63	220.16
Cultivated commercial permanent orchards	313.57	0.25	346.95	0.28	10.64
Cultivated commercial permanent vines	162.35	0.13	188.71	0.15	16.23
Cultivated semi-commercials and subsistence crops	1 984.30	1.59	2 040.53	1.63	2.83
Settlements (incl. small holdings)	2 742.92	2.20	2 908.28	2.33	6.03
Wetlands	1 526.14	1.22	1 025.90	0.82	-32.78
Grasslands	27 490.97	22.01	25 793.97	20.65	-6.17
Mines	291.76	0.23	328.97	0.26	12.76
Waterbodies	2 202.04 [a]	1.76	2 045.62 [a]	1.64	-7.10
Bare ground	13 902.45	11.13	13 057.93	10.45	-6.07
Degraded	1 489.36	1.19	944.06	0.76	-36.61
Total	**124 929.82** [a]		**124 929.82** [a]		

[a] *Includes an ocean component which is removed (as discussed in section 5.5.3) for the purpose of the inventory.*

Emissions

The *Land* sector was estimated to be a sink in 2017, which increased significantly since 2014 (Figure 5.6). In 2017 *Forest land* was the main contributor to the CO_2 sink, followed by *Grasslands.* The increasing *Forest land* sink was mainly due the increasing forest land area, which leads to increased woody growth and carbon gains, and the decrease in carbon losses (particularly disturbance losses) (see section 5.4.5). In *Grasslands* the soil carbon dominates the sink (see section 5.4.7), particularly from *land converted to*

Grasslands. *Croplands, Wetlands* and *Other lands* were estimated to be sources of CO_2 (Table 5.33). *Other land* was dominated by the sub-category *land converted to Other land*. In these converted areas all carbon is removed from the system therefore a loss of CO_2 (i.e. CO_2 source) occurs (see section 5.4.10). *Forest lands* were a sink throughout the time period, while *Settlements* were a small source in some years and a small sink in others.

A detailed summary table of emissions and removals for the *Land* sector in 2017 are provided in Appendix 5A.

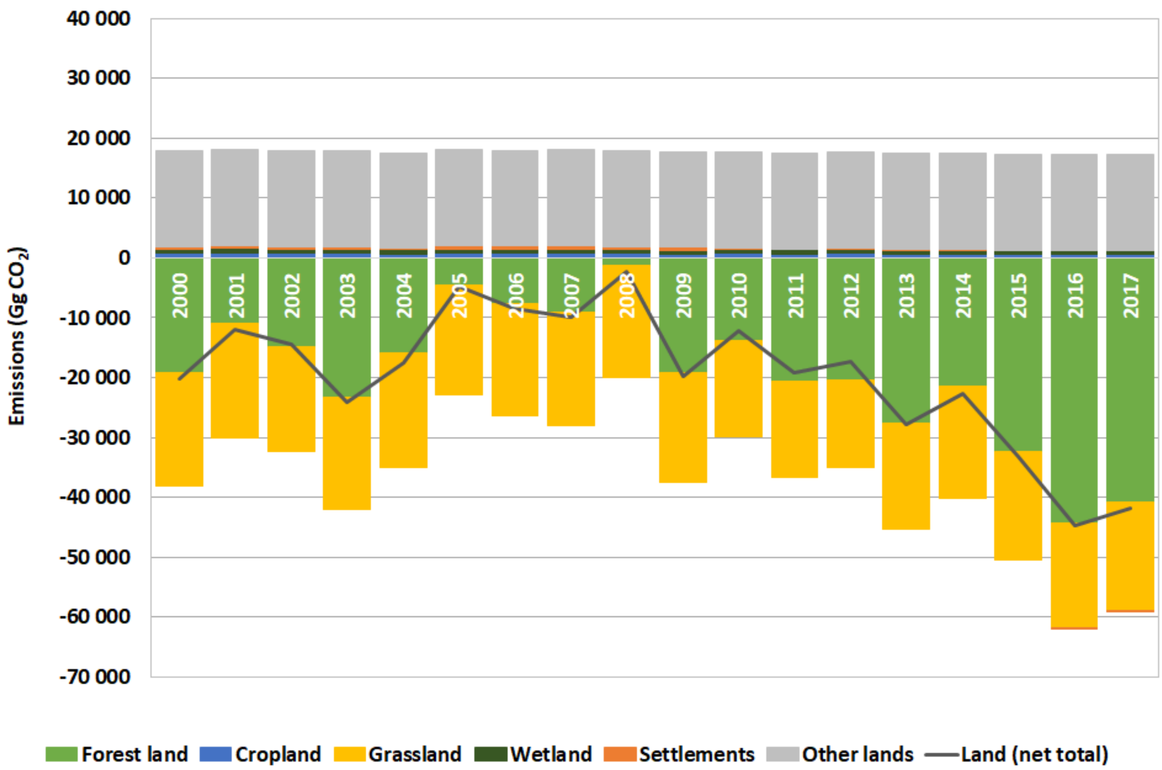


Figure 5.7: Time series for GHG emissions and removals (Gg CO_2) in the Land sector in South Africa.

Table 5.33: Trends in emissions and removals between 2000 and 2017 from the Land sector in South Africa.

	Emissions and removals (Gg CO_2e)

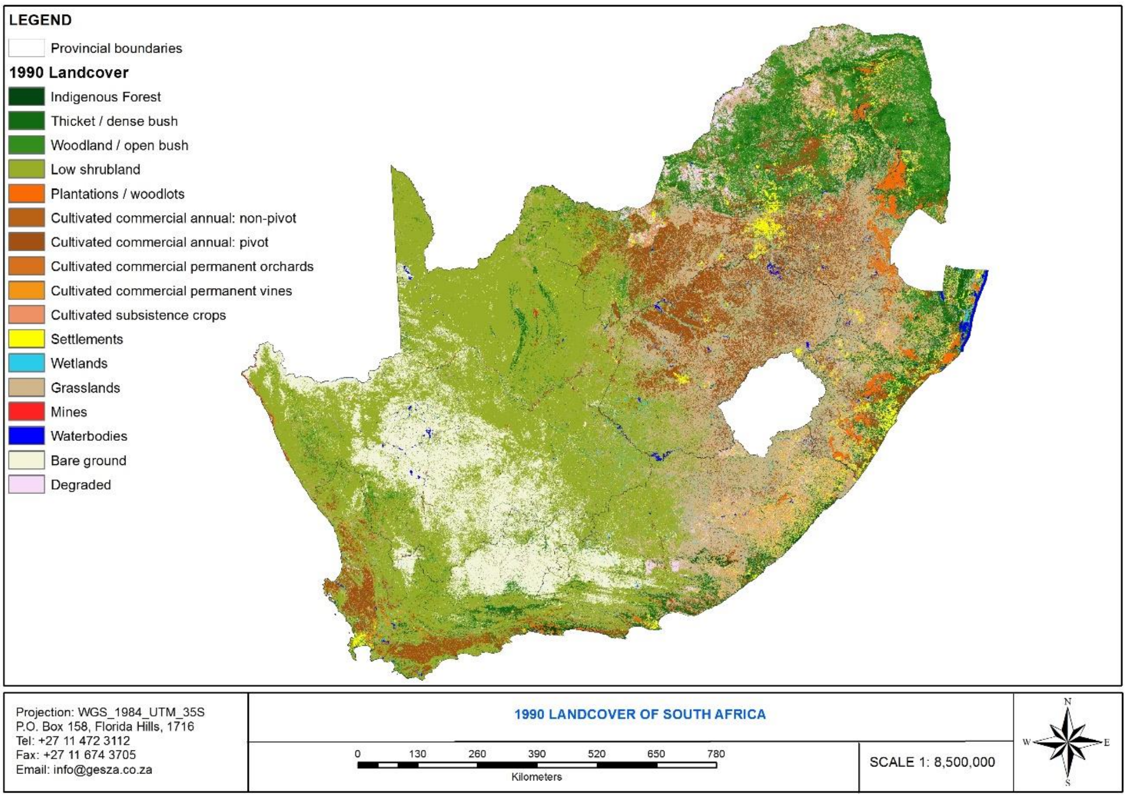
	3B1 Forest land	3B2 Cropland	3B3 Grassland	3B4 Wetlands	3B5 Settlements	3B6 Other lands
2000	-19 212.9	768.2	-18 903.7	666.6	399.5	16 044.8
2001	-10 984.9	852.5	-19 029.1	666.6	458.7	16 044.8
2002	-14 785.9	772.2	-17 582.7	666.6	386.6	16 044.8
2003	-23 367.5	766.5	-18 577.0	666.6	310.8	16 044.8
2004	-15 863.7	659.2	-19 247.3	666.6	205.7	16 044.8
2005	-4 515.7	770.8	-18 437.4	666.6	672.6	16 044.8
2006	-7 586.2	701.0	-18 824.0	666.6	568.3	16 044.8
2007	-9 099.2	784.3	-19 031.0	666.6	646.2	16 044.8
2008	-1 260.0	839.5	-18 841.1	666.6	333.6	16 044.8
2009	-19 149.0	632.0	-18 388.8	666.6	435.6	16 044.8
2010	-13 898.3	726.0	-16 042.5	666.6	281.4	16 044.8
2011	-20 623.0	690.2	-16 003.6	666.6	142.2	16 044.8
2012	-20 438.9	750.5	-14 523.0	666.6	132.7	16 044.8
2013	-27 595.3	641.1	-17 791.5	666.6	154.9	16 044.8
2014	-21 517.7	589.9	-18 640.8	666.6	169.1	16 044.8
2015	-32 260.0	562.7	-18 182.4	666.6	44.6	16 044.8
2016	-44 357.3	543.6	-17 466.1	666.6	-101.6	16 044.8
2017	-40 707.4	528.3	-18 155.3	666.6	-105.8	16 044.8

5.4.2 Land representation

Land maps

The South African National Land-Cover Dataset 1990 (GTI, 2015) and 2013-14 (GTI, 2014) (Figure 5.8), developed by GeoTerraImage (GTI), were used for this study to determine long-term changes in land cover[10] and their associated impacts. Land-use changes were mapped using an Approach 2 method as described in 2006 IPCC Guidelines.

[10] The term 'land cover' is used loosely here as the classes are a combination of land cover and land use.


LEGEND
Provincial boundaries
1990 Landcover
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
Projection: WGS_1984_UTM_35S
P.O. Box 158, Florida Hills, 1716
Tel: +27 11 472 3112
Fax: +27 11 674 3705
Email: info@gesza.co.za
1990 LANDCOVER OF SOUTH AFRICA
0 130 260 390 520 650 780
Kilometers
SCALE 1: 8,500,000
N
W
E
S

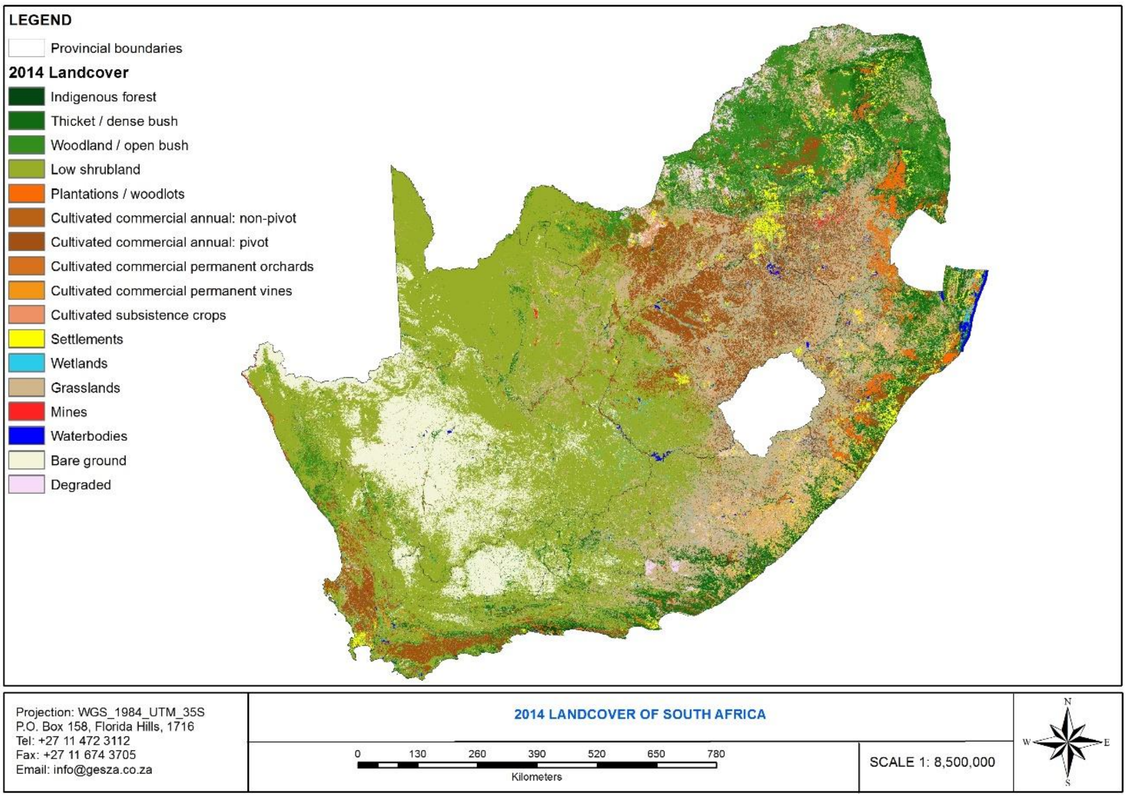


Figure 5.8: Land cover maps for South Africa for 1990 (top) and 2014 (bottom) (Source: GTI, 2014; 2015).

Land category definitions

The 2013-14 National Land Cover Datasets had 72 land classes as well as a condensed 35 class list. For the purpose of this 2017 inventory these were simplified into 17 classes due to the size of the dataset and the available timeframe. Annual land change data had to be derived from the 1990 – 2014 land cover change data, and the more categories that were included the more complex and time consuming the process became. It is, however, recommended that in future an attempt is made to incorporate the more detailed land use classes as this would improve the accuracy of the land data. Information from the detailed classes for settlements and croplands were utilized in the calculations and the methodology is described in further detail in the relevant category methodology sections.

The classes used in the 2017 inventory are provided in Table 5.34. Detailed description of the 35 land cover classes provided in the LC maps are described in detail in GTI (2014; 2015) and the following additional information is provided regarding the IPCC classification:

- *Forest land*:
  - Includes indigenous forests, plantation/woodlots, thicket/dense bush and woodland/open bush, i.e. all areas that have a woodland canopy cover of over 5%.
  - This is in line with the National Forest Act (Act 84 of 1998) (NFA) which states that
    - "forest" include a natural forest, a woodland and a plantation (Section 1(2)(x) of NFA);
    - "natural forest" means a group of trees whose crowns are largely contiguous, or which have been declared by the Minister to be a natural forest (Section 1(2)(xx) of NFA);
    - "plantation" means a group of trees cultivated for exploitation of the wood, bark, leaves or essential oils (Section 1(2)(xxii) of NFA); and
    - "woodland" means a group of indigenous trees which are not a natural forest, but whose crowns cover more than five percent of the area bounded by the trees forming the perimeter of the group (Section 1(2)(xxxix) of NFA).
  - The definition of Forests in South Africa's National Forest Act relates to international definitions and corresponds well with the UNFCCC decision in this regard that was adopted in Marakesh Accord. It also corresponds with the FAO definition of forests except that the FAO regards 10% as the lower boundary for woodland canopy cover. South Africa's NFA definition is lower (5%) and thus also includes degraded woodland into that definition so that other provisions of the statute would still remain applicable even to degraded woodlands.
- *Croplands*:
  - Includes annual commercial croplands (pivot and non-pivot), permanent perennial orchards, permanent perennial vines, and semi-commercial or subsistence croplands.
- *Grasslands*:
  - Includes grasslands, low shrublands and degraded land;
  - Grasslands include range and pasture lands that were not considered cropland. The category also included all grassland from wild lands to recreational areas as well as agricultural and silvi-pastural systems, consistent with national definitions;
  - Low shrublands was, in the previous submission, classes under *Other lands*. This category was re-assessed and according to IPCC 2006 Guidelines (IPCC, 2006) *Other lands* are for lands that have minimal carbon, such as

rocks, ice, etc. Low shrublands are vegetated areas so it would therefore be more appropriate to put them under grasslands instead of *Other lands*. This is also apparent in the way the ALU software deals with *Other lands*.
    - Degraded land was, in the last inventory, classed under *Other lands*. As mentioned in the previous inventory, and through the UNFCCC in-country review, it is better to incorporate degraded land as part of a vegetation class since it has vegetation present. It is not known what class the degraded land belongs to, so in this inventory it is assumed to be part of the *Grassland* category. As data becomes available In future, this degraded land can be reclassified into the various vegetation classes.
- *Settlements*:
    - Includes transportation infrastructure and human settlements. This includes 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, as well as towns and villages;
    - Mines are also included in this category. 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.
- *Wetlands*:
    - Includes all wetlands and waterbodies as defined in GTI (2014; 2015).
- *Other lands*:
    - Includes bare ground, rocks, and degraded land.

Table 5.34: Land classification for the 2017 inventory.

35 class categories	17 class categories	IPCC category 2017 submission
Indigenous forests	Indigenous forests	Forest land
Forest: Fynbos		
Plantations/woodlots	Plantations/woodlots	
Thicket/dense bush	Thicket/dense bush	
Thicket: Fynbos		
Thicket: Nama-Karoo		
Thicket: Succulent Karoo		
Woodland/open bush	Woodland/open bush	
Open bush: Fynbos		
Open bush: Nama-Karoo		
Open bush: Succulent Karoo		
Grasslands	Grasslands	Grassland
Grasslands: Fynbos		
Grasslands: Nama-Karoo		
Grasslands: Succulent Karoo		
Low shrubland	Low shrubland	
Low shrubland: Fynbos		
Low shrubland: Nama-Karoo		
Low shrubland: Succulent Karoo		
Degraded	Degraded	
Bare ground	Bare ground	Other land
Bare ground: Fynbos		
Bare ground: Nama-Karoo		
Bare ground: Succulent Karoo		
Cultivated commercial annual: non-pivot	Cultivated commercial annual: non-pivot	Cropland
Cultivated commercial annual: pivot	Cultivated commercial annual: pivot	
Cultivated commercial permanent orchards	Cultivated commercial permanent orchards	
Cultivated commercial permanent vines	Cultivated commercial permanent vines	
Cultivated subsistence crops	Cultivated subsistence crops	
Settlements	Settlements	Settlements
Mines	Mines	
Waterbodies	Waterbodies	Wetlands
Wetlands	Wetlands	

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Land-use mapping methodology

Mapping approach for 1990 and 2014 LC maps

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.

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 reports (2014, 2015).

As in the previous inventory, some corrections were made to these maps for the purpose of this inventory:

- both land cover datasets contained area of oceans, which was removed from each dataset by extracting the dataset from within the national boundary;
- Wetlands were extracted from each dataset, merged into a single wetland dataset (1990 and 2014 combined wetlands) and merged with the 1990 and 2014 land cover datasets. This was conducted to mitigate against dry versus wet years where moisture availability would influence the area detected, rather than the land cover actually undergoing a land change process; and

- the same process was applied to the degraded land class for similar reasons. As such, the 1990 and 2014 datasets contained the exact same area for wetlands and degraded land.

After implementing these changes the land area was 122 518 007 ha.

Land use change

The land cover datasets for 1990 and 2014 (GTI, 2014; 2015) both had the identical 17 classes and had a pixel size of 30 m x 30 m, which was maintained throughout the GIS analysis component of this project. As mentioned above, some corrections were made to these maps and these were then overlaid to produce a land change map (Figure 5.9). A land change matrix was derived from the LC map.

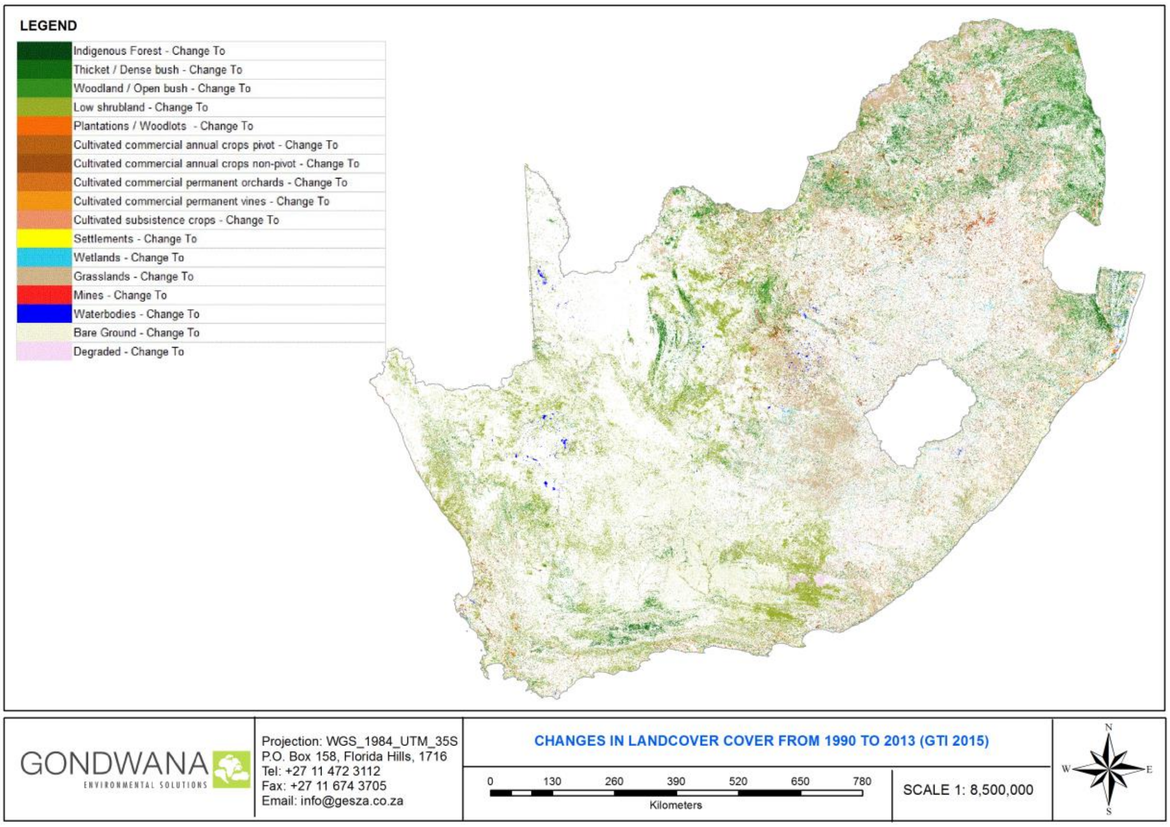

Figure 5.9: Land cover change in South Africa between 1990 and 2014.

Plantation area correction

Plantation areas were compared to Forestry SA data and it was found that the LC maps had much larger plantation areas. Corrections were therefore made on the land change matrix in excel to correct for this.

In order to carry out the corrections some assumptions had to be made. It was assumed that conversions only occur between grassland, croplands and plantations as Forestry SA indicated this to be the case. All land change areas from other land uses were converted back to the original land use. The plantation area for 2014 from Forestry SA was applied in place of the 2014 area from the map. Since the afforestation and deforestation[11] area provided did not match the change in plantation area reported the afforested area was assumed to be correct and the deforested area was calculated from the plantation areas. In 2014 the area of plantation remaining plantation was equal to the plantation area minus the afforested area over the 24-year period. The area converted to other lands was determined from the plantation area in 1990 minus the plantation area remaining plantation area. To distribute this converted area between the different cropland types the relative converted areas from the original land change matrix was utilised.

