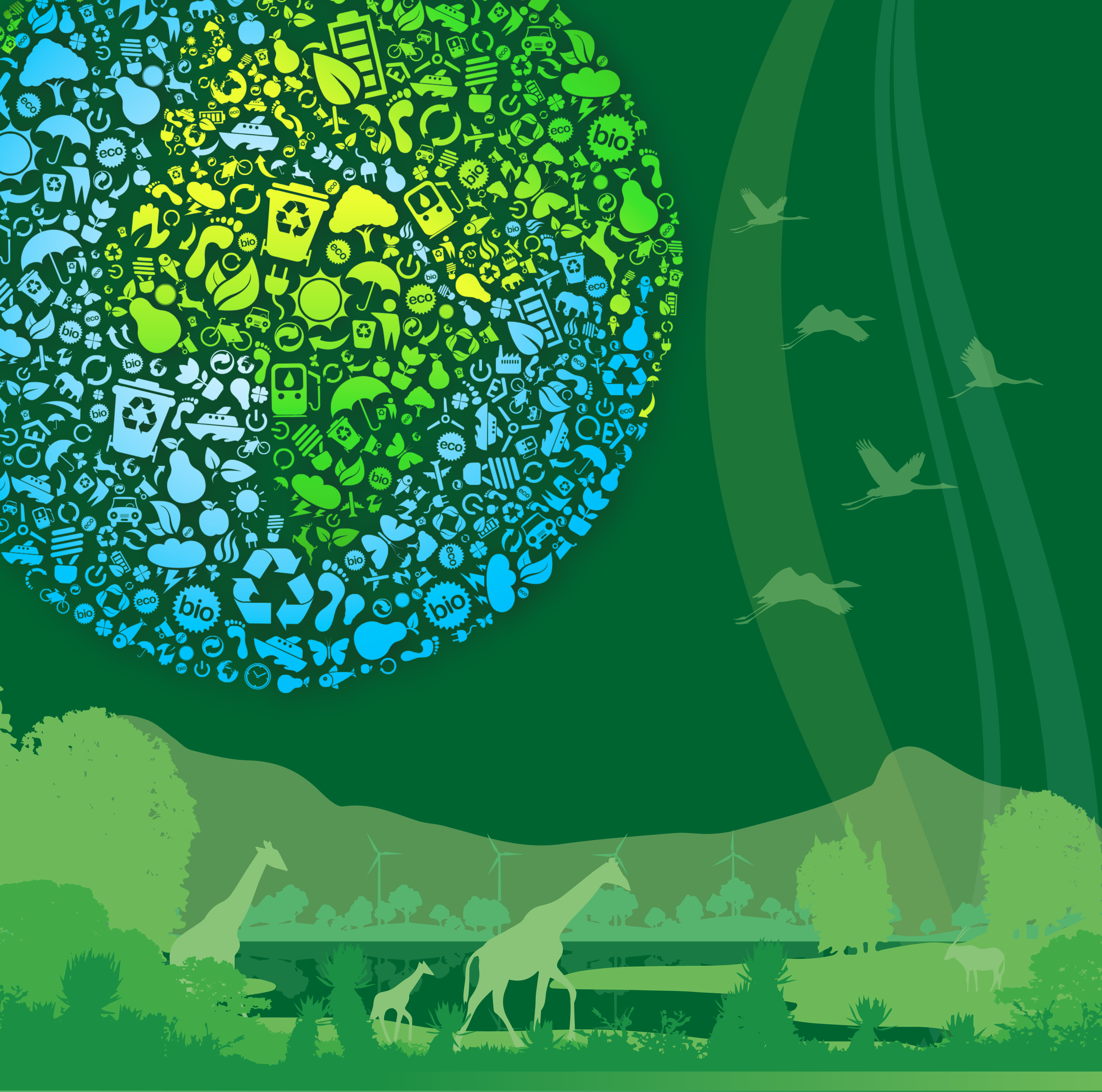

National GHG Inventory Report South Africa

2017

forestry, fisheries & the environment
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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, SF6 and NF3
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 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)

South Africa recently developed a National GHG Inventory Management System (NGHGIS) to manage files during the inventory compilation process and improve the preparation process of the inventory report. This will assist South Africa in meeting its climate change obligations to the UNFCCC in a transparent and timeous manner. 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 DFFE) 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. DFFE 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.

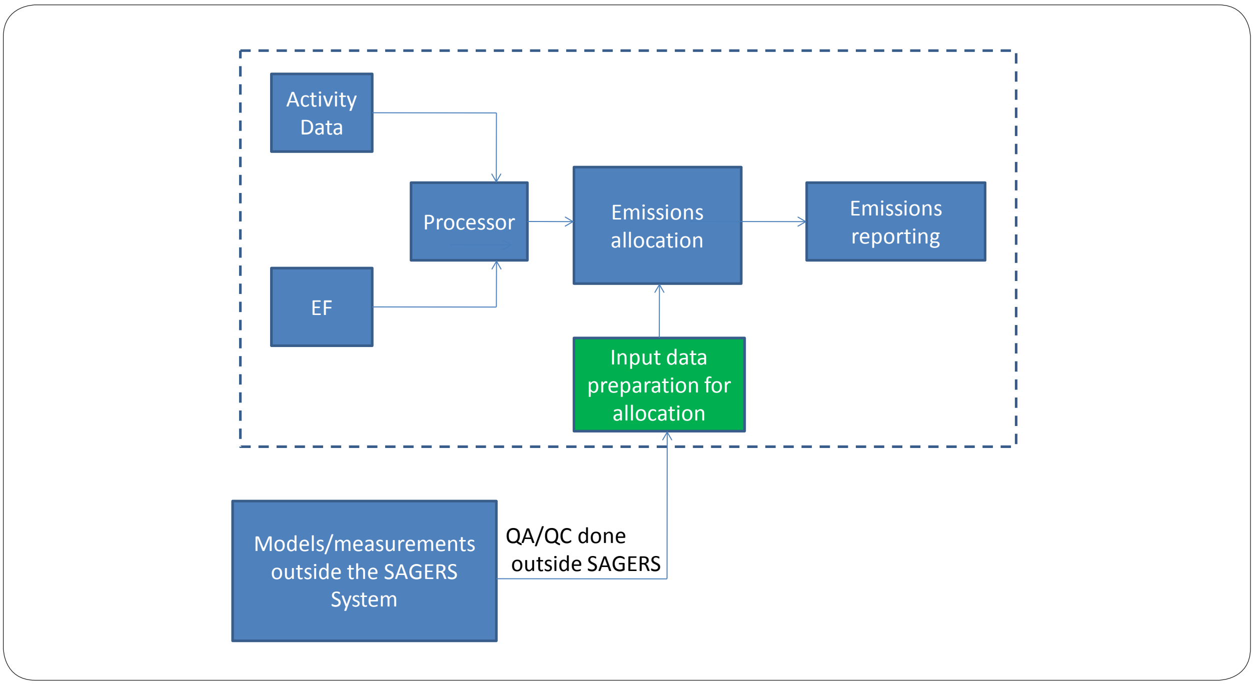

Figure A: Expected information flow in the South African's Greenhouse Gas Emissions Reporting System (SAGERS) which forms part of the National Emissions Inventory System (NAEIS)

Current inventory process

The current inventory process has used the previous inventories as building blocks to improve. South Africa has begun utilising annual data sheets which depicts trend information and improves the countries data records. As South Africa moves forward, more emphasis is being 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 lists. 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, however this is an ongoing process.

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

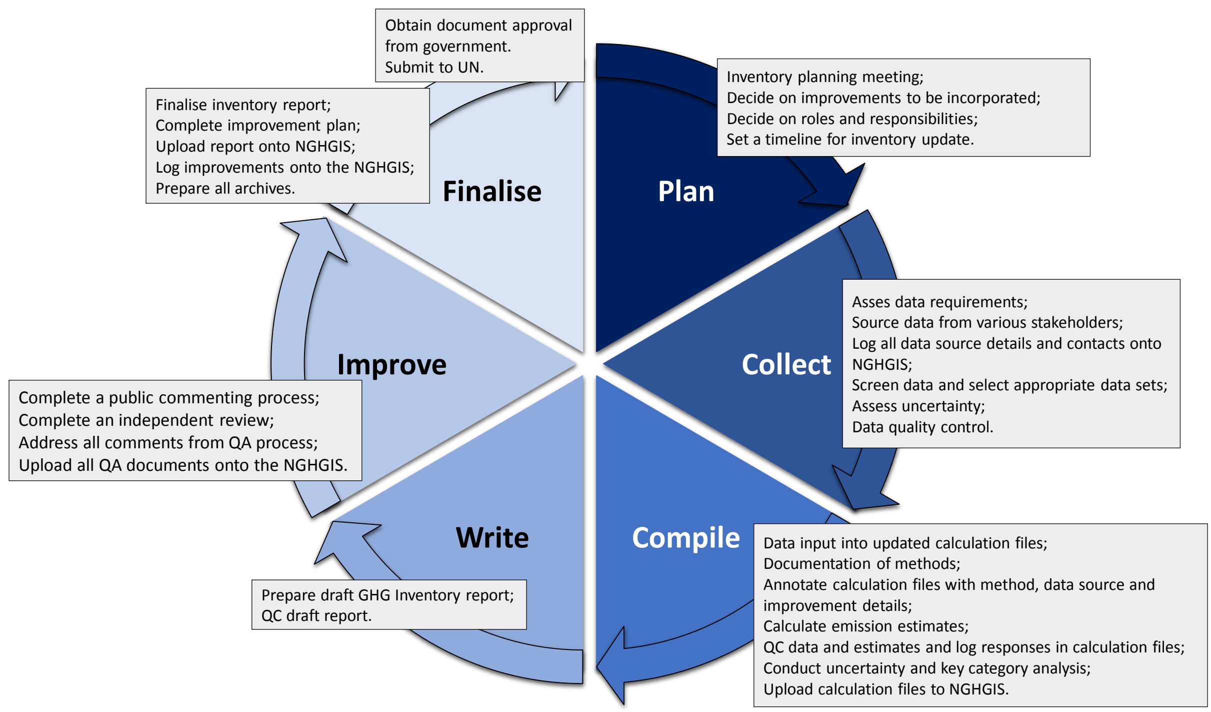

Figure B: Overview of the phases of the GHG inventory compilation and improvement process undertaken for South Africa's 2017 GHG inventory.

INSTITUTIONAL ARRANGEMENTS FOR INVENTORY PREPARATION

The DFFE 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 DFFE 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.

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.

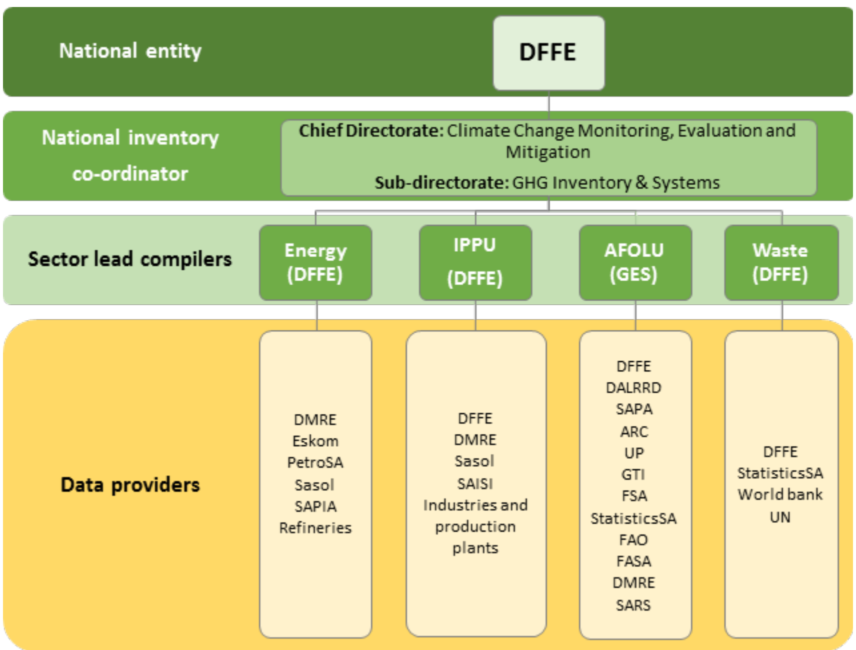

Figure C: Institutional arrangements for the compilation of the 2000 – 2017 inventory for South Africa.

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 this section (National trends) of the executive summary. All text references, tables and graphs throughout the report 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 448 874 Gg CO_2e in 2000 and these increased by 63 787 Gg CO_2e (or 14.2%) by 2017 (Table A and B). Emissions increased slowly over the 17-year period with an average annual growth rate of 0.8%. The Energy sector is the largest contributor (80.1% in 2017) to emissions (excl. FOLU) and is responsible for 96.6% of the increase over the 17-year period.

2015 - 2017

Emissions (excl. FOLU) decreased by 2.8% between 2015 and 2017 (Table B). The decrease is due to a 22.1%, 6.1% and a 0.8% decrease in the emissions from the IPPU, AFOLU and Energy sectors respectively.

Total 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 6.0% in 2017. Emissions (incl. FOLU) were estimated at 482 016 Gg CO_2e in 2017 and showed an increase of 10.4% 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 5.1% between 2015 and 2017 (Table B). This reduction was attributed to the 37.2% decline in the *AFOLU* sector emissions because of the increasing land sink.

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).

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	448 874.2	436 733.5	451 824.4	439 683.6
2001	445 277.9	438 848.1	448 291.8	441 861.9
2002	454 992.6	443 108.2	458 015.7	446 131.4
2003	473 489.0	455 301.9	476 547.0	458 360.0
2004	488 144.5	474 931.1	491 229.1	478 015.7
2005	484 911.5	485 400.6	488 023.0	488 512.1
2006	488 884.2	485 942.0	492 055.8	489 113.6
2007	524 645.6	518 721.0	527 802.8	521 878.1
2008	518 453.4	518 465.8	521 728.7	521 741.1
2009	535 887.6	522 296.3	539 222.1	525 630.9
2010	521 839.2	511 202.8	525 290.1	514 653.8
2011	512 928.2	501 602.8	516 279.4	504 953.9
2012	525 788.3	514 400.3	529 196.5	517 808.5
2013	528 816.2	509 388.1	532 297.4	512 869.3
2014	528 548.1	511 236.9	532 234.4	514 923.2
2015	527 301.0	504 157.9	531 043.6	507 900.4
2016	514 498.8	481 464.3	518 239.3	485 204.8
2017	512 660.6	482 016.3	516 429.9	485 785.5

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	448 874.2	527 301.0	512 660.6	63 786.4	14.2	-14 640.4	-2.8
	TAR	451 824.4	531 043.6	516 429.9	64 605.5	14.3	-14 613.7	-2.8
Emissions (incl. FOLU)	SAR	436 733.5	504 157.9	482 016.3	45 282.8	10.4	-22 141.5	-4.4
	TAR	439 683.6	507 900.4	485 785.5	46 101.9	10.5	-22 114.9	-4.4

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 slightly from 83.2% in 2000 to 84.5% in 2017 (Figure D). The CO_2 emissions (excl. FOLU) in 2017 were estimated at 433 406 Gg CO_2e, while CO_2 emissions (incl. FOLU) were 402 095 Gg CO_2e (Table C). The *Energy* sector is by far the largest contributor to CO_2 emissions, contributing an average of 91.7% (of emissions excluding FOLU) between 2000 and 2017, and 93.2% in 2017.

Methane

National CH_4 emissions (excl. FOLU) increased from 45 452 Gg CO_2e (2 164 Gg CH_4) to 49 700 Gg CO_2e (2 367 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 10.1% to 9.7% over this period (Figure D). The *Waste* sector and *AFOLU* livestock category were the major contributors, providing 41.0% and 50.4%, respectively, to the total CH_4 emissions (excl. FOLU) in 2017. The Land sector contributed 667 Gg CO_2e to the total, bringing the CH_4 total (incl. FOLU) to 50 367 Gg CO_2e.

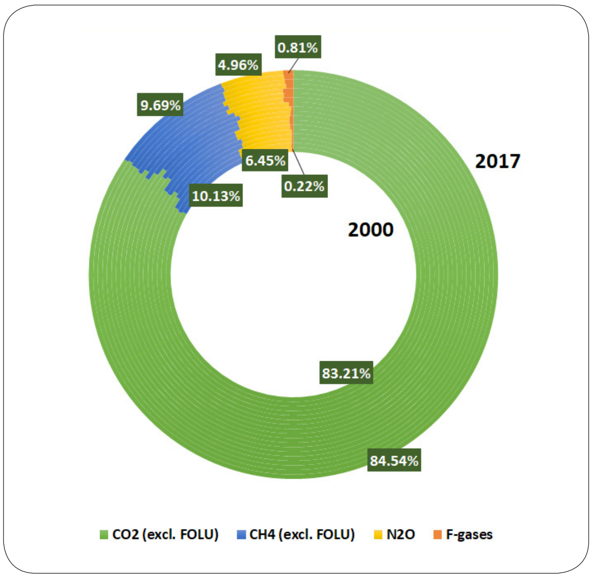

Figure D: Gas contribution to South Africa's emissions (excl. FOLU) between 2000 and 2017.

Total emissions including FOLU

Nitrous oxide contribution to the emissions (excl. FOLU) declined from 6.5% in 2000 to 5.0% in 2017 (Figure D). The N_2O emissions decreased over the 2000 to 2017 period from 28 942 Gg CO_2e (93 Gg N_2O) to 25 427 Gg CO_2e (82 Gg N_2O) (Table C). A 10.7% decline in the AFOLU N_2O emissions and a decline of 1 352 Gg CO_2e in the IPPU N_2O emissions were the main reasons for the overall reduction in N_2O. The AFOLU and Energy sectors were the largest contributors, 85.3% and 10.2% respectively, to the total N_2O emissions in 2017.

F-gases

The F-gas emissions increased from 983 Gg CO_2e to 4 127 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 97.3% to the total F-gas emissions. The F-gas contribution to total emissions (excl. FOLU) has increased from 0.2% to 0.8% 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 (excl. FOLU)		CH_4 (incl. FOLU)		N_2O		F-gases
	Gg CO_2		Gg CO_2e	Gg CH_4	Gg CO_2e	Gg CH_4	Gg CO_2e	Gg N_2O	Gg CO_2e
2000	373 497.4	360 690.0	45 451.9	2 164.4	46 118.5	2 196.1	28 941.8	93.4	983.2
2001	369 587.6	362 491.2	46 009.3	2 190.9	46 675.9	2 222.7	28 673.3	92.5	1 007.7
2002	378 606.8	366 055.9	46 284.3	2 204.0	46 950.9	2 235.8	29 204.4	94.2	897.1
2003	399 290.4	380 436.7	45 831.5	2 182.5	46 498.1	2 214.2	27 470.9	88.6	896.2
2004	413 542.6	399 662.6	46 149.1	2 197.6	46 815.7	2 229.3	27 563.4	88.9	889.4
2005	407 914.3	407 736.8	46 832.4	2 230.1	47 499.0	2 261.9	28 451.4	91.8	1 713.4
2006	411 672.8	408 064.0	46 835.0	2 230.2	47 501.6	2 262.0	28 395.6	91.6	1 980.9
2007	448 544.0	441 952.7	46 715.5	2 224.5	47 382.1	2 256.3	27 352.1	88.2	2 034.1
2008	441 813.2	441 159.0	47 661.7	2 269.6	48 328.3	2 301.3	27 404.9	88.4	1 573.6
2009	460 193.3	445 935.5	47 765.5	2 274.5	48 432.1	2 306.3	26 828.5	86.5	1 100.3
2010	443 953.6	432 650.7	48 767.8	2 322.3	49 434.5	2 354.0	26 914.0	86.8	2 203.7
2011	432 081.0	420 088.9	49 182.6	2 342.0	49 849.2	2 373.8	26 979.4	87.0	4 685.2
2012	445 974.7	433 920.1	48 989.2	2 332.8	49 655.8	2 364.6	26 317.6	84.9	4 506.8
2013	445 848.3	425 753.6	50 264.5	2 393.5	50 931.2	2 425.3	27 871.6	89.9	4 831.7
2014	446 620.7	428 642.8	50 819.0	2 420.0	51 485.6	2 451.7	27 820.2	89.7	3 288.2
2015	445 562.7	421 752.9	50 782.7	2 418.2	51 449.3	2 450.0	27 252.9	87.9	3 702.7
2016	435 579.7	401 878.6	49 655.1	2 364.5	50 321.7	2 396.3	25 398.6	81.9	3 865.4
2017	433 406.2	402 095.3	49 700.0	2 366.7	50 366.6	2 398.4	25 426.8	82.0	4 127.7

* All Gg CO_2e were calculated with SAR GWP

ES.5 SECTOR TRENDS

Energy

2017

Total emissions from the *Energy* sector for 2017 were estimated to be 410 685 Gg CO_2e (Table D) which is 80.1% of the total emissions (excl. FOLU) for South Africa. *Energy industries* were the main contributor, accounting for 60.7% of emissions from the Energy sector. This was followed by *Transport* (13.3%), *Other sectors* (9.3%) and *Manufacturing industries and construction* (7.0%).

2000 - 2017

Energy emissions showed an overall increasing trend between 2000 and 2017. The emissions in this sector increased by 17.6% over this period. Emissions increased to a peak in 2009, after which emissions showed a slight declining trend to 2017. Between 2009 and 2011 there was a 6.1% decrease, followed by a 3.6% increase to 2012. Energy emissions declined to 404 754 Gg CO_2e by 2016. A 1.5% increase was seen in 2017.

The overall growth in emissions is mainly due to the 13.0% increase in *Energy industries* emissions, as well as a 45.6% increase in the *Other sector* emissions from 26 123 Gg CO_2e to 38 022 Gg CO_2e. Emissions from *Fuel combustion activities* increased by 20.2%, while *Fugitive emissions from fuels* declined by 7.7%. The *Energy* sector contribution to the total emissions (excl. FOLU) increased from 77.8% to 80.1% over the 17-year period (Figure E).

2015 - 2017

Energy emissions decreased by 0.8% between 2015 and 2017. *Fuel combustion activities* decreased by 1.1%, while *Fugitive emissions from fuels* increased by 3.8% over the same period. *Energy industries* showed a 4.5% 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	349 099.7	413 973.2	410 685.3	61 585.6	17.6	-3 287.9	-0.8
IPPU	32 987.3	41 173.3	32 084.6	-902.7	-2.7	-9 088.7	-22.1
AFOLU (excl. FOLU)	53 229.4	51 804.3	48 641.8	-4 587.6	-8.6	-3 162.5	-6.1
AFOLU (incl. FOLU)	41 088.7	28 661.2	17 997.5	-23 091.2	-56.2	-10 663.7	-37.2
Waste	13 557.8	20 350.2	21 249.0	7 691.1	56.7	898.8	4.4

* Calculated with SAR GWP

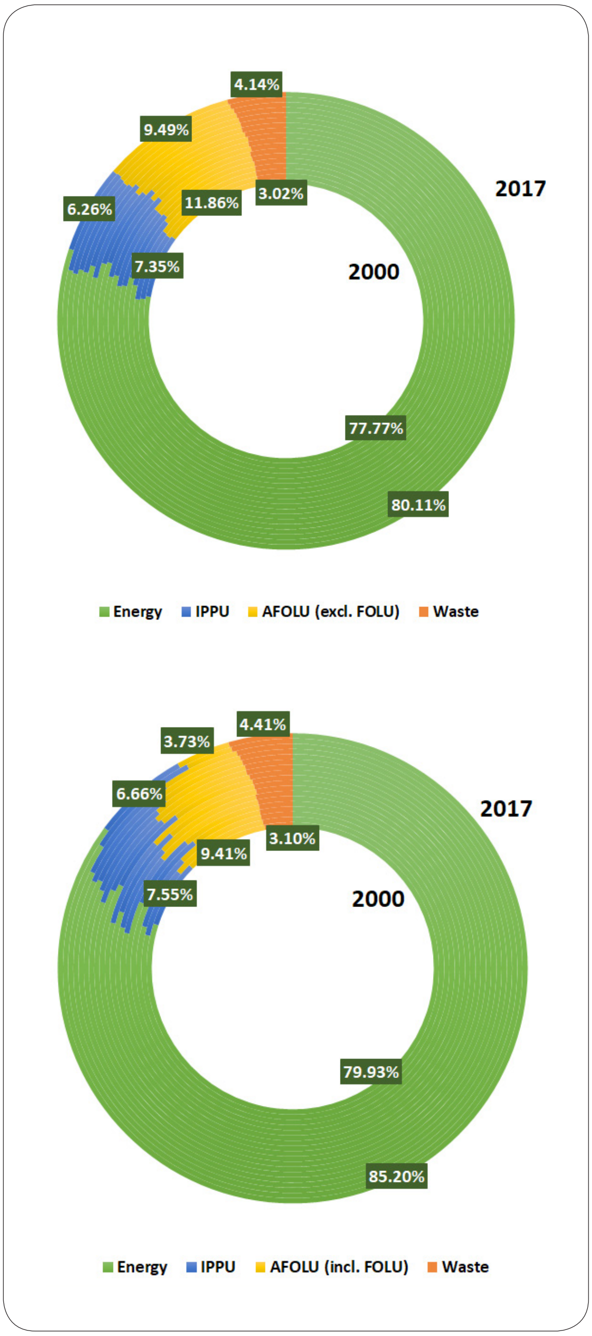

Figure E: Sector contribution to total emissions excluding FOLU) (top) and including FOLU (bottom) in South Africa between 2000 and 2017.

Industrial processes and product use (IPPU)

2017

In 2017 the *IPPU* sector produced 32 084.6 Gg CO_2e, which is 6.3% of South Africa's emissions (excl. FOLU) (Figure E). The largest source category is the *Metal industry* category, which contributes 63.6% 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 7 725 Gg CO_2e and 11 330 Gg CO_2e, respectively. The *Mineral industry* and the *Product uses as substitute ODS* subsectors contribute 19.5% and 12.5%, 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 2.7% lower than the emissions in 2000 (Table D). This was mainly due to a 49.6% (7 609 Gg CO_2e) decrease in the *Iron and steel production* emissions, and a 67.8% (1 880 Gg CO_2e) decrease in the *Chemical industry* emissions. *IPPU* emissions increased by 17.9% between 2000 and 2006, after which there was a 0.2% decline to 2009 due to a recession. Emissions then increased again by 6.0% by 2015. Emissions were then seen to decline by 22.1% by 2017, however there are time-series inconsistencies in the data for some categories since 2014. This is due to the introduction of updated data from the South African GHG Emission Reporting System (SAGERS), which is the system through which companies report their emissions under the newly introduced National Greenhouse Gas Emissions Reporting Regulations (NGERs). Companies have only been reporting since 2015 in most cases. SAGERS data was utilised in categories 2A1-2A4, 2B2, 2B5, 2C1, and 2C2. These time-series irregularities will be improved in the next inventory.

The *IPPU* contribution to the national emissions (excl. FOLU) decreased from 7.4% to 6.3% between 2000 and 2017 (Figure E).

2015 - 2017

As mentioned above, the *IPPU* emissions showed a decrease of 9 089 Gg CO_2e between 2015 and 2017 (Table D). Emissions declined by 1 210 Gg CO_2e between 2015 and 2016, and by 7 879 Gg CO_2e between 2016 and 2017. The large decline in 2017 is impacted by the 42.8% (5 781 Gg CO_2e) decline in emissions from *Iron and steel production* industries. Company data reported in the SAGERS system for this category showed a higher allocation of production to sinter and less to pig iron and direct reduced iron than in previous years, leading to a reduction in emissions. This time-series is inconsistent but historical data will be sought in the next inventory to resolve this, and other inconsistencies in the *IPPU* sector.

Emissions from the *Mineral industry* and *Product uses as substitutes for ozone depleting substances* increased by 2.3% (138 Gg CO_2e) and 15.2% (532 Gg CO_2e), respectively, between 2015 and 2017, while emissions from the *Non-energy products from fuels and solvents* and *Chemical industry* decreased by 56.4% (1 965 Gg CO_2e) and 16.6% (178 Gg CO_2e), respectively.

Agriculture, forestry and land use change (AFOLU)

2017

The *AFOLU* emissions (excl. FOLU) were 48 642 Gg CO_2e (or 9.5% of the total) in 2017, while *AFOLU* emissions (incl. FOLU) were 17 998 Gg CO_2e or 3.7% (Figure E). *Livestock* and *Aggregated and non-CO_2 emissions from land* categories contributed 26 272 Gg CO_2e and 22 370 Gg CO_2e respectively in 2017, while the *Land* and *Other* (i.e. HWP) categories were both sinks (29 867 Gg CO_2e and 777 Gg CO_2e, respectively).

2000 - 2017

AFOLU emissions (excl. FOLU) declined by 4 588 Gg CO_2e (8.6%) and emissions (incl. FOLU) by 23 091 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) showed an annual average change of -0.6% between 2000 and 2017. *AFOLU* emissions (incl. FOLU) varied annually, reaching a peak in 2008, after which emissions started to decline due to increasing land sinks. There was a 65% decline in emissions between 2008 and 2017. 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 11.9% in 2000 to 9.5% in 2017 (Figure E). The *AFOLU* contribution to the total emissions (incl. FOLU) declined from 9.4% to 3.7%.

2015 - 2017

AFOLU emissions (excl. FOLU) declined by 6.1% between 2015 and 2017 (Table D), due to a 6.2% and 5.9% decline in *Livestock* and *Aggregated and non-CO_2 emissions on land*. On the other hand, *AFOLU* emissions (incl. FOLU) declined by 10 664 Gg CO_2e over the same period due to an increase of 7 333 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 4.1% 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.

ES.6 IMPROVEMENTS AND RECALCULATIONS

Improvements introduced in the current inventory

Energy

A recent fuel consumption study (DFFE, 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. In the *Energy* sector the coal and diesel consumption data in the *Road transport, Manufacturing industries and construction, Other sectors and Non-specified emissions from energy production* categories was updated due to an updated DMRE energy balance data.

IPPU

Due to the reporting of company emissions data for to the recently introduced NGER, updated company emission data was incorporated where available. These included updated production data (particularly for the years from 2014) for cement production, lime production, glass production, nitric acid production, iron and steel production, ferroalloys production and lead production. Additional improvements were the application of the hydrated lime emission factor, corrected emission factors for the iron and steel industry, and an update in the lubricant and paraffin wax production data due to updates in the energy balance data.

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 N2O 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. 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 FSOM 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 2.5% and 1.6% decrease in emission estimates excluding and including FOLU, respectively, for 2015 (Figure F, Table E). Recalculated estimates were 3.7% and 1.7% less than previous estimates for the *Energy* and *IPPU* sectors, while the estimates for *AFOLU* (excl. FOLU), *AFOLU* (incl. FOLU) and *Waste* sector estimates were 4.6%, 36.1% and 4.2% higher, respectively, than the previous submission for 2015.

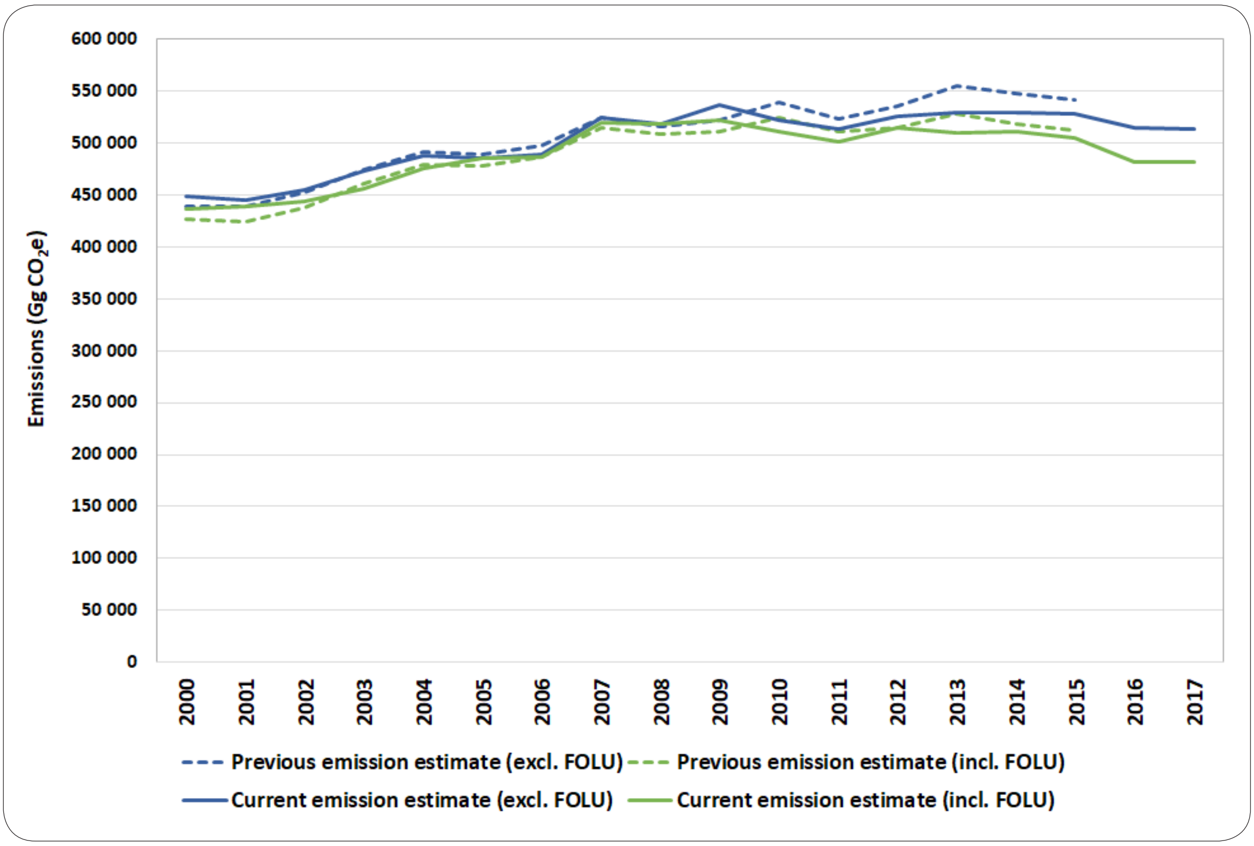

Figure F: Changes in overall emission estimates due to recalculations.

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	448 874.2	2.19	426 213.9	436 733.5	2.47
2001	438 167.5	445 277.9	1.62	423 800.0	438 848.1	3.55
2002	452 260.9	454 992.6	0.60	436 968.8	443 108.2	1.40
2003	473 942.1	473 489.0	-0.10	460 781.2	455 301.9	-1.19
2004	490 972.2	488 144.5	-0.58	479 410.2	474 931.1	-0.93
2005	488 656.5	484 911.5	-0.77	477 796.6	485 400.6	1.59
2006	496 908.3	488 884.2	-1.61	485 908.7	485 942.0	0.01
2007	523 801.9	524 645.6	0.16	514 472.5	518 721.0	0.83
2008	516 256.1	518 453.4	0.43	508 699.4	518 465.8	1.92
2009	521 245.7	535 887.6	2.81	510 168.2	522 296.3	2.38
2010	538 778.1	521 839.2	-3.14	524 296.5	511 202.8	-2.50
2011	522 861.4	512 928.2	-1.90	511 376.8	501 602.8	-1.91
2012	534 696.8	525 788.3	-1.67	514 519.9	514 400.3	-0.02
2013	554 705.3	528 816.2	-4.67	527 468.1	509 388.1	-3.43
2014	547 509.5	528 548.1	-3.46	518 249.7	511 236.9	-1.35
2015	540 853.9	527 301.0	-2.51	512 382.8	504 157.9	-1.61
2016		514 498.8			481 464.3	
2017		512 660.6			482 016.3	

KEY CATEGORY ANALYSIS

ES.7

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 GHG's in terms of the absolute level of emissions and removals, the trend in emissions and removals, or uncertainty in emissions or removals. This includes both source and sink categories.

A Tier 1 level and trend assessment were 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).affect trends across and within ecosystems (Sydeman *et al.*, 2014). Increase in wind velocity and wave height are projected consequences of climate change along South African coasts. Constant monitoring of coastal winds is therefore necessary.

Table F: Key categories excluding FOLU.

IPCC Category code	IPCC Category	GHG	Identification criteria
1A1a	Electricity and Heat Production (solid fuel)	CO_2	L1
1A1a	Electricity and Heat Production	CO_2	T1
1A1b	Petroleum Refining (Liquid)	CO_2	T1
1A1b	Petroleum Refining (Gas)	CO_2	L1
1A1c	Manufacture of Solid Fuels and Other Energy Industries (Liquid fuel)	CO_2	L1,T1
1A2	Manufacturing Industries and Construction (Solid fuel)	CO_2	L1,T1
1A2	Manufacturing Industries and Construction (Liquid fuel)	CO_2	L1,T1
1A2	Manufacturing Industries and Construction (Gas)	CO_2	L1,T1
1A3a	Civil Aviation (Liquid)	CO_2	T1
1A3b	Road Transport (Liquid fuel)	CO_2	L1,T1
1A4a	Commercial/Institutional (Solid fuel)	CO_2	L1,T1
1A4a	Commercial/Institutional (Liquid fuel)	CO_2	L1
1A4b	Residential	CO_2	T1
1A4b	Residential	N_2O	T1
1A4b	Residential (Liquid fuel)	CO_2	L1,T1
1A4c	Agriculture/Forestry/Fishing/Fish Farms (Liquid fuel)	CO_2	L1,T1
1A5a	Stationary (Solid fuel)	CO_2	L1,T1
1B3	Other Emissions from Energy Production	CO_2	L1,T1
1B3	Other Emissions from Energy Production	CH_4	L1,T1
2A1	Cement Production	CO_2	L1,T1
2A2	Lime Production	CO_2	T1

IPCC Category code	IPCC Category	GHG	Identification criteria
2B3	Nitric acid production	N_2O	TI
2B6	Titanium dioxide production	CO_2	TI
2C1	Iron and Steel Production	CO_2	LI,TI
2C2	Ferroalloys Production	CO_2	LI,TI
2C3	Aluminium Production	PFCs	TI
2F1	Refrigeration and Air Conditioning	HFCs	LI,TI
3A1a	Enteric fermentation - cattle	CH_4	LI,TI
3A1c	Enteric fermentation - sheep	CH_4	LI,TI
3C1c	Biomass burning in grasslands	N_2O	TI
3C1c	Biomass burning in grasslands	CH_4	TI
3C2	Liming	CO_2	TI
3C3	Urea application	CO_2	TI
3C4	Direct N_2O emissions from managed soils	N_2O	LI,TI
3C5	Indirect N_2O emissions from managed soils	N_2O	LI,TI
4A	Solid Waste Disposal	CH_4	LI,TI
4D1	Wastewater Treatment and Discharge	CH_4	LI

Table G: Key categories including FOLU.

IPCC Category code	IPCC Category	GHG	Identification criteria
1A1a	Electricity and Heat Production (Solid fuel)	CO_2	LI,TI
1A1a	Electricity and Heat Production	CO_2	TI
1A1b	Petroleum Refining (Gas)	CO_2	LI
1A1b	Petroleum Refining (Liquid)	CO_2	TI
1A1c	Manufacture of Solid Fuels and Other Energy Industries (Liquid fuel)	CO_2	LI,TI
1A2	Manufacturing Industries and Construction (Solid fuel)	CO_2	LI,TI
1A2	Manufacturing Industries and Construction (Liquid fuel)	CO_2	LI,TI
1A2	Manufacturing Industries and Construction (Gas)	CO_2	LI,TI
1A3a	Civil Aviation (Liquid)	CO_2	TI
1A3b	Road Transport (Liquid fuel)	CO_2	LI,TI
1A4a	Commercial/Institutional (Solid fuel)	CO_2	LI,TI
1A4a	Commercial/Institutional (Liquid fuel)	CO_2	LI
1A4b	Residential (Liquid fuel)	CO_2	LI,TI
1A4b	Residential (Solid fuel)	CO_2	TI

IPCC Category code	IPCC Category	GHG	Identification criteria
1A4c	Agriculture/Forestry/Fishing/Fish Farms (Liquid fuel)	CO_2	L1,T1
1A5a	Stationary (Solid fuel)	CO_2	L1,T1
1B3	Other Emissions from Energy Production	CO_2	L1,T1
1B3	Other Emissions from Energy Production	CH4	L1,T1
2A1	Cement Production	CO_2	L1,T1
2A2	Lime Production	CO_2	T1
2B3	Nitric acid production	N_2O	T1
2B6	Titanium dioxide production	CO_2	T1
2C1	Iron and Steel Production	CO_2	L1,T1
2C2	Ferroalloys Production	CO_2	L1,T1
2C3	Aluminium Production	PFCs	T1
2F1	Refrigeration and Air Conditioning	HFCs	L1,T1
3A1a	Enteric fermentation - cattle	CH_4	L1,T1
3A1c	Enteric fermentation - sheep	CH_4	L1,T1
3B1a	Forest land remaining forest land	CO_2	L1,T1
3B1b	Land converted to forest land	CO_2	L1,T1
3B2b	Land converted to cropland	CO_2	L1
3B3a	Grassland remaining grassland	CO_2	L1,T1
3B3b	Land converted to grassland	CO_2	L1,T1
3B5a	Settlements remaining settlements	CO_2	T1
3B6b	Land converted to other lands	CO_2	L1,T1
3C1c	Biomass burning in grasslands	N_2O	T1
3C1c	Biomass burning in grasslands	CH_4	T1
3C2	Liming	CO_2	T1
3C4	Direct N_2O emissions from managed soils	N_2O	L1,T1
3C5	Indirect N_2O emissions from managed soils	N_2O	L1,T1
3D1	Harvested wood products	CO_2	L1,T1
4A	Solid Waste Disposal	CH_4	L1,T1
4D1	Wastewater Treatment and Discharge	CH_4	L1,T1

ES.8 INDICATOR TRENDS

The carbon intensity of the population (i.e. total net emissions per capita) increased between 2000 and 2007 to a peak of 10.8 t CO_2e per capita, after which it declined to 8.5 t CO_2e per capita in 2017 (Figure G). The carbon intensity of the economy has shown a declining trend and declined by 31.2% between 2000 and 2017. The carbon intensity of the energy supply (i.e. total net emissions per energy unit) remained fairly constant between 2000 and 2013, after which there was a slight decline in the trend to 2017.

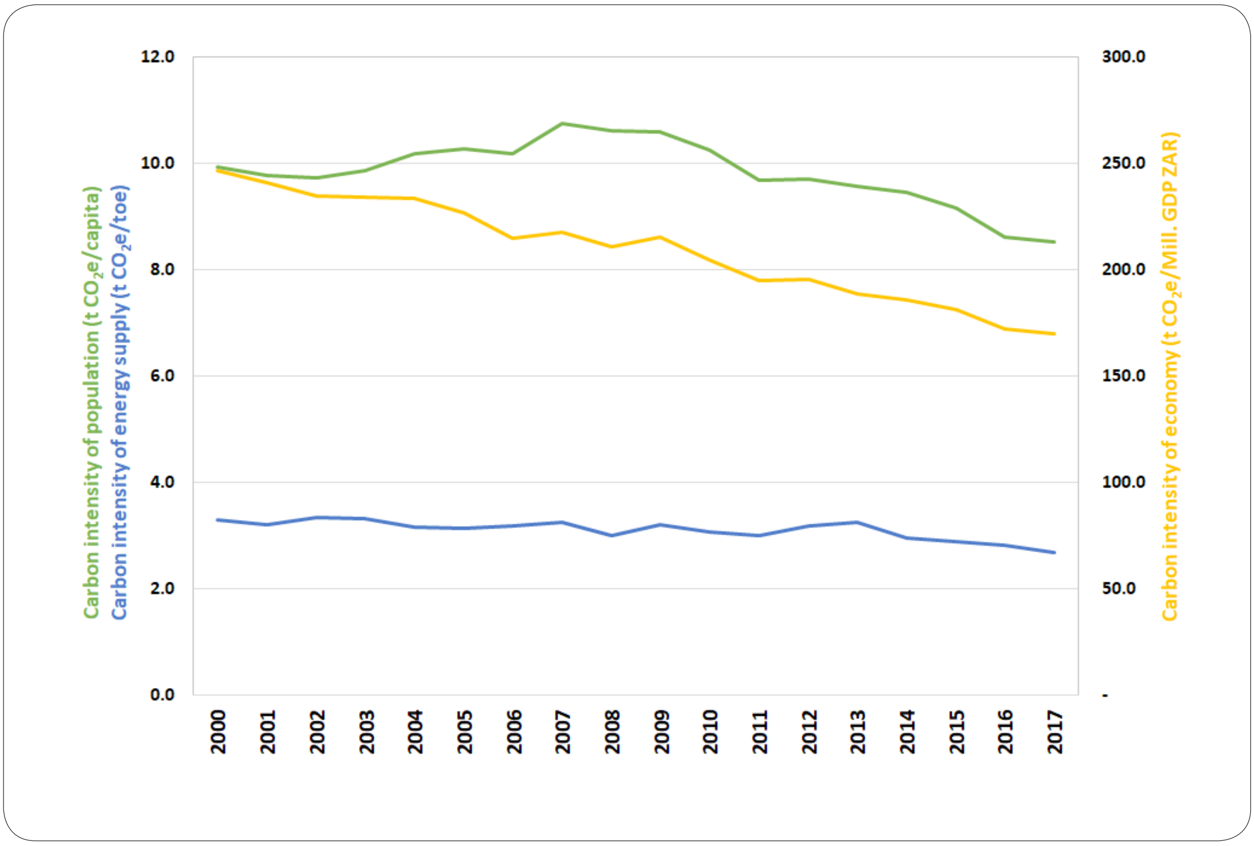

Figure G: Trend in carbon intensity indicators for South Africa between 2000 and 2017.

OTHER INFORMATION

ES.9

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 10.2%, with a trend uncertainty of 7.1%. Excluding FOLU reduced the overall uncertainty to 9.4%, with the trend uncertainty dropping to 6.7%.

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 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	IPCC Category	Activity	Comments
NE	1B2	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
	1B1b	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
	1B1ai2	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
	1C1	CO_2 transport	Insufficient data to include
	1C2	Injection and storage	Insufficient data to include
	2A4	Other process use of carbonates	Emissions from this source category will be included in the next inventory submission
	2C1	N_2O emissions from iron and steel production	This will be considered in the next inventory
	2C2	N_2O emissions from ferroalloy production	This will be considered in the next inventory
	2D2	CH_4 and N_2O emissions from paraffin wax use	Insufficient data to include
	2E	Electronics industry	A study needs to be undertaken to understand emissions from this source category
	2F5	PFCs and HFCs from solvents	Insufficient data to include
	2G1	PFCs from electrical equipment	Insufficient data to include
	2G2	PFCs from other product uses	Insufficient data to include
	2G3	N_2O from product uses	Insufficient data to include
	3B	CO_2 from organic soils	Insufficient data on the distribution and extent of organic soils. Project was completed by DFFE to identify and map organic soils. This data will be considered in the next inventory
	3B	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.
	3B4	CO_2 emissions from wetlands	Insufficient data and wetland area not considered to be significant. A recent study initiated by DFFE could provide further data which will be considered in the next inventory

NE, IE or NO	IPCC Category	Activity	Comments
	3C4	N_2O from organic soils	Insufficient data on the distribution and extent of organic soils. Project was completed by DFFE to identify and map organic soils. This data will be considered in the next inventory
	4B	CH_4, N_2O emissions from biological treatment of waste	Insufficient data to include, but will be considered for inclusion in next inventory
	4C1	CO_2, CH_4 and N_2O from waste incineration	Insufficient data to include
	2	SF6 emissions in the IPPU sector	Insufficient data. It is planned to include these by the 2021 inventory.
	All sectors	NOx, CO, NMVOC emissions	These have only been included for biomass burning due to a lack of data in other sectors
	All sectors	SO_2 emissions	Insufficient data. It is planned to include these by the 2021 inventory.
IE	1A1aii	CO_2, CH_4 and N_2O emissions from Combined Heat and Power (CHP) combustion systems	Not separated out but is included within 1A1ai
	1A3eii	CO_2, CH_4 and N_2O emissions from off-road vehicles and other machinery	Included under Road transportation.
	3B	Precursor emissions from controlled burning	Emissions from controlled burning are not separated from biomass burning and so are included under Biomass burning (3C1)
	3C1	CO_2 emissions from biomass burning	These are not included under biomass burning, but rather under disturbance losses in the Land sector (3B).
	4 D1	Domestic wastewater treatment and discharge emissions	Reported under the total for Wastewater treatment and discharge
	4D2	Industrial wastewater treatment and discharge emissions	Reported under the total for Wastewater treatment and discharge
NO	2B7	CO_2, CH_4 and N_2O emissions from Soda Ash Production	
	2B3	CO_2, CH_4 and N_2O emissions from Adipic acid production	
	2B4	CO_2, CH_4 and N_2O Caprolactam, Glyoxal and Glyoxylic acid production	
	3C7	Rice cultivation	

Planned improvements

GHG improvement programme

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

DFFE 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; and
- Petrochemical industry – development of EFs, carbon content of fuels, and NCVs of liquid fuels.

Table I: DFFE 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	Completed
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

GHG regulation reporting

DFFE 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 has been developed under this project and this 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.

This inventory has started to incorporate information from the SAGERS system, however further data will be included in the next inventory. The inclusion of this data has led to some time-series inconsistencies, but these will be addressed in eh next inventory.

General inventory improvements

The transparency of the inventory and the quality control procedures will continue to be improved in the next inventory as these were mentioned in the review report. Other general areas that have been highlighted for improvement are:

- Improved descriptions of drivers and trends;
- Extension of time-series back to 1990. 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;
- Improve time-series consistency; and
- Incorporate SOx and SF6 emissions.

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 2.0% between 2000 and 2009, and then emissions stabilised and declined with an average annual decline of 1.0%.

Energy emissions were highest in 2009, after which there was a 3.1% decline to 2011. In 2012 there was a 3.6% increase in emissions, followed by an average annual decline of 0.8% to 2016. A 1.5% increase was seen in the 2017 emissions from the energy sector. *IPPU* emissions reached a maximum in 2007, followed by an annual average decline of 5.8% to 2010. There was an 11.5% increase in 2011, after which emissions stabilised to 2016 with a 0.3% annual average rate of increase. A large decline of 19.7% was evident in 2017, however this change is not a true decline in emissions, but rather reflects the change in the data sources due to the introduction of emission reporting for the NGER. *AFOLU* emissions excluding FOLU declined by 4.6% between 2002 and 2003, after which emissions remained stable with an average annual decline of 0.35. There was a decline of 6.1% between 2015 and 2017. *AFOLU* emissions including Land fluctuate annually, reaching a peak in 2008. Emissions increased by 25.8% between 2000 and 2008, after which there was a decline of 65.27% to 2017. *Waste* sector has shown a steady increase since 2000, with an average annual increase of 2.7%.

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* data was sourced from publicly available data as well as from data submitted by companies. Increasing the amount of company level data will enhance the accuracy of emission estimates and help reduce uncertainty associated with the estimates. The mandatory reporting regime which is driven by the NGERs will provide enhanced data for this sector. This data has begun to be included in the recent years of the inventory but does pose some issues in terms of time-series consistency due to the data not being available prior to 2015 in most cases. These are issues which will be improved over the next two inventory cycles and as more data becomes available.

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. There is a need for more land change data and there are projects currently underway to address this issue, so these will lead to improvements over the next two inventory cycles. 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, and a national forest inventory would assist in providing some of this data. 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

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 (NOX), 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 DFFE 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. 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 quality assurance and quality control (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 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 system 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 the 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).

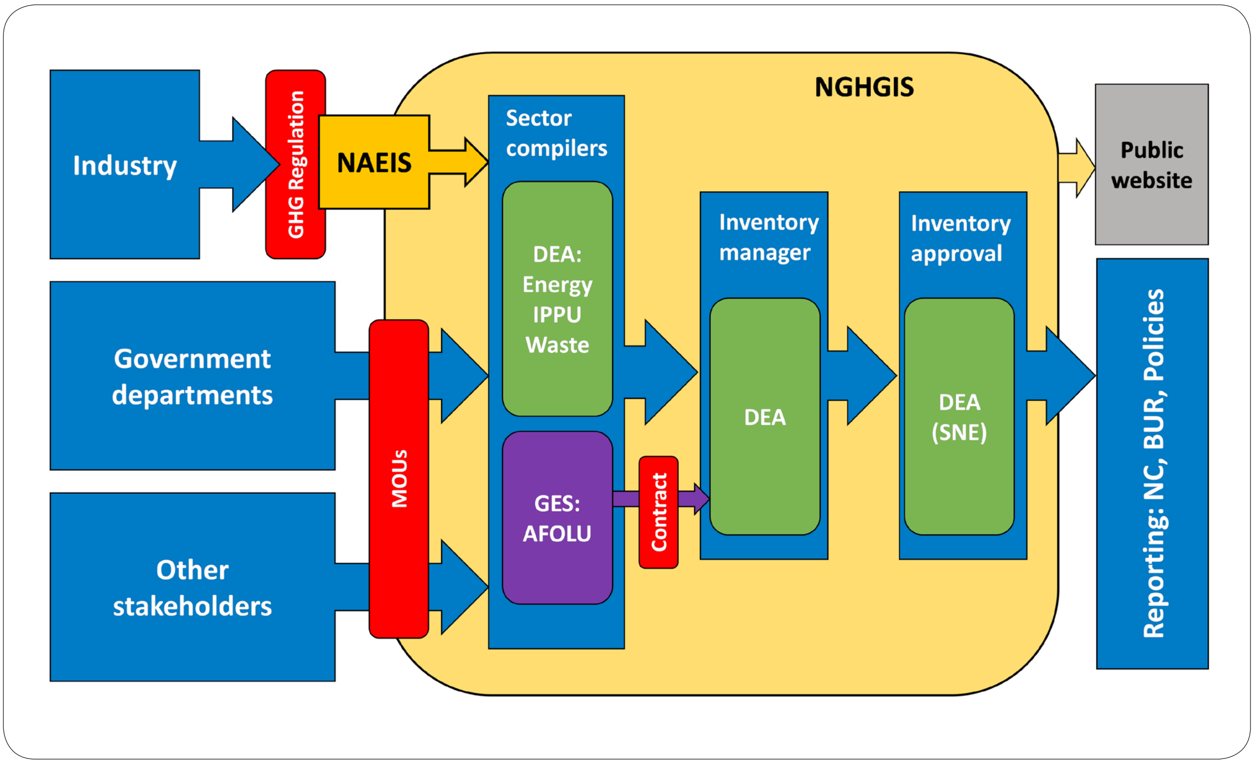

Figure 1.1: The inventory compilation process is co-ordinated through a central web-based inventory management system as depicted in this illustration.

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 DFFE is the central co-ordinating and policy-making authority with respect to environmental conservation. The DFFE 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 DFFE 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 DFFE 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 DFFE 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).

DFFE 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 DFFE (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

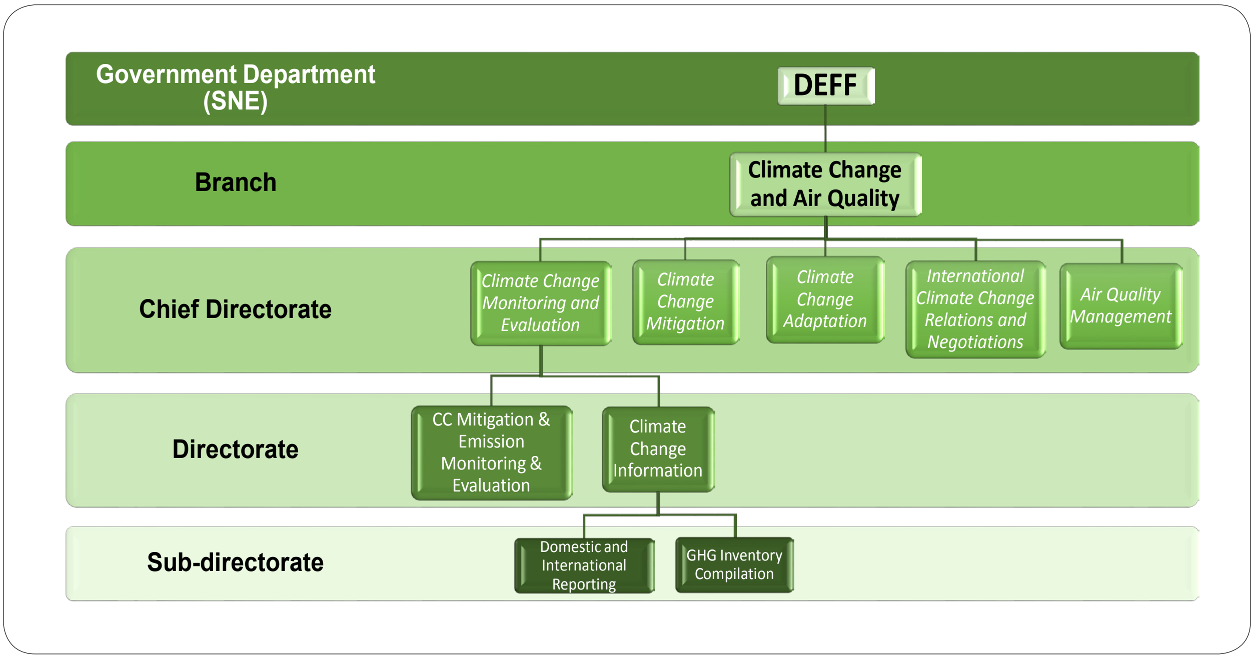

Figure 1.2: Organogram showing where the GHG Inventory compilation occurs within DFFE.

- 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.

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 will continue to be developed over time.

At this stage template MoU's (for private companies and for other government departments) have been developed but have not yet been implemented. DFFE has begun discussions with several government departments regarding the collection and provision of activity data for the GHG inventory, but nothing formal has been put in place.