Annual land change matrix

An annual land change matrix was created for all land categories for the period 1990 to 2014 (Table 5.35).

Incorporating the 20-year transition period

Each land type is divided into land remaining land and land converted to that land class. IPCC states that land remains in the land converted to category for the default 20-yr period. After 20 years the converted land moves to the land remaining land category. In this inventory the 20-year transition period was included for each land category. It was assumed that the same annual rate of change occurred prior to 1990, therefore the area of land converted to and land remaining land for each land type in 1990 was calculated as:

$LC_{i\ 1990} = ALC_{i\ 1990} * 20\ yrs$

[11] Forestry SA reports on "Area converted out of plantation".

$LRL_{i\ 1990} = A_{i\ 1990} - LC_{i\ 1990}$

Where:

$LC_{i\ 1990}$ = area (ha) of land in land converted to land category *i* in 1990;
$ALC_{i\ 1990}$ = annual total area (ha) converted to land category *I* in 1990;
$LRL_{i\ 1990}$ = area (ha) of land in the land remaining in the land category *i* in 1990;
$A_{i\ 1990}$ = total area of land in category *i* in 1990.

For subsequent years these categories were calculated as follows:

$LC_{i\ t} = LC_{i\ t-1} + ALC_{i\ t} - ALC_{i\ (t-20)}$

$LRL_{i\ t} = LRL_{i\ t-1} + ALC_{i\ t} - ACF_{i\ t}$

Where:

$LC_{i\ t}$ = area (ha) of land in land converted to land category *i* in year t;
$LC_{i\ t-1}$ = area (ha) of land in land converted to land category *i* in year t-1;
$ALC_{i\ t}$ = annual total area(ha) converted to land category *i* in year t;
$ALC_{i\ (t-20)}$ = annual total area (ha) converted to land category *i* in year t-20;
$LRL_{i\ t}$ = area (ha) of land in the land remaining in the land category *i* in year t;
$LRL_{i\ t-1}$ = area (ha) of land in the land remaining in the land category *i* in year t-1;
$ACF_{i\ t}$ = annual total area (ha) converted from land category *i* to another land category in year t.

Since the land change map for 2014 to 2018 was not available at the time of compiling this inventory it was assumed that the annual change between 1990 and 2014 continued to 2017. This assumption will be corrected in the next inventory when the updated maps will be utilised.

Table 5.35: Annual land conversion areas (ha) for South Africa between 1990 and 2014.

Land categories		2014																
		Indigenous Forest	Thicket/ dense bush	Woodland/ open bush	Low s hrubland	Plantations/ woodlots	Commercial Annual crop:	Commercial Annual crop:	Permanent orchards	Permanent vines	Cultivated subsistence crops	Settlements	Wetlands	Grasslands	Mines	Waterbodie s	Bare ground	Degraded
1990	Indigenous Forest		1 857	325	60	0	35	1	28	0	41	84	0	280	11	1	23	0
	Thicket/ dense bush	2 003		53 279	15 913	0	4 225	375	981	161	2 132	1 970	0	34 718	357	435	888	0
	Woodland/ open bush	420	63 139		54 184	0	4 021	1 424	484	71	2 945	3 384	0	76 698	637	481	6 666	0
	Low shrubland	206	25 088	59 216		0	9 566	2 675	575	581	397	2 367	0	172 823	324	519	104 651	0
	Plantations/ woodlots	0	0	0	0		7 169	165	1 778	206	652	0	0	0	0	0	0	0
	Commercial annual crop: non-pivot	30	3 892	9 264	16 655	0		16 223	1 322	361	717	1 158	0	33 744	1 559	91	424	0
	Commercial annual crop: pivot	0	118	241	119	0	1 037		146	39	15	39	0	222	27	2	7	0
	Permanent orchards	6	616	355	250	0	753	153		421	168	45	0	409	2	5	7	0
	Permanent vines	0	211	23	221	0	121	24	143		0	23	0	60	0	7	7	0
	Cultivated subsistence crops	11	3 474	7 520	564	0	1 879	75	116	11		362	0	3 245	59	40	239	0
	Settlements	43	2 964	1 394	793	0	747	5	30	9	1 306		0	4 143	60	25	136	0
	Wetlands	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0

	Grasslands	989	69 807	127 370	161 299	9 635	26 490	2 826	452	76	9 451	8 031	0		2 170	928	9 040	0
	Mines	0	309	784	366	0	46	5	0	0	17	53	0	2 091		8	107	0
	Waterbodies	10	1 091	618	1 153	0	157	7	12	6	34	43	0	1 456	10		3 677	0
	Bare ground	11	3 338	8 747	146 389	0	122	75	9	112	14	190	0	7 931	36	1 036		0
	Degraded	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Climate

Long term climate maps were developed for South Africa (Moeletsi et al., 2015) which categorize the climate into the classes provided by 2006 IPCC Guidelines (Figure 5.10).

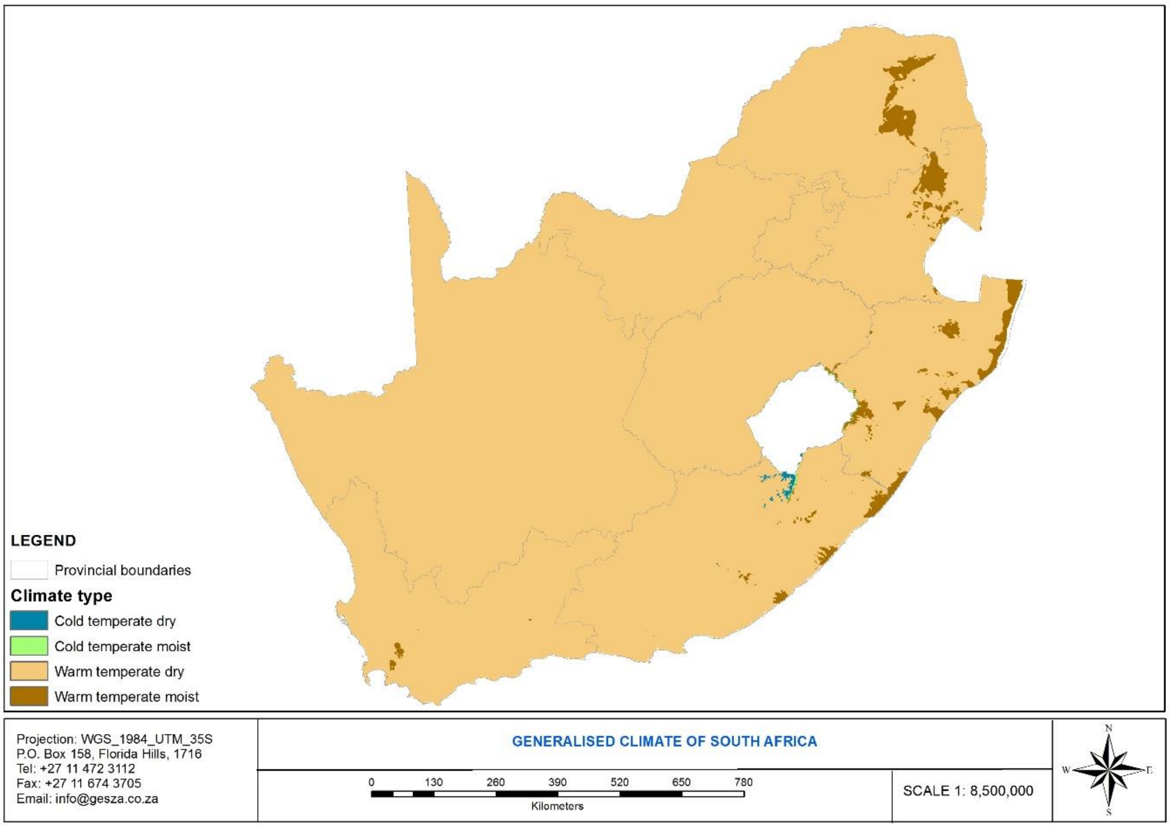

Figure 5.10: South Africa's long term climate map classified into the IPCC climate classes (Source: Moeletsi et al., 2015).

Soil

South Africa's detailed soils map was reclassified into the eight soil classes provided by IPCC 2006 Guidelines (Moeletsi et al., 2015) (Figure 5.11).

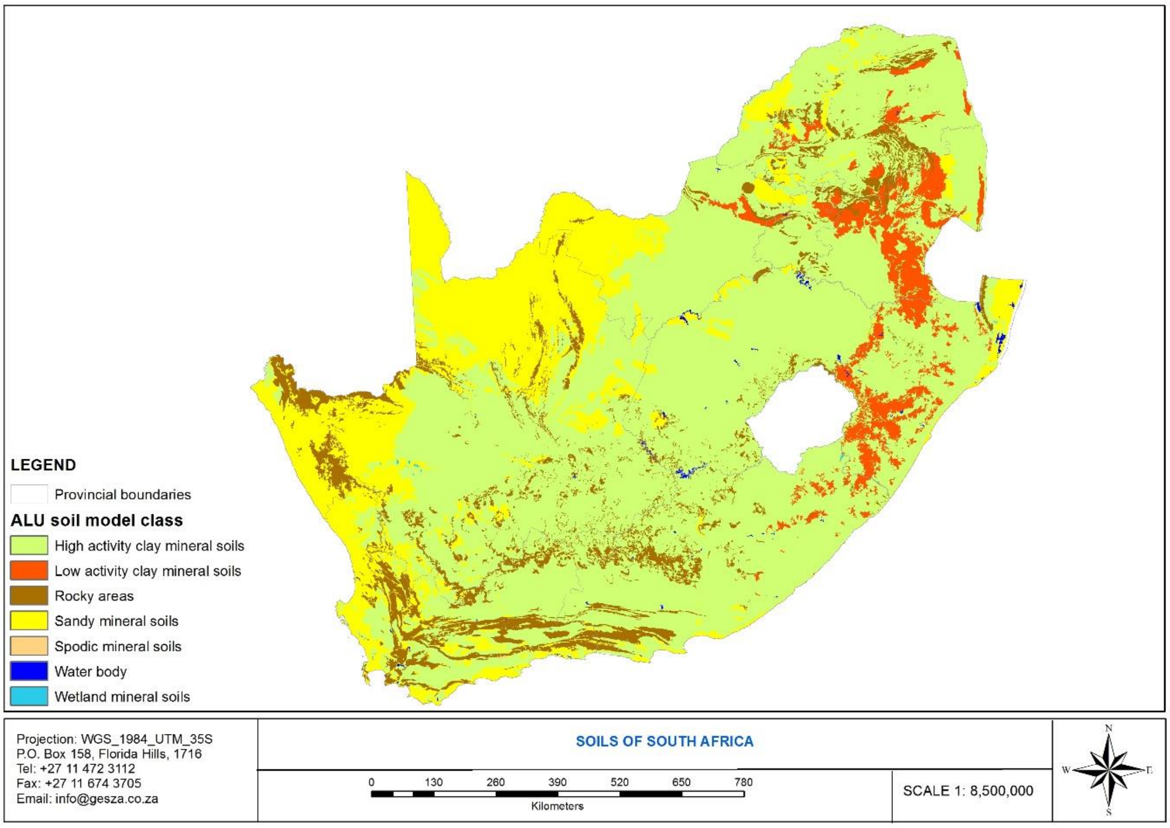

Figure 5.11: South African soils classified into the IPCC classes (Moeletsi et al., 2015).

Annual change by soil, climate and land type

To determine the area of each land class in a particular soil and climate type, the climate and soil datasets were extracted using the national boundary to represent South Africa only. Each dataset was re-projected into the same projection as the land cover datasets (UTM 35s). Each dataset was resampled to a 30 m x 30 m pixel size to match the land cover datasets. Once the 1990 and 2014 land cover datasets and the climate and soil datasets were processed into the same projection and pixel size, they were combined with each other to generate a land cover change dataset, within each climate and soil category. An output table was then generated and annual areas calculated in a similar manner to that mentioned above.

A correction was also applied to the SOC data which was the overlay of land cover, climate and soil type. Since the overlays were all different resolutions it was found that a small amount of land area was lost and therefore the areas did not match the area in the biomass and DOM files. This was corrected by taking the ratio of the various soil and climate sub-categories and applying it to the actual area for the various land type (i.e the areas in the biomass data files). In this way both the total area was corrected as well as the 20 year transition period.

5.4.3 Methodology

South Africa uses a combination of Tier 1, and Tier 2 methods for estimating emissions for the *Land* category. 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 with country specific data. For plantations the Tier 2 approach of this equation was applied. The annual decrease in carbon stocks due to biomass losses were estimated from Equations 2.11 to 2.14 of the IPCC 2006 Guidelines. A Tier 2 approach was implemented for the estimation of carbon biomass stock change in *Forest land* for both *land remaining land* and *land converted to forest land*, while for all the other land classes a Tier 1 for *land remaining land* and a Tier 2 for *land converted to other land* (IPCC 2006 Equations 2.15 and 2.16) were applied. The dead organic matter pool only includes litter estimates due to a lack of dead wood data, and it is assumed that all litter pool carbon losses occur entirely in the year of transition (Tier 1). Carbon stock changes in litter were estimated with the stock-difference method (Tier 1), according to Equation 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 with a Tier 1 approach from the formulation B of Equation 2.25 (IPCC, 2006 Guidelines, volume 4, p. 2.34). A summary of the methods used are provided in Table 5.5.

Emission factors

The emission factors required to estimate carbon stock changes are provided in Table 5.36. In the previous inventory the BCEF for plantations was taken from Dovey (2009), however after a more detailed investigation of the data suggests that these BCEF were not appropriate for the following reasons: (a) these values were determined from mature stands only, therefore are not applicable as a plantation average; and (b) it states that the conversion for branches includes live and dead biomass so is not comparable with the BCEF from IPCC. These two reasons may also explain why the Dovey (2009) factors were lower than the IPCC values. In this submission the IPCC 2006 default values for temperate climate were applied as no other country-specific data was available. A country-specific study has recently been completed but the data was still in review at the time of compilation, therefore, this data can be utilised in the next inventory.

Table 5.36: Factors applied in the calculation of the land sources and sinks in South Africa.

Land class	Biomass C stock (AGB + BGB)	Root to shoot ratio	Biomass growth rate	Biomass increment	Litter C stock
	(t C/ha)		(t dm/ ha/yr)	(t dm/ ha/yr)	(t C/ha)
Indigenous forest	62.86[1]	0.28[4]	0.92[10,11]		9[1]
Plantations				10.8[14]	9[1]
Softwoods	52[2]	0.28[5]			
Euc. Grandis	44[2]	0.24[5]			
Other Euc.	44[2]	0.24[5]			
Wattle	44[2]	0.34[5]			
Other hardwoods	44[2]	0.34[5]			
Thicket/dense bush	21.16[1]	0.49[6,7]	1.5[7,11]		2.54[1]
Woodland/open bush	5.43[3]	0.24[8]	0.9[12]		1.21[1]
Annual crop (pivot)	5.36[3]				2.16[3]
Annual crop (non-pivot)	4.15[3]				3.16[3]
Subsistence crop	1.86[1]				1.1[3]
Perennial orchard	26.6[1]		1.1[13]		6.23[3]
Perennial vine	9.8[1]		0.4[13]		10.77[3]
Wetland	9.04[3]				2.14[3]
Grassland	4.42[1]				0.9[1]
Low shrubland	2.42[3]		0.12		2.53[3]
Settlements Woodland/open bush	4.21[1]	0.24[9]			1.67[3]
Mine	4.21				1.03[3]
Other land	0				0

[1] *NTCSA report (DEA, 2015)*
[2] *Alembong (2014)*
[3] *NTCSA data overlay*

[4] *Seydack (1995)*
[5] *Du Toit et al. (2016)*
[6] *Mills et al. (2005)*
[7] *Van der Vyver et al. (2013)*
[8] *NIR for SA for 2000 (DEA, 2009)*
[9] *Van Leeuwen et al. (2014)*
[10] *Midgley and Seydack (2006)*
[11] *Geldenhuys (2011)*
[12] *Hoffman and Franco (2003)*
[13] *Calculated from biomass and applied an average harvest cycle of 25 years (CGA Stats Book, 2016)*
[14] *Weighted average determined from FSA data on MAI per species and per product type.*

Emission calculations

The general equation for calculating emissions from biomass changes on land remaining land is the IPCC (2006) equation 2.4:

$$\Delta C_B = \Delta C_G - \Delta C_L \qquad \text{(Eq. 5. 1)}$$

Where:

ΔC_B = annual change in carbon stocks in biomass for each land sub-category (tonnes C yr^{-1});
ΔC_G = annual increase in carbon stocks due to biomass growth for each land sub-category (tonnes C yr^{-1});
ΔC_L = annual decrease in carbon stocks due to biomass loss (due to harvesting, fuel wood removals and disturbance) for each land sub-category (tonnes C yr^{-1}).

The general equation for calculating emissions from biomass changes on land conversions (IPCC, 2006; equation 2.15) is:

$$\Delta C_B = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L \qquad \text{(Eq. 5. 2)}$$

Where:

ΔC_B = annual change in carbon stocks in biomass for each land sub-category (tonnes C yr^{-1});
ΔC_G = annual increase in carbon stocks due to biomass growth for each land sub-category (tonnes C yr^{-1});
ΔC_L = annual decrease in carbon stocks due to biomass loss (due to harvesting, fuel wood removals and disturbance) for each land sub-category (tonnes C yr^{-1}).

Also (IPCC, 2006; equation 2.16),

$$\Delta C_{CONVERSION} = \sum\{(B_{AFTERi} - B_{BEFOREi}) * \Delta A_{TO\_OTHERSi}\} * CF \qquad \text{(Eq. 5. 3)}$$

Where:

$\Delta C_{CONVERSION}$ = initial change in biomass carbon stocks on land converted to another land category (tonnes C yr^{-1});
B_{AFTER} = biomass stocks on land type *i* immediately after conversion (tonnes C yr^{-1});
B_{BEFORE} = biomass stocks on land type *i* before the conversion (tonnes C yr^{-1});
ΔA_{TO_OTHERS} = area of land use *i* converted to another land-use category in a certain year (ha yr^{-1});
CF = carbon fraction of dry matter (tonne C (tonnes d.m.)$^{-1}$.

Changes in litter were calculated with the IPCC (2006) equation 2.23:

$$\Delta C_{DOM} = \{(C_n - C_o) * A_{on}\}/T_{on} \qquad \text{(Eq. 5.4)}$$

Where:

ΔC_{DOM} = annual change in carbon stocks in litter (tonnes C yr^{-1});
C_n = litter stock under the new land-use category (tonnes C yr^{-1});
C_o = litter stock under the old land-use category (tonnes C yr^{-1});
A_{on} = area undergoing conversion from old to new land-use category (ha);
T_{on} = time period of transition from old to new land-use category (yr). Tier 1 default is 20 years.

Land areas were stratified by default soil types and climate regions in order to obtain SOC reference values and which were incorporated into the following general equation (IPCC, 2006; equation 2.25 and Box 2.1):

$$\Delta C_{Mineral} = [\sum[\{(SOC_{REF}*F_{LU}*F_{MG}*F_I)_0 - (SOC_{REF}*F_{LU}*F_{MG}*F_I)_{(0-T)}\}*A]]/D \qquad \text{(Eq. 5.5)}$$

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

5.4.4 Recalculations since the 2015 inventory

Recalculations were performed for the entire time series for the *Land* sector due to several updates and improvements:

- Land area corrections:
  - Degraded land was moved from *Other land* to *Grassland* category;

- Plantation area from land cover was corrected to reflect the areas provided by Forestry SA;
- Area corrections for the 20 year IPCC default transition period; and
- Corrections and simplification of area data from overlay of soil, climate and land cover maps were made.

- Biomass losses:
  - Burnt area data was updated to MODIS collection 6 data;
  - Annual burnt area was applied instead of 5-year averages; and
  - The assumption that fires don't occur in forests and thickets was removed and burnt area was determined for these categories;
- Biomass, DOM and SOC factors:
  - Biomass factors and carbon stock data was updated to be in alignment with the NTCSA (DEA, 2015);
  - The Tier 1 assumption that the final carbon stock in Other lands is zero was applied; and
  - For Croplands the soil stock change factors were updated with the values from the IPCC 2019 Refinement.

The recalculations produced a sink estimate that was 18.7% greater than the previous submission for the year 2015. The recalculation impacts did, however, vary from year to year, with some years showing and increased sink and others a decreased sink (Figure 5.12).

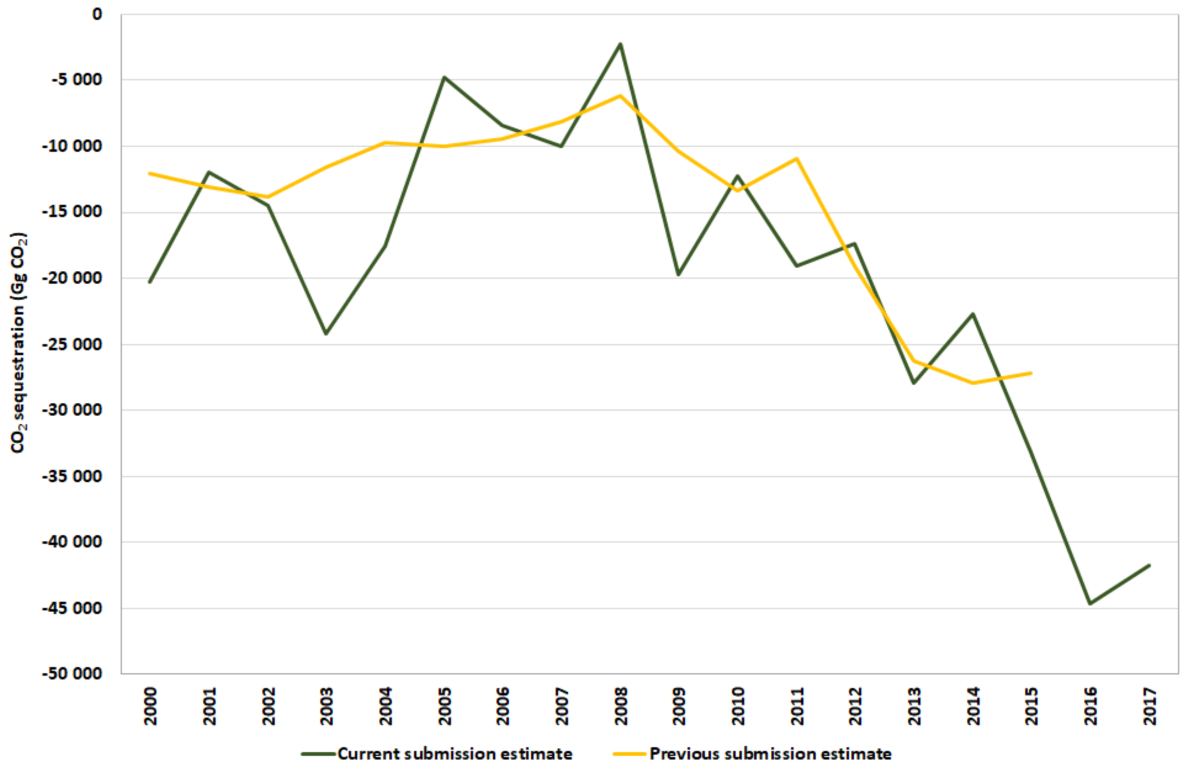

Figure 5.12: Recalculated Land category emissions compared to 2015 submission data, 2000 – 2017.

5.4.5 Source Category 3.B.1 Forest land

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. *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 category 3C1 (see Section 5.5.3). Also all emissions from the burning of fuelwood for energy or heating purposes were reported as part of the energy sector. Emissions from *harvested wood products* are included under 3D1.