National GHG Emissions Reporting Regulation (NGER)

The purpose of the National GHG Emission Reporting Regulation (NGER) is to introduce a single national reporting system for the transparent reporting of greenhouse gas emissions, which will be used (a) to update

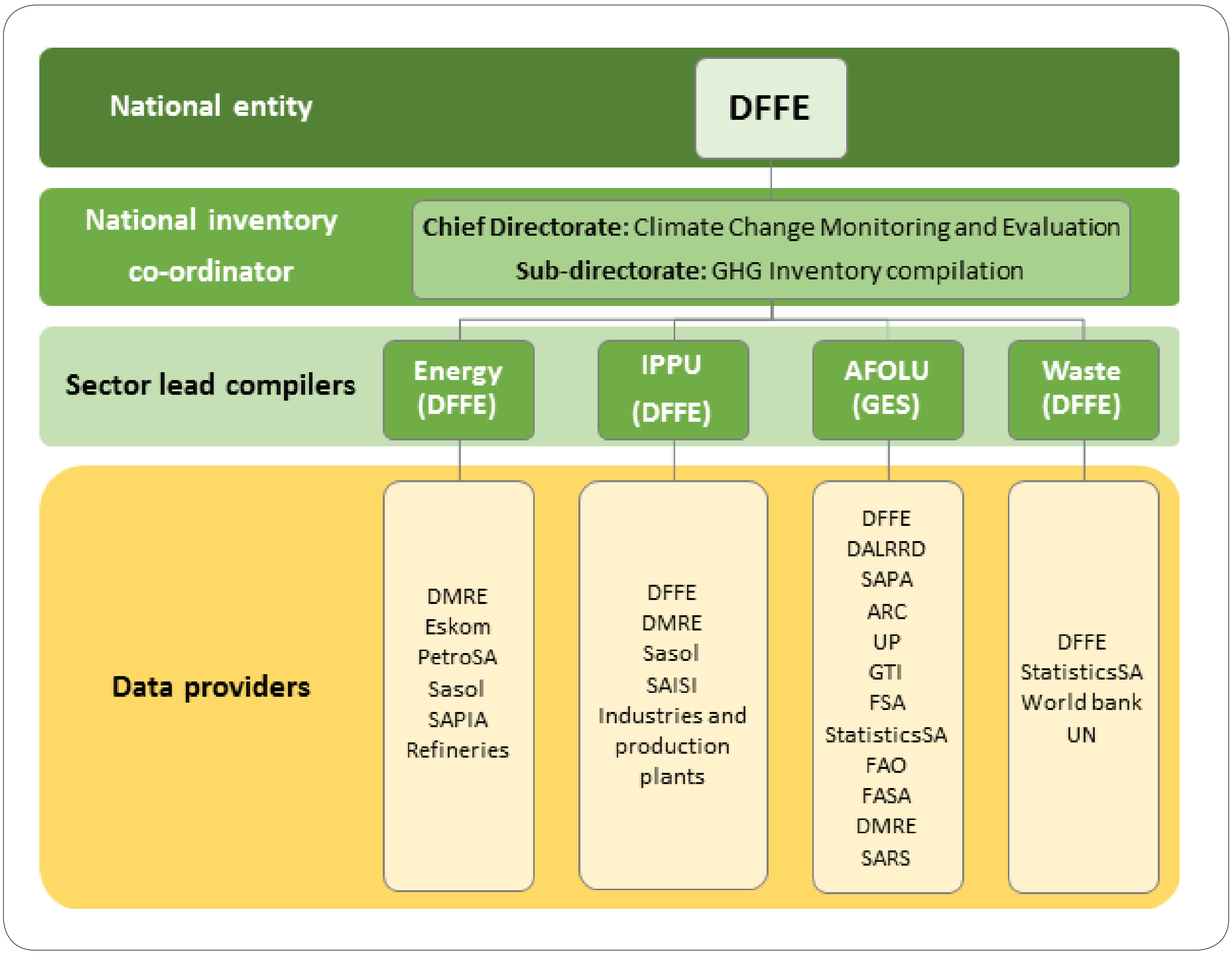

Figure 1.3: Current institutional arrangements for South Africa's GHG Inventory compilation.

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 DFFE) in a centralised manner. Currently DFFE 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 (NIR) to DFFE.

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 (KCA). 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.

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

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, annual reports from South African Petroleum Industry Association (SAPIA) and Transnet. There are currently no formal processes in place for requesting or obtaining this data. The data collection process for the Energy sector is shown in Figure 1.4.

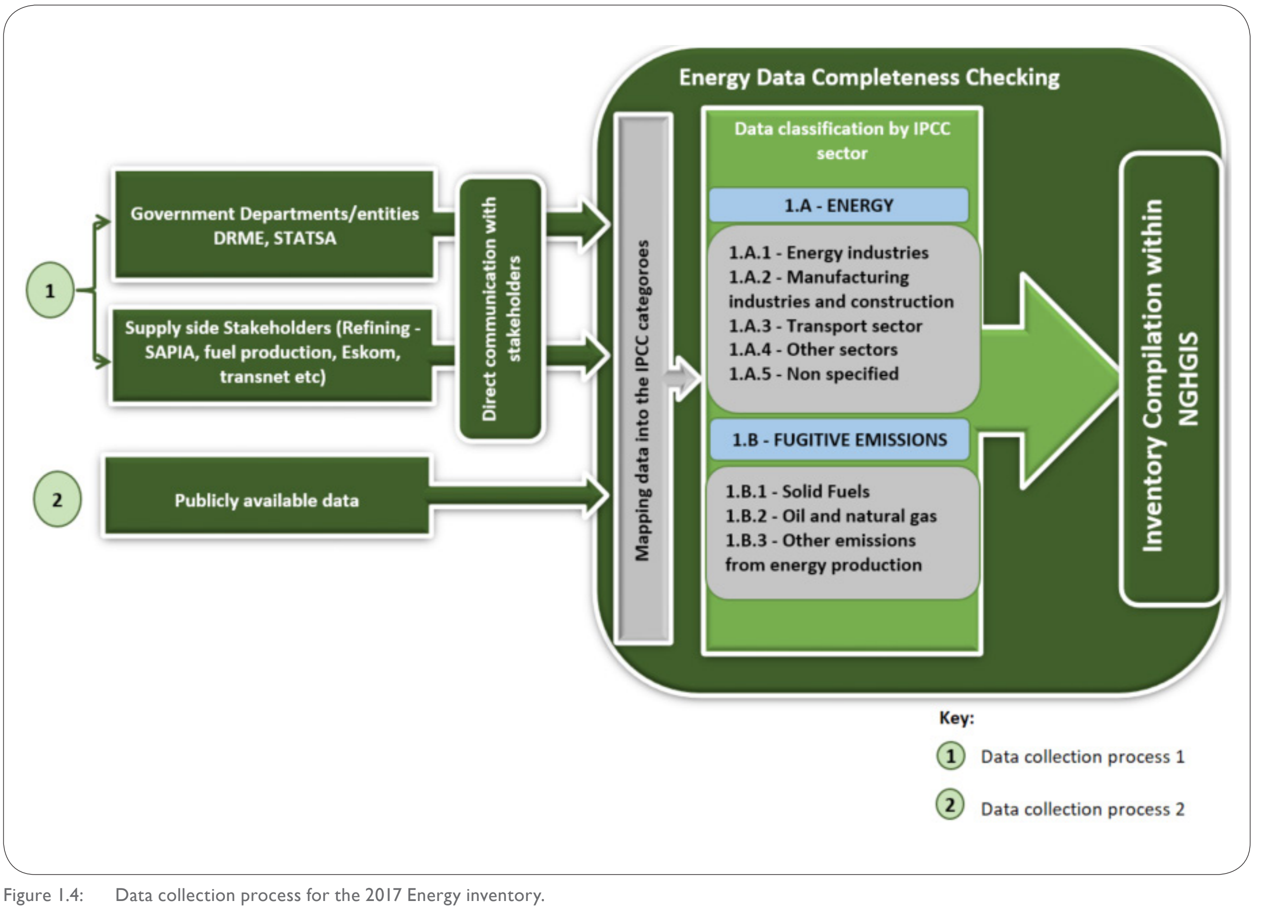

Figure 1.4: Data collection process for the 2017 Energy inventory.

Industry data

Industry data was obtained from publicly available data sets as well as from data supplied by companies. South Africa is aiming to include more company specific data into the inventory and is moving towards a more formalised data collection systems for industry. DFFE 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 has been made to this system so that it can manage the mandatory reporting of GHG emissions (see section 1.2.1), as it is currently aimed at air quality information. This component of NAEIS is 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 1.5). Some companies have started to report via SAGERS and this data was included in the current inventory.

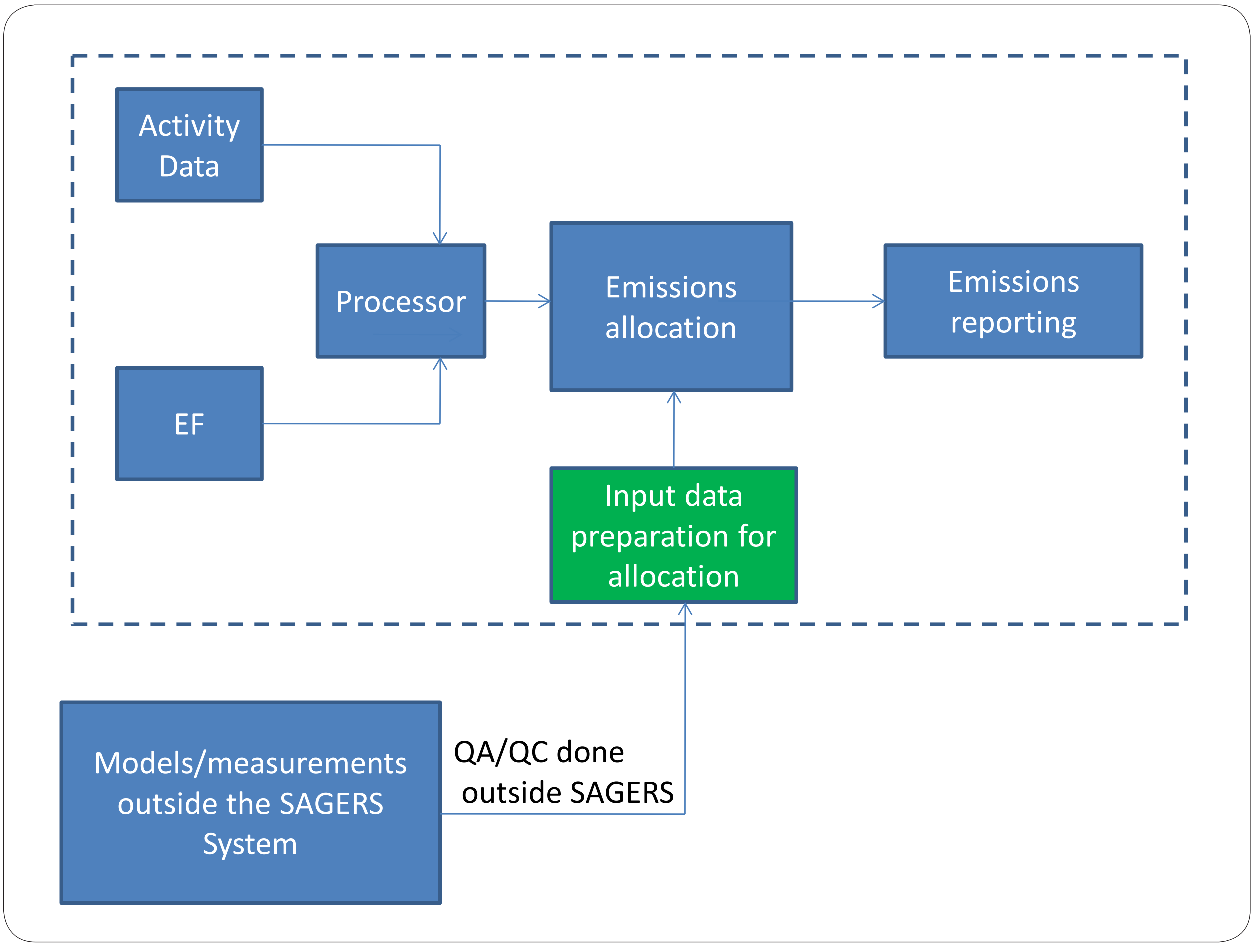

Figure 1.5: Expected Information flow in the South African Greenhouse Emissions Reporting Systems (SAGERS) which forms part of the National Atmospheric Emissions Inventory System (NAEIS).

HFC and PFC data

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

Land cover and change maps

The DFFE 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 the Department of Agriculture, Land Reform and Rural Development (DALRRD), Agricultural Research Council (ARC) and Tshwane University of Technology (TUT). DALRRD produces annual statistics reports which are publicly available. The data from ARC and TUT is done on a project-by-project basis. TUT completed a once off study on livestock emission factors, and ARC completes period studies on livestock emissions, manure management and direct N2O emissions from soils. There are currently no formal procedure for obtaining this data, but the NGHGIS has set up template MOUs and DFFE 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, DFFE, Department of Water and Sanitation (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. In addition to this, DFFE has an Electronic Document Management System in Place for archiving the 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
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

ID	Type of check	Description	Level
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
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

ID	Type of check	Description	Level
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
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

ID	Type of check	Description	Level
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
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 Guidance*, 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 public review (Figure 1.6). 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.

Verification

Emission and activity data are verified by comparing them with other available data compiled independently of the

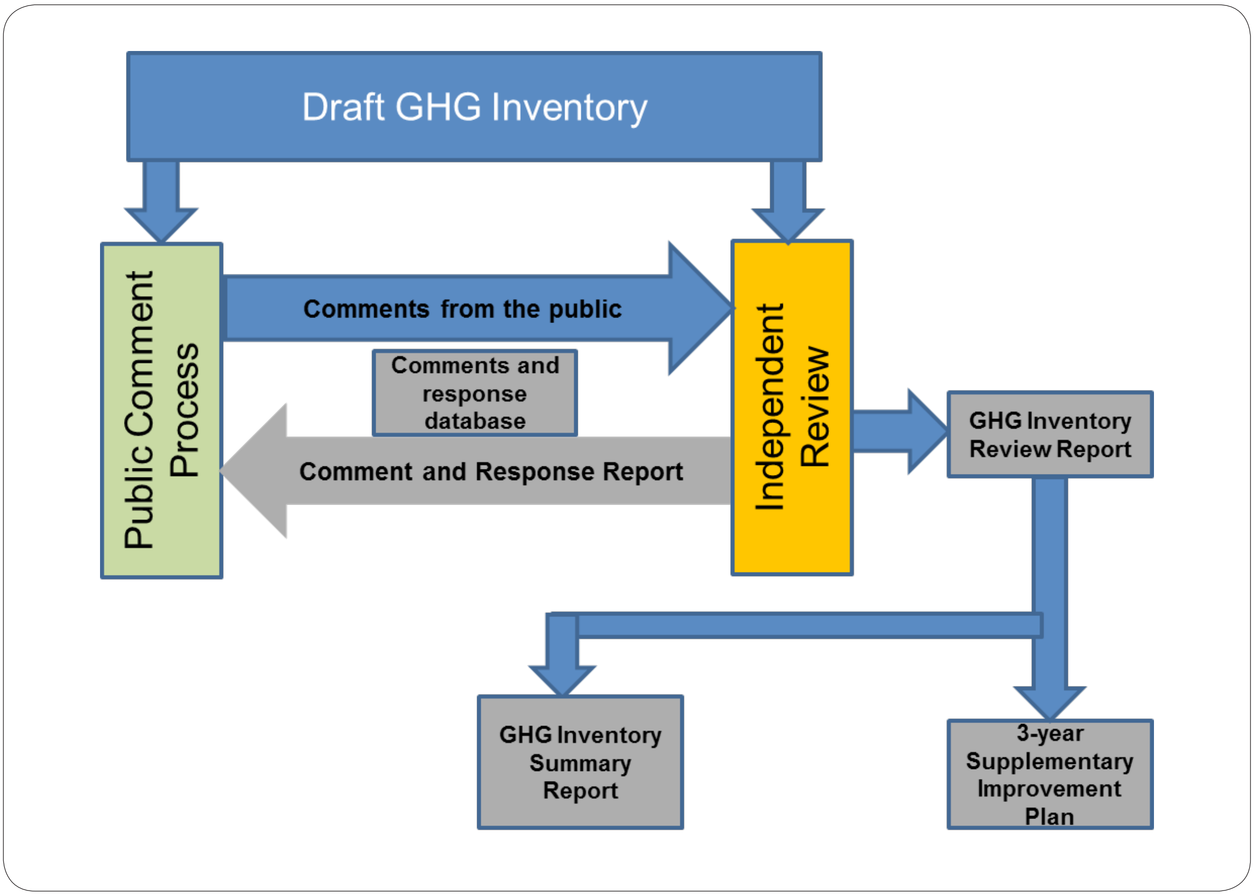

Figure 1.6: The independent review process for the 2000 – 2017 inventory.

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 several categories where there is only one company involved and so the data is reported as confidential. A mix of approaches is used for this category, with *Petrochemical and carbon black production* applying a Tier 1, *Titanium dioxide production* a Tier 2 and *Ammonia production*, *Nitric acid production* and *Carbide production* applying the Tier 3 methodology. The Metal industries also used a mix of approaches. Iron and stell production a Tier 1 and Tier 2 approach, Ferroalloy production a Tier 1 and Tier 3 approach, and the rest a Tier 1 approach. Tier 1 is also applied to the *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 (DAFF, 2019) 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 DFFE 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 DMRE; Individual production companies	For earlier years data was from publicly available datasets, but companies are now reporting through SAGERS due to the implementation of the GHG Regulation. Cement, Lime and Glass data reported as part of the NGER
	SAGERS	
2B Chemical industry	Individual production industries	Sasol, nitric acid production plants, carbide production plants, titanium dioxide production plants, Orion Engineered Carbons (Pty) Ltd
	SAGERS	For later years (2015 – 2017) nitric acid production data reported through SAGERS for NGER was incorporated
2C Metal industry	South African Mineral Industry Report compiled by DMRE	Publicly available dataset
	Iron and steel manufacturers	Data obtained from companies
	SAGERS	For Iron and steel and Lead production the data for recent years was obtained from SAGERS due to the implementation of the NGER.

Category	Principal data source	Principal data collection mechanism
2D Non-energy products from fuels and solvent use	DMRE Energy Balance Data	Discussions are on-going between DFFE and DMRE to develop an MoU
2F Product uses as substitutes for ozone depleting substances	DFFE	ODS databases and 5-year periodic surveys
3A Livestock	DALRRD	DFFE is in the process of developing an MOU with DAFF
3A Livestock	FAO	Statistics available on FAO Stats website
3A Livestock	South African Poultry Association (SAPA)	Information obtained through direct contact. No formal mechanism is in place.
3A Livestock	TUT and University of Pretoria	Data is available through scientific publications.
3B Land	DALRRD	DFFE is in the process of developing an MOU with DALRRD
3B Land	GeoTerraImage	Developed land cover maps as a once off project for DEA. Future consistent sources for this data are being sort.
3B Land	Forestry South Africa	Data obtained through direct request, no formal mechanism in place.
3B Land	DEA	Some data and land maps are developed or funded through DFFE.
3B Land	ARC	DFFE 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.
3C Aggregated and non-CO_2 emissions from land	MODIS burnt area data – obtained from website but processed by Gondwana Environmental Solutions	No formal process for obtaining this data but DFFE is considering compiling this data in-house.
3C Aggregated and non-CO_2 emissions from land	FAO	Statistics available on FAO Stats website
3C Aggregated and non-CO_2 emissions from land	ARC	DFFE is in the process of developing an MOU with ARC.
3C Aggregated and non-CO_2 emissions from land	Statistics SA	Agricultural census data are available from Statistics SA. No formal agreement exists between DFFE 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

BRIEF DESCRIPTION OF KEY SOURCE CATEGORIES 1.5

A key category is one that is prioritised within the national inventory system because its estimate has a significant influence (either as a source or a sink) on a country's total inventory of GHG's 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). Key categories based on uncertainty have not yet been included due to a lack of country specific data on uncertainties. The level and trend key category analysis identify 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. This includes both source and sink categories. The level assessment was conducted on the current year (2017) only, while the trend assessment utilised the base year (2000) and 2017. In the next inventory a level assessment will be completed for both the base year and the current year.

Identifying key categories will allow resources to be allocated to the appropriate activities to improve those specific subcategory emissions in future submissions. In this inventory a ranking system was added to allow the key categories to be ranked in order of prioritisation based on the findings from both the level and trend assessment. The ranking system works by allocating a score based on how high categories rank in the current year level assessment and the trend assessment. The top-ranking category gets a score of 1 and the second a score of 2, etc. The ranking score from both approaches are then added together to get the overall score for each category. The categories are then ranked from lowest score to highest, with draws in score resolved by the most recent year level assessment. This ranking approach was only applied to the assessments including LULUCF. The key categories identified in 2017, along with their ranking, are summarised in Table 1.4. The full key category analysis (level and trend, including and excluding FOLU) is provided in Appendix 1.A.

Table 1.4: Key categories for South Africa for 2017 (including FOLU) and their ranking.

Rank	IPCC Category code	IPCC Category	GHG
1	1A3b	Road Transport (Liquid fuel)	CO_2
2	1A1a	Electricity and Heat Production (Solid fuel)	CO_2
3	1A4a	Commercial/Institutional (Solid fuel)	CO_2
4	3B1a	Forest land remaining forest land	CO_2
5	1A1c	Manufacture of Solid Fuels and Other Energy Industries (Liquid fuel)	CO_2
6	1B3	Other Emissions from Energy Production	CO_2
7	4A	Solid Waste Disposal	CH_4
8	3A1a	Enteric fermentation - cattle	CH_4
9	2C1	Iron and Steel Production	CO_2
10	1A5a	Stationary (Solid fuel)	CO_2
11	3C4	Direct N_2O emissions from managed soils	N_2O
12	3B3b	Land converted to grassland	CO_2
13	1A2	Manufacturing Industries and Construction (Solid fuel)	CO_2
14	2C2	Ferroalloys Production	CO_2
15	2F1	Refrigeration and Air Conditioning	HFCs
16	3B6b	Land converted to other lands	CO_2
17	1A2	Manufacturing Industries and Construction (Liquid fuel)	CO_2
18	1A4c	Agriculture/Forestry/Fishing/Fish Farms (Liquid fuel)	CO_2
19	3B1b	Land converted to forest land	CO_2
20	1A2	Manufacturing Industries and Construction (Gas)	CO_2
21	2A1	Cement Production	CO_2
22	1A4b	Residential (Solid fuel)	CO_2
23	3A1c	Enteric fermentation - sheep	CH_4
24	1A4b	Residential (Liquid fuel)	CO_2
25	3B3a	Grassland remaining grassland	CO_2
26	1A1a	Electricity and Heat Production	CO_2
27	1A3a	Civil Aviation (Liquid)	CO_2
28	4D1	Wastewater Treatment and Discharge	CH_4
29	3C5	Indirect N_2O emissions from managed soils	N_2O
30	3C2	Liming	CO_2
31	1B3	Other Emissions from Energy Production	CH_4
32	1A1b	Petroleum Refining (Liquid)	CO_2

Rank	IPCC Category code	IPCC Category	GHG
33	3B2b	Land converted to cropland	CO_2
34	1A1b	Petroleum Refining (Gas)	CO_2
35	3D1	Harvested wood products	CO_2
36	2B3	Nitric acid production	N_2O
37	2A2	Lime Production	CO_2
38	1A4a	Commercial/Institutional (Liquid fuel)	CO_2
39	3B5a	Settlements remaining settlements	CO_2
41	3C1c	Biomass burning in grasslands	N_2O
42	3C1c	Biomass burning in grasslands	CH_4
43	2C3	Aluminium Production	PFCs
44	2B6	Titanium dioxide production	CO_2

1.5.1 Changes since the 2015 submission

In this inventory a disaggregation by fuel type (solid, liquid, gas) in the energy sector was included, which was not done in the previous inventory. This difference made direct comparison with the 2015 submission difficult, however a comparison was done by adding the percentage contribution for solid, liquid and gaseous fuels for each category that appeared on the 2017 level assessment (including FOLU) key category list (Figure 1.7). Three new key categories were identified, namely, *Land converted to grassland, Stationary* (Solid fuels, CO_2), and *Coal mining and handling* (CH_4). Updates in the Land sector changed the allocation between the *Forest land remaining forest land* and the *Land converted to forest land* categories, leading to a change in their contribution. There was also a change in contribution from the *Residential* category due to updated activity data.

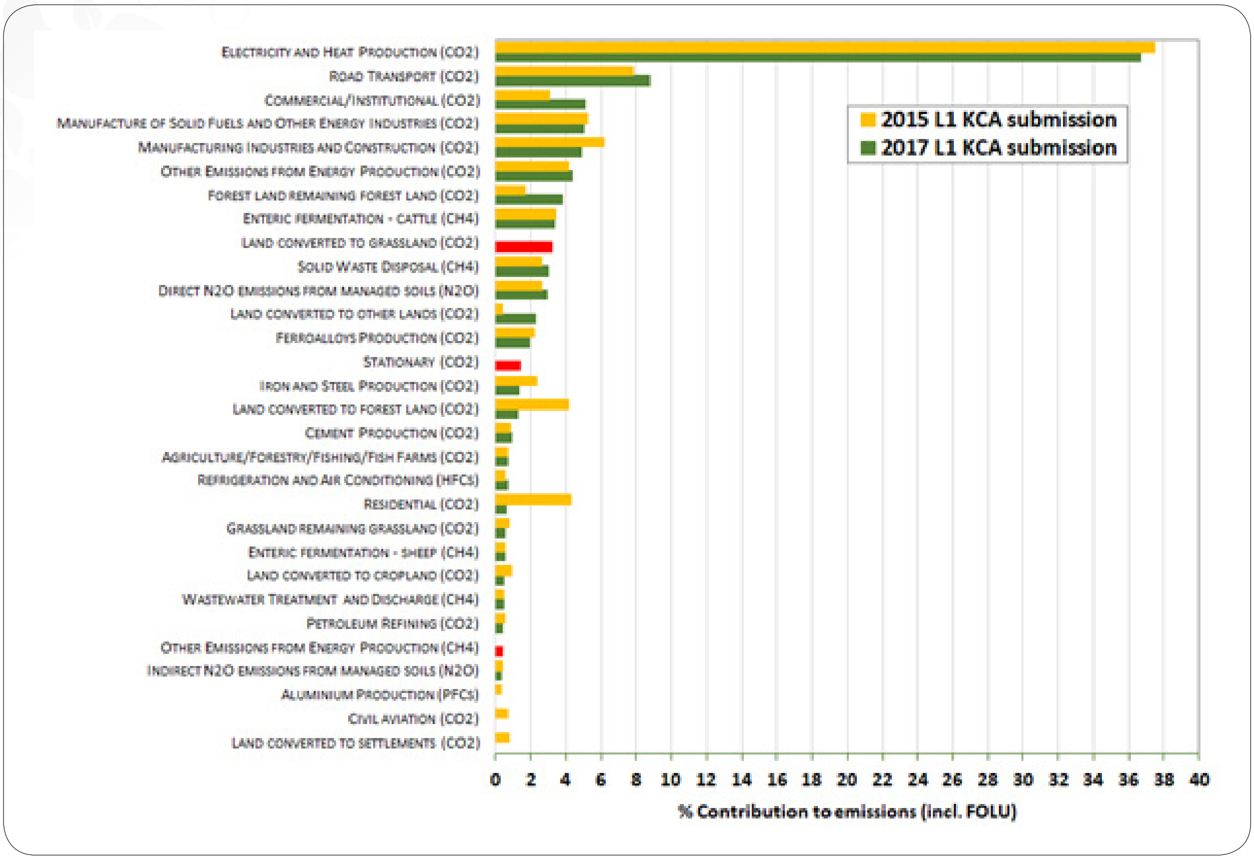

Figure 1.7: Comparison of level assessment key categories and their contribution to emissions (incl. FOLU) in the current and previous 2015 submission. New key categories in 2017 are shown in red.

GENERAL UNCERTAINTY EVALUATION 1.6

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 10.2%, while the uncertainty in the emission trend is estimated at 7.1%. If FOLU is excluded, then the overall uncertainty is reduced to 9.4% with the uncertainty on trend being 6.7%.

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 1.5 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 1.5: Activities in the 2017 inventory which are not estimated (NE), included elsewhere (IE) or not occurring (NO).

NE, IE or NO	IPCC Category	Activity	Comments
NE	1B2	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
	1B1b	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
	1B1ai2	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
	1C1	CO_2 transport	Insufficient data to include
	1C2	Injection and storage	Insufficient data to include
	2A4	Other process use of carbonates	Emissions from this source category will be included in the next inventory submission
	2C1	N_2O emissions from iron and steel production	This will be considered in the next inventory
	2C2	N_2O emissions from ferroalloy production	This will be considered in the next inventory
	2D2	CH_4 and N_2O emissions from paraffin wax use	Insufficient data to include
	2E	Electronics industry	A study needs to be undertaken to understand emissions from this source category
	2F5	PFCs and HFCs from solvents	Insufficient data to include
	2G1	PFCs from electrical equipment	Insufficient data to include
	2G2	PFCs from other product uses	Insufficient data to include
	2G3	N_2O from product uses	Insufficient data to include
	3B	CO_2 from organic soils	Insufficient data on the distribution and extent of organic soils. Project was completed by DFFE to identify and map organic soils. This data will be considered in the next inventory
	3B	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.

NE, IE or NO	IPCC Category	Activity	Comments
NE	3B4	CO_2 emissions from wetlands	Insufficient data and wetland area not considered to be significant. A recent study initiated by DFFE could provide further data which will be considered in the next inventory
	3C4	N_2O from organic soils	Insufficient data on the distribution and extent of organic soils. Project was completed by DFFE to identify and map organic soils. This data will be considered in the next inventory
	4B	CH_4, N_2O emissions from biological treatment of waste	Insufficient data to include, but will be considered for inclusion in next inventory
	4C1	CO_2, CH_4 and N_2O from waste incineration	Insufficient data to include
	2	SF_6 emissions in the IPPU sector	Insufficient data. It is planned to include these by the 2021 inventory.
	All sectors	NOx, CO, NMVOC emissions	These have only been included for biomass burning due to a lack of data in other sectors
	All sectors	SO_2 emissions	Insufficient data. It is planned to include these by the 2021 inventory.
IE	1A1aii	CO_2, CH_4 and N_2O emissions from Combined Heat and Power (CHP) combustion systems	Not separated out but is included within 1A1ai
	1A3eii	CO_2, CH_4 and N_2O emissions from off-road vehicles and other machinery	Included under Road transportation.
	3B	Precursor emissions from controlled burning	Emissions from controlled burning are not separated from biomass burning and so are included under Biomass burning (3C1)
	3C1	CO_2 emissions from biomass burning	These are not included under biomass burning, but rather under disturbance losses in the Land sector (3B).
	4 D1	Domestic wastewater treatment and discharge emissions	Reported under the total for Wastewater treatment and discharge
	4D2	Industrial wastewater treatment and discharge emissions	Reported under the total for Wastewater treatment and discharge
NO	2B7	CO_2, CH_4 and N_2O emissions from Soda Ash Production	
	2B3	CO_2, CH_4 and N_2O emissions from Adipic acid production	
	2B4	CO_2, CH_4 and N_2O Caprolactam, Glyoxal and Glyoxylic acid production	
	3C7	Rice cultivation	

1.8 INVENTORY IMPROVEMENTS INTRODUCED

1.8.1 Energy

In the Energy sector the consumption data in the Road transport, Manufacturing industries and construction, Other sectors and Non-specified emissions from energy production categories was updated due to an updated fuel allocation in the DMRE energy balance data. The main fuels that necessitated recalculation are coal and diesel in those sectors. In addition, a recent parc model study (DFFE, 2020) was completed for the transport sector which provided consumption data based on vehicle kilometres travelled (VKT). This data was incorporated into the inventory.