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). Calculations are carried out on the basis of a 20-year transition period in that once a land area is converted it remains in the converted land category for 20 years.

Overview of shares and trends in emissions

2000 - 2017

In 2017 *Forest land* was estimated to be a sink and the trends are shown in Figure 5.13. Forest land remaining forest land is a source of emissions between 2000 to 2012 and then becomes a sink. The source is due to increased biomass losses in the earlier years because of higher burnt areas and a larger amount of wood being removed for fuel wood. Fuel wood removal could not be split between land remaining and land converted to forest land categories, therefore, all fuelwood losses were allocated to forest land remaining forest land. This would also contribute to the higher carbon losses and emissions from forest land remaining forest land. Furthermore, there are emissions due to conversion between the various forest types and a conversion from indigenous forest to woodland, for example, leads to a loss of carbon. The sink increases with time due to the increase in forest area, mainly woodlands and thickets, combined with reduced disturbance losses. *Grasslands* converted to *forest lands* are the largest sink component in the converted lands category. Biomass is the dominant carbon pool (Table 5.37).

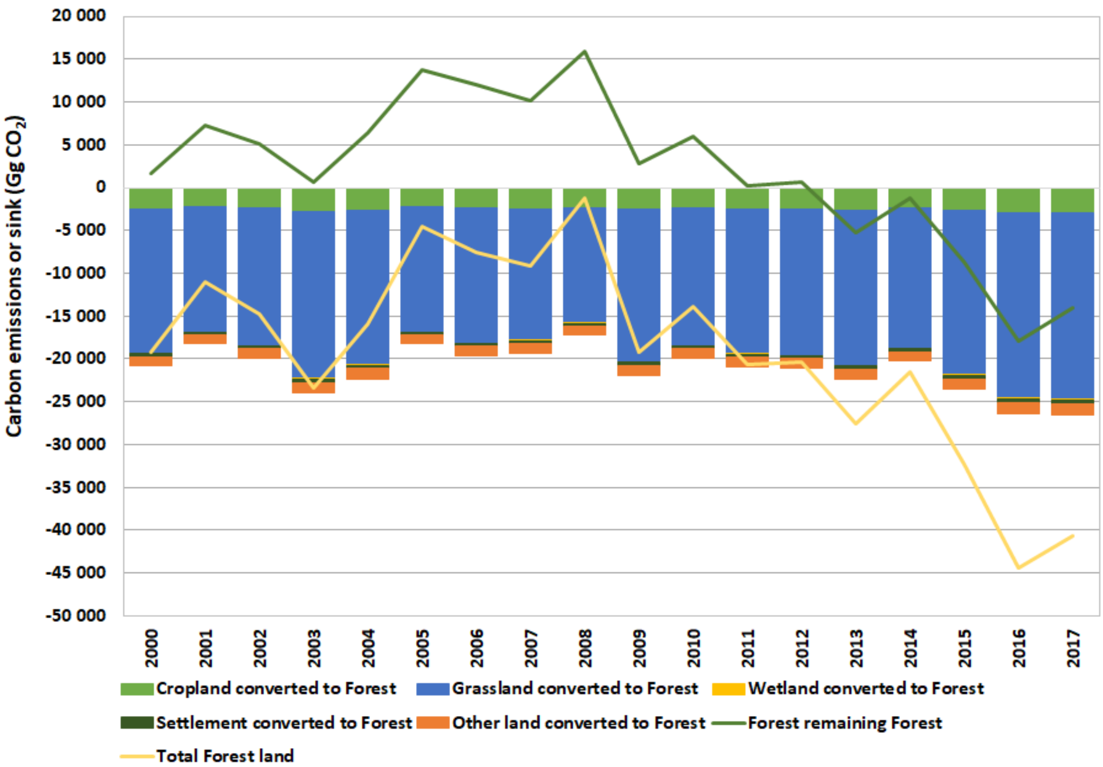

Figure 5.13: CO_2 emissions and removals (Gg CO_2) due to changes in carbon stocks between 2000 and 2017 for South Africa's Forest land.

Table 5.37: South Africa's net carbon stock change (Gg CO_2) by carbon pool for the Forest land, 2000 – 2017.

	Forest land remaining forest land			Land converted to forest land		
	Biomass	Litter	Mineral soil	Biomass	Litter	Mineral soil
2000	2 261.6	-628.4	0.0	-11 716.6	-1 748.3	-7 381.2
2001	7 854.3	-628.4	0.0	-9 081.3	-1 748.3	-7 381.2
2002	5 735.7	-628.4	0.0	-10 763.8	-1 748.3	-7 381.2
2003	1 233.3	-628.4	0.0	-14 843.0	-1 748.3	-7 381.2
2004	7 083.2	-628.4	0.0	-13 189.1	-1 748.3	-7 381.2
2005	14 370.7	-628.4	0.0	-9 128.5	-1 748.3	-7 381.2
2006	12 662.5	-628.4	0.0	-10 490.9	-1 748.3	-7 381.2
2007	10 853.6	-628.4	0.0	-10 194.9	-1 748.3	-7 381.2

2008	16 574.3	-628.4	0.0	-8 076.4	-1 748.3	-7 381.2
2009	3 389.6	-628.4	0.0	-12 780.8	-1 748.3	-7 381.2
2010	6 614.0	-628.4	0.0	-10 754.4	-1 748.3	-7 381.2
2011	913.3	-628.4	0.0	-11 778.5	-1 748.3	-7 381.2
2012	1 282.0	-628.4	0.0	-11 963.0	-1 748.3	-7 381.2
2013	-4 616.5	-628.4	0.0	-13 221.0	-1 748.3	-7 381.2
2014	-652.3	-628.4	0.0	-11 107.5	-1 748.3	-7 381.2
2015	-8 096.1	-628.4	0.0	-14 406.0	-1 748.3	-7 381.2
2016	-17 303.3	-628.4	0.0	-17 296.1	-1 748.3	-7 381.2
2017	-13 465.2	-628.4	0.0	-17 484.4	-1 748.3	-7 381.2

Methodology

Biomass

A list of emission factors is provided in Table 5.36.

Forest land remaining forest land

The total carbon flux (ΔC) was calculated from the IPCC 2006 Guidelines (Equations 2.7 and 2.11) where carbon losses are subtracted from the carbon gains:

$$\Delta C = \Delta C_G - L_{wood\text{-}removals} - L_{fuelwood} - L_{disturbaNces} \quad \text{(Eq. 5. 6)}$$

Carbon gains

Removals and emissions of CO_2 from changes in above- and below-ground biomass are estimated using the Tier 2 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):

$$\Delta CG = \sum(A_i * G_{TOTALi} * CF_i) \quad \text{(Eq. 5.7)}$$

where for G_{TOTAL} a Tier 1 approach was used for natural vegetation classes and a Tier 2 approach was applied for plantations as MAI data per species and management objective were provided by Forestry SA (IPCC, 2006; equation 2.10). This was combined with the IPCC temperate climate default BCEFs. For indigenous forests the growth rate provided by Midgley and Seydack (2006) was applied (Table 5.36). Future inventories should consider further divisions of this category so that more accurate data can be applied to the specific vegetation zones.

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.

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.

Losses due to wood harvesting

Loss of carbon from harvested wood was calculated for plantations only and followed the equation (Equation 2.12 IPCC 2006 Guidelines):

$$L_{wood\text{-}removals} = [H * BCEF_R * (1+R) * CF \qquad (Eq.\ 5.8)$$

Where:
H = annual wood removals ($m^3\ yr^{-1}$)
$BCEF_R$ = biomass conversion and expansion factor for conversion of wood removal volume to above-ground biomass removal(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 due to wood harvesting was only determined for plantations using FSA data (DAFF, 2015) as wood harvesting does not occur in woodlands/open bush, thickets or indigenous forests. The industry conversion factors provided were used to convert between tonnes and m^3. The $BCEF_R$ were taken from IPCC (2006; temperate climate).

All losses due to harvesting were allocated to *Forest land remaining forest land* as it was assumed that recently converted land would not have harvesting due to the long harvest cycle.

Losses due to fuelwood removals

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

$$L_{fuelwood} = [FG_{trees} * BCEF_R * (1+R) + FG_{part} * D] * CF \qquad \text{(Eq. 5.9)}$$

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)$^{-1}$)

The volume of plantation wood that is harvested for fuelwood and charcoal purposes was determined from forestry statistics (DAFF, 2015) and were included in the equation as whole tree removals.

Fuelwood collection from natural forest classes is limited, particularly at the national scale. 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 (StatisticsSA, 2016). The fuelwood consumption numbers are within the range of the value provided by the FAO. The fuelwood consumption estimates show a decline since 2000 due to the increased electrification and reduction in households using fuelwood. There is very little information on how this amount is split between the various vegetation types, therefore, the whole amount was allocated to woodlands/open bush with no removal from forests and thickets.

In the previous inventory the harvested wood from woodlands was incorporated into this equation as removal of whole trees. This has been changed in this inventory as only parts of trees are collected for fuelwood. Therefore the annual volume of fuelwood collected from woodlands was multiplied by a wood density and carbon fraction (as shown by the second part of Eq. 5.9 above).

All losses due to fuelwood collection are allocated to the *Forest land remaining forest land* as there was insufficient data to provide a split on the losses between remaining and converted lands.

Losses due to disturbance

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

$$L_{disturbances} = A_{disturbaNce} * B_W * (1+R) * CF * fd \qquad (Eq.\ 5.10)$$

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

The only disturbance losses that were estimated for all forest land classes were those from fire. For plantations the loss due to other disturbances was also included. Forestry statistics (DAFF, 2015) provides data on the area damaged during fire and other disturbances. The fd for plantation hardwoods and softwoods were determined from FSA data to be 0.63 and 0.68, respectively for fire disturbance, and 0.29 and 0.36, respectively for other disturbances. The AGB (B_W) data are provided in Table 5.36.

For losses due to fire, the burnt area was determined as discussed in detail in Section 5.5.3. The fraction of the total vegetation class area that was burnt was determined so that this fraction could be applied to all climate and soil categories within the *Forest land remaining forest land* and the *land converted to forest land* sub-categories. For natural forest land categories, the fd was taken to be the same as the combustion coefficient used in the biomass burning calculations. The fd of 0.74 was applied for woodland/open bush, which is the average of the early and late season woody savanna default combustion coefficients.

The land converted to plantations could not be split into the various plantation types due to a lack of data so a weighted average Bw value was applied to the plantation data.

Losses due to fire disturbance were calculated for both the *Forest land remaining forest land* and *land converted to forest land* by applying the percentage burnt area to each of the land sub-categories.

Land converted to forest land

The gains and losses for converted land were calculated in the same way as the *Forest land remaining forest land*. On converted land though, the additional component of the initial loss of carbon due to the conversion. This accounts specifically for abrupt changes. It was assumed that all land being converted to plantations were first cleared (i.e. B_{AFTER} = 0), while all other transitions are assumed to be slow transitions and so there is no initial change in biomass carbon stocks due to conversion. The B_{BEFORE} is determined from the biomass data provided in Table 5.36.

Dead organic matter

Forest land remaining forest land

The Tier 1 assumption for the litter pool is that the stocks in *Forest land remaining forest land* are not changing over time, therefore DOM changes are reported to be zero. This is only applicable to areas that remain as a particular forest type, however, in this category there were conversions between the various forest types. Changes in DOM were calculated for these areas using Eq.5.4 above.

Land converted to forest land

The changes in litter are determined from the data provided in Table 5.36 and Eq.5.4 above. It is assumed that the change occurs slowly over the 20 year default transition period.

Soil organic carbon

Annual change in carbon stocks in mineral soils for *forest land remaining forest land* and *land converted to forest land* were calculated by applying a Tier 1 method with Equation 2.25 (IPCC, 2006, Volume 4, p. 2.30). IPCC 2006 default soil carbon reference values were assigned based on the climate and soil type.

For Forest land soil carbon stocks are assumed equal to the reference values (i.e. the stock change factors for management and input are equal to 1). Stock change factors for the various land types converted to forests are dealt with in the relevant land sections.

Uncertainties and time series consistency

All data sources and calculations are consistent throughout the time period.

Uncertainty estimates on emission factors and activity data is limited, but where data is available the uncertainty has been calculated. The overall accuracy for the 2013-2014 land cover map was determined to be 82.5% (GTI, 2015). No uncertainty was provided for the climate and soil maps. Mapping was estimated to have an uncertainty of 5% to 15% depending on the land class, and expert opinion was that area corrections had an uncertainty of 10%. There is a large amount of statistics for plantations and the FSA statistics have a high confidence rating (80% (Vorster, 2008)) with an uncertainty range from -11% to 3% based on a comparison with the RSA yearbook (DEAT, 2009). Activity data uncertainty was difficult to estimate for the other vegetation sub-categories due to a lack of data. Uncertainty would, however, be higher than that for the forestry industry. IPCC 2006 default uncertainties of 30% for land conversions was assumed.

Source specific QA/QC and verification

All general QC listed in Table 1.2 were completed for this category. Land areas were checked. The plantation carbon stock and change data was compared to the data provided in Alembong (2015). Total forest land carbon stock data was compared to the outputs of the National Terrestrial Carbon Sinks Assessment (DEA, 2015).

Source specific planned improvements

No specific improvements are planned however the following areas of improvement have been identified:

- the land-use change maps start to include further woodland/open bush categories so that more accurate biomass data can be applied to the different woodland types;
- calculate carbon stock change for plantations using forestry data;
- improved national estimates of fuelwood collection data;
- collect more data on tree growth rates; and
- undertake a more detailed uncertainty analysis.

5.4.6 Source Category 3.B.2 Croplands

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 and litter. *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 20-year transition period in that once a land area is converted it remains in the converted land category for 20 years.

Overview of shares and trends in emissions

2000 - 2017

Croplands are estimated to be an overall source of CO_2. *Cropland remaining cropland* is a small sink, while *land converted to croplands* emit twice as much CO_2 (Figure 5.14). Conversion of forest land to cropland is the largest contributor to the emissions from this category. The trend remains fairly constant over the 17-year time period, mainly due to little change in the area of perennial crops. The soil carbon pool is the dominant contributor to the source (Table 5.38).

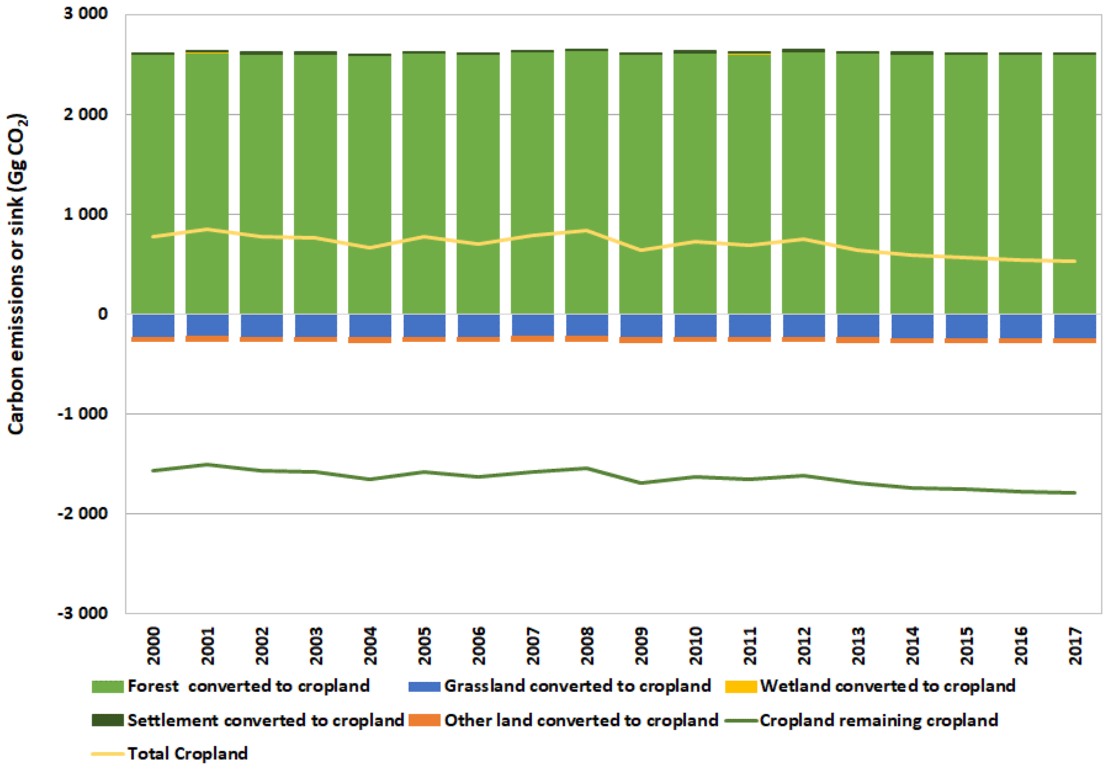

Figure 5.14: CO_2 emissions and removals (Gg CO_2) due to changes in carbon stocks between 2000 and 2017 for South Africa's Cropland.

Table 5.38: South Africa's net carbon stock change (Gg CO_2) by carbon pool for Croplands, 2000 – 2017.

	Cropland remaining cropland			Land converted to cropland		
	Biomass	Litter	Mineral soil	Biomass	Litter	Mineral soil
2000	-929.4	-166.0	-474.0	1 827.9	-868.9	1 378.7
2001	-870.0	-169.3	-474.0	1 857.6	-870.4	1 378.7
2002	-927.8	-172.6	-474.0	1 839.7	-871.9	1 378.7
2003	-930.7	-175.8	-474.0	1 841.8	-873.4	1 378.7
2004	-1 009.9	-179.1	-474.0	1 843.2	-874.9	1 378.7
2005	-927.6	-182.3	-474.0	1 852.5	-876.3	1 378.7
2006	-976.3	-185.6	-474.0	1 836.1	-877.8	1 378.7
2007	-916.8	-188.8	-474.0	1 864.6	-879.3	1 378.7
2008	-876.0	-192.1	-474.0	1 883.8	-880.8	1 378.7
2009	-1 027.2	-195.3	-474.0	1 832.2	-882.3	1 378.7
2010	-956.2	-198.6	-474.0	1 860.0	-883.8	1 378.7

2011	-977.0	-201.9	-474.0	1 849.8	-885.3	1 378.7
2012	-937.5	-205.1	-474.0	1 875.3	-886.8	1 378.7
2013	-1 017.7	-208.4	-474.0	1 850.8	-888.3	1 378.7
2014	-1 056.6	-211.6	-474.0	1 843.2	-889.8	1 378.7
2015	-1 072.6	-214.9	-474.0	1 836.9	-891.3	1 378.7
2016	-1 086.9	-218.1	-474.0	1 836.8	-892.8	1 378.7
2017	-1 097.6	-221.4	-474.0	1 836.9	-894.3	1 378.7

Methodology

Biomass carbon

A complete list of emission factors is provided in Table 5.36.

Croplands remaining croplands

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*.

The change in biomass is, therefore, only estimated for perennial woody crops. 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:

$$\Delta C_B = A * (\Delta C_G - \Delta C_L) \quad \text{(Eq. 5.11)}$$

Where:

ΔC_B = annual change in carbon stocks in biomass (tonnes C yr^{-1});
A = annual area of cropland (ha);
ΔC_G = annual growth rate of perennial woody biomass (tonnes C ha^{-1} yr^{-1});
ΔC_L = annual carbon stock in biomass removed (tonnes C ha^{-1} yr^{-1})

Only the carbon gains from orchards and vines were included. An average biomass growth rate for orchards and another for vines (Table 5.36) was applied in the calculation. Considering statistics for orchards and vineyards (CGA Stats book, 2016; Hortgro, 2015) the age distribution of the perennial 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. Biomass was assumed to accumulate linearly for the entire 25 year period, therefore, the growth rate was calculated as the biomass divided by harvest cycle. These derived growth rates (1.1 t dm ha^{-1} for orchards and 0.41 t dm ha^{-1} for vineyards) are much lower than the IPCC default values, but similar low growth rates have been used by other countries (National Inventory Report, New Zealand). In future inventories the biomass and harvest cycle of different perennial crop types should be incorporated to improve the accuracy of the biomass gains data.

In terms of losses, only losses due to fire disturbance was included due to a lack of data on other disturbances. The carbon losses from fire disturbance in annual Croplands is not 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 Eq. 5.10 above.

Land converted to croplands

For this a Tier 2 approach was applied. The annual increase in carbon stocks in biomass due to land conversions was estimated using equation 5.2 and 5.3 above. Carbon gains and losses are calculated as for *Cropland remaining cropland*, with only the woody perennial crops being included. Losses are also only for fire disturbance. The carbon stock change due to the removal of biomass from the initial land use (i.e. $\Delta C_{CONVERSION}$) is only calculated for the area of lands undergoing a conversion in a given year, and is subsequent years it is zero.

Dead organic matter

Only litter is included in this pool due to a lack of dead wood data.

Cropland remaining cropland

The Tier 1 assumption for the litter pool is that the stocks in *Cropland remaining cropland* are not changing over time, therefore DOM changes are reported to be zero. This was applied to areas where the crop type did not change, however, there were conversions between the various crop types so changes in DOM were calculated for these areas using Eq.5.4.

Land converted to cropland

The changes in litter are determined from the data provided in Table 5.36 and Eq.5.4. It is assumed that the change occurs slowly over the 20 year default transition period.

Soil organic carbon

Annual change in carbon stocks in mineral soils for *croplands remaining croplands* and *land converted to croplands* were calculated by applying a Tier 1 method with Equation 2.25 of the IPCC 2006 Guidelines (IPCC, 2006, Volume 4, p. 2.30) as described above.

IPCC (2006) default soil carbon reference values were utilized. Stock change factors for management, input and land use were determined from data reported in Moeletsi et al. (2015) and Tongwane et al. (2016). Management and inputs differ between the crop types, therefore data on the area planted to the various commercial annual crops, orchards and vineyards was sourced from DAFF (2016), CGA Stats book (2016), national statistics (Stats SA, 2007), Crop Estimates Committee, SATI (2016), SAWI (2016) and FAO (FAOStats, 2017). This area was compared to the area from the LC maps and it was found that planted area was much less than the total cropland area and this was therefore investigated. For annual crops the LC cropland area includes fallow land and pastures. Moeletsi et al. (2015) provides fallow land as a percentage of the crop types, therefore the area of fallow land was calculated from this data. For pastures, the GIS expert (Fanie Ferrera, pers. Comm., 2017) provided some data for three provinces that indicated the area of pastures. From this data an average percentage of pastures was determined and this was applied to the whole cropland area supplied in the LC maps. It was also assumed that this percentage remained the same each year of the time series.

The management and input data was combined with the IPCC 2019 Refinement default stock change factors and climate data to determine the stock change factors for each crop type (Table 5.39). The 2019 Refinement data was selected as it has greater disaggregation than the 2006 Guidelines. These factors were assumed to remain constant throughout the time period due to a lack of annual management data.

Stock change factors for *Forest land*, *Grasslands*, *Wetlands*, *Settlements* and *Other lands* are provided in the specific land category sections of this report.

Table 5.39: Stock change factors for the various crop types in South Africa.