1.8.2 IPPU

Companies have started to report their emissions via the SAGERS system due to the introduction of the GHG regulation. Improved company data was available from the system from 2014 onward for several of the IPPU sub-categories. This improved data was incorporated. Improvements in the IPPU sector included:

- updated Cement production activity data;
- the application of the hydrated lime emission factor;
- updated Carbide production activity data for 2014 onwards;
- updated Titanium dioxide production activity data;
- updated Carbon black production activity data for 2015;
- a correction in the direct reduced iron and sinter emission factors for Iron and steel production;
- an update in the emission factor for emissions from the Corex process (included under the Other category for Steel and iron production);
- updated activity data for ferrosilicon 65% Si production for 2015 onwards;
- updated activity data for Aluminium production for 2014 onwards;
- updated activity data for Lead and Zinc production for 2013 onwards; and
- improved energy balance activity data for lubricants and paraffin wax.

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 FSOM 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.

1.9 RECALCULATIONS

Recalculations due to improvements led to a 2.5% and 1.6% decrease in emission estimates excluding and including FOLU, respectively, for 2015. Recalculated estimates were 3.7% and 1.7% less than previous estimates for the *Energy* and *IPPU* sectors, while the estimates for *AFOLU* (excl. FOLU), *AFOLU* (incl. FOLU) and *Waste* sector estimates were 4.6%, 36.1% and 4.2% higher, respectively, than the previous submission for 2015 (Table 1.6). The percentage change did, however, change across the time-series.

Table 1.6: Percentage difference between previous submission and current submission emission estimates per sector.

	Energy	IPPU	AFOLU (excl. FOLU)	AFOLU (incl. FOLU)	Waste	Total (excl. FOLU)	Total (incl. FOLU)
	(%)						
2000	1.54	-3.18	5.32	9.53	25.10	2.19	2.47
2001	0.70	-2.41	5.93	30.44	22.16	1.62	3.55
2002	-0.42	-2.55	5.42	17.34	19.66	0.60	1.40
2003	-1.01	-3.05	4.46	-7.86	17.48	-0.10	-1.19
2004	-1.41	-3.23	3.60	0.32	15.58	-0.58	-0.93
2005	-1.87	-3.27	5.94	38.11	13.91	-0.77	1.59
2006	-2.83	-3.13	5.27	28.32	12.43	-1.61	0.01
2007	-1.74	11.22	4.68	14.65	11.11	0.16	0.83
2008	-1.45	11.99	4.72	23.67	9.93	0.43	1.92
2009	1.40	13.04	5.86	0.75	8.87	2.81	2.38
2010	-4.62	-2.67	5.97	19.71	7.91	-3.14	-2.50
2011	-3.21	-1.74	5.92	8.15	7.01	-1.90	-1.91
2012	-2.85	-0.73	5.18	40.32	6.20	-1.67	-0.02
2013	-6.41	-2.76	5.62	47.05	5.47	-4.67	-3.43
2014	-4.47	-7.38	5.42	70.03	4.80	-3.46	-1.35
2015	-3.71	-1.69	4.59	36.09	4.18	-2.51	-1.61

There was a 3.1% and 2.5% decline in the overall CO_2 emission estimates excluding and including FOLU, respectively (Table 1.7). This was due to recalculations in all sectors except *Waste*, with changes in *Energy* and *AFOLU* dominating. After recalculations, the 2015 CH_4 emissions were estimated to be 1.2% higher. The main contributor was a 1.5% increase from the *Energy* sector recalculations, which was offset by a decline in the estimates for the other sectors. Recalculated N_2O emissions were 11.8% higher in this submission, mainly due to a 14.1% increase in *AFOLU* sector estimates, and a decline in the N_2O from the *Energy* sector. F-gas recalculations led to a lowering of emission estimates between 2013 and 2015 compared to the previous submission. In 2015 there was a 34.7% difference, and this is mainly due to updated Aluminium production data.

Table 1.7: Percentage difference between previous submission and current submission emission estimates per gas.

	CO_2 (excl. FOLU)	CO_2 (incl. FOLU)	CH_4 (excl. FOLU)	CH_4 (incl. FOLU)	N_2O	F-gases
	(%)					
2000	1.21	1.32	5.55	5.54	13.39	0.00
2001	0.51	2.59	5.54	5.53	13.63	0.00
2002	-0.66	0.06	5.26	5.26	13.98	0.00
2003	-1.13	-2.63	3.60	3.62	13.01	0.00
2004	-1.53	-2.14	2.87	2.90	11.92	0.00
2005	-1.98	0.61	3.56	3.58	14.07	0.00
2006	-2.85	-1.13	2.82	2.85	13.52	0.00
2007	-0.63	-0.02	1.99	2.04	14.18	0.00
2008	-0.24	1.34	0.93	0.98	14.51	0.00
2009	2.44	1.78	1.92	1.96	14.57	0.00
2010	-4.35	-3.78	1.27	1.32	13.82	0.00
2011	-3.02	-3.22	1.84	1.88	13.78	0.00
2012	-2.57	-0.84	1.11	1.16	12.69	0.00
2013	-5.31	-4.03	-5.72	-5.59	13.36	-8.81
2014	-4.34	-2.05	1.57	1.61	13.10	-38.53
2015	-3.13	-2.25	1.12	1.17	11.75	-34.68

1.10 PLANNED IMPROVEMENTS

Table 1.8 shows planned improvements and the timelines for these improvements.

Table 1.8: List of planned improvements for South Africa's GHG inventory.

Sector	Improvement	Priority	Reason	Status	Completion timeframe	Barriers and constraints
Cross cutting	Improve uncertainty data for all sectors but incorporating more country specific uncertainty values.	Medium	Accuracy	Proposed	Incorporated as data becomes available	Lack of uncertainty data constrains this activity. As data becomes available it will be incorporated, but there are no specific planned projects for this activity at this stage.
	Improve transparency in reporting by including more detailed description of methodologies and activity data, particularly in energy and IPPU sectors.	High	Transparency	Planned	5th BUR (2019 inventory)	Lack of resources and time have hindered the completion of this activity. The enhanced inventory team should assist in completing this task.
	Incorporate data from SAGERS into inventory (data reported due to NGER)	High	Accuracy	Planned	5th BUR (2019 inventory)	Companies have started reporting through SAGERS and some initial data was included in this inventory, but further data will be incorporated into the next inventory as more companies report.
	Extend time-series back to 1990 for energy, IPPU and waste sectors.	Medium	Completeness	Planned	6th BUR (2021 inventory)	Lack of data for years prior to 2000, particularly for categories where data is highly variable (such as HFCs and PFCs), have constrained the completion of this task. A study is planned to extend/extrapolate the data back to1990 for the three IPCC sectors.
	Investigate inconsistencies in lime activity data (for lime production in IPPU and lime application emission in AFOLU), explore alternative data sources or improve consistency.	Low	Consistency	Planned	5th BUR (2019 inventory)	Inconsistencies in lime data have been noted in previous reviews and has not yet been updated due to time constraints and low priority. It is planned that this issue will be addressed in the next inventory.

Sector	Improvement	Priority	Reason	Status	Completion timeframe	Barriers and constraints
Cross cutting	Set up MOUs with key data providers, e.g. DMRE, Eskom, SAPIA	High	Transparency	Not completed		This has proved to be difficult and is not working, therefore regulatory processes and the GHGIP (see section ES.9) are being used for data gathering instead.
	Improve QA/QC process by addressing all issues in external review	High	Transparency	In progress	5th BUR (2019 inventory)	Challenges in addressing external review comments have been limited by resources and process management. The DFFE inventory team has increased in size which should assist in addressing this issue. External reviewers should also use QC procedures suggested in the QA/QC plan for commenting on the calculation files to assist with the speed of the process.
	Improve the improvement plan by incorporating all review activities not addressed in current inventory	High	Transparency	In progress	5th BUR (2019 inventory)	Challenges around inclusion of further improvements into the improvement plan are limited resources and process management. The DFFE inventory team has increased in size, including an inventory co-ordinator, which should assist in addressing this issue.
	Incorporate NOx, CO, NMVOC, and SOx emissions	High	Completeness	Proposed	5th BUR (2019 inventory)	These emissions will first be implemented in the transport sector especially the road transport sector. A study which looked at vehicle kilometres travelled by vehicle technology is being concluded in April 2020 and will enable the estimation of these emissions from the Energy Sector. Data for energy sector will be included in 2019 inventory, followed both other sectors in the 2021 inventory.

Sector	Improvement	Priority	Reason	Status	Completion timeframe	Barriers and constraints
Energy	Incorporate all updated information from the recent fuel consumption study.	High	Key category; Accuracy	In progress	5th BUR (2019 inventory)	Completion of the fuel consumption study is a barrier to completing this task, however it should be completed in 2020 by the next inventory. The results of the study will be incorporated to produce an enhanced inventory. Sections that have been completed have already begun to be incorporated into the inventory.
	CO_2 and CH_4 fugitive emissions from oil and natural gas operations	Medium	Completeness	Planned	5th BUR (2019 inventory)	Emissions from this source category will be added in the next inventory as information will be obtained through the NGER.
	CO_2, CH_4 and N_2O from spontaneous combustion of coal seams	Low	Completeness	Planned	6th BUR (2021 inventory)	New research will allow this category to be included in the 2021 inventory.
	CH_4 emissions from abandoned mines	Low	Completeness	Planned	6th BUR (2021 inventory)	New research outputs will enable this activity to be included in the 2021 inventory.
	Fugitive emissions from coke production to be reported separately from 2C process emissions	Low	Transparency	Planned	5th BUR (2019 inventory)	Progress on this has been slow but reporting through the NGER will allow this activity to be incorporated in the next inventory.
	Improve understanding of difference between reference and sectoral approach	Medium	Key category; Transparency	Planned	5th BUR (2019 inventory)	The fuel consumption study that will be concluded in April 2020, will be used to estimate emissions from sectoral approach and the data from supply side such as Eskom, Sasol and (SAPIA) will be used to estimate emissions using the reference approach. Inclusion of this study will assist the inventory team in understanding the differences between reference and sectoral approaches.
	Incorporate emissions from biogas	Low	Completeness	Proposed		This would require a study and so should be recommended as a project under the GHGIP (see section ES.9).
	CO_2 transport and storage	Low	Completeness	Proposed		

Sector	Improvement	Priority	Reason	Status	Completion timeframe	Barriers and constraints
Energy	CO_2, CH_4 and N_2O emissions from combined heat and power (CHP) combustion systems	Medium	Completeness	Proposed		
	Develop EFs, carbon content of fuels and NCVs of liquid fuels	High	Key category; Accuracy	Planned	6th BUR (2021 inventory)	Resources and funding are required to complete this study so it will be incorporated into the GHGIP (see section ES.9). This study was planned to start in 2020.
	Development of T3 methods for CTL-GTC and GTL		Accuracy	Proposed		Resources and funding are required to complete this study so it will be incorporated into the GHGIP (see section ES.9).
	Improve explanation of large changes in trends		Transparency	Planned	5th BUR (2019 inventory)	This aspect will be incorporated in the next inventory and BUR.
IPPU	Calculate CH_4 emissions from Iron and steel production	High	Key category; Completeness	Planned	5th BUR (2019 inventory)	Data is available for this activity so it will be incorporated in the next inventory.
	Estimate emissions from OPUC category using currently available data	Medium	Completeness	Planned	5th BUR (2019 inventory)	Emissions from this category can be calculated form existing data, so this will be included in the next inventory.
	Development of country specific EF for ferroalloy industry	Medium	Key category; Accuracy	Proposed	6th BUR (2021 inventory)	Resources and funding are required to complete this study so it will be incorporated into the GHGIP (see section ES.9).
	Development of Tier 3 methodologies for aluminium production	Medium	Key category; Accuracy	Proposed		Resources and funding are required to complete this study so it will be incorporated into the GHGIP (see section ES.9).
	Include emissions from electronics industry	Medium	Completeness	Planned	6th BUR (2021 inventory)	A study needs to be undertaken to understand emissions from this source so it should be highlighted as a project for the GHGIP (see section ES.9).
	Incorporate emissions SF6 emissions	Medium	Completeness	In progress	5th BUR (2019 inventory)	Lack of data has been a challenge.

Sector	Improvement	Priority	Reason	Status	Completion timeframe	Barriers and constraints
AFOLU	Incorporate all background data and equations for the tier 2 calculations of enteric fermentation	High	Key category; Accuracy; Transparency	Planned	6th BUR (2021 inventory)	Lack of time and resources have been barriers to incorporating this information. With the increase in inventory team members this should now be possible.
	Incorporate 2018 NLC map and update land use change data for 2015-2018	High	Key category; Accuracy	Planned	5th BUR (2019 inventory)	NLC maps were not available at the time of preparing the 2017 inventory but this has now been completed (see section ES.9).
	Incorporate organic soils study to include emissions from organic soils	Medium	Completeness	Planned	5th BUR (2019 inventory)	Time has been the main barrier for this activity as for the 2015 inventory the soil map was not complete, and in the 2017 inventory there was insufficient time to complete all the mapping integration and land cover overlays. Some of this work has now been done as part of the NTCSA.
	Include deadwood in the DOM pool for all land categories	Low	Completeness	Planned	6th BUR (2021 inventory)	The recently updated NTCSA included dead wood estimates, so this data will be considered in the next inventory. However a literature search for forest lands during the current inventory revealed that there is insufficient data to support the inclusion of deadwood, therefore more research may be required and deadwood would then only be included in the 2021 inventory.
	Incorporate updated National Terrestrial Carbon Sinks Assessment (NTCSA) data to improve estimates, particularly for soils	High	Key category; Accuracy	Planned	5th BUR (2019 inventory)	NTCSA update has just been completed, so data will begin to be incorporated.
	Complete an assessment of crop types and areas and investigate discrepancies between crop statistics and NLC data	Medium	Consistency; Comparability	Planned	6th BUR (2021 inventory)	Variability in crop classifications from the various data sources have made this challenging. Funding will be required to complete a proper assessment of croplands so this project can be included in the GHGIP.

Sector	Improvement	Priority	Reason	Status	Completion timeframe	Barriers and constraints
AFOLU	Include CO_2 estimates for wetlands	Low	Completeness	Proposed	6th BUR (2021 inventory)	Lack of data has been the barrier to including this activity and it has been a low priority due to small area of wetlands. Data from NTCSA will be considered, and other data explored, so that estimates can be included by the 2021 inventory. A Blue Carbon project is also currently underway which may provide further data for wetlands.
	Update HWP with country specific data	Low	Accuracy	Planned	5th BUR (2019 inventory)	Time constraints and priority level are the reasons for this not being completed yet. This will be considered in the next inventory.
Waste	Data collection on quantities of waste disposed of into managed and unmanaged landfills		Key category; Accuracy	In progress	5th BUR (2019 inventory)	Project is underway so data will be included in 2019 inventory.
	Improve MCF and rate constants		Key category; Accuracy	Proposed		This would require a study so will be recommended as a project under the GHGIP.
	Include economic data for different population groups		Key category; Accuracy	In progress	5th BUR (2019 inventory)	Study was completed in March 2020 so data will be included in next inventory.
	Include information on population distribution in rural and urban areas as a function of income		Key category; Accuracy	In progress	5th BUR (2019 inventory)	Study was completed in March 2020 so data will be included in next inventory.
	Include HWP in solid waste	Medium	Key category; Completeness	Proposed		Insufficient data.
	Obtain data on waste streams and the bucket system		Accuracy	In progress	5th BUR (2019 inventory)	Study was completed in March 2020 so data will be included in next inventory.
	CH_4, N_2O emissions from biological treatment of waste	Medium	Completeness	In progress	5th BUR (2019 inventory)	Study was completed in March 2020 so data will be included in next inventory.
	CO_2, CH_4 and N_2O from waste incineration	High	Completeness	In progress	5th BUR (2019 inventory)	Study was completed in March 2020 so data will be included in next 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	214175.9	0.418	0.418
1A3b	Road Transport	Liquid	CO_2	51 206.4	0.100	0.518
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	CO_2	29 369.4	0.057	0.575
1A4a	Commercial/Institutional	Solid	CO_2	27 473.4	0.054	0.629
1B3	Other Emissions from Energy Production		CO_2	25 746.5	0.050	0.679
1A2	Manufacturing Industries and Construction	Solid	CO_2	19 833.5	0.039	0.717
3A1a	Enteric fermentation - cattle		CH_4	19 764.6	0.039	0.756
4A	Solid Waste Disposal		CH_4	17 366.0	0.034	0.790
3C4	Direct N2O emissions from managed soils		N_2O	17 049.1	0.033	0.823
2C2	Ferroalloys Production		CO_2	11 328.4	0.022	0.845
1A5a	Stationary	Solid	CO_2	8 229.4	0.016	0.861
2C1	Iron and Steel Production		CO_2	7 725.0	0.015	0.876
2A1	Cement Production		CO_2	5 246.4	0.010	0.887
1A2	Manufacturing Industries and Construction	Liquid	CO_2	4 993.8	0.010	0.896
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	CO_2	4 161.3	0.008	0.904
2F1	Refrigeration and Air Conditioning		HFCs	3 963.5	0.008	0.912
1A2	Manufacturing Industries and Construction	Gas	CO_2	3 817.9	0.007	0.920
3A1c	Enteric fermentation - sheep		CH_4	3 214.6	0.006	0.926
4D1	Wastewater Treatment and Discharge		CH_4	2 753.3	0.005	0.931
1A4a	Commercial/Institutional	Liquid	CO_2	2 426.6	0.005	0.936
1A1b	Petroleum Refining	Gas	CO_2	2 215.0	0.004	0.940
1B3	Other Emissions from Energy Production		CH_4	2 183.9	0.004	0.945
3C5	Indirect N2O emissions from managed soils		N_2O	2 126.3	0.004	0.949
1A4b	Residential	Liquid	CO_2	1 829.2	0.004	0.952
1B1a	Coal mining and handling		CH_4	1 551.4	0.003	0.955
1A4b	Residential	Solid	CO_2	1 523.2	0.003	0.958
1A3a	Civil Aviation	Liquid	CO_2	1 522.1	0.003	0.961
1A5a	Stationary	Liquid	CO_2	1 450.0	0.003	0.964
3C2	Liming		CO_2	1 222.1	0.002	0.966

IPCC Category code	IPCC Category	Fuel type	GHG	2017 Ex,t (Gg CO_2 Eq)	Lx,t	Cumulative Total
1A1a	Electricity and Heat Production	Liquid	CO_2	1 220.2	0.002	0.969
2C3	Aluminium Production		CO_2	1 143.1	0.002	0.971
1A1b	Petroleum Refining	Liquid	CO_2	1 113.0	0.002	0.973
1A1a	Electricity and Heat Production	Solid	N_2O	1 034.7	0.002	0.975
2A2	Lime Production		CO_2	890.0	0.002	0.977
3A2a	Manure management - cattle		N_2O	826.1	0.002	0.979
1A3b	Road Transport	Liquid	N_2O	791.9	0.002	0.980
4D1	Wastewater Treatment and Discharge		N_2O	769.6	0.002	0.982
3A1d	Enteric fermentation - goats		CH_4	709.2	0.001	0.983
3C3	Urea application		CO_2	679.6	0.001	0.984
1B2a	Oil		CO_2	641.8	0.001	0.986
3A2i	Manure management - poultry		N_2O	641.3	0.001	0.987
3C6	Indirect N2O emissions from manure management		N_2O	464.9	0.001	0.988
1A3c	Railways	Liquid	CO_2	442.8	0.001	0.989
3A2h	Manure management - swine		CH_4	438.6	0.001	0.989
2D1	Lubricant Use		CO_2	424.5	0.001	0.990
1A3d	Water-Borne Navigation	Liquid	CO_2	355.7	0.001	0.991
2B	Chemical industry		C	C	0.001	0.992
1A4a	Commercial/Institutional	Solid	N_2O	265.5	0.001	0.992
1A3b	Road Transport	Liquid	CH_4	249.4	0.000	0.993
3A2a	Manure management - cattle		CH_4	244.6	0.000	0.993
3C1c	Biomass burning in grasslands		N_2O	241.8	0.000	0.994
2B	Chemical industry		C	C	0.000	0.994
4C2	Open Burning of Waste		CH_4	240.7	0.000	0.994
3C1c	Biomass burning in grasslands		CH_4	204.8	0.000	0.995
2B	Chemical industry		C	C	0.000	0.995
3C1a	Biomass burning in forest land		CH_4	145.0	0.000	0.995
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	N_2O	141.8	0.000	0.996
3C1a	Biomass burning in forest land		N_2O	129.1	0.000	0.996
1A4b	Residential	Solid	N_2O	122.3	0.000	0.996
2B	Chemical industry		C	C	0.000	0.996
3A1f	Enteric fermentation - horses		CH_4	122.0	0.000	0.997
2A3	Glass Production		CO_2	120.9	0.000	0.997

IPCC Category code	IPCC Category	Fuel type	GHG	2017 Ex,t (Gg CO_2 Eq)	Lx,t	Cumulative Total
2C3	Aluminium Production		PFCs	113.1	0.000	0.997
2D2	Paraffin Wax Use		CO_2	106.2	0.000	0.997
3A2c	Manure management - sheep		N_2O	103.6	0.000	0.998
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	CO_2	103.1	0.000	0.998
1A2	Manufacturing Industries and Construction	Solid	N_2O	95.8	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
2B	Chemical industry		C	C	0.000	0.998
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
1A4b	Residential	Solid	CH_4	55.0	0.000	0.999
2C6	Zinc Production		CO_2	52.9	0.000	0.999
2F3	Fire Protection		HFCs	51.1	0.000	0.999
1A3c	Railways	Liquid	N_2O	47.0	0.000	0.999
1A1a	Electricity and Heat Production	Solid	CH_4	46.7	0.000	0.999
1A5a	Stationary	Solid	N_2O	39.8	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
2C5	Lead Production		CO_2	25.0	0.000	1.000
3C1b	Biomass burning in croplands		N_2O	21.9	0.000	1.000
1B1a	Coal mining and handling		CO_2	19.5	0.000	1.000
3C1d	Biomass burning in wetlands		N_2O	13.8	0.000	1.000
1A2	Manufacturing Industries and Construction	Liquid	N_2O	12.3	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
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	CH_4	7.9	0.000	1.000
1A4a	Commercial/Institutional	Solid	CH_4	6.0	0.000	1.000
1A4a	Commercial/Institutional	Liquid	N_2O	5.9	0.000	1.000
1A2	Manufacturing Industries and Construction	Solid	CH_4	4.3	0.000	1.000

IPCC Category code	IPCC Category	Fuel type	GHG	2017 Ex,t (Gg CO_2 Eq)	Lx,t	Cumulative Total
1A2	Manufacturing Industries and Construction	Liquid	CH_4	4.2	0.000	1.000
1A3a	Civil Aviation	Liquid	N_2O	4.0	0.000	1.000
1A5a	Stationary	Liquid	N_2O	3.8	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	CH_4	3.6	0.000	1.000
1A1a	Electricity and Heat Production	Liquid	N_2O	2.9	0.000	1.000
1A4b	Residential	Liquid	N_2O	2.4	0.000	1.000
1A1b	Petroleum Refining	Liquid	N_2O	2.2	0.000	1.000
1A3d	Water-Borne Navigation	Liquid	N_2O	2.1	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
1A4a	Commercial/Institutional	Liquid	CH_4	2.0	0.000	1.000
1A5a	Stationary	Solid	CH_4	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
1A3a	Civil Aviation	Liquid	CH_4	1.3	0.000	1.000
1A5a	Stationary	Liquid	CH_4	1.3	0.000	1.000
1A1b	Petroleum Refining	Gas	N_2O	1.2	0.000	1.000
2C2	Ferroalloys Production		CH_4	1.1	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	N_2O	1.0	0.000	1.000
1A1a	Electricity and Heat Production	Liquid	CH_4	1.0	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	Liquid	CH_4	0.7	0.000	1.000
1A3d	Water-Borne Navigation	Liquid	CH_4	0.7	0.000	1.000
1A3c	Railways	Liquid	CH_4	0.5	0.000	1.000
2B	Chemical industry		C	C	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

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	214 175.9	0.367	0.367
1A3b	Road Transport	Liquid	CO_2	51 206.4	0.088	0.454
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	CO_2	29 369.4	0.050	0.504
1A4a	Commercial/Institutional	Solid	CO_2	27 473.4	0.047	0.551
1B3	Other Emissions from Energy Production		CO_2	25 746.5	0.044	0.595
3B1a	Forest land remaining forest land		CO_2	-22 249.8	0.038	0.634
1A2	Manufacturing Industries and Construction	Solid	CO_2	19 833.5	0.034	0.667
3A1a	Enteric fermentation – cattle		CH_4	19 764.6	0.034	0.701
3B3b	Land converted to grassland		CO_2	-18 920.1	0.032	0.734
4A	Solid Waste Disposal		CH_4	17 366.0	0.030	0.763
3C4	Direct N2O emissions from managed soils		N_2O	17 049.1	0.029	0.793
3B6b	Land converted to other lands		CO_2	13 512.9	0.023	0.816
2C2	Ferroalloys Production		CO_2	11 328.4	0.019	0.835
1A5a	Stationary	Solid	CO_2	8 229.4	0.014	0.849
2C1	Iron and Steel Production		CO_2	7 725.0	0.013	0.862
3B1b	Land converted to forest land		CO_2	-7 367.1	0.013	0.875
2A1	Cement Production		CO_2	5 246.4	0.009	0.884
1A2	Manufacturing Industries and Construction	Liquid	CO_2	4 993.8	0.009	0.893
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	CO_2	4 161.3	0.007	0.900
2F1	Refrigeration and Air Conditioning		HFCs	3 963.5	0.007	0.906
1A2	Manufacturing Industries and Construction	Gas	CO_2	3 817.9	0.007	0.913
3B3a	Grassland remaining grassland		CO_2	3 306.2	0.006	0.919
3A1c	Enteric fermentation – sheep		CH_4	3 214.6	0.006	0.924
3B2b	Land converted to cropland		CO_2	2 756.0	0.005	0.929
4D1	Wastewater Treatment and Discharge		CH_4	2 753.3	0.005	0.934
1A4a	Commercial/Institutional	Liquid	CO_2	2 426.6	0.004	0.938
1A1b	Petroleum Refining	Gas	CO_2	2 215.0	0.004	0.941
1B3	Other Emissions from Energy Production		CH_4	2 183.9	0.004	0.945
3C5	Indirect N2O emissions from managed soils		N_2O	2 126.3	0.004	0.949
1A4b	Residential	Liquid	CO_2	1 829.2	0.003	0.952
1B1a	Coal mining and handling		CH_4	1 551.4	0.003	0.955
1A4b	Residential	Solid	CO_2	1 523.2	0.003	0.957

IPCC Category code	IPCC Category	Fuel type	GHG	2017 Ex,t (Gg CO_2 Eq)	Lx,t	Cumulative Total
1A3a	Civil Aviation	Liquid	CO_2	1 522.1	0.003	0.960
1A5a	Stationary	Liquid	CO_2	1 450.0	0.002	0.962
3C2	Liming		CO_2	1 222.1	0.002	0.964
1A1a	Electricity and Heat Production	Liquid	CO_2	1 220.2	0.002	0.967
3B2a	Cropland remaining cropland		CO_2	-1 175.2	0.002	0.969
2C3	Aluminium Production		CO_2	1 143.1	0.002	0.970
1A1b	Petroleum Refining	Liquid	CO_2	1 113.0	0.002	0.972
1A1a	Electricity and Heat Production	Solid	N_2O	1 034.7	0.002	0.974
2A2	Lime Production		CO_2	890.0	0.002	0.976
3A2a	Manure management – cattle		N_2O	826.1	0.001	0.977
1A3b	Road Transport	Liquid	N_2O	791.9	0.001	0.978
3D1	Harvested wood products		CO_2	-776.9	0.001	0.980
4D1	Wastewater Treatment and Discharge		N_2O	769.6	0.001	0.981
3A1d	Enteric fermentation – goats		CH_4	709.2	0.001	0.982
3B5a	Settlements remaining settlements		CO_2	-687.5	0.001	0.983
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
3C6	Indirect N2O emissions from manure management		N_2O	464.9	0.001	0.989
1A3c	Railways	Liquid	CO_2	442.8	0.001	0.990
3A2h	Manure management – swine		CH_4	438.6	0.001	0.990
2D1	Lubricant Use		CO_2	424.5	0.001	0.991
1A3d	Water-Borne Navigation	Liquid	CO_2	355.7	0.001	0.992
2B	Chemical industry		C	C	0.001	0.992
3B5b	Land converted to settlements		CO_2	290.4	0.000	0.993
1A4a	Commercial/Institutional	Solid	N_2O	265.5	0.000	0.993
1A3b	Road Transport	Liquid	CH_4	249.4	0.000	0.994
3A2a	Manure management - cattle		CH_4	244.6	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	0.996