Crop type	Stock change factors					
	Land use (F_{LU})		Management (F_{MG})		Inputs (F_I)	
	Dry climate[a]	Moist climate[b]	Dry climate[a]	Moist climate[b]	Dry climate[a]	Moist climate[b]
Barley	0.8	0.69	1	1	0.98	0.97
Cabbage			1	1	1.04	1.11
Cotton			1	1	0.51	0.53
Drybeans			1.001	1.002	0.99	0.99
General vegetables			1	1	1.04	1.12
Groundnut			1	1	1.01	1.02
Legumes			1	1	1.01	1.02
Lucerne			1	1	0.92	0.93
Maize			1.003	1.006	0.95	0.96
Onions			1	1	1.03	1.1
Other field crops			1	1	0.96	0.97
Other fodder crops			1	1	0.53	0.53
Other oil seeds			1	1	0.99	0.99
Other summer cereal			1.003	1.006	0.95	0.96
Other winter cereals			1.001	1.002	0.99	1
Potato			1	1	1.04	1.1
Silage			1.002	1.005	0.95	0.96
Sorghum			1	1.001	1.00	1.01
Soybean			1	1.001	0.56	0.55
Sugarcane			1	1	0.96	0.95
Sunflower			1	1	0.87	0.86
Teff			1.002	1.005	0.53	0.52

Tabacco			1	1	1.02	1.06
Tomato			1	1	1.02	1.06
Wheat			1.001	1.002	1	1
General annual crop			1.003	1.005	0.95	0.96
Fallow land			1.13	1.19	0	0
Pasture			1.13	1.19	0.51	0.53
Orchards and vines	1	1	1	1	1	1

[a] *Cold temperate dry (CTD) and warm temperate dry (WTD) as defined by IPCC.*
[b] *Cold temperate moist (CTM) and warm temperate moist (WTM) as defined by IPCC.*

Uncertainties and time series consistency

The time series is consistent. Uncertainties are as discussed under *Forest lands*.

Source specific QA/QC and verification

All general QC listed in Table 1.2 were completed for this category. Land areas were checked. There is very little data available on carbon stock changes in croplands, making verification difficult. Carbon emission factors were compared to literature, and to IPCC values. Where possible outputs were compared to the National Terrestrial Carbon Sinks Assessment (DEA, 2015).

Source specific planned improvements

No specific plans have been put in place, however the following areas for improvement have been identified:

- Undertake a full assessment of crop area estimates and crop type classifications to obtain improved crop area estimates for all crop types;
- Include more crop type detail in the LU maps; and
- Continue to obtain further uncertainty data.

5.4.7 Source Category 3.B.3 Grasslands

Source category description

The *Grassland* category includes all grasslands, managed pastures and rangelands. The IPCC does recommend separating out improved grasslands so an attempt was made in this inventory to include improved and degraded grasslands. A change in this submission is the incorporation of degraded land into this category. In the previous submission degraded land was included under *Other land*.

This section deals with emissions and removals of CO_2 in the biomass, litter and mineral soil carbon pools. However, there was insufficient data to include the dead wood component. Estimates are provided for *Grasslands remaining grasslands* and *land converted to grasslands*. CO_2 emissions from biomass burning of grasslands were not reported since emissions are largely balanced by the CO_2 that is reincorporated back into the biomass via photosynthetic activity.

Overview of shares and trends in emissions

2000 – 2017

Grasslands remaining grasslands are a small sink of CO_2 in most years (Figure 5.15). Between 2010 and 2012 it was a source. *Land converted to grassland* are a large sink, with *Other land converted to grasslands* being the dominant contributor. This is because Other lands are considered not to have biomass carbon and the soil carbon is assumed to reduce to zero after 20 years. Therefore, *Other land* converted to any other land category will lead to a sink, With *Grasslands* the gain in carbon is mostly in the soils (Table 5.40).

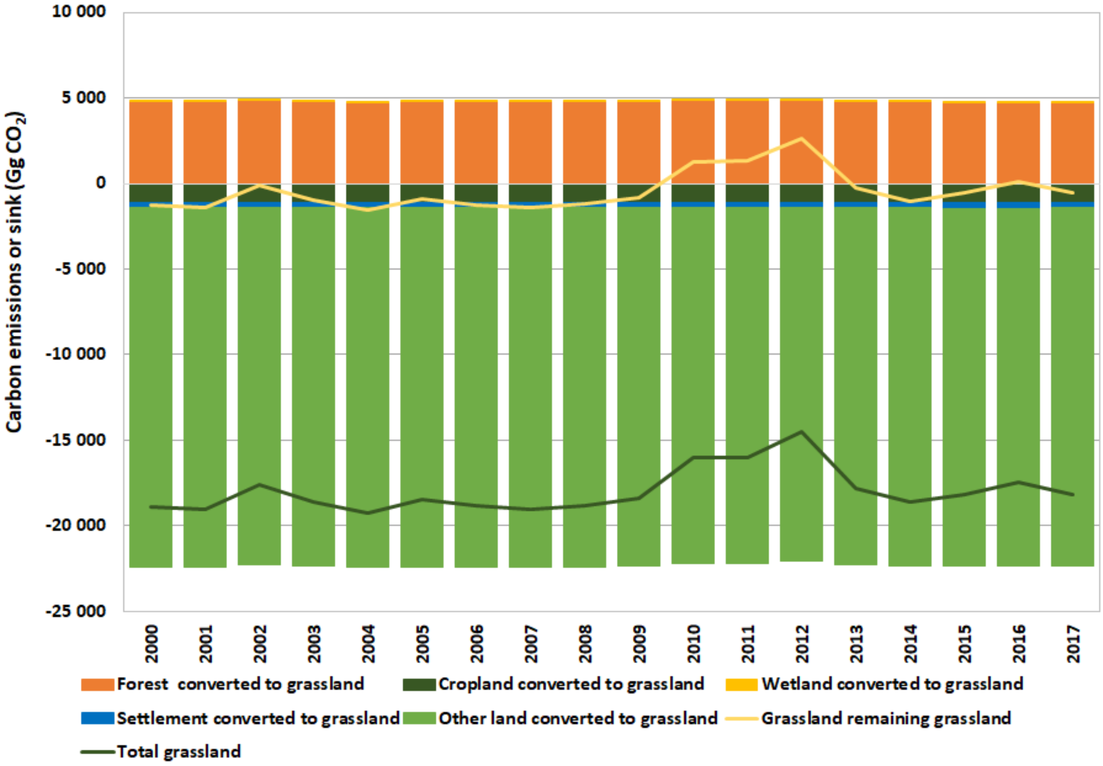

Figure 5.15: CO_2 emissions and removals (Gg CO_2) due to changes in carbon stocks between 2000 and 2017 for South Africa's Grassland.

Table 5.40: South Africa's net carbon stock change (Gg CO_2) by carbon pool for Grasslands, 2000 – 2017.

	Grassland remaining grassland			Land converted to grassland		
	Biomass	Litter	Mineral soil	Biomass	Litter	Mineral soil
2000	-226.8	-1 081.9	36.1	2 613.3	-2 163.6	-18 080.9
2001	-361.7	-1 081.9	36.1	2 622.8	-2 163.6	-18 080.9
2002	926.0	-1 081.9	36.1	2 795.1	-2 163.6	-18 080.9
2003	55.7	-1 081.9	36.1	2 638.2	-2 163.6	-18 080.9
2004	-506.2	-1 081.9	36.1	2 536.6	-2 163.6	-18 080.9
2005	173.0	-1 081.9	36.1	2 707.2	-2 163.6	-18 080.9
2006	-177.1	-1 081.9	36.1	2 632.6	-2 163.6	-18 080.9
2007	-344.0	-1 081.9	36.1	2 598.6	-2 163.6	-18 080.9
2008	-161.1	-1 081.9	36.1	2 608.6	-2 163.6	-18 080.9
2009	237.5	-1 081.9	36.1	2 670.2	-2 163.6	-18 080.9
2010	2 342.1	-1 081.9	36.1	2 919.9	-2 163.6	-18 080.9

2011	2 363.3	-1 081.9	36.1	2 924.0	-2 163.6	-18 080.9
2012	3 700.5	-1 081.9	36.1	3 073.6	-2 163.6	-18 080.9
2013	760.8	-1 081.9	36.1	2 715.7	-2 163.6	-18 080.9
2014	33.3	-1 081.9	36.1	2 605.0	-2 163.6	-18 080.9
2015	485.9	-1 081.9	36.1	2 621.9	-2 163.6	-18 080.9
2016	1 159.6	-1 081.9	36.1	2 664.5	-2 163.6	-18 080.9
2017	535.5	-1 081.9	36.1	2 582.1	-2 163.6	-18 080.9

Methodology

Biomass carbon

A complete list of emission factors is provided in Table 5.36.

Grasslands remaining grasslands

According to the IPCC Tier 1, the change in biomass is only estimated for woody vegetation because for annual grasses the increase in biomass stocks in a single year is assumed to equal the biomass losses in that same year. Therefore only carbon gains from shrubs (low shrublands) was included. In terms of losses, only losses due to fire disturbance in low shrublands was included due to a lack of data on other disturbances. The carbon losses from fire disturbance in annual grasses is not 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 low shrublands were included by using Eq. 5.10 above. Biomass stock changes in shrubs was calculated following Eq. 5.6 above. Where there has been land-use change between the grasslands and low shrublands, carbon stock changes are reported under *Grasslands remaining grasslands.*

Land converted to grasslands

For *land converted to grasslands* only the biomass increase for shrubs were included for the annual area undergoing change, while in annual grasslands carbon stocks were assumed to be in balance and not included in the annual gain calculation. Converted lands remain in the converted category for a period of 20 years.

For land conversions a Tier 2 approach was applied. The annual increase in carbon stocks in biomass due to land conversions was estimated following Eq. 5.3 and Eq. 5.4 above.

Carbon gains and losses are calculated as for *Grasslands remaining grasslands*, with only the woody shrubs being included. Losses are also only for fire disturbance. The carbon stock change due to the removal of biomass from the initial land use (i.e. $\Delta C_{CONVERSION}$) is only calculated for the area of lands undergoing a conversion in a given year, and in subsequent years it is zero. It is assumed that only croplands and plantations are cleared before being converted to a grassland, while all other conversions are slow transitions and not abrupt changes.

Dead organic matter

Only litter is included in this pool due to a lack of dead wood data.

Grassland remaining grassland

The Tier 1 assumption for the litter pool is that the stocks in *Grassland remaining grassland* are not changing over time, therefore DOM changes are reported to be zero. This applies to grasslands remaining grasslands and low shrublands remaining low shrublands, however for conversion between these two grassland subcategories changes in DOM were estimated using Eq.5.4.

Land converted to grassland

The changes in litter are determined from the data provided in Table 5.36 and Eq.5.4. It is assumed that change occurs slowly over the 20 year default transition period.

Soil organic carbon

Annual change in carbon stocks in mineral soils for *grasslands remaining grasslands* and *land converted to grasslands* were calculated by applying a Tier 1 method with Equation 2.25 (IPCC, 2006, Volume 4, p. 2.30). IPCC 2006 default soil carbon reference values were assigned based on the climate and soil type.

In the previous submission Grassland mineral soil carbon stocks were assumed equal to the reference values (i.e. the stock change factors for management and input are equal to

1). In this inventory an attempt was made to incorporate improved and degraded grasslands. The 2013-2014 land cover maps do not have any division for grasslands, however the land cover maps for 1994/95 (Fairbanks et al., 2000) had degraded and improved lands incorporated. These maps indicated that 0.45% of grasslands were improved. Matsika (2007) researched degradation in grasslands and showed that 26.7% of grasslands had low degradation, 58.7% moderate degradation and 14.6% had high degradation. Unfortunately spatial data for this could not be incorporated due to not all the data being available and also the maps were all for different years and scales making it hard to combine. This could be something to include in future. Since the data was not spatial the percentage improved and degraded was combined with the IPCC default stock change factors to obtain weighted average management stock change factor for grasslands for each climate type (Table 5.41). These were then applied to *grassland remaining grassland* and *land converted to grassland* area. The grassland management data is only once-off data therefore it was assumed, for now, that the amount improved and degraded has remained constant over the 2000 to 2015 period. This is another aspect which needs requires more data in order to improve the estimates in future submissions.

Stock change factors for *Forest land*, *Croplands*, *Wetlands*, *Settlements* and *Other lands* are provided in the specific land category sections of this report.

Table 5.41: Stock change factors for grasslands in South Africa.

Grassland type	Stock change factors					
	Land use (F_{LU})	Management (F_{MG})[a]				Inputs (F_I)
		CTD[b] climate	CTM[c] climate	WTD[d] climate	WTM[e] climate	
Grasslands	1	0.928	0.928	0.934	0.939	1
Low shrublands	1	1	1	1	1	1

[a] Weighted averages
[b] Cool temperate dry (CTD) as defined by IPCC.
[c] Cool temperate moist (CTM) as defined by IPCC.
[d] Warm temperate dry (WTD) as defined by IPCC.
[e] Warm temperate moist (WTM) as defined by IPCC.

Uncertainties and time series consistency

The time series is consistent and uncertainties are as discussed for *Forest lands*.

Source specific QA/QC and verification

All general QC listed in Table 1.2 were completed for this category. Land areas were checked. There is very little data available on carbon stock changes in croplands, making verification difficult. Carbon emission factors were compared to literature, and to IPCC values. Where possible outputs were compared to the National Terrestrial Carbon Sinks Assessment (DEA, 2015).

Source specific planned improvements

No specific plans have been put in place, however the following areas for improvement are highlighted:

- Include additional categories of grasslands in the land change maps (at least a dry and moist division) so that more accurate biomass factors can be applied;
- Include land management (unimproved, improved, degraded) into the land change maps;
- Undertake studies to determine growth rates in low shrublands;
- Undertake studies to determine carbon changes in land converted to grasslands; and
- Continue to obtain further uncertainty data.

5.4.8 Source Category 3.B.4 Wetlands

Source category description

Waterbodies and wetlands are the two sub-divisions in the wetland category and are defined in GTI (2015). 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.

Since waterbodies are assumed to have no carbon, and the wetland area was kept constant across the years (see section 0) CO_2 emissions were not estimated for this category. As land change maps are improved in future the emissions associated with conversion to wetlands can be incorporated. On the other hand, CH_4 emissions were included and is the only emission reported for this category.

Overview of shares and trends in emissions

2000 - 2017

In 2015 *Wetlands* were estimated to be a small source of 667 Gg CO_2 due to CH_4 emissions from wetlands. Carbon stock changes were not estimated as there is limited data on wetlands and peatlands.

Methodology

Methane emissions from wetlands

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

$$CH_4\ emissions_{WWFlood} = P * E(CH_4)_{diff} * A * 10^{-6} \quad (Eq.\ 5.12)$$

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).

The area of wetlands was taken from the GeoTerraImage (2014) land cover maps. As indicated in section 5.4.2 the wetland area was adjusted to remove coastal waters. 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.

Uncertainties and time series consistency

The time series is consistent and uncertainties are as discussed for *Forest lands*.

Source specific QA/QC and verification

All general QC listed in Table 1.2 were completed for this category and no additional specific QA/QC was undertaken.

Source specific planned improvements

In the next submission the methodology in the 2013 wetland supplement (IPCC, 2014) should be considered. It was considered for the methane emission estimates in this inventory but the emission factor of 235 kg ha^{-1} yr^{-1} for mineral soils in temperate climates is much higher than the previous emission factor of 16.06 kg ha^{-1} yr^{-1}. This new emission factor is in line with a study done in South Africa (Otter et al., 2000), however there was insufficient time to do a proper assessment of the new guidelines and do a validation of the higher emission outputs for wetlands for this submission. These upgrades will be considered in the next submission.

5.4.9 Source Category 3.B.5 Settlements

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. 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. Settlements were divided into wooded and non-wooded areas.

This section deals with emissions and removals of CO_2 in the biomass, litter and mineral soil carbon pools, but there was insufficient data to include the dead wood component. Gains and losses are only determined for the wooded areas. Estimates are provided for both *Settlements remaining settlements* and *land converted to settlements*. Converted lands remain in the converted category for a period of 20 years.

Overview of shares and trends in emissions

2000 - 2017

Settlements were estimated to be a small source of CO_2 (Figure 5.16) between 2000 and 2015, but this turn to a very small sink in eh last two years. *Settlements remaining settlements* are a small sink of CO_2 because of the woody vegetation within settlements. *Land converted to settlements* are a source, with conversions from forests and grasslands contributing equally to this source. Conversion to settlements from all land types except *Other lands* leads to a loss of carbon. With conversion of Other ands, which is bare ground, there is a small gain in carbon due to the increase in vegetation as on average settlements have a small fraction of vegetation. All pools have some contribution to the overall emissions in Settlements (Table 5.42).

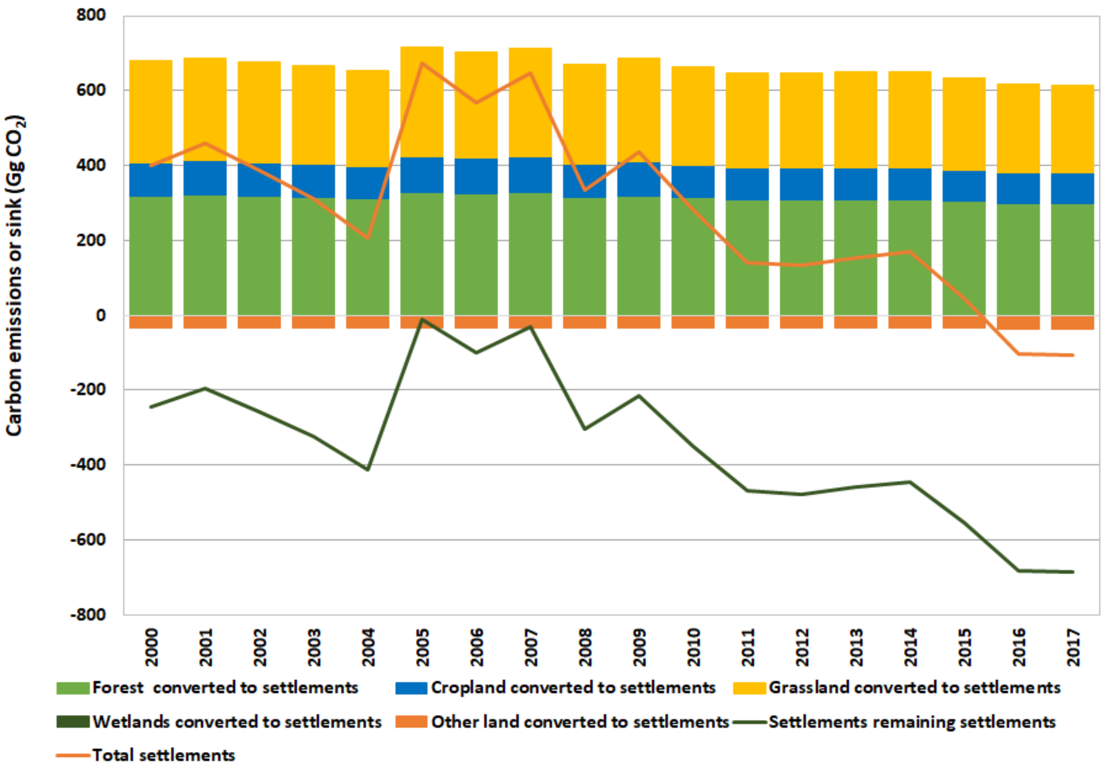

Figure 5.16: CO_2 emissions and removals (Gg CO_2) due to changes in carbon stocks between 2000 and 2017 for South Africa's Settlements.

Table 5.42: South Africa's net carbon stock change (Gg CO_2) by carbon pool for Settlements, 2000 – 2015.

	Settlements remaining settlements			Land converted to settlements		
	Biomass	Litter	Mineral soil	Biomass	Litter	Mineral soil
2000	-246.5	-0.4	1.5	177.8	-191.6	658.7
2001	-195.4	-0.4	1.5	185.9	-191.6	658.7
2002	-257.8	-0.4	1.5	176.2	-191.6	658.7
2003	-323.6	-0.4	1.5	166.1	-191.6	658.7
2004	-414.6	-0.4	1.5	152.1	-191.6	658.7

2005	-10.4	-0.4	1.5	214.8	-191.6	658.7
2006	-100.7	-0.4	1.5	200.8	-191.6	658.7
2007	-33.2	-0.4	1.5	211.3	-191.6	658.7
2008	-304.3	-0.4	1.5	169.7	-191.6	658.7
2009	-215.9	-0.4	1.5	183.3	-191.6	658.7
2010	-349.8	-0.4	1.5	163.0	-191.6	658.7
2011	-470.7	-0.4	1.5	144.7	-191.6	658.7
2012	-479.1	-0.4	1.5	143.6	-191.6	658.7
2013	-459.9	-0.4	1.5	146.7	-191.6	658.7
2014	-447.7	-0.4	1.5	148.7	-191.6	658.7
2015	-556.0	-0.4	1.5	132.5	-191.6	658.7
2016	-683.3	-0.4	1.5	113.5	-191.6	658.7
2017	-687.2	-0.4	1.5	113.2	-191.6	658.7

Methodology

Biomass carbon

A complete list of emission factors is provided in Table 5.36.

Settlements remaining settlements

Even though there was no spatial breakdown of the settlement category in the land change maps, a percentage woodland and shrubland area of the total settlement area was determined from Fairbanks et al. (2000). This percentage was then applied to the settlement area, assuming no change over the 17 year period, to determine the area of wooded area of settlements. In future submissions the accuracy of this should be improved by including more detailed settlement categories into the land change map. Biomass gains and losses for the wooded areas only were determined as for *Forest land remaining forest land*.

Land converted to settlements

For this a Tier 2 approach was applied. The annual increase in carbon stocks in biomass due to land conversions was estimated following Eq. 5.2 and Eq. 5.3 above. Only gains and losses in wooded areas were included as it is assumed that the gains and losses in the grass areas are in balance, and where there is infrastructure there is no vegetation and therefore no gains or losses. The carbon stock change due to the removal of biomass from the initial land use (i.e. $\Delta C_{CONVERSION}$) is only calculated for the area of lands undergoing a conversion in a given year, and in subsequent years it is zero. It is assumed that all land is cleared before it is converted to a settlement.

Dead organic matter

Only litter is included in this pool due to a lack of dead wood data.

Settlement remaining settlement

The Tier 1 assumption for the litter pool is that the stocks in *Settlements remaining settlements* are not changing over time, therefore DOM changes are reported to be zero.

Land converted to settlement

The changes in litter are determined from the data provided in Table 5.36 and Eq.5.4. It is assumed that change occurs slowly over the 20-year default transition period.

Soil organic carbon

Annual change in carbon stocks in mineral soils for *settlements remaining settlements* and *land converted to settlements* were calculated by applying a Tier 1 method with Equation 2.25 of the IPCC 2006 Guidelines (IPCC, 2006, Volume 4, p. 2.30). IPCC 2006 default soil carbon reference values were assigned based on the climate and soil type.

The Settlement mineral soil carbon stocks were assumed equal to the reference values (i.e. the stock change factors for management and input are equal to 1). The land use characteristics of settlements (i.e. barren land, woodlands, infrastructure, etc) were combined with the IPCC 2006 land use stock change factors to estimate a weighted average land use stock change factor for settlements (Table 5.43). This factor was assumed to remain constant for the period 2000 to 2015, and this can be improved in future inventories if data becomes available.

Stock change factors for *Forest land*, *Croplands*, *Grasslands*, *Wetlands* and *Other lands* are provided in the specific land category sections of this report.

Table 5.43: Stock change factors for settlements in South Africa.

Grassland type	Stock change factors		
	Land use (F_{LU})	Management (F_{MG})	Inputs (F_I)
Settlements	0.831	1	1
Mines	1	1	1

Uncertainties and time series consistency

The time series is consistent and uncertainties are as discussed for *Forest lands*.

Source specific QA/QC and verification

All general QC listed in Table 1.2 were completed for this category. Land areas were checked. There is very little data available on carbon stock changes in settlements, making verification difficult. Carbon emission factors were compared to any available literature, and to IPCC values.

Source specific planned improvements

No specific plans have been put in place, however it would be useful if in future additional categories of settlements can be incorporated into the land change maps so that more accurate biomass and stock change factors can be applied.