IPCC Category code	IPCC Category	Fuel type	GHG	2017 Ex,t (Gg CO_2 Eq)	Lx,t	Cumulative Total
2B	Chemical industry		C	C	0.000	0.996
3C1a	Biomass burning in forest land		CH_4	145.0	0.000	0.996
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	N_2O	141.8	0.000	0.996
3C1a	Biomass burning in forest land		N_2O	129.1	0.000	0.997
1A4b	Residential	Solid	N_2O	122.3	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	0.997
2C3	Aluminium Production		PFCs	113.1	0.000	0.998
2D2	Paraffin Wax Use		CO_2	106.2	0.000	0.998
3A2c	Manure management - sheep		N2O	103.6	0.000	0.998
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	CO_2	103.1	0.000	0.998
1A2	Manufacturing Industries and Construction	Solid	N_2O	95.8	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
2B	Chemical industry		C	C	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
1A4b	Residential	Solid	CH_4	55.0	0.000	0.999
2C6	Zinc Production		CO_2	52.9	0.000	0.999
2F3	Fire Protection		HFCs	51.1	0.000	0.999
1A3c	Railways	Liquid	N_2O	47.0	0.000	0.999
1A1a	Electricity and Heat Production	Solid	CH_4	46.7	0.000	0.999
1A5a	Stationary	Solid	N_2O	39.8	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	1.000
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
2C5	Lead Production		CO_2	25.0	0.000	1.000
3C1b	Biomass burning in croplands		N_2O	21.9	0.000	1.000
1B1a	Coal mining and handling		CO_2	19.5	0.000	1.000

IPCC Category code	IPCC Category	Fuel type	GHG	2017 Ex,t (Gg CO_2 Eq)	Lx,t	Cumulative Total
3C1d	Biomass burning in wetlands		N_2O	13.8	0.000	1.000
1A2	Manufacturing Industries and Construction	Liquid	N_2O	12.3	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
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	CH_4	7.9	0.000	1.000
1A4a	Commercial/Institutional	Solid	CH_4	6.0	0.000	1.000
1A4a	Commercial/Institutional	Liquid	N_2O	5.9	0.000	1.000
1A2	Manufacturing Industries and Construction	Solid	CH_4	4.3	0.000	1.000
1A2	Manufacturing Industries and Construction	Liquid	CH_4	4.2	0.000	1.000
1A3a	Civil Aviation	Liquid	N_2O	4.0	0.000	1.000
1A5a	Stationary	Liquid	N_2O	3.8	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	CH_4	3.6	0.000	1.000
1A1a	Electricity and Heat Production	Liquid	N_2O	2.9	0.000	1.000
1A4b	Residential	Liquid	N_2O	2.4	0.000	1.000
1A1b	Petroleum Refining	Liquid	N_2O	2.2	0.000	1.000
1A3d	Water-Borne Navigation	Liquid	N_2O	2.1	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
1A4a	Commercial/Institutional	Liquid	CH_4	2.0	0.000	1.000
1A5a	Stationary	Solid	CH_4	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
1A3a	Civil Aviation	Liquid	CH_4	1.3	0.000	1.000
1A5a	Stationary	Liquid	CH_4	1.3	0.000	1.000
1A1b	Petroleum Refining	Gas	N_2O	1.2	0.000	1.000
2C2	Ferroalloys Production		CH_4	1.1	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	N_2O	1.0	0.000	1.000
1A1a	Electricity and Heat Production	Liquid	CH_4	1.0	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	Liquid	CH_4	0.7	0.000	1.000

IPCC Category code	IPCC Category	Fuel type	GHG	2017 Ex,t ($Gg\ CO_2$ Eq)	Lx,t	Cumulative Total
1A3d	Water-Borne Navigation	Liquid	CH_4	0.7	0.000	1.000
1A3c	Railways	Liquid	CH_4	0.5	0.000	1.000
2B	Chemical industry		C	C	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

C=Confidential data

Table A.3: 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	2000 Ex,t	2017 Ex,t	Tx,t	% contribution to trend	Cumulative Total
				($Gg\ CO_2$ Eq)				
1A4a	Electricity and Heat Production	Solid	CO_2	14 399.1	27 473.4	0.025	0.112	0.112
2C1	Iron and Steel Production		CO_2	15 334.4	7 725.0	0.022	0.100	0.212
1A3b	Road Transport	Liquid	CO_2	37 152.3	51 206.4	0.020	0.089	0.301
1B3	Other Emissions from Energy Production		CO_2	28 146.6	25 746.5	0.014	0.065	0.366
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	CO_2	30 454.7	29 369.4	0.012	0.055	0.421
4A	Solid Waste Disposal		CH_4	10 533.9	17 366.0	0.012	0.054	0.475
3A1a	Enteric fermentation - cattle		CH_4	21 502.9	19 764.6	0.011	0.049	0.524
3C4	Direct N_2O emissions from managed soils		N_2O	18 955.0	17 049.1	0.010	0.047	0.571
1A5a	Stationary	Solid	CO_2	3 228.6	8 229.4	0.010	0.046	0.617
2F1	Refrigeration and Air Conditioning		HFCs	0.0	3 963.5	0.009	0.040	0.657
1A1a	Electricity and Heat Production	Solid	CO_2	185 027.4	214 175.9	0.006	0.029	0.686
1A4b	Residential	Solid	CO_2	3 604.2	1 523.2	0.006	0.026	0.713
1A2	Manufacturing Industries and Construction	Solid	CO_2	19 514.6	19 833.5	0.005	0.025	0.738
2C2	Ferroalloys Production		CO_2	8 079.1	11 328.4	0.005	0.021	0.759
1A2	Manufacturing Industries and Construction	Liquid	CO_2	2 572.0	4 993.8	0.005	0.021	0.780
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	CO_2	2 207.2	4 161.3	0.004	0.017	0.797

IPCC Category code	IPCC Category	Fuel type	GHG	2000 Ex,t	2017 Ex,t	Tx,t	% contribution to trend	Cumulative Total
				(Gg CO_2 Eq)				
2B	Chemical industry		C	C	C	0.004	0.016	0.813
1A4b	Residential	Liquid	CO_2	2 868.9	1 829.2	0.003	0.015	0.827
1A2	Manufacturing Industries and Construction	Gas	CO_2	2 217.7	3 817.9	0.003	0.013	0.841
1A1a	Electricity and Heat Production	Liquid	CO_2	0.0	1 220.2	0.003	0.012	0.853
3A1c	Enteric fermentation - sheep		CH_4	3 800.5	3 214.6	0.003	0.011	0.864
1A3a	Civil Aviation	Liquid	CO_2	2 249.1	1 522.1	0.002	0.011	0.875
2C3	Aluminium Production		PFCs	983.2	113.1	0.002	0.010	0.885
1A1b	Petroleum Refining	Liquid	CO_2	1 735.5	1 113.0	0.002	0.009	0.894
2A1	Cement Production		CO_2	3 870.6	5 246.4	0.002	0.008	0.903
3C2	Liming		CO_2	384.1	1 222.1	0.002	0.008	0.911
3C5	Indirect N_2O emissions from managed soils		N_2O	2 342.4	2 126.3	0.001	0.006	0.916
3C1c	Biomass burning in grasslands		N_2O	668.6	241.8	0.001	0.005	0.921
2B	Chemical industry		C	C	C	0.001	0.005	0.926
1B3	Other Emissions from Energy Production		CH_4	2 318.6	2 183.9	0.001	0.005	0.931
1A1b	Petroleum Refining	Gas	CO_2	2 307.1	2 215.0	0.001	0.004	0.935
2A2	Lime Production		CO_2	434.1	890.0	0.001	0.004	0.939
3C1c	Biomass burning in grasslands		CH_4	508.9	204.8	0.001	0.004	0.943
1A4b	Residential	Solid	N_2O	424.0	122.3	0.001	0.004	0.947
3C3	Urea application		CO_2	297.3	679.6	0.001	0.003	0.950
3A1d	Enteric fermentation - goats		CH_4	906.2	709.2	0.001	0.003	0.954
2B	Chemical industry		C	C	C	0.001	0.003	0.957
4D1	Wastewater Treatment and Discharge		CH_4	2 144.1	2 753.3	0.001	0.003	0.960
1A5a	Stationary	Liquid	CO_2	1 008.5	1 450.0	0.001	0.003	0.963
3C1a	Biomass burning in forest land		N_2O	350.2	129.1	0.001	0.003	0.966
3C1a	Biomass burning in forest land		CH_4	348.0	145.0	0.001	0.003	0.968
1B2a	Oil		CO_2	752.0	641.8	0.000	0.002	0.971
2D1	Lubricant Use		CO_2	188.5	424.5	0.000	0.002	0.973
3C1b	Biomass burning in croplands		CH_4	220.7	57.2	0.000	0.002	0.975
1A3c	Railways	Liquid	CO_2	551.5	442.8	0.000	0.002	0.977
1A4b	Residential	Solid	CH_4	198.5	55.0	0.000	0.002	0.978

IPCC Category code	IPCC Category	Fuel type	GHG	2000 Ex,t	2017 Ex,t	Tx,t	% contribution to trend	Cumulative Total
				(Gg CO_2 Eq)				
1A3b	Road Transport	Liquid	N_2O	558.9	791.9	0.000	0.002	0.980
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	CO_2	199.5	103.1	0.000	0.001	0.981
3A2h	Manure management - swine		CH_4	487.7	438.6	0.000	0.001	0.982
1A4a	Commercial/Institutional	Liquid	CO_2	2 028.6	2 426.6	0.000	0.001	0.984
3A2i	Manure management - poultry		N_2O	466.5	641.3	0.000	0.001	0.985
1A4a	Commercial/Institutional	Solid	N_2O	139.1	265.5	0.000	0.001	0.986
2C3	Aluminium Production		CO_2	1 091.3	1 143.1	0.000	0.001	0.987
1A3d	Water-Borne Navigation	Liquid	CO_2	222.2	355.7	0.000	0.001	0.988
2D2	Paraffin Wax Use		CO_2	7.4	106.2	0.000	0.001	0.989
2B	Chemical industry		C	C	C	0.000	0.001	0.990
4D1	Wastewater Treatment and Discharge		N_2O	599.3	769.6	0.000	0.001	0.991
3C1b	Biomass burning in croplands		N_2O	84.5	21.9	0.000	0.001	0.991
1B1a	Coal mining and handling		CH_4	1 421.0	1 551.4	0.000	0.001	0.992
2C6	Zinc Production		CO_2	108.4	52.9	0.000	0.001	0.993
2B	Chemical industry		C	C	C	0.000	0.001	0.993
1A3b	Road Transport	Gas	CO_2	3.4	70.7	0.000	0.001	0.994
3A2a	Manure management - cattle		N_2O	775.0	826.1	0.000	0.001	0.995
2F3	Fire Protection		HFCs	0.0	51.1	0.000	0.001	0.995
3A2c	Manure management - sheep		N_2O	122.5	103.6	0.000	0.000	0.996
2B	Chemical industry		C	C	C	0.000	0.000	0.996
2A3	Glass Production		CO_2	74.4	120.9	0.000	0.000	0.996
1A3b	Road Transport	Liquid	CH_4	249.3	249.4	0.000	0.000	0.997
1A3c	Railways	Liquid	N_2O	66.0	47.0	0.000	0.000	0.997
4C2	Open Burning of Waste		CH_4	187.5	240.7	0.000	0.000	0.997
1A5a	Stationary	Solid	N_2O	15.6	39.8	0.000	0.000	0.998
2C5	Lead Production		CO_2	39.2	25.0	0.000	0.000	0.998
3A2a	Manure management - cattle		CH_4	229.9	244.6	0.000	0.000	0.998
3A2d	Manure management - goats		N_2O	46.4	36.3	0.000	0.000	0.998
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	N_2O	110.3	141.8	0.000	0.000	0.998
3C1e	Biomass burning in settlements		N_2O	15.1	2.1	0.000	0.000	0.998

IPCC Category code	IPCC Category	Fuel type	GHG	2000 Ex,t	2017 Ex,t	Tx,t	% contribution to trend	Cumulative Total
				(Gg CO_2 Eq)				
1A1a	Electricity and Heat Production	Solid	N_2O	893.9	1 034.7	0.000	0.000	0.999
1A2	Manufacturing Industries and Construction	Solid	N_2O	94.3	95.8	0.000	0.000	0.999
3C1e	Biomass burning in settlements		CH_4	11.2	1.6	0.000	0.000	0.999
3A1h	Enteric fermentation - swine		CH_4	43.5	39.1	0.000	0.000	0.999
3A2h	Manure management - swine		N_2O	41.3	37.1	0.000	0.000	0.999
3A2i	Manure management - poultry		CH_4	43.1	59.2	0.000	0.000	0.999
3C1d	Biomass burning in wetlands		N_2O	20.2	13.8	0.000	0.000	0.999
4C2	Open Burning of Waste		N_2O	63.9	82.0	0.000	0.000	0.999
3C1d	Biomass burning in wetlands		CH_4	15.0	10.2	0.000	0.000	0.999
3A1f	Enteric fermentation - horses		CH_4	102.1	122.0	0.000	0.000	0.999
3A1g	Enteric fermentation - mules and asses		CH_4	34.4	34.2	0.000	0.000	0.999
1A2	Manufacturing Industries and Construction	Liquid	N_2O	6.4	12.3	0.000	0.000	0.999
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	CH_4	10.6	7.9	0.000	0.000	1.000
4C2	Open Burning of Waste		CO_2	29.2	37.5	0.000	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	N_2O	5.6	10.5	0.000	0.000	1.000
1A4b	Residential	Liquid	N_2O	5.4	2.4	0.000	0.000	1.000
3C6	Indirect N_2O emissions from manure management		N_2O	404.1	464.9	0.000	0.000	1.000
1A1a	Electricity and Heat Production	Liquid	N_2O	0.0	2.9	0.000	0.000	1.000
1A3a	Civil Aviation	Liquid	N_2O	5.9	4.0	0.000	0.000	1.000
2C2	Ferroalloys Production		CH_4	3.3	1.1	0.000	0.000	1.000
1A4a	Commercial/Institutional	Solid	CH_4	3.1	6.0	0.000	0.000	1.000
1A1b	Petroleum Refining	Liquid	N_2O	3.6	2.2	0.000	0.000	1.000
1A2	Manufacturing Industries and Construction	Liquid	CH_4	2.2	4.2	0.000	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	CH_4	1.9	3.6	0.000	0.000	1.000
1A4b	Residential	Liquid	CH_4	2.0	1.0	0.000	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	N_2O	1.9	1.0	0.000	0.000	1.000

IPCC Category code	IPCC Category	Fuel type	GHG	2000 Ex,t	2017 Ex,t	Tx,t	% contribution to trend	Cumulative Total
				(Gg CO_2 Eq)				
1A4a	Commercial/Institutional	Gas	CO_2	27.5	30.4	0.000	0.000	1.000
1A1a	Electricity and Heat Production	Liquid	CH_4	0.0	1.0	0.000	0.000	1.000
1A5a	Stationary	Solid	CH_4	0.7	1.8	0.000	0.000	1.000
1A3a	Civil Aviation	Liquid	CH_4	2.0	1.3	0.000	0.000	1.000
1B1a	Coal mining and handling		CO_2	17.9	19.5	0.000	0.000	1.000
1A5a	Stationary	Liquid	N_2O	2.7	3.8	0.000	0.000	1.000
1A2	Manufacturing Industries and Construction	Gas	N_2O	1.2	2.1	0.000	0.000	1.000
1A1b	Petroleum Refining	Liquid	CH_4	1.2	0.7	0.000	0.000	1.000
1A1a	Electricity and Heat Production	Solid	CH_4	40.4	46.7	0.000	0.000	1.000
1A3d	Water-Borne Navigation	Liquid	N_2O	1.3	2.1	0.000	0.000	1.000
1A2	Manufacturing Industries and Construction	Solid	CH_4	4.3	4.3	0.000	0.000	1.000
1A2	Manufacturing Industries and Construction	Gas	CH_4	0.8	1.4	0.000	0.000	1.000
3A2d	Manure management - goats		CH_4	1.0	0.8	0.000	0.000	1.000
3A2c	Manure management - sheep		CH_4	1.0	0.9	0.000	0.000	1.000
1A4a	Commercial/Institutional	Liquid	N_2O	4.9	5.9	0.000	0.000	1.000
1A3c	Railways	Liquid	CH_4	0.6	0.5	0.000	0.000	1.000
1A5a	Stationary	Liquid	CH_4	0.9	1.3	0.000	0.000	1.000
1A1b	Petroleum Refining	Gas	N_2O	1.2	1.2	0.000	0.000	1.000
1A3d	Water-Borne Navigation	Liquid	CH_4	0.4	0.7	0.000	0.000	1.000
1A1b	Petroleum Refining	Gas	CH_4	0.8	0.8	0.000	0.000	1.000
1A4a	Commercial/Institutional	Liquid	CH_4	1.7	2.0	0.000	0.000	1.000
1A3b	Road Transport	Gas	CH_4	0.1	0.0	0.000	0.000	1.000
1A3b	Road Transport	Gas	N_2O	0.0	0.0	0.000	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	CH_4	0.0	0.0	0.000	0.000	1.000
2B	Chemical industry		C	C	C	0.000	0.000	1.000
3A2f	Manure management - horses		CH_4	0.1	0.1	0.000	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	GHG	2000 Ex,t	2017 Ex,t	Tx,t	% contribution to trend	Cumulative Total
				(Gg CO_2 Eq)				
3B1a	Forest land remaining forest land		CO_2	-4 709.1	-22 249.8	0.036	0.142	0.142
1A4a	Commercial/Institutional	Solid	CO_2	14 399.1	27 473.4	0.023	0.091	0.232
1A3b	Road Transport	Liquid	CO_2	37 152.3	51 206.4	0.020	0.080	0.313
1A1a	Electricity and Heat Production	Solid	CO_2	185 027.4	214 175.9	0.020	0.078	0.391
2C1	Iron and Steel Production		CO_2	15 334.4	7 725.0	0.018	0.072	0.463
4A	Solid Waste Disposal		CH_4	10 533.9	17 366.0	0.011	0.045	0.508
1B3	Other Emissions from Energy Production		CO_2	28 146.6	25 746.5	0.011	0.042	0.550
1A5a	Stationary	Solid	CO_2	3 228.6	8 229.4	0.009	0.037	0.586
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	CO_2	30 454.7	29 369.4	0.008	0.033	0.620
3A1a	Enteric fermentation - cattle		CH_4	21 502.9	19 764.6	0.008	0.031	0.651
2F1	Refrigeration and Air Conditioning		HFCs	0.0	3 963.5	0.008	0.031	0.682
3C4	Direct N_2O emissions from managed soils		N_2O	18 955.0	17 049.1	0.008	0.030	0.712
1A4b	Residential	Solid	CO_2	3 604.2	1 523.2	0.005	0.019	0.732
2C2	Ferroalloys Production		CO_2	8 079.1	11 328.4	0.005	0.019	0.751
1A2	Manufacturing Industries and Construction	Liquid	CO_2	2 572.0	4 993.8	0.004	0.017	0.768
3B3b	Land converted to grassland		CO_2	-18 957.0	-18 920.1	0.004	0.015	0.783
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	CO_2	2 207.2	4 161.3	0.003	0.014	0.796
1A2	Manufacturing Industries and Construction	Solid	CO_2	19 514.6	19 833.5	0.003	0.013	0.810
2B	Chemical industry		C	C	C	0.003	0.012	0.822
3B6b	Land converted to other lands		CO_2	13 512.9	13 512.9	0.003	0.011	0.833
1A2	Manufacturing Industries and Construction	Gas	CO_2	2 217.7	3 817.9	0.003	0.011	0.843
1A4b	Residential	Liquid	CO_2	2 868.9	1 829.2	0.003	0.010	0.854
1A1a	Electricity and Heat Production	Liquid	CO_2	0.0	1 220.2	0.002	0.010	0.863
3B1b	Land converted to forest land		CO_2	-6 886.1	-7 367.1	0.002	0.009	0.873
3A1c	Enteric fermentation – sheep		CH_4	3 800.5	3 214.6	0.002	0.008	0.881
2A1	Cement Production		CO_2	3 870.6	5 246.4	0.002	0.008	0.888

IPCC Category code	IPCC Category	Fuel type	GHG	2000 Ex,t	2017 Ex,t	Tx,t	% contribution to trend	Cumulative Total
				(Gg CO_2 Eq)				
2C3	Aluminium Production		PFCs	983.2	113.1	0.002	0.008	0.896
1A3a	Civil Aviation	Liquid	CO_2	2 249.1	1 522.1	0.002	0.008	0.903
1A1b	Petroleum Refining	Liquid	CO_2	1 735.5	1 113.0	0.002	0.006	0.910
3C2	Liming		CO_2	384.1	1 222.1	0.002	0.006	0.916
3D1	Harvested wood products		CO_2	-290.4	-776.9	0.001	0.004	0.920
3C1c	Biomass burning in grasslands		N_2O	668.6	241.8	0.001	0.004	0.924
2B	Chemical industry		C	C	C	0.001	0.004	0.928
3B5a	Settlements remaining settlements		CO_2	-246.7	-687.5	0.001	0.004	0.931
3C5	Indirect N_2O emissions from managed soils		N_2O	2 342.4	2 126.3	0.001	0.004	0.935
3B3a	Grassland remaining grassland		CO_2	2 593.3	3 306.2	0.001	0.003	0.938
2A2	Lime Production		CO_2	434.1	890.0	0.001	0.003	0.942
4D1	Wastewater Treatment and Discharge		CH_4	2 144.1	2 753.3	0.001	0.003	0.945
1B3	Other Emissions from Energy Production		CH_4	2 318.6	2 183.9	0.001	0.003	0.948
3C1c	Biomass burning in grasslands		CH_4	508.9	204.8	0.001	0.003	0.950
3C3	Urea application		CO_2	297.3	679.6	0.001	0.003	0.953
1A4b	Residential	Solid	N_2O	424.0	122.3	0.001	0.003	0.956
1A5a	Stationary	Liquid	CO_2	1 008.5	1 450.0	0.001	0.003	0.959
1A1b	Petroleum Refining	Gas	CO_2	2 307.1	2 215.0	0.001	0.003	0.961
3B2a	Cropland remaining cropland		CO_2	-951.6	-1 175.2	0.001	0.003	0.964
3B2b	Land converted to cropland		CO_2	2 772.3	2 756.0	0.001	0.002	0.966
2B	Chemical industry		C	C	C	0.001	0.002	0.968
3A1d	Enteric fermentation – goats		CH_4	906.2	709.2	0.001	0.002	0.971
3C1a	Biomass burning in forest land		N_2O	350.2	129.1	0.001	0.002	0.973
3C1a	Biomass burning in forest land		CH_4	348.0	145.0	0.000	0.002	0.975
2D1	Lubricant Use		CO_2	188.5	424.5	0.000	0.002	0.976
1B2a	Oil		CO_2	752.0	641.8	0.000	0.001	0.978
1A4a	Commercial/Institutional	Liquid	CO_2	2 028.6	2 426.6	0.000	0.001	0.979
3C1b	Biomass burning in croplands		CH_4	220.7	57.2	0.000	0.001	0.981
1A3b	Road Transport	Liquid	N_2O	558.9	791.9	0.000	0.001	0.982
1A3c	Railways	Liquid	CO_2	551.5	442.8	0.000	0.001	0.983

IPCC Category code	IPCC Category	Fuel type	GHG	2000 Ex,t	2017 Ex,t	Tx,t	% contribution to trend	Cumulative Total
				($Gg\ CO_2$ Eq)				
1A4b	Residential	Solid	CH_4	198.5	55.0	0.000	0.001	0.985
3A2i	Manure management - poultry		N_2O	466.5	641.3	0.000	0.001	0.986
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	CO_2	199.5	103.1	0.000	0.001	0.987
1A4a	Commercial/Institutional	Solid	N_2O	139.1	265.5	0.000	0.001	0.987
1A3d	Water-Borne Navigation	Liquid	CO_2	222.2	355.7	0.000	0.001	0.988
4D1	Wastewater Treatment and Discharge		N_2O	599.3	769.6	0.000	0.001	0.989
3B5b	Land converted to settlements		CO_2	355.0	290.4	0.000	0.001	0.990
3A2h	Manure management – swine		CH_4	487.7	438.6	0.000	0.001	0.991
2D2	Paraffin Wax Use		CO_2	7.4	106.2	0.000	0.001	0.991
2B	Chemical industry		C	C	C	0.000	0.001	0.992
3C1b	Biomass burning in croplands		N_2O	84.5	21.9	0.000	0.001	0.993
3B4	Wetland		CH_4	666.6	666.6	0.000	0.001	0.993
2B	Chemical industry		C	C	C	0.000	0.001	0.994
1A3b	Road Transport	Gas	CO_2	3.4	70.7	0.000	0.001	0.994
2C6	Zinc Production		CO_2	108.4	52.9	0.000	0.001	0.995
2C3	Aluminium Production		CO_2	1 091.3	1 143.1	0.000	0.000	0.995
2F3	Fire Protection		HFCs	0.0	51.1	0.000	0.000	0.996
1A1a	Electricity and Heat Production	Solid	N_2O	893.9	1 034.7	0.000	0.000	0.996
2A3	Glass Production		CO_2	74.4	120.9	0.000	0.000	0.996
4C2	Open Burning of Waste		CH_4	187.5	240.7	0.000	0.000	0.997
3A2c	Manure management – sheep		N_2O	122.5	103.6	0.000	0.000	0.997
2B	Chemical industry		C	C	C	0.000	0.000	0.997
3A2a	Manure management – cattle		N_2O	775.0	826.1	0.000	0.000	0.997
1A3c	Railways	Liquid	N_2O	66.0	47.0	0.000	0.000	0.998
1A3b	Road Transport	Liquid	CH_4	249.3	249.4	0.000	0.000	0.998
1A5a	Stationary	Solid	N_2O	15.6	39.8	0.000	0.000	0.998
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	N_2O	110.3	141.8	0.000	0.000	0.998
3C6	Indirect N_2O emissions from manure management		N_2O	404.1	464.9	0.000	0.000	0.998
2C5	Lead Production		CO_2	39.2	25.0	0.000	0.000	0.998
1B1a	Coal mining and handling		CH_4	1 421.0	1 551.4	0.000	0.000	0.999

IPCC Category code	IPCC Category	Fuel type	GHG	2000 Ex,t	2017 Ex,t	Tx,t	% contribution to trend	Cumulative Total
				(Gg CO_2 Eq)				
3A2d	Manure management – goats		N_2O	46.4	36.3	0.000	0.000	0.999
3C1e	Biomass burning in settlements		N_2O	15.1	2.1	0.000	0.000	0.999
3A2i	Manure management – poultry		CH_4	43.1	59.2	0.000	0.000	0.999
4C2	Open Burning of Waste		N_2O	63.9	82.0	0.000	0.000	0.999
3C1e	Biomass burning in settlements		CH_4	11.2	1.6	0.000	0.000	0.999
3A1f	Enteric fermentation – horses		CH_4	102.1	122.0	0.000	0.000	0.999
3A2a	Manure management – cattle		CH_4	229.9	244.6	0.000	0.000	0.999
3A1h	Enteric fermentation – swine		CH_4	43.5	39.1	0.000	0.000	0.999
3C1d	Biomass burning in wetlands		N_2O	20.2	13.8	0.000	0.000	0.999
3A2h	Manure management – swine		N_2O	41.3	37.1	0.000	0.000	0.999
1A2	Manufacturing Industries and Construction	Solid	N_2O	94.3	95.8	0.000	0.000	1.000
3C1d	Biomass burning in wetlands		CH_4	15.0	10.2	0.000	0.000	1.000
1A2	Manufacturing Industries and Construction	Liquid	N_2O	6.4	12.3	0.000	0.000	1.000
4C2	Open Burning of Waste		CO_2	29.2	37.5	0.000	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	N_2O	5.6	10.5	0.000	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	CH_4	10.6	7.9	0.000	0.000	1.000
3A1g	Enteric fermentation - mules and asses		CH_4	34.4	34.2	0.000	0.000	1.000
1A4b	Residential	Liquid	N_2O	5.4	2.4	0.000	0.000	1.000
1A1a	Electricity and Heat Production	Liquid	N_2O	0.0	2.9	0.000	0.000	1.000
1A4a	Commercial/Institutional	Solid	CH_4	3.1	6.0	0.000	0.000	1.000
2C2	Ferroalloys Production		CH_4	3.3	1.1	0.000	0.000	1.000
1A3a	Civil Aviation	Liquid	N_2O	5.9	4.0	0.000	0.000	1.000
1A1a	Electricity and Heat Production	Solid	CH_4	40.4	46.7	0.000	0.000	1.000
1A1b	Petroleum Refining	Liquid	N_2O	3.6	2.2	0.000	0.000	1.000
1A2	Manufacturing Industries and Construction	Liquid	CH_4	2.2	4.2	0.000	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	CH_4	1.9	3.6	0.000	0.000	1.000
1A4b	Residential	Liquid	CH_4	2.0	1.0	0.000	0.000	1.000

IPCC Category code	IPCC Category	Fuel type	GHG	2000 Ex,t	2017 Ex,t	Tx,t	% contribution to trend	Cumulative Total
				(Gg CO_2 Eq)				
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	N_2O	1.9	1.0	0.000	0.000	1.000
1A5a	Stationary	Solid	CH_4	0.7	1.8	0.000	0.000	1.000
1A1a	Electricity and Heat Production	Liquid	CH_4	0.0	1.0	0.000	0.000	1.000
1A5a	Stationary	Liquid	N_2O	2.7	3.8	0.000	0.000	1.000
1A3a	Civil Aviation	Liquid	CH_4	2.0	1.3	0.000	0.000	1.000
1A2	Manufacturing Industries and Construction	Gas	N_2O	1.2	2.1	0.000	0.000	1.000
1A3d	Water-Borne Navigation	Liquid	N_2O	1.3	2.1	0.000	0.000	1.000
1A1b	Petroleum Refining	Liquid	CH_4	1.2	0.7	0.000	0.000	1.000
1A2	Manufacturing Industries and Construction	Gas	CH_4	0.8	1.4	0.000	0.000	1.000
1A4a	Commercial/Institutional	Liquid	N_2O	4.9	5.9	0.000	0.000	1.000
1A2	Manufacturing Industries and Construction	Solid	CH_4	4.3	4.3	0.000	0.000	1.000
3A2d	Manure management – goats		CH_4	1.0	0.8	0.000	0.000	1.000
1A5a	Stationary	Liquid	CH_4	0.9	1.3	0.000	0.000	1.000
3A2c	Manure management – sheep		CH_4	1.0	0.9	0.000	0.000	1.000
1A3c	Railways	Liquid	CH_4	0.6	0.5	0.000	0.000	1.000
1B1a	Coal mining and handling		CO_2	17.9	19.5	0.000	0.000	1.000
1A3d	Water-Borne Navigation	Liquid	CH_4	0.4	0.7	0.000	0.000	1.000
1A1b	Petroleum Refining	Gas	N_2O	1.2	1.2	0.000	0.000	1.000
1A4a	Commercial/Institutional	Liquid	CH_4	1.7	2.0	0.000	0.000	1.000
1A1b	Petroleum Refining	Gas	CH_4	0.8	0.8	0.000	0.000	1.000
1A3b	Road Transport	Gas	CH_4	0.1	0.0	0.000	0.000	1.000
1A4a	Commercial/Institutional	Gas	CO_2	27.5	30.4	0.000	0.000	1.000
1A3b	Road Transport	Gas	N_2O	0.0	0.0	0.000	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	CH_4	0.0	0.0	0.000	0.000	1.000
2B	Chemical industry		C	C	C	0.000	0.000	1.000
3A2f	Manure management – horses		CH_4	0.1	0.1	0.000	0.000	1.000

C=Confidential data

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 CO_2e	Gg CO_2e	(-)%	(+)%	(-)%	(+)%	(-)%	(+)%	(fraction)	%	%	%
1A1a	Electricity and Heat Production	CO_2	185 027.4	215 396.2	3	5	7	7	7.62	8.60	14.78	0.18	3.49	12.19
1A1b	Petroleum Refining	CO_2	4 042.6	3 328.0	3	5	7	7	7.62	8.60	0.00	0.02	0.05	0.00
1A1c	Manufacture of Solid Fuels and Other Energy Industries	CO_2	30 454.7	29 369.4	3	5	7	7	7.62	8.60	0.27	0.07	0.48	0.23
1A1a	Electricity and Heat Production	CH_4	40.4	47.7	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	7.9	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	1 037.7	3	5	75	75	75.06	75.17	0.03	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

IPCC Category		Gas	Base year emissions/ removals (2000)	Year t emissions/ removals (2017)	Activity data uncertainty		Emission factor/ estimation parameter uncertainty		Combined uncertainty		Contri-bution to variance in Year t	Uncertainty in trend in national emissions introduced by EF/ estimation parameter uncertainty	Uncertainty in trend in national emissions in-troduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
			Gg CO_2e	Gg CO_2e	(-)%	(+)%	(-)%	(+)%	(-)%	(+)%	(fraction)	%	%	%
1A1c	Manufacture of Solid Fuels and Other Energy Industries	N_2O	110.3	141.8	3	5	75	75	75.06	75.17	0.00	0.00	0.00	0.00
1A2	Manufacturing Industries and Construction	CO_2	24 304.3	28 645.3	5	10	7	7	8.60	12.21	0.53	0.03	0.93	0.86
1A2	Manufacturing Industries and Construction	CH_4	7.2	9.9	5	10	75	75	75.17	75.66	0.00	0.00	0.00	0.00
1A2	Manufacturing Industries and Construction	N_2O	101.9	110.3	5	10	75	75	75.17	75.66	0.00	0.00	0.00	0.00
1A3a	Civil Aviation	CO_2	2 249.1	1 522.1	5	5	1.5	1.5	5.22	5.22	0.00	0.00	0.02	0.00
1A3b	Road Transport	CO_2	37 155.7	51 277.1	5	5	2	2	5.39	5.39	0.33	0.05	0.83	0.69
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	222.2	355.7	5	5	3	3	5.83	5.83	0.00	0.00	0.01	0.00
1A3a	Civil Aviation	CH_4	2.0	1.3	5	5	70	50	70.18	50.25	0.00	0.00	0.00	0.00
1A3b	Road Transport	CH_4	249.3	249.4	5	5	9	9	10.30	10.30	0.00	0.00	0.00	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	0.4	0.7	5	5	50	50	50.25	50.25	0.00	0.00	0.00	0.00
1A3a	Civil Aviation	N_2O	5.9	4.0	5	5	70	50	70.18	50.25	0.00	0.00	0.00	0.00
1A3b	Road Transport	N_2O	558.9	791.9	5	5	70	72	70.18	72.17	0.01	0.03	0.01	0.00

IPCC Category		Gas	Base year emissions/ removals (2000)	Year t emissions/ removals (2017)	Activity data uncertainty		Emission factor/ estimation parameter uncertainty		Combined uncertainty		Contri-bution to variance in Year t	Uncertainty in trend in national emissions introduced by EF/ estimation parameter uncertainty	Uncertainty in trend in national emissions in-troduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
			Gg CO_2e	Gg CO_2e	(-)%	(+)%	(-)%	(+)%	(-)%	(+)%	(fraction)	%	%	%
1A3c	Railways	N_2O	66.0	47.0	5	5	70	72	70.18	72.17	0.00	0.00	0.00	0.00
1A3d	Water-Borne Navigation	N_2O	1.3	2.1	5	5	40	140	40.31	140.09	0.00	0.00	0.00	0.00
1A4a	Commercial/ Institutional	CO_2	16 455.3	29 930.4	5	10	7	7	8.60	12.21	0.57	0.19	0.97	0.97
1A4b	Residential	CO_2	6 473.1	3 352.4	5	10	7	7	8.60	12.21	0.01	0.06	0.11	0.02
1A4c	Agriculture/ Forestry/ Fishing/Fish Farms	CO_2	2 406.7	4 264.5	5	10	7	7	8.60	12.21	0.01	0.03	0.14	0.02
1A4a	Commercial/ Institutional	CH_4	4.8	8.0	5	10	75	75	75.17	75.66	0.00	0.00	0.00	0.00
1A4b	Residential	CH_4	200.5	56.0	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	144.1	271.4	5	10	75	75	75.17	75.66	0.00	0.02	0.01	0.00
1A4b	Residential	N_2O	429.4	124.6	5	10	75	75	75.17	75.66	0.00	0.06	0.00	0.00
1A4c	Agriculture/ Forestry/ Fishing/Fish Farms	N_2O	7.5	11.5	5	10	75	75	75.17	75.66	0.00	0.00	0.00	0.00
1A5a	Stationary	CO_2	4 237.1	9 679.4	3	5	7	7	7.62	8.60	0.03	0.08	0.16	0.03
1A5a	Stationary	CH_4	1.6	3.1	3	5	75	75	75.06	75.17	0.00	0.00	0.00	0.00
1A5a	Stationary	N_2O	18.3	43.6	3	5	75	75	75.06	75.17	0.00	0.00	0.00	0.00
1B1a	Coal mining and handling	CO_2	17.9	19.5	10	10	63	63	63.79	63.79	0.00	0.00	0.00	0.00

IPCC Category		Gas	Base year emissions/ removals (2000)	Year t emissions/ removals (2017)	Activity data uncertainty		Emission factor/ estimation parameter uncertainty		Combined uncertainty		Contri-bution to variance in Year t	Uncertainty in trend in national emissions introduced by EF/ estimation parameter uncertainty	Uncertainty in trend in national emissions in-troduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
			Gg CO_2e	Gg CO_2e	(-)%	(+)%	(-)%	(+)%	(-)%	(+)%	(fraction)	%	%	%
1B1a	Coal mining and handling	CH_4	1 421.0	1 551.4	10	10	63	63	63.79	63.79	0.04	0.00	0.05	0.00
1B2a	Oil	CO_2	752.0	641.8	25	25	75	75	79.06	79.06	0.01	0.03	0.05	0.00
1B3	Other Emissions from Energy Production	CO_2	28 146.6	25 746.5	25	25	75	75	79.06	79.06	17.83	0.91	2.08	5.18
1B3	Other Emissions from Energy Production	CH_4	2 318.6	2 183.9	25	25	75	75	79.06	79.06	0.13	0.06	0.18	0.04
2A1	Cement Production	CO_2	3 870.6	5 246.4	30	30	4.5	4.5	30.34	30.34	0.11	0.01	0.51	0.26
2A2	Lime Production	CO_2	434.1	890.0	30	30	6	6	30.59	30.59	0.00	0.01	0.09	0.01
2A3	Glass Production	CO_2	74.4	120.9	5	5	60	60	60.21	60.21	0.00	0.01	0.00	0.00
2B1	Ammonia Production	CO_2	485.3	241.4	5	5	6	6	7.81	7.81	0.00	0.00	0.00	0.00
2B1	Ammonia Production	CH_4	65.6	167.2	5	5	6	6	7.81	7.81	0.00	0.00	0.00	0.00
2B3	Nitric Acid Production	N_2O	1 644.5	292.6	2	2	10	10	10.20	10.20	0.00	0.03	0.00	0.00
2B5	Carbide Production	CO_2	2.0	69.7	5	5	10	10	11.18	11.18	0.00	0.00	0.00	0.00
2B6	Titanium Dioxide Production	CO_2	437.6	0.3	5	5	10	10	11.18	11.18	0.00	0.01	0.00	0.00

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			Gg CO_2e	Gg CO_2e	(-)%	(+)%	(-)%	(+)%	(-)%	(+)%	(fraction)	%	%	%
2B8	Petrochemical and Carbon Black Production	CO_2	138.6	122.2	10	10	85	85	85.59	85.59	0.00	0.01	0.00	0.00
2B8	Petrochemical and Carbon Black Production	CH_4	0.1	0.1	10	10	85	85	85.59	85.59	0.00	0.00	0.00	0.00
2C1	Iron and Steel Production	CO_2	15 334.4	7 725.0	5	5	10	10	11.18	11.18	0.03	0.21	0.13	0.06
2C2	Ferroalloys Production	CO_2	8 079.1	11 328.4	5	5	10	10	11.18	11.18	0.07	0.06	0.18	0.04
2C2	Ferroalloys Production	CH_4	3.3	1.1	5	5	25	25	25.50	25.50	0.00	0.00	0.00	0.00
2C3	Aluminium Production	CO_2	1 091.3	1 143.1	5	5	10	10	11.18	11.18	0.00	0.00	0.02	0.00
2C3	Aluminium Production	PFCs	983.2	113.1	5	5	24	24	24.52	24.52	0.00	0.05	0.00	0.00
2C5	Lead Production	CO_2	39.2	25.0	5	5	15	15	15.81	15.81	0.00	0.00	0.00	0.00
2C6	Zinc Production	CO_2	108.4	52.9	10	10	50	50	50.99	50.99	0.00	0.01	0.00	0.00
2D1	Lubricant Use	CO_2	188.5	424.5	10	10	50	50	50.99	50.99	0.00	0.02	0.01	0.00
2D2	Paraffin Wax Use	CO_2	7.4	106.2	10	10	50	50	50.99	50.99	0.00	0.01	0.00	0.00
2F1	Refrigeration and Air Conditioning	HFCs	0.0	3 963.5	25	25	25	25	35.36	35.36	0.08	0.23	0.32	0.15

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			Gg CO_2e	Gg CO_2e	(-)%	(+)%	(-)%	(+)%	(-)%	(+)%	(fraction)	%	%	%
2F2	Foam Blowing Agents	HFCs	0.0	0.0	25	25	25	25	35.36	35.36	0.00	0.00	0.00	0.00
2F3	Fire Protection	HFCs	0.0	51.1	25	25	25	25	35.36	35.36	0.00	0.00	0.00	0.00
2F4	Aerosols	HFCs	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	21 502.9	19 764.6	5.1	20.6	20	20	20.64	28.72	1.39	0.18	1.32	1.77
3A1c	Enteric fermentation - sheep	CH_4	3 800.5	3 214.6	11.2	20.6	20	20	22.91	28.72	0.04	0.04	0.21	0.05
3A1d	Enteric fermentation - goats	CH_4	906.2	709.2	11.2	20.6	20	20	22.91	28.72	0.00	0.01	0.05	0.00
3A1f	Enteric fermentation - horses	CH_4	102.1	122.0	11.2	11.1	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	11.1	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	20.6	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

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			Gg CO_2e	Gg CO_2e	(-)%	(+)%	(-)%	(+)%	(-)%	(+)%	(fraction)	%	%	%
3A2a	Manure management - cattle	CH_4	229.9	244.6	15.8	28.7	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	21.2	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	21.2	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	12.2	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	11.3	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	18.7	20	20	27.39	27.39	0.00	0.00	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	775.0	826.1	52.7	57.8	25	50	58.32	76.49	0.02	0.00	0.15	0.02

IPCC Category		Gas	Base year emissions/ removals (2000)	Year t emissions/ removals (2017)	Activity data uncertainty		Emission factor/ estimation parameter uncertainty		Combined uncertainty		Contri-bution to variance in Year t	Uncertainty in trend in national emissions introduced by EF/ estimation parameter uncertainty	Uncertainty in trend in national emissions in-troduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
			Gg CO_2e	Gg CO_2e	(-)%	(+)%	(-)%	(+)%	(-)%	(+)%	(fraction)	%	%	%
3A2c	Manure management - sheep	N_2O	122.5	103.6	51.7	54.5	25	50	57.45	73.99	0.00	0.00	0.02	0.00
3A2d	Manure management - goats	N_2O	46.4	36.3	51.7	54.5	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	32.7	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	32.7	25	50	37.42	59.79	0.01	0.01	0.07	0.00
3B1a	Forest land remaining forest land - Net CO_2	CO_2	-4 709.1	-22 249.8	18	18.0	25	25	30.82	30.82	2.02	0.98	1.30	2.64
3B1b	Land converted to forest land - Net CO_2	CO_2	-6 886.1	-7 367.1	21.2	21.2	30	30	36.74	36.74	0.32	0.02	0.51	0.26
3B2a	Cropland remaining cropland - Net CO_2	CO_2	-951.6	-1 175.2	12.8	12.8	20	20	23.75	23.75	0.00	0.01	0.05	0.00
3B2b	Land converted to cropland - Net CO_2	CO_2	2 772.3	2 756.0	15.6	15.6	30	30	33.82	33.82	0.04	0.02	0.14	0.02

IPCC Category		Gas	Base year emissions/ removals (2000)	Year t emissions/ removals (2017)	Activity data uncertainty		Emission factor/ estimation parameter uncertainty		Combined uncertainty		Contri-bution to variance in Year t	Uncertainty in trend in national emissions introduced by EF/ estimation parameter uncertainty	Uncertainty in trend in national emissions in-troduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
			Gg CO_2e	Gg CO_2e	(-)%	(+)%	(-)%	(+)%	(-)%	(+)%	(fraction)	%	%	%
3B3a	Grassland remaining grassland - Net CO_2	CO_2	2 593.3	3 306.2	14.1	14.1	25	25	28.72	28.72	0.04	0.03	0.15	0.02
3B3b	Land converted to grassland - Net CO_2	CO_2	-18 957.0	-18 920.1	18	18.0	30	30	35.00	35.00	1.89	0.14	1.10	1.24
3B4a	Wetland remaining wetland	CO_2	0.0	0.0	11.2	11.1	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	14.1	30	30	33.17	33.17	0.00	0.00	0.00	0.00
3B4	Wetland	CH_4	666.6	666.6	11.2	11.1	20	20	22.91	22.91	0.00	0.00	0.02	0.00
3B5a	Settlements remaining settlements - Net CO_2	CO_2	-246.7	-687.5	14.1	14.1	30	30	33.17	33.17	0.00	0.03	0.03	0.00
3B5b	Land converted to settlements - Net CO_2	CO_2	355.0	290.4	14.1	14.1	30	30	33.17	33.17	0.00	0.01	0.01	0.00
3B6b	Land converted to other lands - Net CO_2	CO_2	13 512.9	13 512.9	18	18.0	30	30	35.00	35.00	0.96	0.10	0.79	0.63

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			Gg CO_2e	Gg CO_2e	(-)%	(+)%	(-)%	(+)%	(-)%	(+)%	(fraction)	%	%	%
3C1a	Biomass burning in forest land	CH_4	348.0	145.0	40.6	40.6	40	40	57.01	57.01	0.00	0.02	0.02	0.00
3C1b	Biomass burning in croplands	CH_4	220.7	57.2	21.2	21.2	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	75.8	40	40	85.73	85.73	0.00	0.03	0.05	0.00
3C1d	Biomass burning in wetlands	CH_4	15.0	10.2	75.2	75.1	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	40.3	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	11.1	40	40	41.53	41.53	0.00	0.00	0.00	0.00
3C1a	Biomass burning in forest land	N_2O	350.2	129.1	40.3	40.3	27	27	48.52	48.52	0.00	0.02	0.02	0.00
3C1b	Biomass burning in croplands	N_2O	84.5	21.9	20.6	20.6	27	27	33.97	33.97	0.00	0.00	0.00	0.00
3C1c	Biomass burning in grasslands	N_2O	668.6	241.8	75.2	75.1	48	48	89.19	89.19	0.00	0.05	0.06	0.01

IPCC Category		Gas	Base year emissions/ removals (2000)	Year t emissions/ removals (2017)	Activity data uncertainty		Emission factor/ estimation parameter uncertainty		Combined uncertainty		Contri-bution to variance in Year t	Uncertainty in trend in national emissions introduced by EF/ estimation parameter uncertainty	Uncertainty in trend in national emissions in-troduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
			Gg CO_2e	Gg CO_2e	(-)%	(+)%	(-)%	(+)%	(-)%	(+)%	(fraction)	%	%	%
3C1d	Biomass burning in wetlands	N_2O	20.2	13.8	75.2	75.1	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	40.3	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	11.1	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	0.05	0.09	0.30	0.10
3C3	Urea application	CO_2	297.3	679.6	10	10	50	50	50.99	50.99	0.01	0.04	0.02	0.00
3C4	Direct N_2O emissions from managed soils	N_2O	18 955.0	17 049.1	15	53.8	70	200	71.59	207.11	53.67	1.77	2.97	11.97
3C5	Indirect N_2O emissions from managed soils	N_2O	2 342.4	2 126.3	15	200	80	400	81.39	447.47	3.90	0.42	1.38	2.08
3C6	Indirect N_2O emissions from manure management	N_2O	404.1	464.9	23.5	115	80	400	83.39	416.35	0.16	0.02	0.17	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	5.32	0.53	2.81	8.18

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			Gg CO_2e	Gg CO_2e	(-)%	(+)%	(-)%	(+)%	(-)%	(+)%	(fraction)	%	%	%
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	0.01	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	0.13	0.04	0.45	0.20
4D1	Wastewater Treatment and Discharge	N_2O	599.3	769.6	50	50	90	90	102.96	102.96	0.03	0.02	0.12	0.02

	436 733.5	482 016.3							104.89			50.04
								Uncer-tainty in total inven-tory	10.24		Trend uncertainty	7.07

C=Confidential data

CHAPTER 1: REFERENCES

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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 (IPPU), 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 this report).

2000 - 2017

South Africa's GHG emissions excluding FOLU were 448 874 Gg CO_2e in 2000 and these increased by 14.2% by 2017 (Table 2.1). Emissions (excl. FOLU) in 2017 were estimated at 512 661 Gg CO_2e. Emissions increased slowly between 2000 and 2009 and then started to stabilise. Emissions declined in 2011 but increased again and reached 528 816 Gg CO_2e in 2013. Emissions declined in 2016 and 2017 (Figure 2.1).

The annual change data shows that the number of years with a decrease has increased since 2009 (Table 2.2), and the number of years with consecutive decreases has also increase. The annual average growth rate was 2.0% between 2000 and 2009, however between 2009 and 2017 there is an average annual decline of 0.5%. This shows that the emissions are stabilising and even moving towards a declining trend.

2015 - 2017

Emissions (excl. FOLU) decreased by 2.8% (14 640 Gg CO_2e) between 2015 and 2017 (Table 2.1). The decrease is due to a 0.8%, 22.0%, and 6.1% decline in the *Energy*, *IPPU*, and *AFOLU* sectors, respectively, over this period. It should be noted that the decline in the IPUU sector may not be a true decline in emissions as there are some inconsistencies in the time-series for several categories (details provided in chapter 4). The *Waste* sector was the only sector to show an increase between 2015 and 2017.

2017

The *Energy* sector was the largest contributor to South Africa's gross emissions (excl. FOLU) in 2017, comprising 80.1% of total emissions. This was followed by the *AFOLU* sector (excl. FOLU) (9.5%), *IPPU* sector (6.3%) and the *Waste* sector (4.1%).

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)	448 874.2	527 301.0	512 660.6	63 786.4	14.2	-14 640.4	-2.8
Emissions (incl. FOLU)	436 733.5	504 157.9	482 016.3	45 282.8	10.4	-22 141.5	-4.4

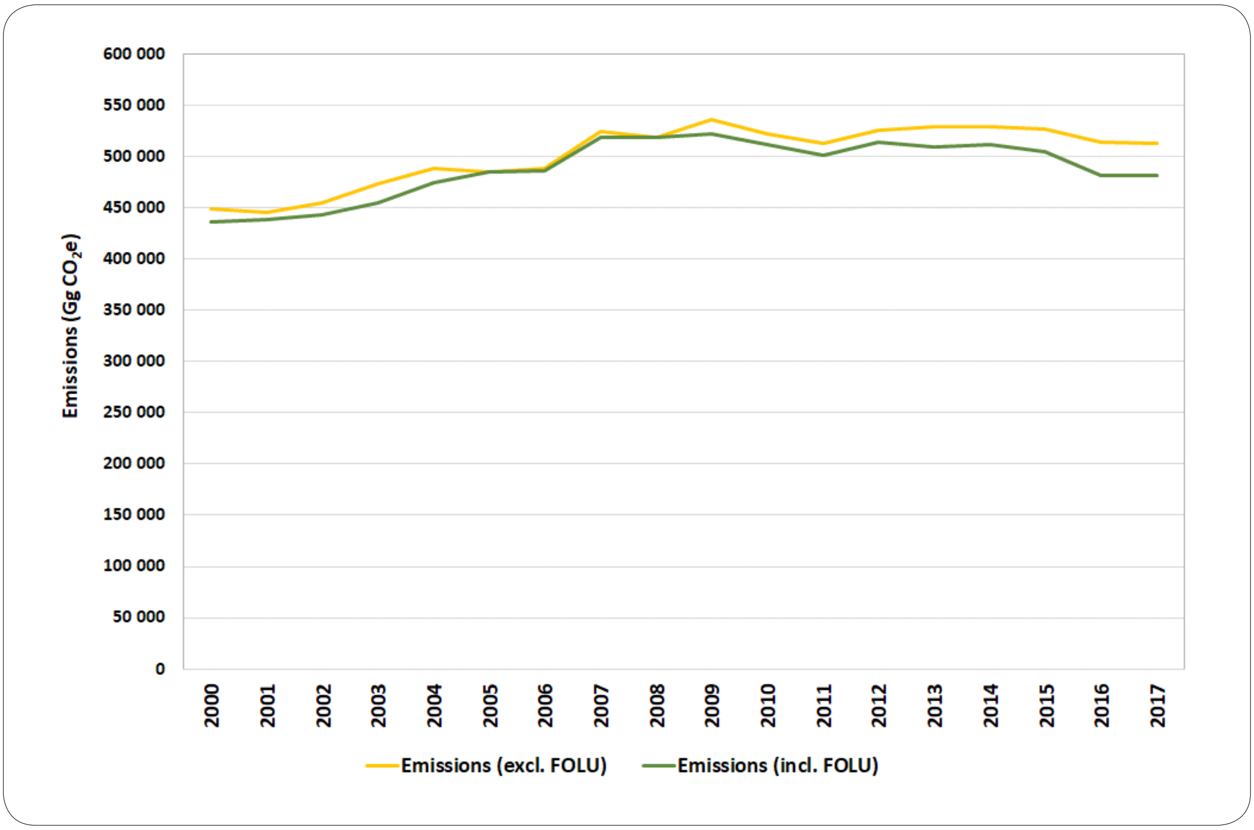

Figure 2.1: National GHG emissions (excl. and incl. FOLU) for South Africa, 2000 – 2017.

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

	Emissions (excl. FOLU)		Emissions (incl. FOLU)	
	$Gg CO_2e$	Annual change (%)	$Gg CO_2e$	Annual change (%)
2000	448 874.2		436 733.5	
2001	445 277.9	-0.80	438 848.1	0.48
2002	454 992.6	2.18	443 108.2	0.97
2003	473 489.0	4.07	455 301.9	2.75
2004	488 144.5	3.10	474 931.1	4.31
2005	484 911.5	-0.66	485 400.6	2.20
2006	488 884.2	0.82	485 942.0	0.11
2007	524 645.6	7.31	518 721.0	6.75
2008	518 453.4	-1.18	518 465.8	-0.05
2009	535 887.6	3.36	522 296.3	0.74

	Emissions (excl. FOLU)		Emissions (incl. FOLU)	
	Gg CO_2e	Annual change (%)	Gg CO_2e	Annual change (%)
2010	521 839.2	-2.62	511 202.8	-2.12
2011	512 928.2	-1.71	501 602.8	-1.88
2012	525 788.3	2.51	514 400.3	2.55
2013	528 816.2	0.58	509 388.1	-0.97
2014	528 548.1	-0.05	511 236.9	0.36
2015	527 301.0	-0.24	504 157.9	-1.38
2016	514 498.8	-2.43	481 464.3	-4.50
2017	512 660.6	-0.36	482 016.3	0.11

Net emissions (incl. FOLU)

Net emissions include all emissions (sources and sinks) from all sectors (i.e. *Energy*, *IPPU*, *AFOLU* and *Waste*).

2000 - 2017

South Africa's GHG emissions (incl. FOLU) were 436 734 Gg CO_2e in 2000 and these increased by 10.4% (45 282 Gg CO_2e) by 2017 (Table 2.1). Emissions (incl. FOLU) in 2017 were estimated at 482 016 Gg CO_2e. The emissions including FOLU followed the same trend as the emissions excluding FOLU but with 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 2009 after which there was a decline to 2017 (Table 22) . Between 2000 and 2017 the average annual growth was 0.6%, however the average annual growth rate between 2000 and 2009 was 2.3% and between 2009 and 2017 there was an average annual decline of 1.0%.

2015 – 2017

Emissions (incl. FOLU) decreased by 4.4% since the last inventory submission (Table 2.1). The reduction was greater than for emissions (excl. FOLU) because of an increased *Land* sink in the more recent years. The increasing sink can be attributed to a decline in the fuelwood and disturbance losses and an increase in woody land area.

2017

The *Energy* sector was the largest contributor to South Africa's net emissions in 2017, comprising 85.2% of total net emissions. This was followed by the *IPPU* sector (6.7%), *Waste* sector (4.4%) and *AFOLU* sector (3.7%).

INDICATOR TRENDS

2.2

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 9.9 t CO_2e in 2000 and this increased to a maximum of 10.8 t CO_2e in 2007, after which it declined again to 8.5 t CO_2e per capita by 2017 (Figure 2.2). The carbon intensity of the economy (i.e. emissions per million Rand of GDP) has declined by 31.2% 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.

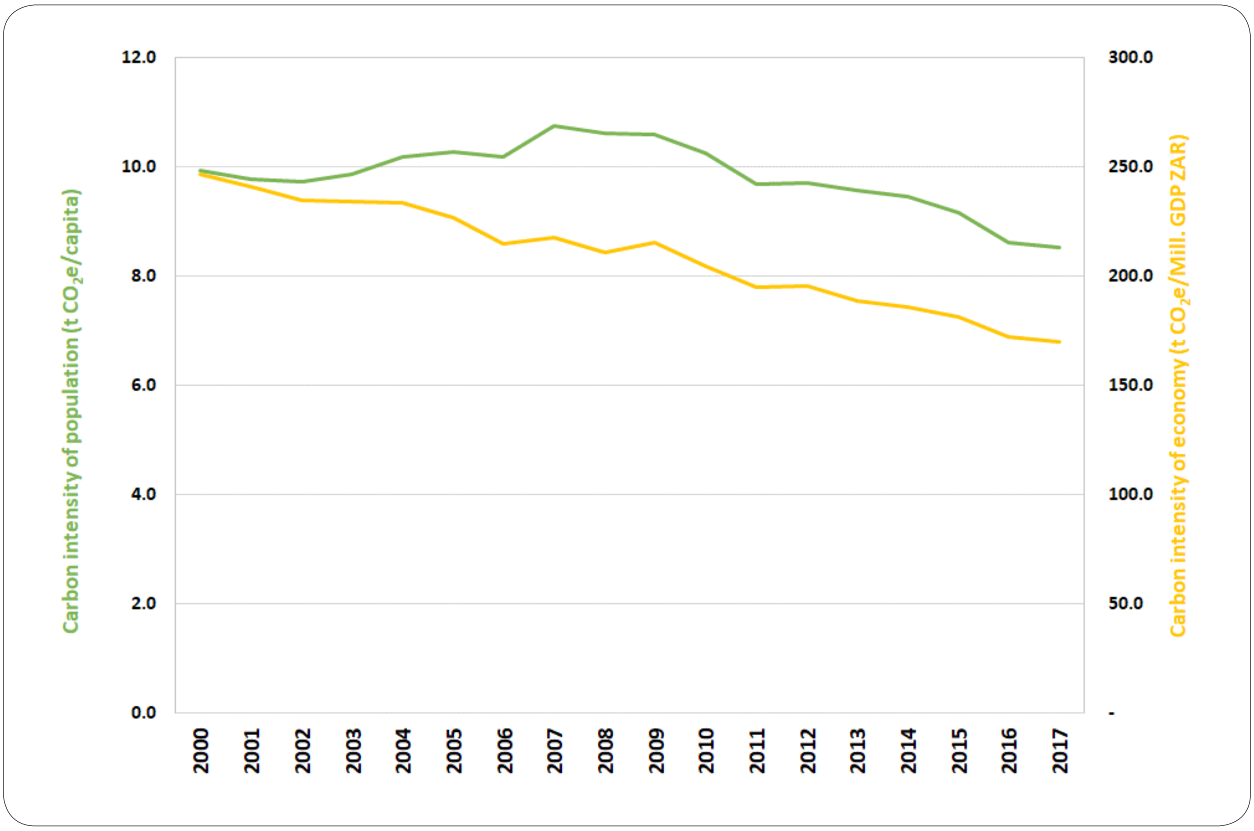

Figure 2.2: Trends in overall carbon intensity of the population and of the economy of South Africa between 2000 and 2017.