5.4.10 Source Category 3.B.6 Other lands

Source category description

Other land includes bare soil, rock, and all other land areas that do not fall into the other land classes. This category includes emissions and sinks for *land converted to other lands*. There are assumed to be no changes in the *Other land remaining Other land* category. For the *land converted to other land* category the biomass, litter and soil carbon changes are included.

Overview of shares and trends in emissions

2000 - 2017

Other lands are estimated to be a source of CO_2 due to the loss of carbon in the *land converted to other lands* (Figure 5.17). The largest contributor to the source is the conversion of grasslands to bare ground. Since the grasslands dominate in this category, it is the soil carbon pool that is most important (Table 5.44).

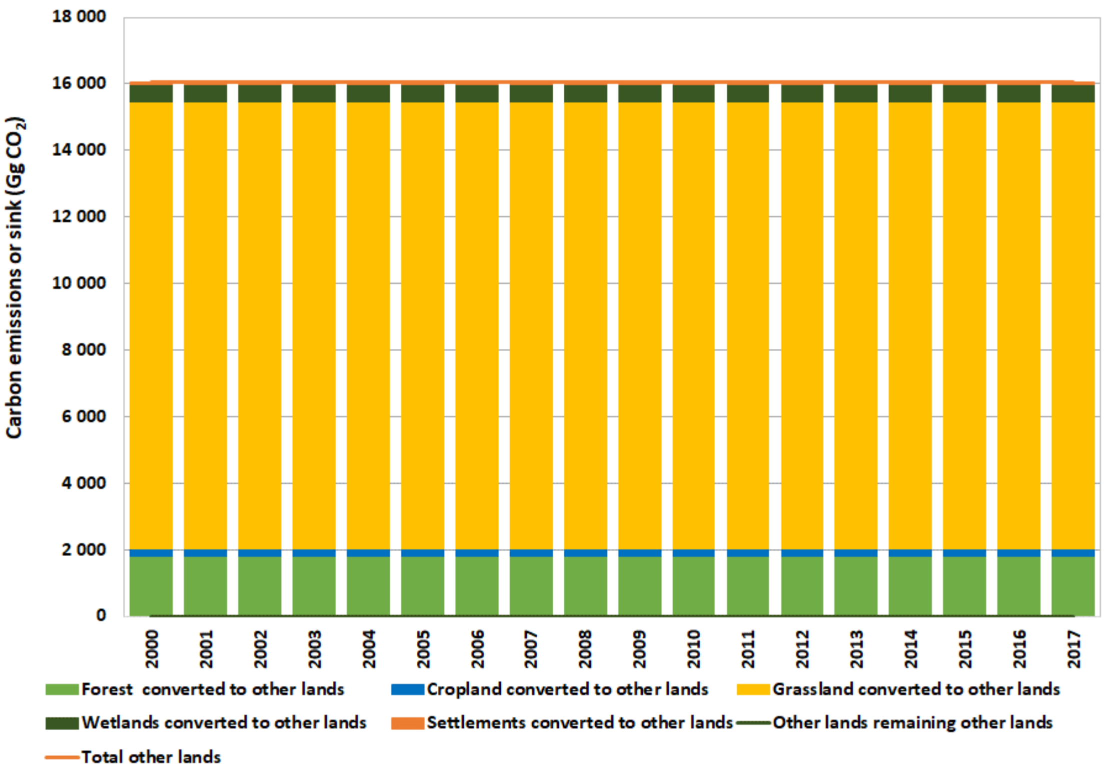

Figure 5.17: CO_2 emissions and removals (Gg CO_2) due to changes in carbon stocks between 2000 and 2017 for South Africa's Other lands.

Table 5.44: South Africa's net carbon stock change (Gg CO_2) by carbon pool for Other lands, 2000 – 2017.

	Land converted to other lands		
	Biomass	Litter	Mineral soil
2000	1 291.5	1 344.1	13 409.2
2001	1 291.5	1 344.1	13 409.2
2002	1 291.5	1 344.1	13 409.2
2003	1 291.5	1 344.1	13 409.2
2004	1 291.5	1 344.1	13 409.2
2005	1 291.5	1 344.1	13 409.2
2006	1 291.5	1 344.1	13 409.2
2007	1 291.5	1 344.1	13 409.2
2008	1 291.5	1 344.1	13 409.2
2009	1 291.5	1 344.1	13 409.2
2010	1 291.5	1 344.1	13 409.2
2011	1 291.5	1 344.1	13 409.2
2012	1 291.5	1 344.1	13 409.2
2013	1 291.5	1 344.1	13 409.2
2014	1 291.5	1 344.1	13 409.2
2015	1 291.5	1 344.1	13 409.2
2016	1 291.5	1 344.1	13 409.2
2017	1 291.5	1 344.1	13 409.2

Methodology

Biomass carbon

A complete list of emission factors is provided in Table 5.36.

Other lands remaining other lands

Tier 1 of IPCC 2006 assumes that there are no carbon gains or losses on *other lands remaining other lands*.

Land converted to other lands

For this a Tier 2 approach was applied. The change in carbon stocks in biomass due to land conversions was estimated following Eq. 5.2 and 5.3 above. Only losses due to conversion were estimated as other lands are assumed to be void of vegetation. The carbon stock change due to the removal of biomass from the initial land use (i.e. $\Delta C_{CONVERSION}$) is only calculated for the area of lands undergoing a conversion in a given year, and in subsequent years it is zero. It is assumed that all land is cleared before it is converted to other lands.

Dead organic matter

Only litter is included in this pool due to a lack of dead wood data.

Other land remaining other land

The Tier 1 assumption for the litter pool is that the stocks in *Other lands remaining other lands* are zero.

Land converted to other lands

The changes in litter are determined from the data provided in Table 5.36 and it assumes that the change occurs slowly over the 20 year default transition period.

Soil organic carbon

Annual change in carbon stocks in mineral soils for *other lands remaining other lands* and *land converted to other lands* were calculated by applying a Tier 1 method with Equation 2.25 of the IPCC 2006 Guidelines (IPCC, 2006, Volume 4, p. 2.30). IPCC 2006 default soil carbon reference values were assigned based on the climate and soil type. The Tier 1 assumption is that the final carbon stock is zero.

Uncertainties and time series consistency

The time series is consistent and uncertainties are as discussed for *Forest lands*.

Source specific QA/QC and verification

All general QC listed in Table 1.2 were completed for this category, but no additional source specific QA/QC was conducted. There is very little data available on carbon stock changes in other lands, making verification very difficult.

Source specific planned improvements

No specific plans have been put in place, however having more frequent land change maps would provide further clarity and verification of the changes between bare ground and low shrublands.

5.5 Source category 3.C Aggregated sources and non-CO_2 emissions on land

5.5.1 Category information

Aggregated and non-CO_2 emissions on land include emissions from biomass burning (3C1), lime (3C2) and urea (3C3) application, direct (3C4) and indirect (3C5) N_2O from managed soils, and indirect N_2O from manure management (3C6). Rice cultivation does not occur in South Africa so this was not included in this section.

Emissions

2000 - 2017

Emissions from *Aggregated and non-CO_2 emissions on land* are summarised in Table 5.45. *Direct N_2O from managed soils* contribute the most toward this category, while *Indirect N_2O from managed soils* is the second largest contributor. This contribution has declined since 2000, while the contribution from *Liming* and *Urea application* have increased (Table 5.45). Emissions in this category have declined slowly over the 17 year period (Figure 5.18).

Table 5.45: Changes in aggregated and non-CO_2 emission sources on land between 2000 and 2017.

Category	Emissions ($Gg\ CO_2e$)		Change (2000 – 2017)	
	2000	2017	Diff	%
Biomass burning	2 101.6	758.8	-1 342.9	-63.9
Liming	384.1	1 222.1	838.0	218.2
Urea application	297.3	679.6	382.3	128.6
Direct N_2O from managed soils	20 072.5	18 081.0	-1 991.5	-9.9
Indirect N_2O from managed soils	2 463.3	2 236.3	-227.0	-9.2
Indirect N_2O from manure management	408.9	469.3	60.4	14.8
Total	**25 727.8**	**23 447.1**	**-2 280.7**	**-8.9**

Note: Numbers may not sum exactly due to rounding off.

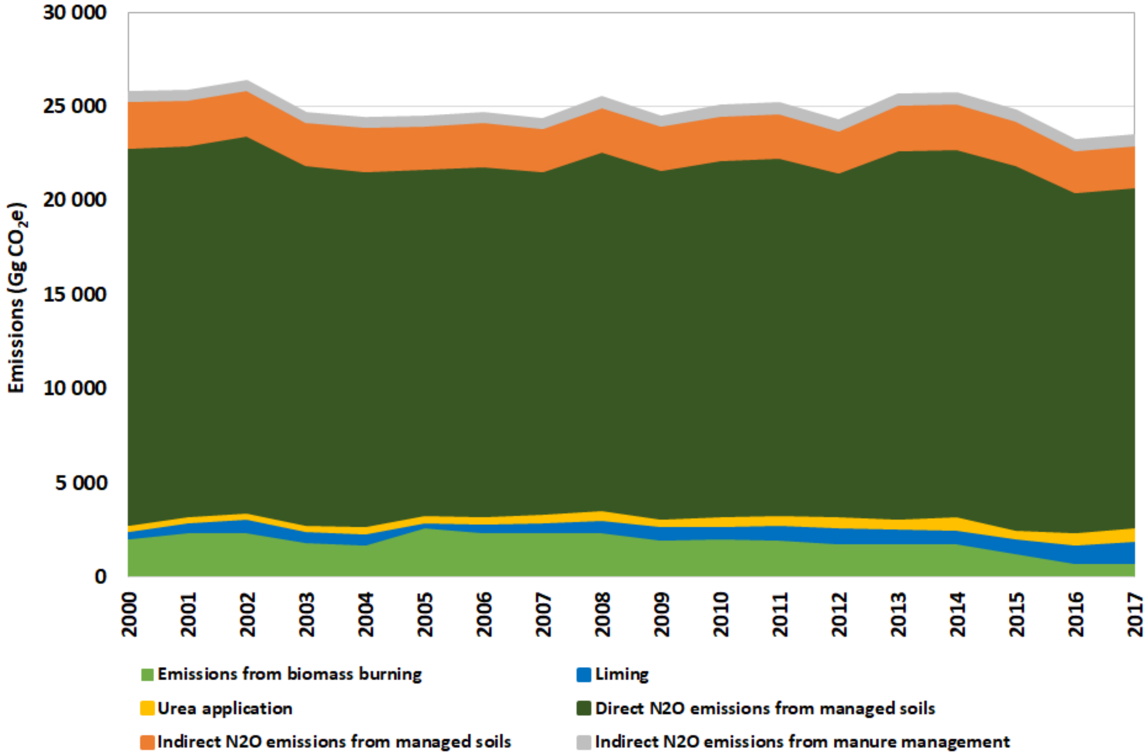

Figure 5.18: Trends in aggregated and non-CO_2 emissions on land, 2000 – 2017.

5.5.2 Recalculations since the 2015 inventory

Recalculations were completed for all years in this category due to the following changes:

- Biomass burning:
  - Improved burnt area data – used MODIS collection 6 instead of the previous MODIS collection 5 burnt area data;
  - Annual burnt area was applied instead of 5-year average data;
  - Land classifications were changed and degraded land was included under *Grasslands* instead of *Other lands*;
  - Burning of indigenous forests and thickets was included;
  - These changes led to a 17.7% reduction in biomass burning emissions in 2015, although for several years there was an increase in the emissions and this variation is due to the use of annual instead of 5-year average burnt area data;

- Liming:
  - Changed activity data source, from 2009, leading to a 69.8% increase in emissions in 2015;
- Direct N_2O from managed soils:
  - Updated manure management data;
  - Movement of daily spread from managed manure to pasture, range and paddock;
  - Moved all dairy heifers, except the lactating class, to Other cattle category;
  - Corrected the total cattle numbers, which led to an increase in the number of subsistence Other cattle numbers;
  - Corrected equation for determining N available for application to soil;
  - Removed sewage sludge inputs due to double counting;
  - Inclusion of F_{SOM} which was not previously estimated;
  - All of these changes meant that emission estimates for 2015 were 22.2% higher than estimated in the previous inventory;
- Indirect N_2O from managed soils:
  - All the updates mentioned above for direct N_2O from managed soils also had an impact on indirect N_2O emission estimates;
  - These changes produced estimates that were 7.32% higher than previously estimated;
- Indirect N_2O from manure management:
  - Updated manure management and livestock population data also impacted indirect emissions;
  - Emission estimates were 27.0% lower than the 2015 estimates in the previous inventory.

Overall the recalculated estimates for *Aggregated and non-CO_2 emissions on land* were 16.7% higher than the estimates in the previous submission (Figure 5.19).

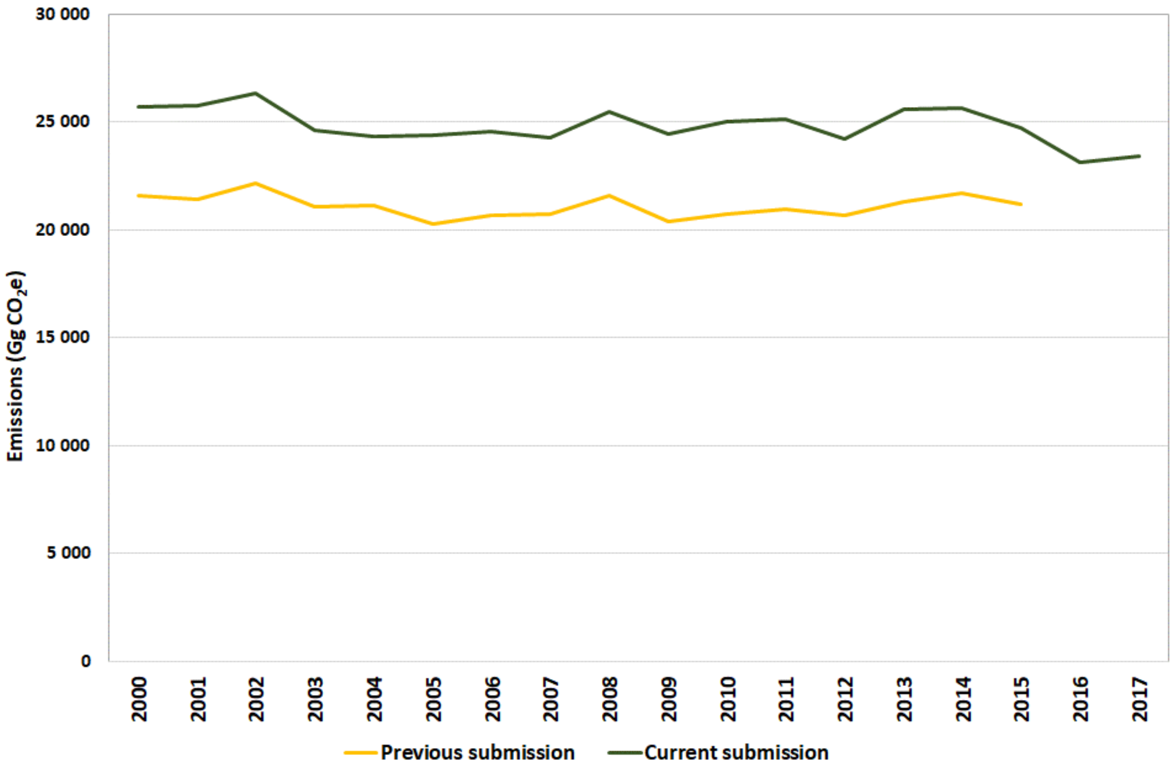

Figure 5.19: Recalculated emissions for the aggregated and non-CO_2 emissions on land.

5.5.3 Source category 3.C.1 Emissions from biomass burning

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 Inventory Report (DEAT, 2009), fire plays an important role in South African biomes, where grassland, savanna and fynbos fires maintain ecological health. In addition to CO_2, 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, NO_x, NH_3, NMVOC and CO are also produced and these are precursors for the formation of GHG in the atmosphere (IPCC, 2006).

Although the IPCC Guidelines only require the calculation of emissions from savanna burning, South Africa reports emissions of non-CO_2 gases (CH_4, CO, N_2O and NO_x) from all land categories. 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 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 all land categories the CO_2 emissions from biomass burning were not reported in this section but rather in the *Land* section under disturbance losses.

Overview of shares and trends in emissions

2000 - 2017

Biomass burning contributed 759 Gg CO_2e in 2017, which is a 63.9% decline from 2000 (Table 5.46). This decline is due to a reduction in the burnt area in recent years. Burning in grasslands contribute the most to this category, followed by forest land and croplands. Emissions show annual variability with no specific trend (Table 5.47). CH_4 contributed 50.6% to the biomass burning emissions, while N_2O contributed the rest.

Emissions of NOx and CO from biomass burning were also estimated and are provided in Table 5.47.

Table 5.46: Trends and changes in biomass burning emissions between 2000 and 2017.

Category	Emissions	Change

	($Gg\ CO_2e$)		(2000 – 2017)	
	2000	2017	Diff	%
Forest lands	557.5	205.4	-352.1	-63.2
Croplands	305.2	79.1	-226.1	-74.1
Grasslands	1 177.5	446.6	-730.9	-62.1
Wetlands	35.1	24.0	-11.2	-31.8
Settlements	26.3	3.7	-22.6	-85.9
Other lands	0.0	0.0	0.0	0.0
Total[a]	**2 101.6**	**758.8**	**-1 342.9**	**-63.9**

[a] *Numbers may not sum exactly due to rounding off.*

Table 5.47: Trend in emission of GHGs, NOx and CO from biomass burning, 2000 – 2017.

	CH_4	N_2O	CH_4	N_2O	Total GHG	NOx	CO
	$Gg\ CH_4$	$Gg\ N_2O$	$Gg\ CO_2e$		$Gg\ CO_2e$	Gg NOx	Gg CO
2000	48.9	3.5	1 026.3	1 075.3	2 101.6	65.8	1 395.5
2001	55.9	4.0	1 174.6	1 249.6	2 424.2	76.3	1 579.9
2002	57.0	4.0	1 197.1	1 244.5	2 441.6	75.9	1 610.5
2003	44.4	3.1	933.0	945.8	1 878.8	56.9	1 242.5
2004	40.9	2.9	858.2	888.1	1 746.3	53.3	1 143.1
2005	62.8	4.4	1 318.1	1 357.3	2 675.4	83.4	1 774.9
2006	57.3	3.9	1 202.4	1 223.3	2 425.8	75.2	1 618.8
2007	57.1	3.8	1 199.2	1 188.4	2 387.5	69.1	1 557.5
2008	57.6	4.0	1 210.3	1 229.6	2 439.9	71.0	1 573.1
2009	48.0	3.4	1 008.2	1 040.6	2 048.8	63.1	1 346.7
2010	49.7	3.4	1 043.8	1 062.8	2 106.6	63.3	1 383.6
2011	48.0	3.3	1 008.6	1 036.8	2 045.4	62.0	1 343.1
2012	43.2	3.0	907.4	918.7	1 826.1	53.2	1 183.0
2013	43.0	3.0	903.4	937.5	1 840.8	55.7	1 196.6
2014	42.0	2.9	881.2	912.7	1 793.9	54.9	1 176.2
2015	30.3	2.1	635.5	660.7	1 296.1	39.2	841.5
2016	19.1	1.3	401.5	397.1	798.6	22.0	511.5
2017	18.1	1.2	380.9	377.8	758.8	21.1	487.8

Methodology

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

$$L_{fire} = A * M_B * Cf * G_{ef} * 10^{-3} \quad \text{(Eq. 3.2)}$$

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)

Burnt area data

Annual burnt-area maps were produced from the MODIS monthly burnt-area product for each year of the inventory (2000 to 2017). The MODIS Collection 5 Burned Area Product (MCD45) Geotiff version from the University of Maryland (ftp://ba1.geog.umd.edu) was used in the previous inventory, however the updated MODIS collection 6 burnt area product was used in this inventory. This is a level 3 gridded 500 m product and the quality of the information is described in Giglio et al. (2018). Every month of data was reprojected into the UTM 35S projection to remain consistent with the 2013-14 land-cover dataset project. The South African portion of each file was extracted to the 2011 national boundary file. Each file contains sub-classes that indicate

(i) area burnt per approximated Julian day (1-366);
(ii) unburned area (0);
(iii) snow or high aerosol (900);
(iv) internal water bodies (9998);
(v) external (sea and oceans) waterbodies (9999); and
(vi) Insufficient data (10000).

Items (ii) to (vi) were reclassed to “No data” to ensure that only the area burnt per Julian day was remaining. In addition, each burnt area identification number was reclassed from one to 12 to provide a single burnt area per month. Each of the 12 months data was combined using the mosaic function to form a single total annual burnt area dataset for each year. Each burnt area dataset was reclassed to reduce the pixel size to a 30 m x 30 m size, which is the same size as the land cover datasets. Each annual burnt area dataset was combined with the 2014 land cover, climate and soil datasets to determine the total burnt area per year in each of the categories. The output dataset for each year was collated in Microsoft Excel and the total area burnt was calculated in hectares.

Mass of fuel available for combustion (M_B) and the combustion factor (C_f)

The values for fuel density were sourced from various sources (

Table 5.48). A weighted average for fuel density and the combustion factor (C_f) 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 C_f values, but these are very different for fynbos (

Table 5.48). A weighted average fuel density and C_f 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 (DEA, 2009; 1994).

Comparing the data to IPCC values 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 5.48: Fuel density and combustion fractions for the various vegetation classes.

Vegetation class	Fuel density (t/ha)			Combustion fraction			Fuel consumption (t/ha)[a]		
	Value	Source	IPCC default	Value	Source	IPCC value	Value	Source	IPCC value
Plantations							33.6	Weighted average based on IPCC (2006)[b]	19.8 – 53.0
Indigenous forests							19.8	IPCC (2006)	19.8
Thickets/ dense bush	1.4	1994 NIR		0.95	1994 NIR				
Woodlands/ open bush	4.4	Van Leeuwen et al. (2014)		0.8	Van Leeuwen et al. (2014)				2.5 – 26.7
Croplands	7	DAFF (2010)		1	DAFF (2010)				4 – 10
Grasslands							4.1	IPCC (2006)	2.1 – 10
Low shrublands	2.42[c]	Weighted average	5.7 – 26.7	0.91[c]	Weighted average	0.61 – 0.95			
Fynbos	*12.9*	*IPCC (2006)*		*1*	*IPCC (2006)*				
Nama karoo	*1*	*1994 NIR*		*0.95*	*1994 NIR*				
Succulent karoo	*0.6*	*1994 NIR*		*0.95*	*1994 NIR*				

Wetlands[d]							4.1	IPCC (2006)	

[a] *Fuel consumption is a product of fuel density and the combustion fraction.*
[b] *Applied IPCC wildfire values for Eucalyptus forests for hardwood plantations and other temperate forests for softwoods.*
[c] *See text for explanation.*
[d] *Assumed the same as grasslands.*

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 5.49.

Table 5.49: Biomass burning emission factors for the various gases and vegetation types (from IPCC, 2006).

Vegetation type	EF		± SE
Plantations; indigenous forests; thickets/dense bush	CO	107	37
	CH_4	4.7	1.9
	N_2O	0.26	3.0
	NO_x	3.0	1.4
Woodland/open bush; grasslands; low shrublands; wetlands	CO	65	20
	CH_4	2.3	0.9
	N_2O	0.21	0.1
	NO_x	3.9	2.4
Croplands	CO	92	84
	CH_4	2.7	
	N_2O	0.07	
	NO_x	2.5	1

Uncertainties and time series consistency

Time series is consistent as same data sources are used throughout.

The MODIS burnt area products have been shown to identify about 75% of the burnt area in Southern Africa (Roy and Boschetti, 2009a & b). Brennan et al. (2019) indicates that MODIS burnt area products have an uncertainty of around 5%. Much of the uncertainty lies with the land-cover maps (see Land section) and some corrections for misclassified pixels were made.

Fuel density varies as a function of type, age and condition of the vegetation. It is also affected by the type of fire. Since the calculations do not distinguish between the type of fire or the season when the fire occurs the uncertainty can be high. The biggest uncertainty is for savannas and woodlands. The IPCC 2006 guideline default values show that for savanna woodlands the fuel consumption can vary between 2.6 t ha^{-1} and 4.6 t ha^{-1} depending on the season, while savanna grassland fuel consumption can vary between 2.1 t ha^{-1} and 10 t ha^{-1}. The standard deviation on fuel loads and fuel consumption in savannas can be as high as 85% and 45% respectively (Van Leeuwen et al., 2014). Van Leeuwen et al. (2014) also estimated the uncertainty of fuel consumption in a South African savanna to be 40%. The standard error on IPCC default fuel combustion values for Eucalyptus and temperate forests is given as 100%.

IPCC default uncertainties for emission factors are provided in the guidelines (IPCC, 2006; Table 2.5).

Source specific QA/QC and verification

All general QC listed in Table 1.2 were completed for this category. In addition, the burnt area data was compared to those from the Meraka Institute[12] (Meraka Institute, 2019) and both the annual (Jan to Dec) datasets show a decline in burnt area between 2014 and 2017. The inventory burnt area data appears to be slightly overestimated on an annual basis, however it is not including the seasonal variation. Meraka Institute also collects the data for the period July to June as using a standard calendar year is indicated to be problematic for detecting fires in Western and Southern Cape.

Source specific planned improvements

In the next inventory burnt area data from Meraka Institute will be considered as a data source. The consideration of the impacts of seasonal variation in fires in the different regions of South Africa will be discussed to determine how best to incorporate the information in the inventory.

5.5.4 Source category 3.C.2 Liming

Source category description

[12] Collection 6 MODIS BA

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.

Overview of shares and trends in emissions

2000 - 2017

Emissions from *Liming* are summarised in Table 5.50. Emissions are highly variable on an annual basis.

Table 5.50: Trends in lime and urea application emissions between 2000 and 2017.

	Lime emissions	Urea emissions
	($Gg\ CO_2e$)	
2000	384.1	297.3
2001	497.2	318.0
2002	683.7	338.6
2003	586.0	359.2
2004	585.5	435.9
2005	267.4	355.1
2006	446.0	393.1
2007	524.9	484.6
2008	658.9	480.2
2009	701.4	380.5
2010	659.2	501.5
2011	728.3	571.2
2012	834.9	587.2
2013	755.3	533.1
2014	778.7	663.8
2015	785.7	486.1
2016	987.2	643.6
2017	1 222.1	679.6

Methodology

A Tier 1 approach of the IPCC 2006 Guidelines was used to calculate annual CO_2 emissions from lime application (Equation 11.12, IPCC 2006).

Activity data

Limestone and dolomite data in previous inventories was obtained from the Fertilizer Association of South Africa (FertSA) (http://www.fssa.org.za/Statistics.html). This data, however stops in 2008 due to restrictions by the South African Competition Commission on the collection of this data. For the years since 2008 the amount of agricultural lime sold was obtained from the SAMI report (DMR, 2017) and it is assumed that what is sold is also applied to the soil. FertSA data was considered more accurate as it reported the consumption for dolomite and limestone. For this reason, the FertSA data was applied until 2008 and the SAMI data was used for the later years. A comparison between the two datasets between 2000 and 2008 is shown in Table 5.51.

The SAMI report does not make a distinction between limestone and dolomite so the historical limestone and dolomite data (1983-2008) from FertSA was used to determine a ratio. Due to a lack of data it was assumed this ratio remained the same over the years. Limestone and dolomite consumption are shown in Table 5.52.

Table 5.51: Comparison between FertSA and SAMI datasets.

	Total lime consumption from FertSA	Total lime consumption from FSAMI report	Difference (%)
	(t)	(t)	
2000	825 252	935 000	13.30
2001	1 068 357	935 000	-12.48
2002	1 467 915	935 000	-36.30
2003	1 265 742	935 000	-26.13
2004	1 264 888	948 000	-25.05
2005	580 444	604 000	4.06
2006	963 118	707 000	-26.59
2007	1 137 646	860 000	-24.41
2008	1 429 803	879 000	-38.52

Table 5.52: Lime consumption between 2000 and 2017.

	Limestone consumption (t)	Dolomite consumption (t)
2000	254 116	571 136
2001	329 996	738 361
2002	436 743	1 031 172
2003	473 006	792 736
2004	474 215	790 673
2005	253 606	326 838
2006	357 970	605 148
2007	474 753	662 893
2008	616 844	812 959
2009	283 499	571 501
2010	259 625	523 375
2011	298 751	602 249
2012	359 098	723 902
2013	314 004	632 996
2014	327 267	659 733
2015	331 246	667 754
2016	445 308	897 692
2017	578 271	1 165 729

Emission factors

The IPCC default emission factors of 0.12 t C (t limestone)$^{-1}$ and 0.13 t C (t dolomite)$^{-1}$ were used to calculate the CO_2 emissions from *Liming*.

Uncertainties and time series consistency

The dolomite and limestone default emission factors have an uncertainty of -50% (IPCC 2006 Guidelines, p. 11.27). Uncertainty was determined from the difference between the SAMI (DMR, 2017) report data and the Fertilizer Association data. For limestone it was -90% to 25% and for dolomite it was determined to be -75% to 15%.

Source specific QA/QC and verification

All general QC listed in Table 1.2 were completed for this category. In addition, the SAMI consumption data was compared to the Fertilizer Association data for 2000 to 2008. Data was also compared to the lime emission estimates provided in Tongwane et al. (2016) where lime consumption was estimated based on crop data and application rates. The Tongwane et al. (2016) emissions were more than double the estimates in this inventory, therefore further investigation in the discrepancies between the datasets need to be undertaken in the next inventory cycle.

Source specific planned improvements

Alternate data sources for lime consumption will be investigated. If no other data sets are available, then the SAMI report data will be assessed in more detail. Lime consumption will also be estimated using crop data and application rates and compared to lime consumption data. The most appropriate activity dataset will be determined based on the outputs of the assessment.

5.5.5 Source category 3.C.3 Urea application

Source category description

Adding urea to soils during fertilization leads to a loss of CO_2 that was fixed in the industrial production process.

Overview of shares and trends in emissions

2000 – 2017

Urea application produced 680 Gg CO_2 in 2017 and this has more than doubled since 2000 (Table 5.50).

Methodology

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

Activity data

Import and export data for urea was obtained from South African Revenue Service (SARS) (downloaded from http://www.sagis.org.za/sars.html on the 12/08/2016) (Table 5.53).

Table 5.53: Urea imports between 2000 and 2017.

	Urea imports (t)
2000	405 434
2001	433 569
2002	461 704
2003	489 839
2004	594 407
2005	484 209
2006	536 026
2007	660 755
2008	654 808
2009	518 924
2010	683 837
2011	778 897
2012	800 756
2013	726 905
2014	905 143
2015	662 863
2016	877 638
2017	926 747

Emission factor

The IPCC default emission factor of 0.2 t C (t urea)$^{-1}$ were used to calculate the CO_2 emissions.

Uncertainties and time series consistency

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). Urea data is based on import data which is well controlled so a nominal 5% uncertainty was assumed. There is also some uncertainty with regards to the use and distribution of this urea. Again there are no uncertainty estimates provided for this so an additional 5% was assumed.

Source specific QA/QC and verification

All general QC listed in Table 1.2 were completed for this category. Urea data was also checked against the FAOStat dataset and found to be very similar.

Source specific planned improvements

No improvements are planned for this category.

5.5.6 Source category 3.C.4 Direct nitrous oxide emissions from managed soils

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.

Overview of shares and trends in emissions

2000 - 2017

Direct N_2O emissions from managed soils decreased by 9.9% between 2000 and 2017 (Table 5.54). The largest contribution is from *Urine and dung deposits in pasture range and paddock*, which accounted for 63.3% of the *Direct N_2O emissions from managed soils* in 2017. The contribution from inorganic and organic fertilizers increased, while the contribution from crop residues and urine and dung inputs declined.

Table 5.54: Trends and changes in emissions from direct N_2O on managed soils between 2000 and 2017.

	Emissions (Gg CO_2e)		Change since 2000	
	2000	2017	Diff	%
Inorganic fertilizers	2 026.2	2 157.6	131.4	6.5
Organic fertilizers (animal manure, compost, sewage sludge)	1 995.2	2 033.2	37.9	1.9

Crop residues	1 296.9	1 034.6	-262.4	-20.2
Urine and dung deposits	13 337.3	11 438.9	-1 898.4	-14.2
N mineralisation from loss of SOC	1 416.9	1 416.9	0.0	0.0
Total direct N_2O from managed soils	**20 072.5**	**18 081.0**	**-1 991.5**	**-9.9**

Note: Numbers may not add up exactly due to rounding off.

Methodology

The N_2O emissions from managed soils were calculated by using the Tier 1 method from the IPCC 2006 Guidelines (Equation 11.1). As in the 2004 agricultural inventory (DAFF, 2010), the contribution of N inputs from F_{OS} (N from managed organic soils) was assumed to be minimal and was therefore excluded from the calculations. DEFF recently conducted a study to identify organic soils (DEA, 2019), however this report was not completed before the inventory was compiled. This information will be assessed and included in the next inventory so that the N from managed organic soils could be considered in future submissions. 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:

$$N_2O_{Direct}\text{-}N = N_2O\text{-}N_{N\ inputs} + N_2O\text{-}N_{PRP} \qquad (Eq.\ 5.13)$$

Where:

$$N_2O\text{-}N_{N\ inputs} = [(F_{SN} + F_{ON} + F_{CR} + F_{SOM}) * EF_1] \qquad (Eq.\ 5.14)$$

$$N_2O\text{-}N_{PRP} = [(F_{PRP,CPP} * EF_{3PRP,CPP}) + (F_{PRP,SO} * EF_{3PRP,SO})] \qquad (Eq.\ 5.15)$$

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;

F_{SOM} = annual amount of N in mineral soils that is mineralised, in association with loss of soil C from soil organic matter as a result of changes to land use or management (kg N yr^{-1});
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 DALRRD's Abstracts of Agricultural Statistics (DAFF, 2018), and supporting data was obtained through scientific articles, guidelines, reports or personal communications with experts as discussed below.

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 managed soils or for feed, fuel or construction was calculated using Equations 10.34 and 11.4 in the IPCC 2006 guidelines. F_{SOM} is calculated as per IPCC equation 11.8. The loss of soil carbon required for this equation was obtained from the Land sector file.

The IPCC 2006 default emission factors (Chapter 11, Volume 4, Table 11.1) shown in Table 5.55 were used to estimate direct N_2O emissions from managed soils.

Each component of Eq. 5.14 to 5.15 are described in more detail in the sections below.

Table 5.55: IPCC default emission factors applied to estimate direct N_2O from managed soils.

	Use	Default value (kg N_2O-N (kg N)$^{-1}$)	Uncertainty range
EF_1	For N additions from mineral fertilizers, organic amendments and crop residues	0.01	0.003 – 0.03
$EF_{3PRP, CPP}$	For cattle, poultry and pigs	0.02	0.007 – 0.06

$EF_{3PRP, SO}$	For sheep and 'other animals'	0.01	0.003 – 0.03

Nitrogen application to managed soils (3C4)

Inorganic nitrogen fertilizer application (3C4a)

For nitrogen emissions the Fertilizer Association of SA reports total N consumption (http://www.fssa.org.za/Statistics.html) (Table 5.56). This value is the total nitrogen consumed in all fertilizer types and it accounts for the different N content of urea, ammonia, etc. It should be noted that the N consumption data between 2000 and 2009 was based on actual data, but thereafter the numbers are estimates. This is due to the Competition Commission placing restrictions on the collection of fertilizer and liming consumption data.

EF_1 (Table 5.55) was used to estimate direct N_2O-N emissions from F_{SN} inputs.

Table 5.56: Total nitrogen fertilizer consumption between 2000 and 2017.

	Total N fertilizer consumption (t)
2000	415 933
2001	395 813
2002	477 072
2003	420 827
2004	427 571
2005	347 260
2006	428 719
2007	439 480
2008	424 123
2009	453 777
2010	395 000
2011	419 000
2012	430 000
2013	416 500
2014	447 547

2015	402 792
2016	430 000
2017	442 900

Organic nitrogen application to soils (3C4b)

The amount of N (kg N yr^{-1}) from organic N additions applied to soil are calculated using the following equation from IPCC 2006 (Equation 11.3, vol 4, chpt 11, page 11.12):

$$F_{ON} = F_{AM} + F_{SEW} + F_{COMP} \quad \text{(Eq. 5.16)}$$

Where:

F_{AM} = animal manure N applied to soil (kg N yr^{-1});
F_{SEW} = amount of total sewage N applied to soils (kg N yr^{-1});
F_{COMP} = amount of compost N applied to soil (kg N yr^{-1}).

Once the amount of N applied has been determined it is combined with the emission factor as shown in Eq. 5.14.

Animal manure

A tier 1 approach was used to calculate N from animal manure applied to soils (IPCC 2006, Equation 11.4, vol 4, chapt 11, page 11.13). The amount of animal manure applied is equal to the amount of managed manure N available for soil application minus that used for feed and construction. The amount of managed manure N available for soil application is calculated from IPCC 2006 Equation 10.34 (vol 4, chpt 10, page 10.65) which requires the following data:

- Livestock population data (see relevant livestock sections under Section 5.2.2);
- N excretion data (see Section 5.3.2);
- Manure management system usage data (Table 5.22, Table 5.23, Table 5.24);
- 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 values provided by IPCC (IPCC, 2006; pg. 10.66) were utilized; 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).

Sewage sludge

Sewage sludge N inputs to managed soils was included in the previous inventory, however on closer investigation it was found that the N_2O emissions from sludge are included in the *Waste* sector. It was therefore excluded here due to double counting.

Compost

The amount of compost used on managed soils each year was estimated from the synthetic fertilizer consumption data. The synthetic fertilizer input changed each year, while the rest of the factors were assumed to remain unchanged over the 17 year period. It was estimated that a total of 5% of all farmers use compost (DAFF, 2010). 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 33% of nutrient needs through compost. All of this was taken into account when estimating N inputs from compost (details provided in DAFF (2010) and Otter (2011)).

Urine and dung deposited in pasture, range and paddock (3C4g)

Manure deposited in pastures, rangelands and paddocks include all the open areas where animal excretions are not removed or managed. It also includes emissions from daily spread. This manure 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 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}; kg N yr^{-1}) was calculated using Equation 11.5 in the IPCC 2006 Guidelines (Chapter 11, Volume 4):

$$F_{PRP} = \sum[(N_{(T)} * Nex_{(T)}) * MS_{(T, PRP)}] \qquad (Eq.\ 5.17)$$

Where:

$N_{(T)}$ = number of head of livestock in species/category T (from section 5.2.2);
$Nex_{(T)}$ = annual average N excretion per head of species/category T (kg N/animal/year) (see section 5.3.2);
$MS_{(T, PRP)}$ = fraction of total annual N excretion for each livestock species/category T that is deposited on PRP.

The IPCC 2006 default emission factor EF_{3PRP} (Table 5.55) 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).

Nitrogen in crop residues (3C4c)

The amount of crop residue available for application was estimated by utilizing the IPCC 2006 Tier 1 approach:

$$F_{CR} = \sum\{Crop_{(T)} * (Area_{(T)} - Area\ burnt_{(T)} * C_f) * Frac_{ReNew(T)} * [R_{AG(T)} * N_{AG(T)} * (1 - Frac_{Remove(T)}) + R_{BG(T)} * N_{BG(T)}]\} \quad (Eq.\ 5.\ 18)$$

Where:

F_{CR} = annual amount of N in crop residues (above and below ground) returned to soils annually (kg N yr^{-1});
$Crop_{(T)}$ = harvested annual dry matter yield for crop T (kg dm ha^{-1});
$Area_{(T)}$ = total annual area harvested of crop T (ha yr^{-1});
$Area\ burnt_{(T)}$ = annual area of crop T burnt (ha yr^{-1});
C_f = combustion factor (dimensionless);
$Frac_{ReNew(T)}$ = fraction of total area under crop T that is renewed annually;
$R_{AG(T)}$ = ratio of above-ground residues dry matter ($AG_{DM(T)}$) to harvested yield for crop T (kg dm $(kg\ dm)^{-1}$);
$N_{AG(T)}$ = N content of above-ground residues for crop T (kg N $(kg\ dm)^{-1}$);
$Frac_{Remove(T)}$ = fraction of above ground residues of crop T removed annually for purposes such as feed, bedding and construction (kg N $(kg\ crop\text{-}N)^{-1}$;
$R_{BG(T)}$ = ratio of below-ground residues to harvested yield for crop T (kg dm $(kg\ dm)^{-1}$);
$N_{BG(T)}$ = N content of below-ground residues for crop T (kg N $(kg\ dm)^{-1}$);
T = crop type.

Harvested area data was obtained from Agricultural abstracts (DAFF, 2016), Statistics SA (StatisticsSA, 2007) and FAO (FAOStat), and the other data requirements and their sources are provided in Table 5.57. The IPCC 2006 default emission factor EF_1 (Table 5.55) was used to estimate direct N_2O-N emissions from crop residues.

Table 5.57: Factors for estimating N from crop residues in South Africa (explanation of abbreviations provided in the text).

Crop type	Harvested yield[a,b,c,d]	Fraction burnt[d,e]	$R_{AG(T)}$[f,g]	$N_{AG(T)}$[f,g]	Fraction removed[d,e]	$R_{BG(T)}$[f,g]	$N_{BG(T)}$[f,g]
	(kg dm ha^{-1})		(kg dm (kg $dm)^{-1}$)	(kg N (kg $dm)^{-1}$)		(kg dm (kg $dm)^{-1}$)	(kg N (kg $dm)^{-1}$)
Barley	3 403	0.20	1.15	0.007	0.62	0.474	
Chicory	4 141	0	1.44	0.016	0.5	0.488	0.014
Cowpeas, dry peas and lentils	400	0.00	3.25	0.008	0.70	0.808	0.008
Cabbage	4 546	0.00	0.33	0.019	0.14	0.267	0.014
Canola [other oil seeds]	1 008	0.00	1.96	0.006	0.70	0.652	0.009
Cotton	3 704	0.00	1.33	0.006	0.00	0.512	0.009
Dry bean	911	0.00	1.11	0.01	0.58	0.000	
General Vegetable	3 170	0.00	0.43	0.019	0.50	0.287	0.014
Groundnuts (N fixing)	626	0.00	3.53	0.016	0.00	0.000	
Lucerne and other hay	26 809	0.00	0.29	0.027	0.95	0.516	0.019
Maize	8 973	0.00	1.10	0.006	0.50	0.462	
Potato	7 942	0.00	0.23	0.019	0.00	0.247	
Sorghum	1 294	0.00	1.91	0.007	0.88	0.000	
Soyabean	1 343	0.08	1.94	0.008	0.56	0.558	
Sugar Cane	53 721	0.16	0.30	0.015	0.47	1.040	0.012
Sunflower	956	0.00	2.01	0.006	0.53	0.662	0.009
Tobacco	2 400	0.00	1.46	0.006	0.00	0.540	0.009
Tomato	13 840	0.01	0.18	0.019	0.19	0.235	0.014
Wheat	3 343	0.01	1.73	0.006	0.51	0.628	
Oats	1 443	0.00	1.53	0.007	0.80	0.632	

[a] *Agricultural abstracts (DAFF, 2018)*
[b] *Statistics SA (Stats SA, 2007)*
[c] *FAO (FAOStat, 2018)*
[d] *Tongwane et al. (2016)*
[e] *Moeletsi et al. (2015)*
[f] *IPCC 2006 Guidelines, Table 11.2*
[g] *Agricultural GHG emission inventory for 2004 (DAFF, 2010)*

Mineralised N resulting from loss of SOC (3C4)

The mineralised N resulting from loss of soil organic carbon stocks in mineral soils through land-use change (F_{SOM}) was estimated following the equation 11.8 from the IPCC 2006 guidelines. The average annual loss of soil carbon from the various land types was taken from the LULUCF calculation file.

Uncertainties and time series consistency

Uncertainty ranges are provided for the default emission factors. For uncertainty on nitrogen consumption data expert opinion was used (Corne Louw, corne@grainsa.co.za) and it was indicated the N consumption would likely be within 15% of the number. Uncertainty of the percentage nitrogen is low so assumed to be 5%. The uncertainty for the crop residue factors are provided in Table 11.2 of the IPCC guidelines (IPCC, 2006). Uncertainty on F_{SN} emission factor is -70% and +200% (IPCC 2006, Table 11.1). The uncertainty on IPCC default emission factors is provided in Table 5.55. A 20% uncertainty on organic amendment activity data was assumed as no uncertainty data was provided.

Source specific QA/QC and verification

All general QC listed in Table 1.2 were completed for this category. Outputs were compared to the data in Moeletsi et al. (2015) and Tongwane et al. (2016). The synthetic fertilizers emission estimate in this submission were 2 094 Gg CO_2e for the year 2012 while Tongwane et al. (2016) reported a value of 2 969 Gg CO_2e. Tongwane et al. (2016) determined the amount of N applied per crop type, and in addition use a slightly lower GWP (i.e. 298) as opposed to the 310 applied in this inventory. There is some uncertainty around the actual crop areas as different data sources have different grouping of crops and often crops are grouped as “other field crops” for example, yet no clarification is provided on exactly what crops are included under “other”. This makes direct comparison difficult.

Tongwane et al. (2016) reported a value of 700 Gg CO_2e for crop residue emissions, which is similar to the 680 Gg CO_2e estimated for 2012 in this submission. Discrepancies can be due to differences in methodology, crop types and GWP. In this submission the below ground residues are also accounted for, which does not seem to be the case for Tongwane et al. (2016).

Source specific planned improvements

The data and methodology of Tongwane et al. (2016) will be considered in the next inventory cycle to determine if any factors need to be updated in the inventory, particularly relating to fertilisers and crop residues. Research is also being completed at the University of Pretoria regarding the emissions from the application of manure in fields and this research could be incorporated in future inventories.

5.5.7 Source category 3.C.5 Indirect nitrous oxide emissions from managed soils

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). Indirect emissions due to atmospheric deposition/volatilisation occur from inorganic and organic N application and urine and dung N inputs, while indirect runoff/leaching emissions can also occur from crop residue application and N losses due to changes in land management practices and land use (see Figure 11.1 of the 2006 IPCC guidelines).

Overview of shares and trends in emissions

2000 - 2017

In 2017 *Indirect N_2O from managed soils* produced 2 236 Gg CO_2e, which is 9.2% less than what was produced in 2000 (Table 5.58). Emissions due to deposition of volatilized N provides 91.0% of the indirect N_2O, and these emissions declined by 9.8% between 2000 and 2017 mostly due to reduced urine and dung inputs to the soil. Volatilization from urine and dung deposits in pasture, range and paddock is the largest contributor to emissions. Emissions from leaching and runoff declined by 3.0%. The contribution from fertilisers (both inorganic and organic) increased between 2000 and 2017, while the contribution from crop residues declined.

Table 5.58: Trends and changes in indirect N_2O emissions from managed soils between 2000 and 2017.