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

2.2.2 Energy emission indicators

The energy carbon intensity of the population (i.e. energy sector emissions per capita) increased significantly (12.1%) between 2001 and 2007, stabilised until 2009 and then showed a decline (16.5%) between 2009 and 2017 (Figure 2.3). Energy emissions per capita accounted for 79.9% of the total emissions (incl. FOLU) per capita in 2000 and this increased to 85.2% 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.

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, shows a declining trend between 2000 and 2017 and declines by 19.5% over the 17 year period (Figure 2.3). The energy intensity of the population (TPES per person) has increased by 13.9% between 2000 and 2017.

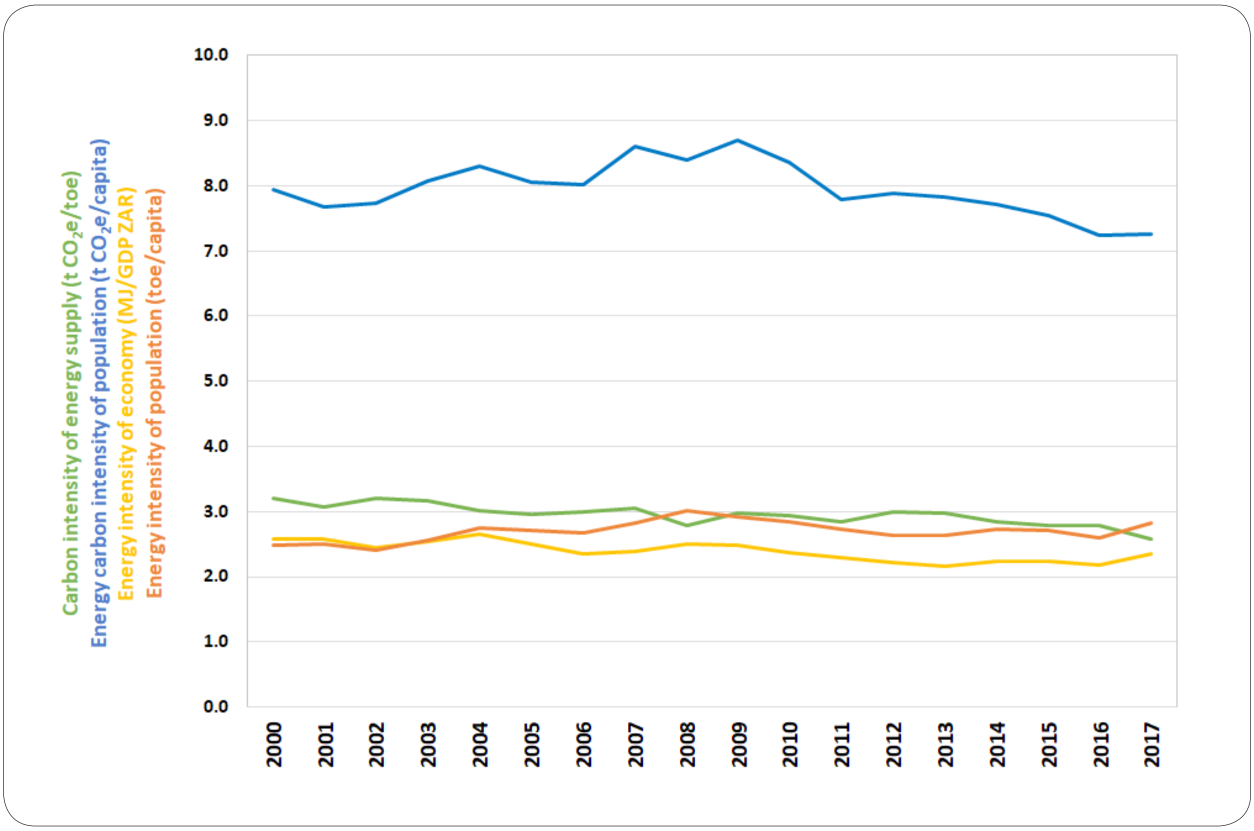

Figure 2.3: Trends in energy intensity indicators for South Africa between 2000 and 2017.

The energy intensity of the economy, which is TPES MJ per unit GDP, has declined between 2000 and 2017 (8.9%). 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.

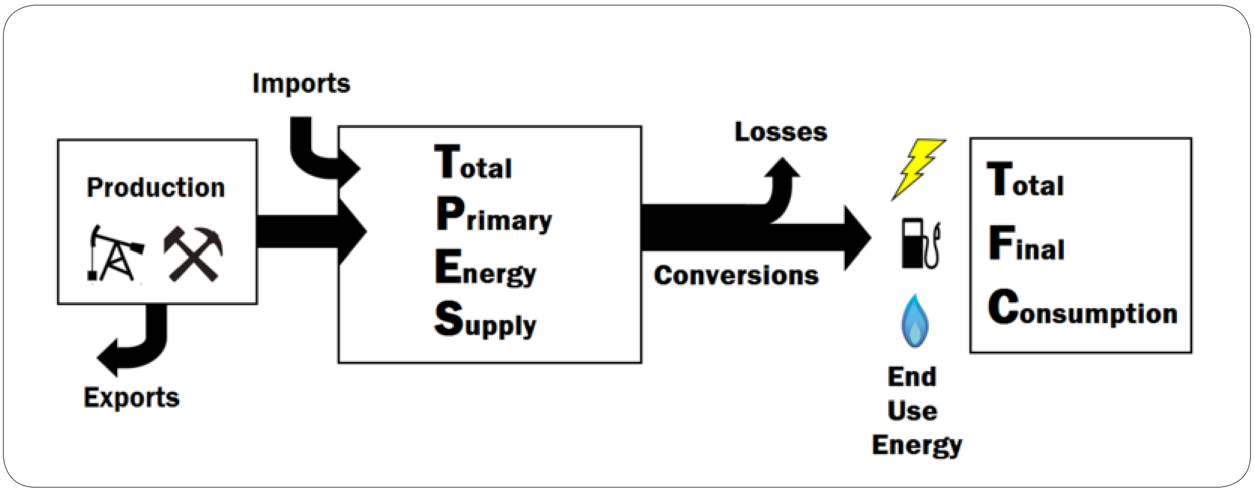

Figure 2.4: Energy flow diagram illustrating the difference between TPES and TFC.

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 1.0%.

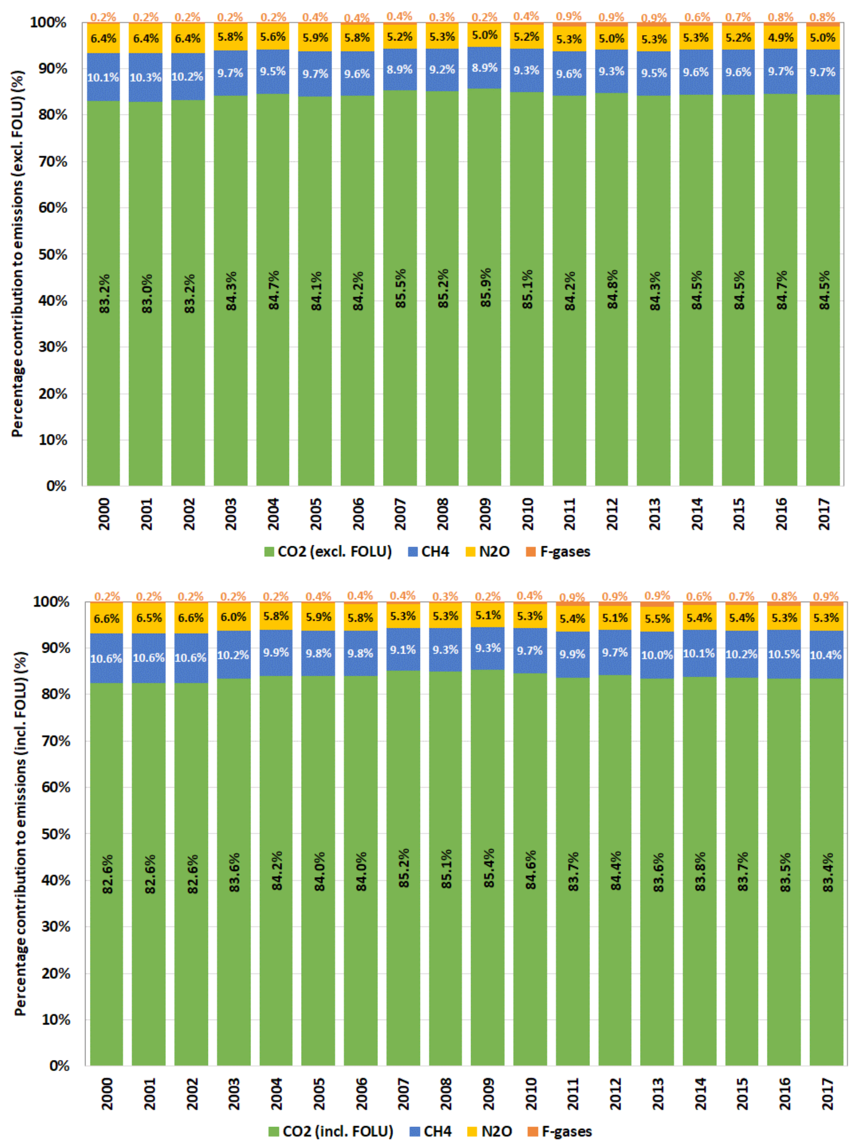

Figure 2.5: Percentage contributions from each of the gases to South Africa's emissions (excl. FOLU (top) and incl. FOLU (bottom)) between 2000 and 2017.

Carbon dioxide

The CO_2 emissions totalled 433 406 Gg CO_2 (excl. FOLU) and 402 095 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 91.7% between 2000 and 2017, and 93.2% in 2017. The categories *1A1 energy industries* (61.4%), *1A3 Transport* (13.3%) and *1A4 Other sectors* (9.3%) were the major contributors to the *Energy* CO_2 emissions in 2017. The *IPPU* sector contributed an average of 8.0% 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 (excl. FOLU) increased from 45 452 Gg CO_2e (2 164 Gg CH_4) in 2000 to 49 700 Gg CO_2e (2 367 Gg CH_4) in 2017 (Table 2.3). In the *Land* sector wetlands contributed an additional 667 Gg CO_2e (31.7 Gg CH_4) to

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 (excl. FOLU)		CH_4 (incl. FOLU)		N_2O		F-gases
	Gg CO_2		Gg CO_2e	Gg CH_4	Gg CO_2e	Gg CH_4	Gg CO_2e	Gg N_2O	Gg CO_2e
2000	373 497.4	360 690.0	45 451.9	2 164.4	46 118.5	2 196.1	28 941.8	93.4	983.2
2001	369 587.6	362 491.2	46 009.3	2 190.9	46 675.9	2 222.7	28 673.3	92.5	1 007.7
2002	378 606.8	366 055.9	46 284.3	2 204.0	46 950.9	2 235.8	29 204.4	94.2	897.1
2003	399 290.4	380 436.7	45 831.5	2 182.5	46 498.1	2 214.2	27 470.9	88.6	896.2
2004	413 542.6	399 662.6	46 149.1	2 197.6	46 815.7	2 229.3	27 563.4	88.9	889.4
2005	407 914.3	407 736.8	46 832.4	2 230.1	47 499.0	2 261.9	28 451.4	91.8	1 713.4
2006	411 672.8	408 064.0	46 835.0	2 230.2	47 501.6	2 262.0	28 395.6	91.6	1 980.9
2007	448 544.0	441 952.7	46 715.5	2 224.5	47 382.1	2 256.3	27 352.1	88.2	2 034.1
2008	441 813.2	441 159.0	47 661.7	2 269.6	48 328.3	2 301.3	27 404.9	88.4	1 573.6
2009	460 193.3	445 935.5	47 765.5	2 274.5	48 432.1	2 306.3	26 828.5	86.5	1 100.3
2010	443 953.6	432 650.7	48 767.8	2 322.3	49 434.5	2 354.0	26 914.0	86.8	2 203.7
2011	432 081.0	420 088.9	49 182.6	2 342.0	49 849.2	2 373.8	26 979.4	87.0	4 685.2
2012	445 974.7	433 920.1	48 989.2	2 332.8	49 655.8	2 364.6	26 317.6	84.9	4 506.8
2013	445 848.3	425 753.6	50 264.5	2 393.5	50 931.2	2 425.3	27 871.6	89.9	4 831.7
2014	446 620.7	428 642.8	50 819.0	2 420.0	51 485.6	2 451.7	27 820.2	89.7	3 288.2
2015	445 562.7	421 752.9	50 782.7	2 418.2	51 449.3	2 450.0	27 252.9	87.9	3 702.7
2016	435 579.7	401 878.6	49 655.1	2 364.5	50 321.7	2 396.3	25 398.6	81.9	3 865.4
2017	433 406.2	402 095.3	49 700.0	2 366.7	50 366.6	2 398.4	25 426.8	82.0	4 127.7

the total CH_4, pushing the total CH_4 (incl. FOLU) to 50 367 Gg CO_2e. The *AFOLU livestock* category and *Waste* sectors were the major contributors, providing 50.4% and 41.0%, respectively, to the total CH_4 emissions in 2017.

The contribution from *livestock* declined by 11.8% (due to a decline in livestock populations), while the contribution from the *Waste* sector increased by 12.7% over the period 2000 to 2017.

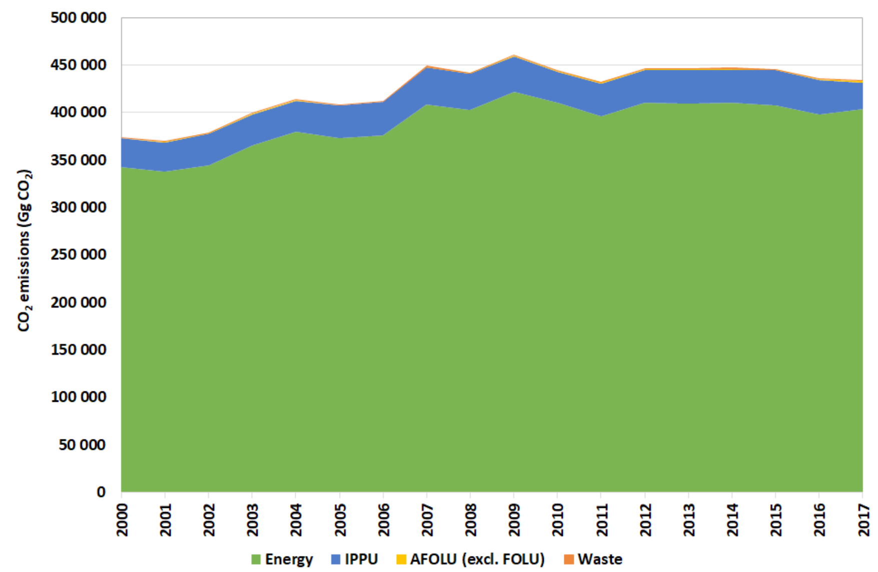

Figure 2.6: Trend and sectoral contribution to CO_2 emissions (excl. FOLU), 2000 – 2017.

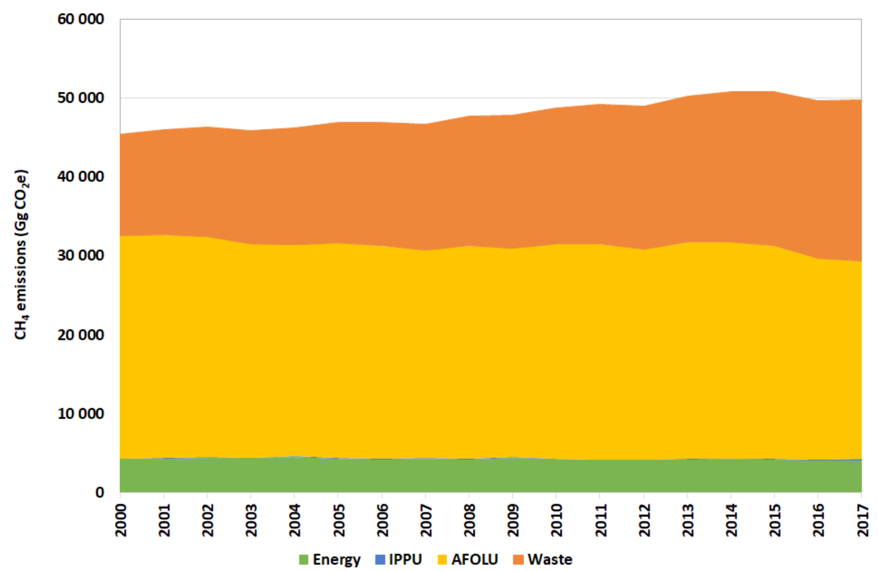

Figure 2.7: Trend and sectoral contribution to the CH4 emissions, 2000 – 2017.

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 12.1% over the 2000 to 2017 period from 28 942 Gg CO2e (93 Gg N_2O) to 25 427 Gg CO_2e (82 Gg N_2O) (Table 2.3). The main contributors are the *AFOLU* (85.3%) and *Energy* (10.2%) 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.

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) and contributed 0.8% to overall emissions (excl. FOLU) 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

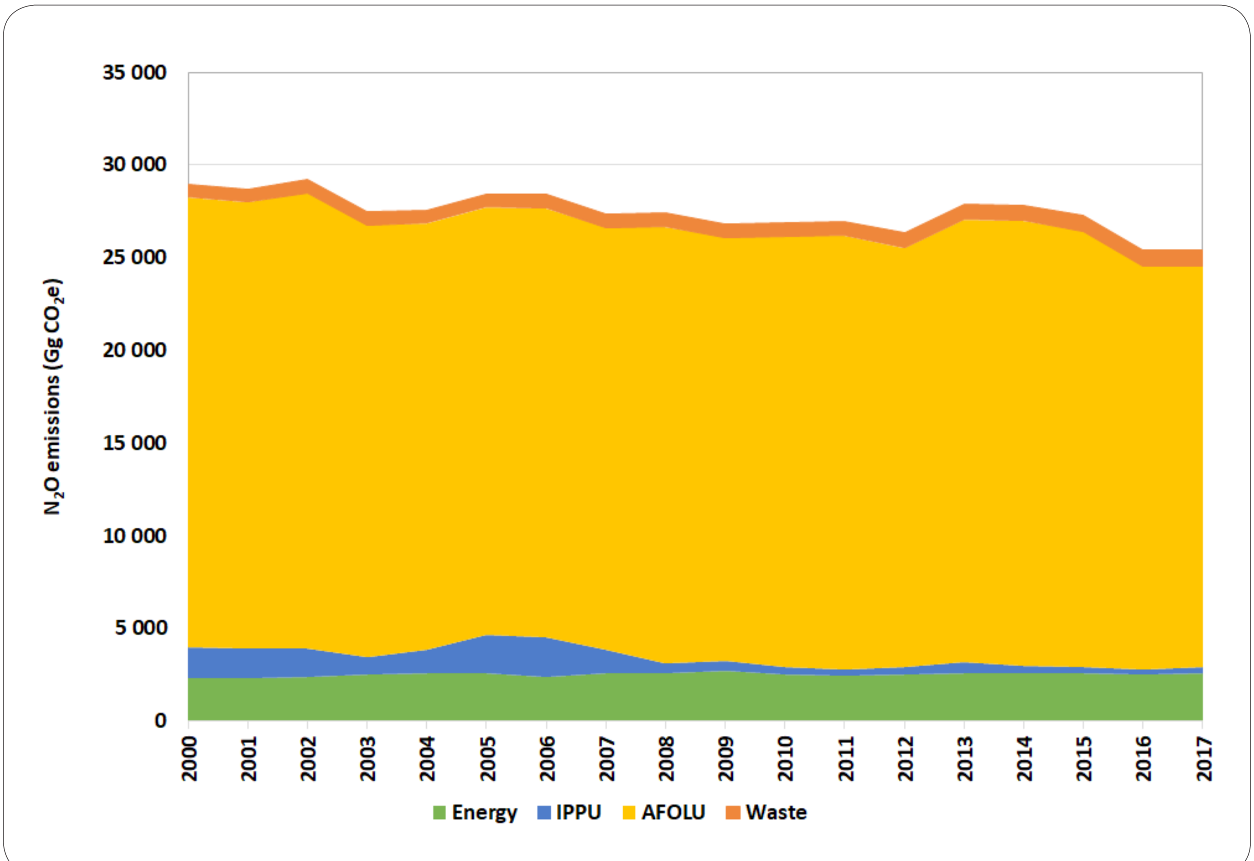

Figure 2.8: Trend and sectoral contribution to N_2O emissions in South Africa, 2000 – 2017.

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 1 979 Gg CO_2e in 2012, then declined to 113 Gg CO_2e in 2017. PFCs are produced during the production of aluminium. The Aluminium production data was updated for the years 2014 onwards and the updated data was an order of magnitude lower than the previous years. This is causing the decline in the PFC emissions. This inconsistency in the time-series will be investigated further in the 2019 inventory. There is a sharp decline in emissions from the *Metal industry* between 2007 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. CF_4 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).

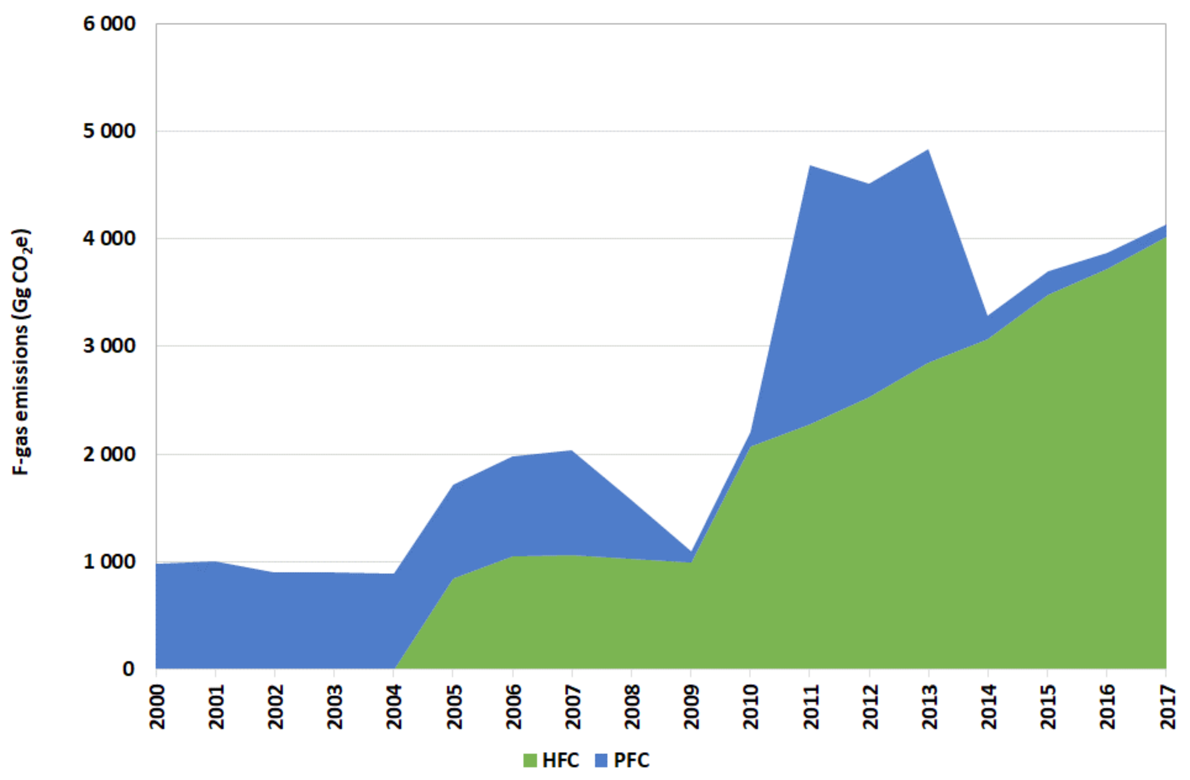

Figure 2.9: Trend in F-gas emissions in South Africa, 2000 – 2017.

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	NE	NE	NE	NE	NE	NE	NE	NE
2001	0.136	0.013	NE	NE	NE	NE	NE	NE	NE	NE
2002	0.122	0.012	NE	NE	NE	NE	NE	NE	NE	NE
2003	0.122	0.012	NE	NE	NE	NE	NE	NE	NE	NE
2004	0.121	0.011	NE	NE	NE	NE	NE	NE	NE	NE
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	0.267	0.027	0.000	0.014	0.066	1.730	0.000	0.099	0.011	0.001
2014	0.029	0.004	0.000	0.020	0.088	1.786	0.000	0.117	0.012	0.000
2015	0.029	0.004	0.000	0.027	0.111	1.935	0.000	0.156	0.015	0.001
2016	0.020	0.002	0.000	0.031	0.126	2.046	0.000	0.171	0.016	0.001
2017	0.015	0.002	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 (NO_x) 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.

	NO_x	CO	NMVOC
	(Gg)		
2000	68.1	1 479.4	70.1
2001	80.0	1 710.6	83.5
2002	79.1	1 722.5	82.8
2003	59.6	1 338.1	66.6
2004	54.3	1 178.6	57.1
2005	86.8	1 895.5	89.1
2006	76.7	1 672.3	75.9
2007	70.2	1 596.3	82.7
2008	69.1	1 507.8	75.9
2009	65.6	1 436.8	70.1
2010	65.6	1 462.9	73.6
2011	64.8	1 442.8	73.1
2012	56.3	1 295.2	71.7
2013	57.3	1 254.4	63.6
2014	59.3	1 331.1	69.6
2015	42.5	957.8	51.9
2016	23.4	562.5	33.9
2017	22.3	528.8	31.1

EMISSION TRENDS BY SECTOR

2.5

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 80.8% 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.

Fuel combustion activities contribute an average of 92.2% to the total energy emission between 2000 and 2017. *Energy industries* contribute an average of 65.2% to the *Fuel combustion activity* emissions, and an average of 63.8% to the total energy emissions between 2000 and 2017. *Transport* and *Other sectors* contributed 54 695 Gg CO_2e (13.3%) and 38 022 Gg CO_2e (9.3%) to the total energy emissions in 2017, and these are up from 41 063 Gg CO_2e and 26 123 Gg CO_2e in 2000, respectively.

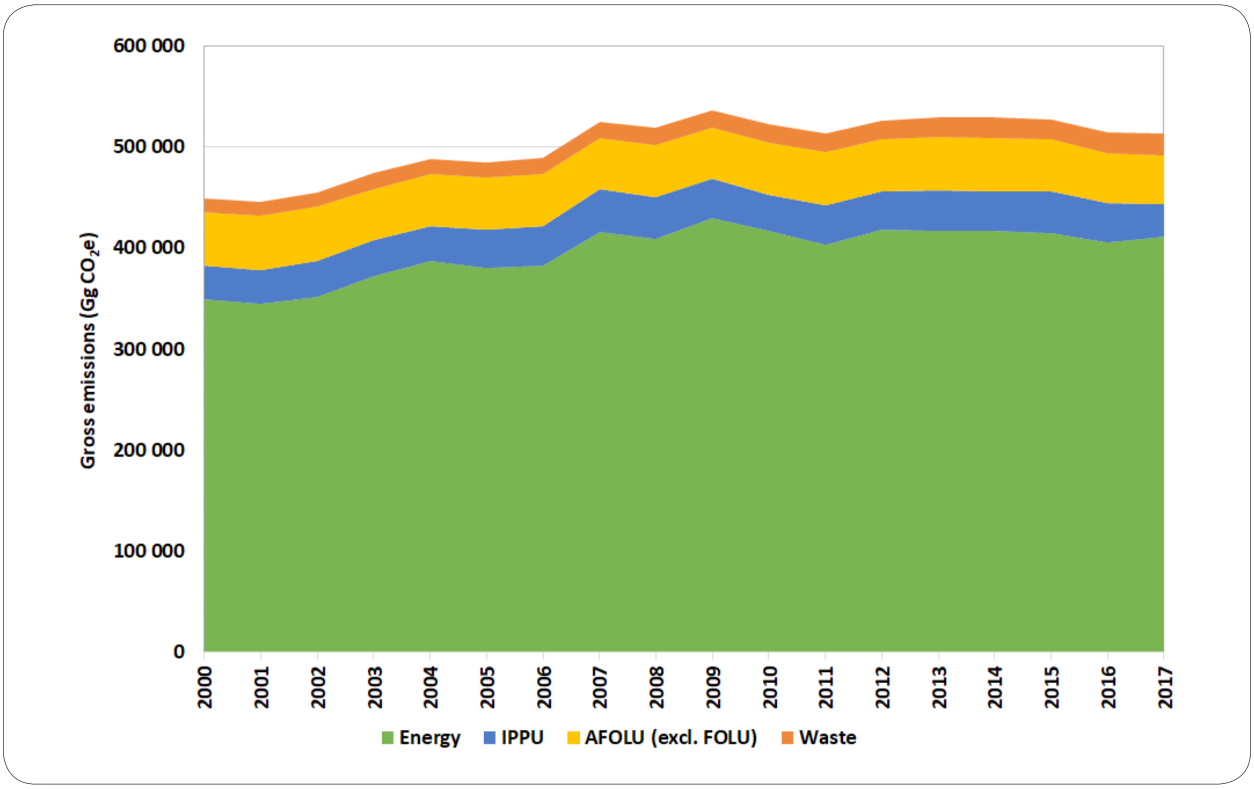

Figure 2.10: Sectoral contribution to the trend in the emissions (excl. FOLU) for South Africa, 2000 – 2017.