	Emissions ($Gg CO_2e$)		Change since 2000	
	2000	2017	Diff	%
Total indirect N_2O from MS	**2 463.3**	**2 236.3**	**-227.0**	**-9.2**
Indirect N_2O from deposition of volatilized N	***2 255.7***	***2 034.9***	***-220.9***	***-9.8***
Inorganic fertilizers	202.6	215.8	13.1	6.5
Organic fertilizers	399.0	406.6	7.6	1.9
Urine and dung deposits	1 654.1	1 412.5	-241.6	-14.6
Indirect N_2O from leaching/ runoff	***207.6***	***201.4***	***-6.2***	***-3.0***
Inorganic fertilizers	67.6	71.2	3.6	5.3
Organic fertilizers	66.6	67.1	0.5	0.8
Crop residues	43.3	33.4	-9.9	-22.9
Urine and dung deposits	NO	NO		
N mineralisation from SOC losses	30.1	29.7	-0.3	-1.1

Note: Numbers may not add up exactly due to rounding off.

Methodology

Due to limited data a Tier 1 approach was used to calculate the indirect N_2O emissions in this category.

Indirect N_2O from atmospheric deposition of volatilized N (3.C.5.a)

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. The calculation of F_{SN}, F_{ON}, and F_{PRP} are described above. The emission factor (EF_4), and the volatilization fractions ($Frac_{GASF}$ and $Frac_{GASM}$) were all taken from the IPCC 2006 default table (Table 11.3, Chapter 11, Volume 4, IPCC 2006).

Indirect N_2O from leaching/runoff (3.C.5.b)

The annual amount of N_2O-N produced from leaching and runoff of N additions to managed soils ($N_2O_{(L)}$-N) is determined by IPCC 2006 Equation 11.10. The values for F_{SN}, F_{ON}, F_{PRP}, and F_{CR} are described above. IPCC (2006, page 11.24, table 11.3) indicates that the term $Frac_{LEACH-(H)}$ only applies to regions where soil water-holding capacity is exceeded as a result of rainfall and/or irrigation (excluding drip irrigation) and for other regions $Frac_{LEACH-(H)}$ is taken as zero. Since South Africa is generally a dry country, using the default $Frac_{LEACH-(H)}$ value of 0.3 kg N (kg N additions or deposition by grazing animals)$^{-1}$ for all crop regions and urine and dung deposition would overestimate the emissions. Urine and dung deposited in pasture, range and paddock usually dries quickly due to dry conditions, therefore $Frac_{LEACH}$ for urine and dung is assumed to be zero based on the IPCC definition. The fraction of all N added to/mineralised in cultivated lands that is lost through leaching and runoff ($Frac_{LEACH-(H)}$) was determined by using a weighted average (based on the area of irrigated land) of the value in IPCC 2006 Table 11.3 for manure amendments, nitrogen fertilizers and other organic amendments. The crop management data from Moeletsi et al. (2015) showed that 15% of the crop area is irrigated and these areas were assumed to have the default $Frac_{LEACH-(H)}$ value of 0.3 kg N (kg N additions)$^{-1}$, while other crop areas were assigned a value of zero. The weighted average for $Frac_{LEACH-(H)}$ for cultivated lands was, therefore, determine to be 0.045 kg N (kg N additions)$^{-1}$. This may be a slight overestimate as drip irrigation may be included in the irrigated area, but it may also be an underestimate as there may be some cropland areas that are in higher rainfall and humidity areas. The emission factor (EF_5) was taken from the IPCC 2006 default table (Table 11.3, Chapter 11, Volume 4, IPCC 2006).

Uncertainties and time series consistency

IPCC default values were used for the emission factors and the uncertainty on the activity data is discussed previously in the relevant sections. Uncertainty on irrigated area was determined to be 50% and this was based on differences between data from field studies and land cover maps. Field data indicates 15% of croplands are irrigated, while land cover maps show that pivot crops are 7% of cropland area. This was taken to be the lower limit as non-pivot crops can be irrigated by other means. Uncertainty on $Frac_{LEACH-(H)}$ is given in Table 11.3 of 2006 IPCC guidelines.

Source specific QA/QC

All general QA/QC checks were completed, but no source specific QA/QC procedures were undertaken.

Source specific planned improvements

In the next few inventory cycles the fraction of added N that is lost through leaching and runoff will be re-evaluated and updated based on a more detailed analysis.

5.5.8 Source category 3.C.6 Indirect nitrous oxide emissions from manure management

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 ii) through runoff and leaching from land where N was applied (IPCC, 2006).

Overview of shares and trends in emissions

2000 - 2017

Indirect N_2O from manure management produced 473 Gg CO_2e in 2017, which is an 14.8% increase from the 412 Gg CO_2e produced in 2000. Losses due to volatilisation accounted for 78.2% of the emissions.

Methodology

A Tier 1 method was used to determine N_2O emissions from deposition of volatilized N.

Indirect N_2O from volatilization (3C6a)

Indirect N_2O losses from manure management due to volatilization were calculated using the Tier 1 method as described by IPCC 2006 Eq 10.26 and 10.27. This requires N excretion data, manure management system data (Table 5.22), and default fractions of N losses from manure management systems due to volatilization and runoff/leaching (IPCC 2006, Table 10.22). 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 + NO_x-N volatilized)$^{-1}$) was used. For leaching the emission factor was 0.0075 kg N_2O-N (kg N leaching/runoff)$^{-1}$.

Uncertainties and time series consistency

Default uncertainties are applied on the default values, while uncertainty on activity data is discussed in previous sections.

Source specific QA/QC

No source specific QA/QC was undertaken for this category, just the general QA/QC procedures for the AFOLU sector.

Source specific planned improvements

No source specific improvements are planned for this category.

5.6 Source category 3.D Other

5.6.1 Source category 3.D.1 Harvested wood products

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.

Overview of shares and trends in emissions

2000 - 2017

In 2017 harvested wood products were a sink of 777 Gg CO_2 (Table 5.59), which is more than double the sink in 2000. However, the sink varied annually, with some years showing an increase and others a decrease.

Table 5.59: Trends in HWP net emissions and removals between 2000 and 2017.

	HWP
	Gg CO_2e
2000	-290.4
2001	-557.0

2002	-735.5
2003	-893.1
2004	-1 151.0
2005	-251.7
2006	-869.1
2007	-629.0
2008	-792.3
2009	-119.1
2010	-513.1
2011	57.2
2012	-441.4
2013	-282.9
2014	-535.4
2015	-608.3
2016	-1 091.1
2017	-776.9

Note: Negative values are a sink, while positive values show emissions.

Methodology

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/).

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 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 5.45 and 5.46 (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. 5.19)

Where:

$f_{IRW}(i)$ = share of industrial roundwood for the domestic production of 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. 5.20)

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 5.47 (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. 5.21)

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 5.48 (Eq 12.1 in 2006 IPCC Guidelines)) was applied to estimate the HWP contribution:

$$C(i+1) = e^{-k} * C(i) + ((1 - e^{-k})/k) * Inflow(i) \qquad \text{(Eq. 5.22)}$$

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 (t_0) from which the activity data start. This means that as a proxy $\Delta C(t_0)$ 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):

$$C(t_0) = Inflow_{average}/k \qquad \text{(Eq. 5.23)}$$

Where:

$$Inflow_{average} = \left(\sum_{i=t0}^{t4} Inflow(i)\right)/5 \qquad \text{(Eq. 5.24)}$$

$C(t_0)$ was taken to be 1990 (S. Ruter, pers. comm.) and was substituted into Eq 5.22 so that $C(i)$ and $\Delta C(i)$ in the sequential time instants can be calculated.

Uncertainties 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.

Source specific QA/QC

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 giving confidence to the emission estimates presented here.

Source specific planned improvements

There are no planned improvements for this sub-category.

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Appendix 5.A Summary table for the AFOLU sector

Table 5A.1: Summary table of emissions from the AFOLU sector in 2017.

	Net CO_2 emissions / removals	Emissions					Total emissions
	(Gg)						(Gg CO_2e)
	CO_2	CH_4	N_2O	NOx	CO	NMVOCs	
3 - Agriculture, Forestry, and Other Land Use	**-41 288.06**	**1 309.57**	**73.78**	**487.79**	**20.29**	**27.24**	**9 085.24**
3 - AFOLU (excluding FOLU)	**1 901.70**	**1 277.83**	**73.78**	**487.79**	**20.29**	**27.24**	**51 608.40**
3.A - Livestock	**0.00**	**1 259.69**	**5.51**	**0.00**	**0.00**	**0.00**	**28 161.29**
3.A.1 - Enteric Fermentation	0.00	1 224.23	0.00	0.00	0.00	0.00	25 708.88
3.A.1.a - Cattle		1 028.08					21 589.73
3.A.1.a.i - Dairy Cows		*144.31*					*3 030.42*
3.A.1.a.ii - Other Cattle		*883.78*					*18 559.31*
3.A.1.b - Buffalo		*NO*					NO
3.A.1.c - Sheep		*153.08*					3 214.58
3.A.1.d - Goats		*33.77*					709.22
3.A.1.e - Camels		*NO*					NO
3.A.1.f - Horses		*5.81*					122.01
3.A.1.g - Mules and Asses		*1.63*					34.19

3.A.1.h - Swine		*1.86*					39.14
3.A.1.j - Other		*NO*					NO
3.A.2 - Manure Management (1)	0.00	35.45	5.51	0.00	0.00	0.00	2 452.41
3.A.2.a - Cattle		11.67	2.87				1 134.50
3.A.2.a.i - Dairy cows		*10.49*	*0.35*				330.13
3.A.2.a.ii - Other cattle		*1.17*	*2.52*				804.37
3.A.2.b - Buffalo		*NO*	*NO*				NO
3.A.2.c - Sheep		*0.04*	*0.33*				0.88
3.A.2.d - Goats		*0.04*	*0.12*				0.80
3.A.2.e - Camels		*NO*	*NO*				NO
3.A.2.f - Horses		*0.00*	*0.00*				0.09
3.A.2.g - Mules and Asses		*0.00*	*0.00*				0.02
3.A.2.h - Swine		*20.89*	*0.12*				438.59
3.A.2.i - Poultry		*2.82*	*2.07*				59.21
3.A.2.j - Other		*NO*	*NO*				NO
3.B - Land	**-42 412.84**	**31.74**	**0.00**	**0.00**	**0.00**	**0.00**	**-41 746.24**
3.B.1 - Forest land	-40 707.43	0.00	0.00	0.00	0.00	0.00	-40 707.43
3.B.1.a - Forest land Remaining Forest land	-14 093.58						-14 093.58
3.B.1.b - Land Converted to Forest land	-26 613.85						-26 613.85
3.B.1.b.i - Cropland converted to Forest Land	*-2 928.81*						-2 928.81
3.B.1.b.ii - Grassland converted to Forest Land	*-21 821.33*						-21 821.33
3.B.1.b.iii - Wetlands converted to Forest Land	*-106.56*						-106.56
3.B.1.b.iv - Settlements converted to Forest Land	*-452.61*						-452.61

3.B.1.b.v - Other Land converted to Forest Land	*-1 304.54*						-1 304.54
3.B.2 - Cropland	528.27	0.00	0.00	0.00	0.00	0.00	528.27
3.B.2.a - Cropland Remaining Cropland	-1 793.05						-1 793.05
3.B.2.b - Land Converted to Cropland	2 321.32						2 321.32
3.B.2.b.i - Forest Land converted to Cropland	*2 594.32*						2 594.32
3.B.2.b.ii - Grassland converted to Cropland	*-248.22*						-248.22
3.B.2.b.iii - Wetlands converted to Cropland	*2.05*						2.05
3.B.2.b.iv - Settlements converted to Cropland	*15.73*						15.73
3.B.2.b.v - Other Land converted to Cropland	*-42.57*						-42.57
3.B.3 - Grassland	-18 172.65	0.00	0.00	0.00	0.00	0.00	-18 172.65
3.B.3.a - Grassland Remaining Grassland	-510.35						-510.35
3.B.3.b - Land Converted to Grassland	-17 662.31						-17 662.31
3.B.3.b.i - Forest Land converted to Grassland	*4 708.09*						4 708.09
3.B.3.b.ii - Cropland converted to Grassland	*-1 133.96*						-1 133.96
3.B.3.b.iii - Wetlands converted to Grassland	*1.25*						1.25
3.B.3.b.iv - Settlements converted to Grassland	*-319.77*						-319.77
3.B.3.b.v - Other Land converted to Grassland	*-20 917.92*						-20 917.92
3.B.4 - Wetlands	0.00	31.74	0.00	0.00	0.00	0.00	666.60
3.B.4.a - Wetlands Remaining Wetlands	0.00	31.74					666.60
3.B.5 - Settlements	-105.85	0.00	0.00	0.00	0.00	0.00	-105.85
3.B.5.a - Settlements Remaining Settlements	-686.16						-686.16
3.B.5.b - Land Converted to Settlements	580.31						580.31
3.B.5.b.i - Forest Land converted to Settlements	*299.93*						299.93

3.B.5.b.ii - Cropland converted to Settlements	*79.77*						79.77
3.B.5.b.iii - Grassland converted to Settlements	*236.33*						236.33
3.B.5.b.iv - Wetlands converted to Settlements	*-1.03*						-1.03
3.B.5.b.v - Other Land converted to Settlements	*-34.69*						-34.69
3.B.6 - Other Land	16 044.82	0.00	0.00	0.00	0.00	0.00	16 044.82
3.B.6.a - Other land Remaining Other land	0.00						0.00
3.B.6.b - Land Converted to Other land	16 044.82						16 044.82
3.B.6.b.i - Forest Land converted to Other Land	*1 817.48*						1 817.48
3.B.6.b.ii - Cropland converted to Other Land	*201.97*						201.97
3.B.6.b.iii - Grassland converted to Other Land	*13 435.95*						13 435.95
3.B.6.b.iv - Wetlands converted to Other Land	*535.96*						535.96
3.B.6.b.v - Settlements converted to Other Land	*53.46*						53.46
3.C - Aggregate sources and non-CO2 emissions sources on land (2)	**1 901.70**	**18.14**	**68.27**	**487.79**	**20.29**	**27.24**	**23 447.11**
3.C.1 - Emissions from biomass burning	0.00	18.14	1.22	487.79	20.29	27.24	758.75
3.C.1.a - Biomass burning in forest lands	IE	5.10	0.32	121.47	4.27	10.24	205.41
3.C.1.b - Biomass burning in croplands	IE	2.72	0.07	92.80	2.52	0.00	79.08
3.C.1.c - Biomass burning in grasslands	IE	9.75	0.78	257.67	13.37	16.17	446.61
3.C.1.d - Biomass burning in wetlands	IE	0.49	0.04	13.73	0.00	0.72	23.96
3.C.1.e - Biomass burning in settlements	IE	0.08	0.01	2.12	0.13	0.11	3.70
3.C.1.f - Biomass burning in other lands	IE	0.00	0.00	0.00	0.00	0.00	0.00
3.C.2 - Liming	1 222.09						1 222.09
3.C.3 - Urea application	679.61						679.61

3.C.4 - Direct N2O Emissions from managed soils (3)			58.33				18 081.05
3.C.5 - Indirect N2O Emissions from managed soils			7.21				2 236.26
3.C.6 - Indirect N2O Emissions from manure management			1.51				469.35
3.C.7 - Rice cultivations	NO	NO	NO				NO
3.C.8 - Other (please specify)							0.00
3.D - Other	**-776.92**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**-776.92**
3.D.1 - Harvested Wood Products	-776.92						-776.92
3.D.2 - Other (please specify)							0.00

Table 5A.2: Summary table of 2015 emissions and removals in the Land sector.

Categories	Activity Data		Net carbon stock change and CO2 emissions									Net CO_2 emissions (Gg CO2)
			Biomass				Dead organic matter			Soils		
	Total Area (ha)	Thereof: Area of organic soils (ha)	Increase (Gg C)	Decrease (Gg C)	Carbon emitted as CH_4 and CO from fires (1) (Gg C)	Net carbon stock change (Gg C)	Carbon stock change (Gg C)	Carbon emitted as CH_4 and CO from fires (1) (Gg C)	Net carbon stock change (Gg C)	Net carbon stock change in mineral soils (2) (Gg C)	Carbon loss from drained organic soils (Gg C)	
3.B - Land	**122 518 007**	**0**	**22 679.72**	**-14 064.54**	**0.00**	**7 151.85**	**0.00**	**0.00**	**1 523.38**	**520.45**	**0.00**	**-42 412.84**
3.B.1 - Forest land	**22 753 961**	**0**	**21 411.65**	**-12 970.86**	**0.00**	**8 440.79**	**0.00**	**0.00**	**648.19**	**2 013.05**	**0.00**	**-40 707.43**
3.B.1.a - Forest land Remaining Forest land	16 006 306	NE	15 837.07	-12 164.75		3 672.32			171.38	0.00	NE	-14 093.58
3.B.1.b - Land Converted to Forest land	6 747 655	NE	5 574.58	-806.11	IE	4 768.47	IE	IE	476.81	2 013.05	NE	-26 613.85
3.B.1.b.i - Cropland converted to Forest Land	*515 244*	NE	*357.71*	*-52.92*		*304.79*	IE		*16.20*	*477.78*	NE	*-2 928.81*
3.B.1.b.ii - Grassland converted to Forest Land	*5 846 206*	NE	*4 933.24*	*-717.71*		*4 215.53*	IE		*425.82*	*1 309.93*	NE	*-21 821.33*
3.B.1.b.iii - Wetlands converted to Forest Land	*34 369*	NE	*29.50*	*-4.23*		*25.27*	IE		*3.79*	*0.00*	NE	*-106.56*
3.B.1.b.iv - Settlements converted to Forest Land	*109 910*	NE	*92.11*	*-13.09*		*79.02*	IE		*10.88*	*33.54*	NE	*-452.61*
3.B.1.b.v - Other Land converted to Forest Land	*241 927*	NE	*162.01*	*-18.15*		*143.86*	IE		*20.12*	*191.80*	NE	*-1 304.54*
3.B.2 - Cropland	**13 793 331**	**0**	**443.50**	**-645.12**	**0.00**	**-201.62**	**0.00**	**0.00**	**304.27**	**-1 192.12**	**0.00**	**528.27**

3.B.2.a - Cropland Remaining Cropland	12 112 976	NE	341.36	-42.01		299.36			60.38	129.28	NE	-1 793.05
3.B.2.b - Land Converted to Cropland	1 680 355	NE	102.13	-603.11	IE	-500.98	IE	IE	243.89	-1 321.39	NE	2 321.32
3.B.2.b.i - Forest Land converted to Cropland	*544 741*	NE	*73.06*	*-583.22*		*-510.16*	IE		*82.58*	*-279.96*	NE	*2 594.32*
3.B.2.b.ii - Grassland converted to Cropland	*1 081 003*	NE	*26.99*	*-18.12*		*8.87*	IE		*155.04*	*-96.21*	NE	*-248.22*
3.B.2.b.iii - Wetlands converted to Cropland	*4 337*	NE	*0.29*	*0.71*		*1.00*	IE		*0.72*	*-2.28*	NE	*2.05*
3.B.2.b.iv - Settlements converted to Cropland	*43 357*	NE	*0.72*	*-3.06*		*-2.35*	IE		*3.61*	*-5.55*	NE	*15.73*
3.B.2.b.v - Other Land converted to Cropland	*6 918*	NE	*1.08*	*0.58*		*1.65*	IE		*1.94*	*8.02*	NE	*-42.57*
3.B.3 - Grassland	**67 831 841**	**0**	**571.69**	**0.00**	**0.00**	**-704.22**	**0.00**	**0.00**	**885.13**	**4 921.30**	**0.00**	**-18 172.65**
3.B.3.a - Grassland Remaining Grassland	59 798 527	NE	389.63	-535.66		-146.04			295.07	-9.85	NE	-510.35
3.B.3.b - Land Converted to Grassland	8 033 314	NE	571.69	-1 275.90	IE	-704.22	IE	IE	590.06	4 931.15	NE	-17 662.31
3.B.3.b.i - Forest Land converted to Grassland	*3 637 034*	NE	*169.47*	*-1 172.71*		*-1 003.24*	IE		*198.12*	*-478.90*	NE	*4 708.09*
3.B.3.b.ii - Cropland converted to Grassland	*1 109 796*	NE	*43.02*	*-55.88*		*-12.86*	IE		*-14.11*	*336.24*	NE	*-1 133.96*
3.B.3.b.iii - Wetlands converted to Grassland	*52 194*	NE	*2.79*	*-0.50*		*2.29*	IE		*4.44*	*-7.07*	NE	*1.25*
3.B.3.b.iv - Settlements converted to Grassland	*147 879*	NE	*2.80*	*-2.43*		*0.37*	IE		*5.15*	*81.70*	NE	*-319.77*
3.B.3.b.v - Other Land converted to Grassland	*3 086 411*	NE	*353.61*	*-44.38*		*309.23*	IE		*396.46*	*4 999.19*	NE	*-20 917.92*
3.B.4 - Wetlands (1)	**2 445 103**	**NE**	**0.00**	**0.00**	**0.00**	**0.00**	**IE**	**0.00**	**0.00**	**0.00**	**NE**	**0.00**

3.B.5 - Settlements	**3 243 421**	**0**	**252.89**	**-96.33**	**0.00**	**-30.87**	**0.00**	**0.00**	**52.36**	**-180.05**	**0.00**	**-105.85**
3.B.5.a - Settlements Remaining Settlements	2 785 592	NE	206.68	-19.25		187.43			0.11	-0.41	NE	-686.16
3.B.5.b - Land Converted to Settlements	457 829	NE	46.21	-77.09	IE	-30.87	IE	IE	52.24	-179.64	NE	580.31
3.B.5.b.i - Forest Land converted to Settlements	*128 889*	NE	*19.07*	*-54.98*		*-35.91*	IE		*18.31*	*-64.20*	NE	*299.93*
3.B.5.b.ii - Cropland converted to Settlements	*65 503*	NE	*5.99*	*-8.44*		*-2.45*	IE		*13.94*	*-33.25*	NE	*79.77*
3.B.5.b.iii - Grassland converted to Settlements	*257 853*	NE	*20.84*	*-13.63*		*7.22*	IE		*19.38*	*-91.05*	NE	*236.33*
3.B.5.b.iv - Wetlands converted to Settlements	*1 068*	NE	*0.31*	*-0.01*		*0.30*	IE		*0.59*	*-0.61*	NE	*-1.03*
3.B.5.b.v - Other Land converted to Settlements	*4 516*	NE	*0.00*	*-0.03*		*-0.03*	IE		*0.02*	*9.47*	NE	*-34.69*
3.B.6 - Other Land	**12 450 349**	**0**	**0.00**	**-352.23**	**0.00**	**-352.23**	**0.00**	**0.00**	**-366.57**	**-3 657.07**	**0.00**	**16 044.82**
3.B.6.a - Other land Remaining Other land	9 932 899	NE								0.00	NE	0.00
3.B.6.b - Land Converted to Other land	2 517 450	NE	0.00	-352.23	IE	-352.23	0.00	0.00	-366.57	-3 657.07	NE	16 044.82
3.B.6.b.i - Forest Land converted to Other Land	*151 522*	NE	*0.00*	*-56.40*		*-56.40*			*-210.50*	*-228.78*	NE	*1 817.48*
3.B.6.b.ii - Cropland converted to Other Land	*13 688*	NE	*0.00*	*-2.51*		*-2.51*			*-34.83*	*-17.74*	NE	*201.97*
3.B.6.b.iii - Grassland converted to Other Land	*2 273 833*	NE	*0.00*	*-292.75*		*-292.75*			*-109.00*	*-3 262.60*	NE	*13 435.95*
3.B.6.b.iv - Wetlands converted to Other Land	*73 546*	NE	*0.00*	*0.00*		*0.00*			*0.00*	*-146.17*	NE	*535.96*
3.B.6.b.v - Settlements converted to Other Land	*4 862*	NE	*0.00*	*-0.57*		*-0.57*			*-12.23*	*-1.78*	NE	*53.46*

CH4 emissions	***Gg CH4***	***Gg CO2e***										
3.B.4 - Wetlands (1)	*31.74*	*666.60*										

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Chapter 6: Waste

6.1 Sector overview

6.1.1 Introduction

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, open burning of waste and wastewater treatment systems in South Africa, estimated using the IPCC 2006 Guidelines.

The waste sector in the national inventory of South Africa comprises three sources:

- 4A Solid waste disposal;
- 4C Incineration and open burning of waste (only open burning of waste is estimated); and
- 4D Wastewater treatment and discharge.

For completeness in this sector, emissions from incineration and biological treatment of organic waste still need to be addressed.

6.1.2 Overview of shares and trends in emissions

South Africa's *Waste* sector produces mainly CH_4 (95.8%), with smaller amounts of N_2O (4.0%) and CO_2 (0.2%) in 2017 (Table 6.1). *Solid waste disposal* increased its contribution to the total *Waste* sector emissions by 4.0% since 2000. *Incineration and open burning of waste* decreased its contribution since 2000 by 0.4%, while the contribution from *Wastewater treatment and discharge* declined by 3.7%.

A detailed summary table of the 2017 Waste sector emissions is provided in Appendix 6A.

2017

In 2017 the *Waste* sector produced 21 249 Gg CO_2e. The largest source category is the *Solid waste disposal* which contributed 87.1% (17 366 Gg CO_2e) towards the total sector emissions.

Table 6.1: Summary of the estimated emissions from the Waste sector in 2017 for South Africa.

Greenhouse gas source categories	CO_2	CH_4	N_2O	Total
	Gg CO_2e			
4.Waste	**37.5**	**20 359.9**	**851.6**	**21 249.0**
4.A Solid waste disposal		17 366.0		17 366.0
4.B Biological treatment of solid waste	NE	NE	NE	NE
4.C Incineration and open burning of waste	33.5	240.7	82	360.2
4.D Wastewater treatment and discharge		2 753.3	769.6	3 522.8

Numbers may not sum exactly due to rounding off.

2000 – 2017

Waste sector emissions have increased by 56.7% from the 13 558 Gg CO_2e in 2000 (Table 6.2). Emissions increased steadily between 2000 and 2017 (Figure 6.1; Table 6.3). 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.

Emissions from *Solid waste disposal* increased by 64.8% (6 832 Gg CO_2e) since 2000 (10 534 Gg CO_2e), while emissions from *Incineration and open burning of waste* and *Wastewater treatment and discharge* each increased by 28.4% over this period.

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Table 6.2: GHG emissions from South Africa's Waste sector between 2000 and 2017.

Source category	Emissions ($Gg\ CO_2e$)		Change 2000-2017	
	2000	2017	Diff	%
4 Waste sector	**13 557.8**	**21 249.0**	**7 691.1**	**0.6**
4.A Solid waste disposal	10 533.9	17 366.0	6 832.0	0.6
4.B Biological treatment of solid waste	NE	NE		
4.C Incineration and open burning of waste	280.5	360.2	79.7	0.3
4.D Waste water treatment and discharge	2 743.4	3 522.8	779.4	0.3

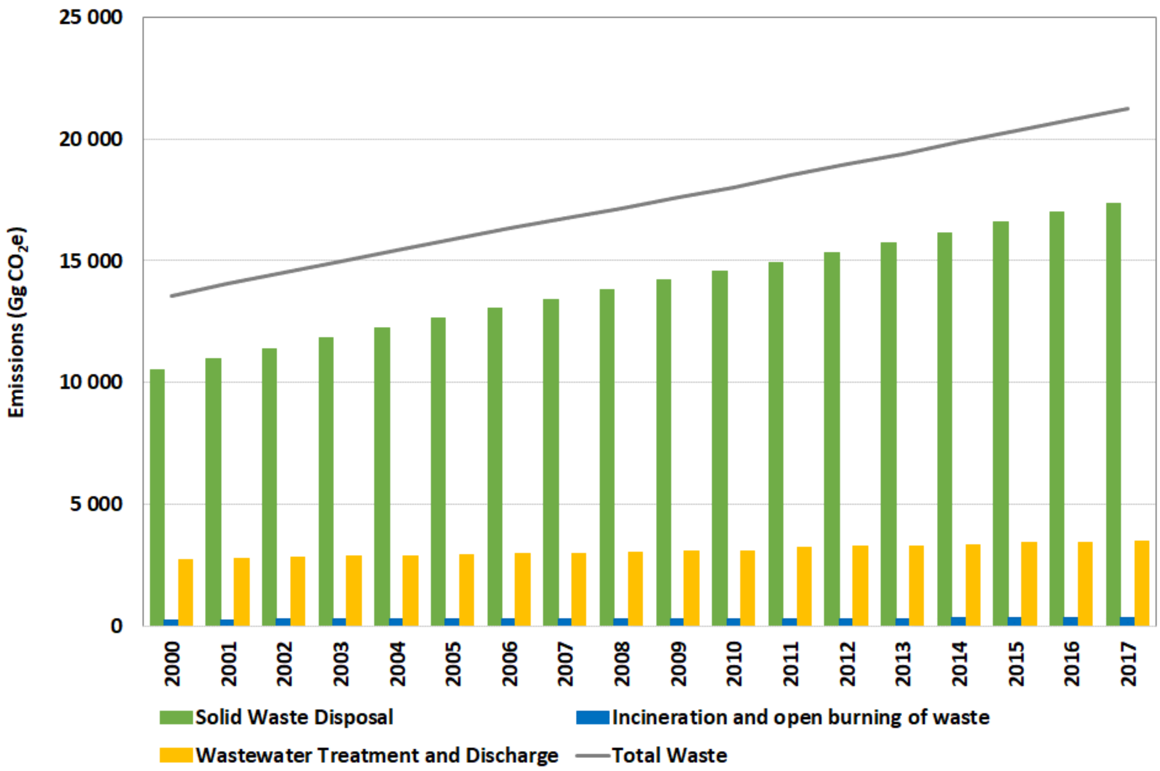

Figure 6.1: Trend in emissions from Waste sector, 2000 - 2017.

Table 6.3: Trend in Waste sector category emissions between 2000 and 2017.

	Solid Waste Disposal	Biological treatment of solid waste	Incineration and open burning of waste	Wastewater Treatment and Discharge	Total Waste
	Emissions (Gg CO_2e)				
2000	10 533.9	NE	280.5	2 743.4	13 557.8
2001	10 964.9	NE	286.3	2 800.2	14 051.4
2002	11 393.8	NE	290.3	2 839.0	14 523.1
2003	11 815.5	NE	294.0	2 875.4	14 984.9
2004	12 229.2	NE	297.5	2 909.6	15 436.3
2005	12 635.4	NE	300.9	2 942.8	15 879.1
2006	13 034.4	NE	304.3	2 976.1	16 314.7
2007	13 426.8	NE	307.6	3 008.9	16 743.3
2008	13 813.0	NE	311.1	3 042.3	17 166.4
2009	14 192.8	NE	314.4	3 075.1	17 582.3
2010	14 563.5	NE	317.9	3 109.4	17 990.8
2011	14 935.2	NE	330.0	3 228.0	18 493.2
2012	15 332.1	NE	337.8	3 303.5	18 973.3
2013	15 738.0	NE	339.1	3 316.6	19 393.6
2014	16 159.4	NE	344.6	3 370.6	19 874.6
2015	16 573.3	NE	350.3	3 426.5	20 350.2
2016	16 975.9	NE	354.4	3 466.7	20 797.1
2017	17 366.0	NE	360.2	3 522.8	21 249.0

6.1.3 Overview of methodology and completeness

The emissions for the *Waste* sector were derived by either using available data or estimates based on accessible surrogate data sourced from the scientific literature. Table 6.4) shows the methods and emission factors applied in this sector. 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.

Table 6.4: Summary of methods and emission factors for the Waste sector and an assessment of the completeness of the Waste sector emissions.

GHG Source and sink category		CO_2		CH_4		N_2O		Details
		Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	
A	Solid waste disposal			T1	DF			Tier 1 FOD model was used.
B	Biological treatment of solid waste	NE		NE		NE		
C	Incineration and open burning of waste	T1	DF	T1	DF	T1	DF	
D	Waste water treatment and discharge	NA		T1	DF	T1	DF	

Data sources

The main data sources for the Waste sector are provided in Table 6.5.

Table 6.5: Main data sources for the Waste sector emission calculations.

Sub-category	Activity data	Data source
Solid waste disposal	Population data	Statistics SA (2015); UN (2012)
	Waste composition	IPCC 2006
	Waste generation rate for each component	DEA (2012)
	GDP	World bank
Open burning of waste	Population data	Statistics SA (2015); UN (2012)
	Fraction of population burning waste	

Wastewater treatment and discharge	Population data	Statistics SA (2015); UN (2012)
	Split of population by income group	Statistics SA (2015)
	BOD generation rates per treatment type	IPCC 2006
	Per capita nitrogen generation rate	IPCC 2006

6.1.4 Key categories in the Waste sector

The key categories in the Waste sector were determined to be:

- Level assessment for 2017:
  - Solid waste disposal (CH_4)
  - Wastewater treatment and discharge (CH_4)
- Trend assessment between 2000 and 2015:
  - Solid waste disposal (CH_4)

6.1.5 Recalculations and improvements since the 2015 submission

Recalculations were performed for the category *Solid waste disposal* for all years between 2000 and 2017 due to the following changes:

- The population, waste per capita and the percentage of waste going to solid waste disposal sites was corrected in the FOD model for the years 1950 to 2000. In the previous submission these numbers were only input for the years from 2000 onwards, while default values were left for the years prior to this.
- The fraction of methane in developed gas was previously indicated to be 0.52 and this was corrected to the IPCC default value of 0.5.

The recalculation in the *Solid waste disposal* emissions produced outputs that were 34.8% higher than previous submission for 2000, and this declined to a 5.2% increase in the recalculated 2015 estimate. Overall the current recalculated estimates for *Waste* were 25.1% higher for 2000 and 4.2% higher 2015.

6.1.6 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. No specific improvements are planned; however South Africa has identified the following areas to be considered in the improvement plan for the future:

(i) obtain data on the quantities of waste disposed of into managed and unmanaged landfills;
(ii) improve the MCF and rate constants;
(iii) 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;
(iv) Obtain information on population distribution trends between rural and urban settlements as a function of income; and
(v) conduct a study to trace waste streams and obtain more information on the bucket system which is still widely used in South Africa.

The DEA is currently undertaking a study to collect actual activity data for this category for the period 2000 – 2015. They will collect the following:

- activity data collection for solid waste disposal in South Africa
- activity data collection for wastewater treatment in South Africa
- activity data collection for waste incineration and open- burning of waste
- activity data collection for biological treatment of solid waste

6.2 Source Category 4.A Solid Waste Disposal

6.2.1 Category information

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.

Overview of shares and trends in emissions

2017

Solid waste disposal was estimated to produce 17 366 Gg CO_2e in 2017, which was all from CH_4 emissions. It contributes 81.7% to the total *Waste* sector emissions.

2000 – 2017

Emissions in this category increased by 56.7% (7 691 Gg CO_2e) since 2000. The main driver of this increase is the population numbers and therefore the amount of waste being generated.

In the previous submission it was indicated that this category more than doubled between 2000 and 2015. The reason for the change is that the recalculated 2000 estimates are now higher than in the previous submission. In the FOD model data was only updated for 2000 onwards and default values were left for the years 1950 to 1999. This correction resulted in a slowing increase in emissions since 1950 and hence higher estimates for 2000.

6.2.2 Methodology

The methodology for calculating GHG emissions from solid waste is consistent with the IPCC tier 1 First Order Decay (FOD) Model (IPCC, 2006). This method utilizes a dynamic model driven by landfill data. It assumes that the degradable organic component (degradable organic carbon, DOC) in waste decays slowly throughout a few decades, during which CH_4 and CO_2 are formed. If conditions are constant, the rate of CH_4

production depends solely on the amount of carbon remaining in the waste. As a result emissions of CH_4 from waste deposited in a disposal site are highest in the first few years after deposition, then gradually decline as the degradable carbon in the waste is consumed by the bacteria responsible for the decay. Input data includes population data (StatsSA, 2015), waste generation rates, GDP (World bank), annual waste generation, 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 (Table 6.6).

The FOD method requires data to be collected or estimated for historical disposals of waste over a time period of 3 to 5 half-lives in order to achieve an acceptably accurate result. It is therefore good practice to use disposal data for at least 50 years as this time frame provides an acceptably accurate result for most typical disposal practices and conditions. Therefore, the activity data used comprised waste quantities disposed of into managed landfills from 1950 to 2015, covering a period of about 75 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 2017 (StatsSA, 2015). Waste generation rates for industrial waste were estimated using GDP values sourced from the World Bank for period 2013 to 2017.

Table 6.6: IPCC default factors utilized in the FOD Model to determine emissions from solid waste disposal.

Factor	Sub-category	Value	Unit
DOC (degradable organic carbon)	Bulk MSW	0.2	Weight fraction (wet basis)
	Industrial waste	0.15	
	Sludge waste	0.05	
DOCf (fraction of DOC dissimilated)		0.05	Fraction
Methane generation rate constant	Bulk MSW	0.05	$Years^{-1}$
	Industrial waste	0.05	
	Sewage sludge	0.06	
Methane correction factor (MCF)	Unmanaged, shallow	0.4	Unitless
	Unmanaged, deep	0.8	
	Managed	1	
	Managed, semi-aerobic	0.5	
	Uncategorized	0.6	
Fraction of methane in generated landfill gas (F)		0.5	Fraction

Oxidation factor (OF)		0	Unitless

In addition, the inventory compilers noted that the information on national waste composition presented in the National Waste Baseline Information Report (DEA, 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 National Waste Information Baseline Report (DEA, 2012) indicated that 11% of waste was recycled in 2011 and then a further 9% goes to open burning. Due to a lack of data for other years, these values were assumed to be constant over the time period and so the percentage of generated waste which goes to solid waste disposal sites was set at 80%.

No detailed analysis of the methane recovery from landfills was accounted for between 2000 and 2017. As noted in the previous inventory, 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.

The key assumptions applied in this method were:

- waste generation rate per capita was assumed to be constant (578.73 kg/cap/yr) (national weighted average from State of Environment Outlook Report) throughout the time series 2000 – 2017
- percentage of MSW going into landfills was assumed to be constant (90%) throughout the time series 2000 – 2017
- Composition of waste going into SWDS was assumed to be 23 % food, 0% garden, 25% paper, 15% wood, 0% textile, 0% nappies and 37% plastic or other inert substance (default IPCC Regional values)
- waste generation rate per GDP (Gg/$m GDP/yr) was assumed to be constant (8 tonnes/per unit of GDP in US dollar) throughout the time series (World bank, 2013).

6.2.3 Uncertainty and time series consistency

Uncertainty

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.

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 (DEAT, 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 provided in Table 6.7.

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.

Table 6.7: Uncertainties associated with emissions from South Africa's solid waste disposal.

Gas	Activity data and emission factors	Uncertainty	
		%	Source
CH_4	Total municipal solid waste	±30	IPCC 2006
	Fraction of MSW sent to SWDS	More than a factor of two	

	Total uncertainty of waste composition	More than a factor of two	
	DOC	±20	
	DOC_f	±20	
	MCF	±10	
	Fraction of CH_4 in generated landfill gas	±5	
	Methane recovery	±50	

6.2.4 Planned improvements

Planned improvements include:

- Collection of actual quantities of waste disposed into landfill sites for period 2000 – 2017.
- Collection of wastewater related activity data for period 2000 – 2017 taking into account different wastewater treatment pathways in South Africa.
- Conducting a detailed analysis of methane recovery from the National Climate Change Response Database, which captures valuable data from mitigation and adaptation projects for future GHG estimates from landfills.

6.3 Source Category 4.C Incineration and open burning of waste

6.3.1 Category information

In this source category only the emissions from *Open burning* have been included.

Overview of shares and trends in emissions

2017

Open burning was estimated to produce 360 Gg CO_2e in 2017. Emissions were 10.4% CO_2 (37 Gg CO_2e), 66.8% CH_4 (241 Gg CO_2e) and 22.8% N_2O (82 Gg CO_2e).

2000 – 2017

Emissions in this category increased by 28.4% (80 Gg CO_2e) between 2000 and 2017 (Table 6.3).

6.3.2 Methodology

A Tier 1 approach, with default IPCC 2006 emission factors, was applied in the calculation of CO_2, CH_4 and N_2O emissions from open burning. The amount of MSW open-burned was determined using Equation 5.7 of the IPCC 2006 Guidelines (IPCC, 2006; vol 5, chapt. 5; pg. 5.16).

Activity data

The activity data for the calculation of MSW are described in section 6.2.2. The fraction of population carrying out open-burning was estimated at 9% (DEA, 2012). CO_2 emissions were calculated for the different waste types using the IPCC default breakdown.

Emission factors

Emission factors are shown in Table 6.8.

Table 6.8: Emission factors for estimating emissions from open burning of waste.

Sub-category	Value	Unit	Source
Dry matter content			
Food	*0.4*	fraction	IPCC 2006
Garden	*0.4*		
Paper	*0.9*		
Wood	*0.85*		
Textile	*0.8*		

Nappies	*0.4*		
Plastics, other inert	*0.9*		
Fraction of carbon in dry matter		fraction	IPCC 2006
Food	*0.38*		
Garden	*0.49*		
Paper	*0.46*		
Wood	*0.5*		
Textile	*0.5*		
Nappies	*0.7*		
Plastics, other inert	*0.03*		
Fraction of fossil C in total carbon		fraction	IPCC 2006
Food	*0*		
Garden	*0*		
Paper	*0.01*		
Wood	*0*		
Textile	*0.2*		
Nappies	*0.1*		
Plastics, other inert	*1.0*		
Oxidation factor	0.58	fraction	IPCC 2006
CH_4 emission factor	6500	g/t MSW	IPCC 2006
N_2O emission factor	150	G N_2O/t waste	IPCC 2006

6.3.3 Uncertainty and time series consistency

Uncertainty

Activity data uncertainty are provided in Table 6.7. Uncertainties associated with CO_2 emission factors for open burning depend on uncertainties related to fraction of dry matter in waste open-burned, fraction of carbon in the dry matter, fraction of fossil carbon in the total carbon, combustion efficiency, and fraction of carbon oxidized and emitted as CO_2. A default value of +/-40% is suggested by IPCC 2006. Uncertainties on default N_2O and CH_4 emission factors have been estimated to be +/- 100%.

Time series consistency

The time series is consistent as the activity data source is the same throughout the time series.

6.3.4 Planned improvements

No improvements are planned for this category.

6.4 Source Category 4.D Wastewater Treatment and Discharge

6.4.1 Category information

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 flared or completely combusted.

Unlike 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.

Overview of shares and trends in emissions

2017

Wastewater treatment and discharge are estimated to produce 3 523 Gg CO_2e in 2017, of which 78.2% (2 753 Gg CO_2e) is from CH_4.

2000 - 2017

Emissions for this sub-category increased by 28.4% (779 Gg CO_2e) between 2000 and 2017 (Table 6.3).

6.4.2 Methodology

In South Africa, most of the wastewater generated from domestic and commercial sources is treated through municipal wastewater treatment systems (MWTPs).

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.

The projected methane emissions from the wastewater follow the same methodology described in the 2012 National GHG Inventory Report (DEA, 2016). 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. 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.

Activity data

To be consistent, the specific-category data described in Section 6.4.1 of the National GHG Inventory Report for 2000 (DEAT, 2009) and its underlying assumptions were adopted. In determining the total quantity of kg BOD yr^{-1}, population data was sourced from Statistics South Africa. This is the same population data as used in the FOD model.

Emission factors

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 6.9) as was the data on distribution and utilization of different treatment and discharge systems (Table 6.10).

Table 6.9: Emission factors for different wastewater treatment and discharge systems (Source: DEAT, 2009).

Type of treatment or discharge	Maximum CH_4 producing capacity (BOD)	CH_4 correction factor for each treatment system	Emission factor
	(kg CH_4/kg BOD)	(MCF)	(kg CH_4/kg BOD)
Septic system	0.6	0.5	0.30
Latrine – rural	0.6	0.1	0.06
Latrine – urban low income	0.6	0.5	0.30
Stagnant sewer (open and warm)	0.6	0.5	0.30
Flowing sewer	0.6	0.0	0.00
Other	0.6	0.1	0.06
None	0.6	0.0	0.00

Table 6.10: Distribution and utilization of different treatment and discharge systems (Source: DEAT, 2009).

Income group	Fraction of population income group	Type of treatment or discharge pathway	Degree of utilization
		(kg CH_4/kg BOD)	(Tij)
Rural	0.39	Septic tank	0.10
		Latrine – rural	0.28
		Sewer stagnant	0.10

		Other	0.04
		None	0.48
Urban high-income	0.12	Sewer closed	0.70
		Septic tank	0.15
		Other	0.15
Urban low-income	0.49	Latrine – urban low income	0.24
		Septic tank	0.17
		Sewer (open and warm)	0.34
		Sewer (flowing)	0.20
		Other	0.05

Nitrous oxide emissions from Domestic and Wastewater Treatment

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 (FAO, 2017).

N_2O emissions from discharge of effluent

The per capita protein consumption value of 27.96 was used consistently throughout the time series (sourced from the 2006 IPCC GLs). Indirect N_2O emissions were then estimated by multiplying the N effluent by the N_2O emission factor to estimate indirect N_2O emissions.

6.4.3 Uncertainty and time series consistency

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 (StatsSA, 2016), the presumed constant country BOD production of about 37 g $person^{-1}$ day^{-1} from 2001 to 2020, and the lack of data on the distribution of wastewater treatment systems in South Africa. It is recommended that, in future inventories, a detailed study on the input parameters merits careful consideration to minimize the uncertainty level. In turn, this approach would improve the reliability of the projected methane estimates from wastewater sources.

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 17-year time series and default IPCC emission factors used.

6.4.4 Planned improvements

There are no planned improvements for this category.

environment, forestry & fisheries

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Appendix 6.A Summary table of Waste sector emissions in 2015

Categories	Emissions (Gg)							Emissions
	CO_2	CH_4	N_2O	NOx	CO	NMVOCs	SO_2	(Gg CO_2e)
4 - Waste	**37.5**	**969.5**	**2.8**	**NE**	**NE**	**NE**	**NE**	**21 249.0**
4.A - Solid Waste Disposal		**827.0**		**0.0**	**0.0**	**0.0**	**0.0**	**17 366.0**
4.A.1 - Managed Waste Disposal Sites				NE	NE	NE	NE	NE
4.A.2 - Unmanaged Waste Disposal Sites				NE	NE	NE	NE	NE
4.A.3 - Uncategorised Waste Disposal Sites				NE	NE	NE	NE	NE
4.B - Biological Treatment of Solid Waste		**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**
4.C - Incineration and Open Burning of Waste	**37.5**	**11.5**	**0.3**	**0.0**	**0.0**	**0.0**	**0.0**	**360.2**
4.C.1 - Waste Incineration	NE	NE	NE	NE	NE	NE	NE	NE
4.C.2 - Open Burning of Waste	37.5	11.5	0.3	NE	NE	NE	NE	360.2
4.D - Wastewater Treatment and Discharge	**0.00**	**131.1**	**2.5**	**0.0**	**0.0**	**0.0**	**0.0**	**3 522.8**
4.D.1 - Domestic Wastewater Treatment and Discharge		IE	IE	NE	NE	NE	NE	NE
4.D.2 - Industrial Wastewater Treatment and Discharge		IE		NE	NE	NE	NE	NE
4.E - Other (please specify)				**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Chapter 6: References

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