IPPU

The *IPPU* sector contributed an average of 7.0% to the total emissions (excl. FOLU) between 2000 and 2017 (Figure 2.11). In 2017 the IPPU contribution was 32 085 Gg CO_2e (Table 2.6). Emissions increased between 2000 and 2007 when it reached a peak of 42 512 Gg CO_2e. This was followed by a decline to 35 468 Gg CO_2e in 2010, and this dip is expected as the economy was going through a recession during this time. Emissions increased slightly in 2011 and then stabilised until 2016. In 2017 emissions are seen to decline to 2000 levels in 2017, however this decline is partly due to a change in data source (between 2015 and 2017) for several categories and therefore may not be a true decline in emissions. Data will be sought in the next inventory to improve this time-series inconsistency.

The main drivers in the *IPPU* sector are the metal industries, particularly *Iron and steel production* and *Ferroalloy production* which contributed 24.1% and 35.3% respectively to the total IPPU emissions in 2017. In addition, the HFC and PFC emissions should be monitored closely since HFC emissions have increased from 842 Gg CO_2e in 2005 to 4 015 Gg CO_2e in 2017. PFC emissions did, however, 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 9.9% to the total emissions (excl. FOLU) between 2000 and 2017 (Figure 2.11). The contribution has declined by 1.8% 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 emission categories.

The *AFOLU* sector produced 48 642 Gg CO_2e (excl. FOLU) in 2017, while the emissions including FOLU were 17 998 Gg CO_2e (Table 2.6). This change is due to the increasing *Land* sink, which strengthened between 2009 and 2017. The sink increase 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 constant, with *Land converted to grasslands* contributing the largest portion to this category. *Other lands* provide a constant source of emissions as carbon is lost when land is converted to *Other lands*. The source from *Other lands* (13 513 Gg CO_2) is almost equal to the sink from Grasslands (15 614 Gg CO_2 in 2017).

Aggregated and non-CO_2 emissions on land contributed 46.0% to the AFOLU (excl. FOLU) emissions in 2017, and the largest contributor to this category (76.2%) is *Direct N_2O from managed soils*. Nitrogen inputs from urine and dung deposits contribute 62.6% to direct N_2O, followed by 12.7% from inorganic N inputs and 10.7% 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 2.9% in 2000 to 4.0% in 2017 (Figure 2.11). Solid waste disposal is the main contributor to this sector and these emissions are driven mainly by population growth.

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	349 099.7	32 987.3	53 229.4	41 088.7	13 557.8
2001	344 786.0	33 237.4	53 203.1	46 773.2	14 051.4
2002	351 670.6	35 219.9	53 578.9	41 694.6	14 523.1
2003	372 599.4	34 519.7	51 385.0	33 198.0	14 984.9
2004	387 189.9	34 629.1	50 889.2	37 675.8	15 436.3
2005	380 194.1	37 839.0	50 999.3	51 488.4	15 879.1
2006	382 630.0	38 915.7	51 023.8	48 081.6	16 314.7
2007	415 277.4	42 512.2	50 112.8	44 188.1	16 743.3
2008	409 225.5	40 369.5	51 692.1	51 704.5	17 166.4
2009	429 089.4	38 831.4	50 384.5	36 793.3	17 582.3
2010	416 728.9	35 468.2	51 651.2	41 014.8	17 990.8
2011	402 890.0	39 527.8	52 017.1	40 691.7	18 493.2
2012	417 486.6	38 670.9	50 657.6	39 269.6	18 973.3
2013	416 638.5	40 205.9	52 578.2	33 150.1	19 393.6
2014	416 956.7	38 786.6	52 930.3	35 619.0	19 874.6
2015	413 973.2	41 173.3	51 804.3	28 661.2	20 350.2
2016	404 753.5	39 963.6	48 984.6	15 950.1	20 797.1
2017	410 685.3	32 084.6	48 641.8	17 997.5	21 249.0

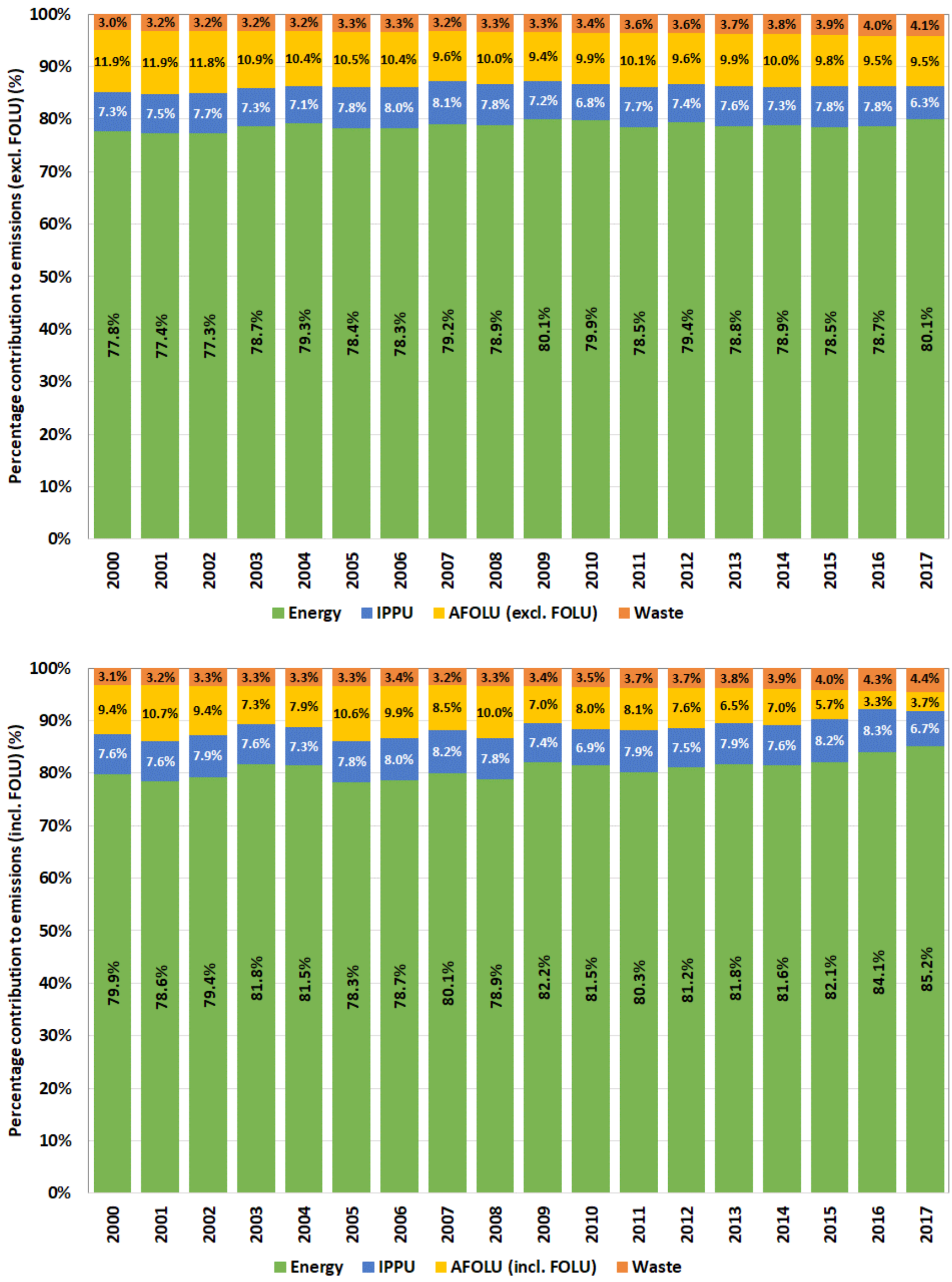

Figure 2.11: Percentage contributions from each of the sectors to South Africa's emissions (excluding (top) and including (bottom) FOLU) between 2000 and 2017.

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)	402 095.3	2 398.4	82.0	4 014.5	113.1	22.3	528.8	31.1	482 016.3
Emissions (excl. FOLU)	433 406.2	2 366.7	82.0	4 014.5	113.1	22.3	528.8	31.1	512 660.6
1 - Energy	**403 971.0**	**196.4**	**8.4**						**410 685.3**
1.A - Fuel Combustion Activities	377 563.2	18.6	8.4			NE	NE	NE	380 542.1
1.A.1 - Energy Industries	248 093.6	2.7	3.8			NE	NE	NE	249 333.7
1.A.2 - Manufacturing Industries and Construction	28 645.3	0.5	0.4			NE	NE	NE	28 765.5
1.A.3 - Transport	53 597.6	12.0	2.7			NE	NE	NE	54 694.5
1.A.4 - Other Sectors	37 547.3	3.2	1.3			NE	NE	NE	38 022.3
1.A.5 - Non-Specified	9 679.4	0.1	0.1			NE	NE	NE	9 726.1
1.B - Fugitive emissions from fuels	26 407.8	177.9	NE			NE	NE	NE	30 143.1
1.B.1 - Solid Fuels	19.5	73.9	NE			NE	NE	NE	1 571.0
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 CO_2	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	**27 496.0**	**8.0**	**0.9**	**4 014.5**	**113.1**				**32 084.6**
2.A - Mineral Industry	6 257.3	NE	NE			NE	NE	NE	6 257.3
2.B - Chemical Industry	433.6	8.0	0.9			NE	NE	NE	893.4
2.C - Metal Industry	20 274.5	0.1	NE	NE	113.1	NE	NE	NE	20 388.7

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)	402 095.3	2 398.4	82.0	4 014.5	113.1	22.3	528.8	31.1	482 016.3
Emissions (excl. FOLU)	433 406.2	2 366.7	82.0	4 014.5	113.1	22.3	528.8	31.1	512 660.6
1 - Energy	**403 971.0**	**196.4**	**8.4**						**410 685.3**
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	-29 409.2	1 224.4	70.0			22.3	528.8	31.1	17 997.5
3.A - Livestock		1 172.8	5.3						26 272.3
3.A.1 - Enteric Fermentation		1 137.3							23 883.7
3.A.2 - Manure Management		35.4	5.3						2 388.6
3.B - Land	-30 534.0	31.7	IE			IE	IE	IE	-29 867.4
3.B.1 - Forest land	-29 616.9	IE	IE			IE	IE	IE	-29 616.9
3.B.2 - Cropland	1 580.8	IE	IE			IE	IE	IE	1 580.8
3.B.3 - Grassland	-15 613.8	IE	IE			IE	IE	IE	-15 613.8
3.B.4 - Wetlands	NE	31.7	IE			IE	IE	IE	666.6
3.B.5 - Settlements	-397.0	IE	IE			IE	IE	IE	-397.0
3.B.6 - Other Land	13 512.9	IE	IE			IE	IE	IE	13 512.9
3.C - Aggregate sources and non-CO_2 emissions sources on land	1 901.7	19.9	64.7			22.3	528.8	31.1	22 369.5
3.C.1 - Emissions from biomass burning	IE	19.9	1.3			22.3	528.8	31.1	827.5
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			55.0						17 049.1
3.C.5 - Indirect N_2O Emissions from managed soils			6.9						2 126.3

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)	402 095.3	2 398.4	82.0	4 014.5	113.1	22.3	528.8	31.1	482 016.3
Emissions (excl. FOLU)	433 406.2	2 366.7	82.0	4 014.5	113.1	22.3	528.8	31.1	512 660.6
1 - Energy	**403 971.0**	**196.4**	**8.4**						**410 685.3**
3.C.6 - Indirect N_2O Emissions from manure management			1.5						464.9
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			NE	NE	NE	17 366.0
4.B - Biological Treatment of Solid Waste		NE	NE			NE	NE	NE	
4.C - Incineration and Open Burning of Waste	37.5	11.5	0.3			NE	NE	NE	360.2
4.D - Wastewater Treatment and Discharge		131.1	2.5			NE	NE	NE	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	6 603.6	0.4	0.1	NA	NA	NA	NA	NA	6 633.5
International aviation	4 929.1	0.2	0.0	NA	NA	NA	NA	NA	4 942.1
International water-borne transport	1 674.4	0.1	0.0	NA	NA	NA	NA	NA	1 691.5
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)	402 095.3	50 366.6	25 426.8	4 014.5	113.1	482 016.3
Emissions (excl. FOLU)	433 406.2	49 700.0	25 426.8	4 014.5	113.1	512 660.6
1 - Energy	**403 971.0**	**4 125.0**	**2 589.3**			**410 685.3**
1.A - Fuel Combustion Activities	**377 563.2**	**389.7**	**2 589.3**			**380 542.1**
1.A.1 - Energy Industries	248 093.6	57.1	1 182.9			249 333.7
1.A.2 - Manufacturing Industries and Construction	28 645.3	9.9	110.3			28 765.5
1.A.3 - Transport	53 597.6	251.9	845.0			54 694.5
1.A.4 - Other Sectors	37 547.3	67.5	407.5			38 022.3
1.A.5 - Non-Specified	9 679.4	3.1	43.6			9 726.1
1.B - Fugitive emissions from fuels	**26 407.8**	**3 735.3**	**NE**			**30 143.1**
1.B.1 - Solid Fuels	19.5	1 551.4	NE			1 571.0
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					

IPCC 2006 category	Emissions					
	Net CO_2	CH_4	N_2O	HFCs	PFCs	Total
	Gg CO_2e					
Emissions (incl. FOLU)	402 095.3	50 366.6	25 426.8	4 014.5	113.1	482 016.3
Emissions (excl. FOLU)	433 406.2	49 700.0	25 426.8	4 014.5	113.1	512 660.6
2 - Industrial Processes and Product Use	**27 496.0**	**168.4**	**292.6**	**4 014.5**	**113.1**	**32 084.6**
2.A - Mineral Industry	6 257.3	NE				NE
2.B - Chemical Industry	433.6	167.3	292.6			NE
2.C - Metal Industry	20 274.5	1.1	NE	NE	113.1	NE
2.D - Non-Energy Products from Fuels and Solvent Use	530.6	NE	NE			530.6
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	**-29 409.2**	**25 713.3**	**21 693.4**			**17 997.5**
3.A - Livestock		**24 627.9**	**1 644.4**			**26 272.3**
3.A.1 - Enteric Fermentation		23 883.7				23 883.7
3.A.2 - Manure Management		744.2	1 644.4			2 388.6
3.B - Land	**-30 534.0**	**666.6**	**NE**			**-29 867.4**

IPCC 2006 category	Emissions					
	Net CO_2	CH_4	N_2O	HFCs	PFCs	Total
	Gg CO_2e					
Emissions (incl. FOLU)	402 095.3	50 366.6	25 426.8	4 014.5	113.1	482 016.3
Emissions (excl. FOLU)	433 406.2	49 700.0	25 426.8	4 014.5	113.1	512 660.6
3.B.1 - Forest land	-29 616.9	NE	NE			-29 616.9
3.B.2 - Cropland	1 580.8	NE	NE			1 580.8
3.B.3 - Grassland	-15 613.8	NE	NE			-15 613.8
3.B.4 - Wetlands	NE	666.6	NE			666.6
3.B.5 - Settlements	-397.0	NE	NE			-397.0
3.B.6 - Other Land	13 512.9	NE	NE			13 512.9
3.C - Aggregate sources and non-CO_2 emissions sources on land	**1 901.7**	**418.8**	**20 049.0**			**22 369.5**
3.C.1 - Emissions from biomass burning	IE	418.8	408.7			827.5
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			17 049.1			17 049.1
3.C.5 - Indirect N_2O Emissions from managed soils			2 126.3			2 126.3
3.C.6 - Indirect N_2O Emissions from manure management			464.9			464.9
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**

IPCC 2006 category	Emissions					
	Net CO_2	CH_4	N_2O	HFCs	PFCs	Total
	Gg CO_2e					
Emissions (incl. FOLU)	402 095.3	50 366.6	25 426.8	4 014.5	113.1	482 016.3
Emissions (excl. FOLU)	433 406.2	49 700.0	25 426.8	4 014.5	113.1	512 660.6
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 NH_3			**NE**			
5.B - Other			**NO**			
Memo items						
International bunkers	**6 603.6**	**3.2**	**26.7**	**NA**	**NA**	**6 633.5**
International aviation	4 929.1	0.1	12.8	NA	NA	4 942.1
International water-borne transport	1 674.4	3.1	13.9	NA	NA	1 691.5
Multilateral operations	NA	NA	NA	NA	NA	

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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 key energy policies seek to achieve the following key objectives:

- Diversifying primary energy sources by increasing penetration of renewable energy resources and reducing dependency on coal and this is mainly achieved through the Integrated Resource Plan (IRP);
- Entrench good governance throughout the energy value system (from generation to demand side), which must also facilitate and encourage private-sector investments in the energy sector;
- Provide an environment that promotes provision of environmentally friendly energy provision;
- Connecting the last 10% of population by using renewable energy resources and;
- Providing 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 410 685 Gg CO_2e (Table 3.1). *Energy industries* were the main contributor, accounting for 60.7% of emissions from the *Energy* sector. This was followed by *transport* (13.3%) and *other sectors* (9.3%) and *manufacturing industries and construction* (7.0%). The *fugitive emissions* and *none specified sectors* accounts for 7.3% and 2.4% respectively. 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.

2000 - 2017

Energy sector emissions increased by 17.6% between 2000 and 2017 (Table 3.2). This growth in emissions is mainly from the 20.3% increase in *fuel combustion activities*. There was an increase of 11 900Gg CO_2e increase in the *other sector* emissions, a 28 747 Gg CO_2e increase in *energy industry* emissions and a 13 632 Gg CO_2e increase in *transport* emissions (Table 3.2). On the other hand, *fugitive emissions from fuels* declined by 7.7%. 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. Emissions increase until 2007, after which the increase is much slower (Figure 3.2). A peak is reached in 2013, after which emissions appear to stabilise. Annual change (Figure 3.2) slows, with more years where there is a decline in emissions.

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	**403 971.0**	**196.4**	**4 125.0**	**8.4**	**2 589.3**	**410 685.3**
1A Fuel combustion activities	377 563.2	18.6	389.7	8.4	2 589.3	380 542.1
1B Fugitive emissions from fuels	26 407.8	177.9	3 735.3	0.0	0.0	30 143.1
1C Carbon dioxide transport and storage	NE	NE	NE	NE	NE	NE

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	**$Gg\ CO_2e$**	**Gg**	**$Gg\ CO_2e$**	**Gg**
1.A Fuel combustion activities	**316 443.6**	**380 542.1**	**64 098.5**	**20.3**
1.A.1 Energy industries	220 587.0	249 333.7	28 746.7	13.0
1.A.1.a Electricity and heat production	*185 961.7*	*216 481.5*	*30 519.8*	*16.4*
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*	*29 519.1*	*-1 056.6*	*-3.5*
1.A.2 Manufacturing industries and construction	24 413.4	28 765.5	4 352.1	17.8
1.A.3 Transport	41 062.9	54 694.5	13 631.6	33.2
1.A.3.a Domestic aviation	*2 256.9*	*1 527.4*	*-729.5*	*-32.3*
1.A.3.b Road transportation	*37 964.0*	*52 318.4*	*14 354.5*	*37.8*
1.A.3.c Railways	*618.1*	*490.3*	*-127.8*	*-20.7*
1.A.3.d Water-borne navigation (domestic)	*224.0*	*358.5*	*134.5*	*60.1*
1.A.3.e Other transportation	*NE*	*NE*		
1.A.4 Other sectors	26 123.3	38 022.3	11 899.0	45.5
1.A.4.a Commercial/Institutional	*16 604.2*	*30 209.8*	*13 605.6*	*81.9*
1.A.4.b Residential	*7 103.0*	*3 533.0*	*-3 570.0*	*-50.3*
1.A.4.c Agriculture/Forestry/Fishing/Fish farms	*2 416.1*	*4 279.5*	*1 863.4*	*77.1*
1.A.5 Non-specified	4 257.0	9 726.1	5 469.1	128.5
1.B Fugitive emissions from fuels	**32 656.1**	**30 143.1**	**-2 512.9**	**-7.7**
1.B.1 Solid fuels	1 438.9	1 571.0	132.1	9.2
1.B.2 Oil and natural gas	752.0	641.8	-110.2	-14.7
1.B.3 Other emissions from energy production	28 146.6	25 746.5	-2 400.1	-8.5
1.C Carbon dioxide transport and storage	NE	NE		

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

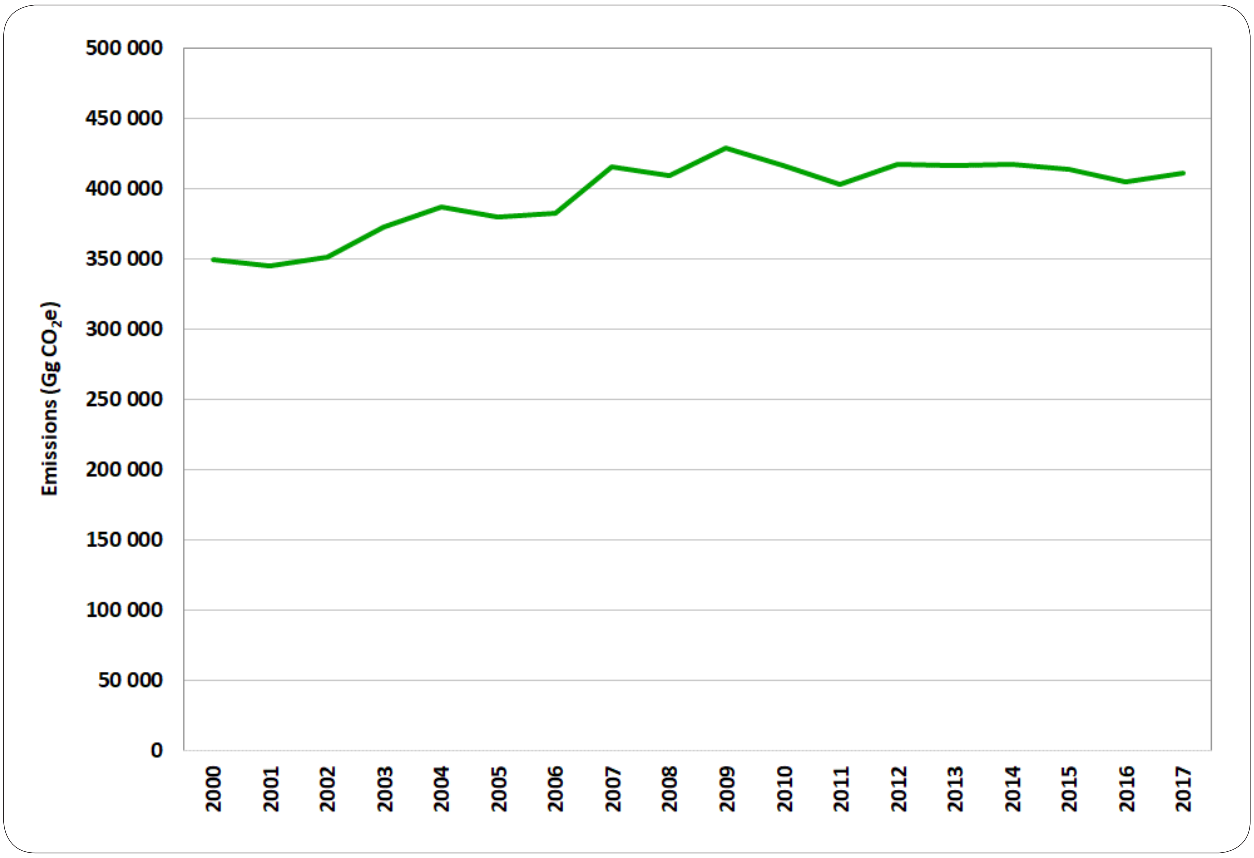

Figure 3.1: Trends in South Africa's energy sector emissions, 2000 – 2017.

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	342 496.2	202.9	7.6	349 099.7
2001	338 166.0	204.6	7.5	344 786.0
2002	344 877.5	211.0	7.6	351 670.6
2003	365 740.7	208.2	8.0	372 599.4
2004	380 087.1	215.7	8.3	387 189.9
2005	373 294.5	205.7	8.3	380 194.1
2006	376 105.3	198.6	7.6	382 630.0
2007	408 416.2	203.9	8.3	415 277.4
2008	402 472.0	199.2	8.3	409 225.5
2009	421 935.3	213.0	8.6	429 089.4
2010	409 897.4	204.1	8.2	416 728.9
2011	396 308.0	197.0	7.9	402 890.0
2012	410 771.1	198.6	8.2	417 486.6
2013	409 830.2	200.9	8.4	416 638.5
2014	410 085.2	202.9	8.4	416 956.7
2015	407 219.4	198.7	8.3	413 973.2
2016	398 186.0	194.4	8.0	404 753.5
2017	403 971.0	196.4	8.4	410 685.3

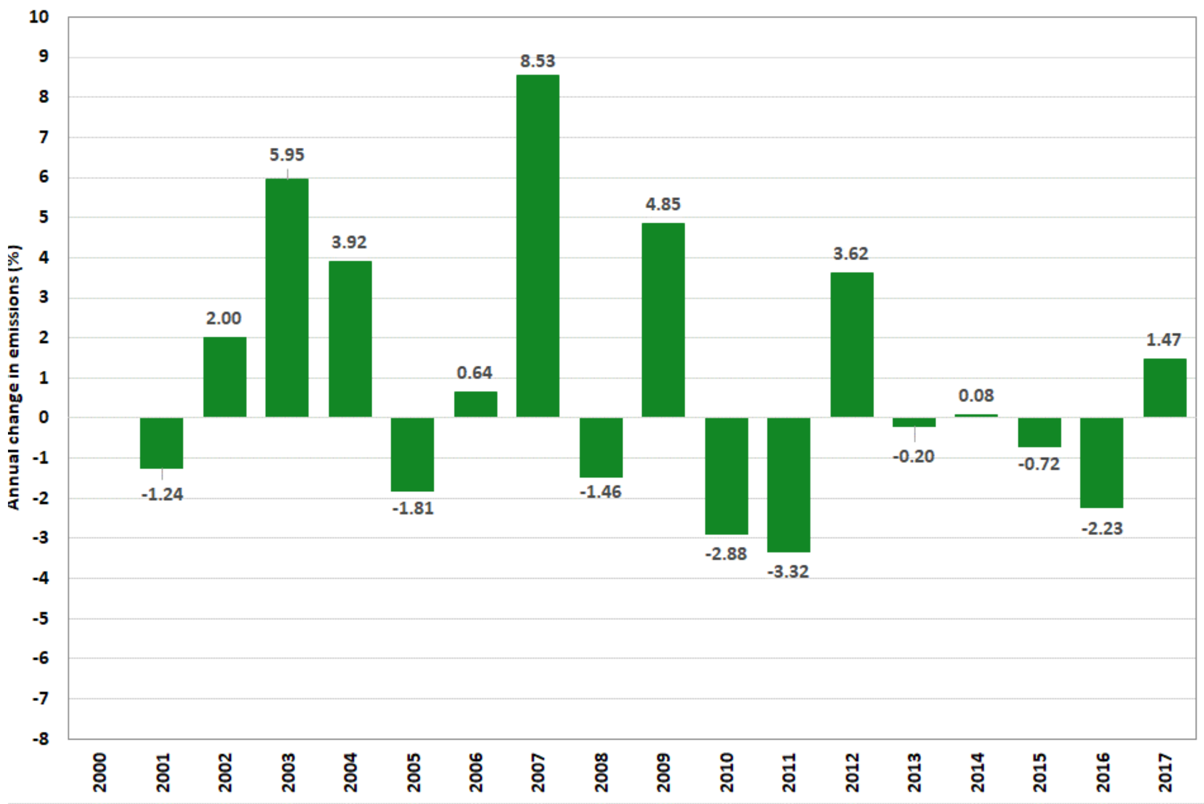

Figure 3.2: Trend in annual change in the total energy emissions in South Africa, 2000 – 2017.

2015 – 2017

Energy emissions decreased by 0.8% (3 288 Gg CO_2e) since 2015. The main contributor to this decrease was the *energy industries* which decreased by 4.5% (11 794 Gg CO_2e). Given that 60.7% of emissions in the *Energy* sector are from *energy industries*, this led to an overall decline of the emissions. This decrease happened despite the 36.7% (10 214 Gg CO_2e) increase in emission in the *other sectors* and 68.2% (3 943 Gg CO_2e) increase in the *non-specified* category. The increase in the other sectors was due to the increased allocation of coal to the commercial sector as per the 2017 SAMI Report (Department of Mineral Resources, 2017). *Transport* decreased by 4.7% (2 675 Gg CO_2e).

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,T2	DF, CS	T1	DF	T1	DF	CS CO_2 EF for sub-bituminous coal (Technical Guidelines)
	c. Agriculture/ Forestry/ Fishing/Fish farms	T1,T2	DF, CS	T1	DF	T1	DF	CS CO_2 EF for sub-bituminous coal (Technical Guidelines)

	GHG Source and sink category	CO_2		CH_4		N_2O		Details
		Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	
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 on average 0.7% lower than previous estimates for the *Energy* sector between 2000 and 2009, then 4.2% lower from 2010 onwards (Figure 3.3).

Fuel combustion activity recalculations were necessary due to an update of the DMRE energy balance data. Recalculated values were on average 4.2% lower than the previous submission for this category. Improvements were made to the consumption data in the *Road transport, Manufacturing industries and construction, Other sectors and Non-specified emissions from energy production* categories. The main fuels that necessitated recalculation in these sectors are sub-bituminous coal and gas/diesel oil. A significant amount of diesel was allocated to 1A5a in the energy balance. Given that in the previous inventories, this category did not have any diesel allocated to it, this led to an increase in diesel consumption in the energy industries. Emissions in this category increased from 1 204 Gg CO_2e in the previous submission to 5 782 Gg CO_2e in 2015 in the current submission. This was counteracted by an average decrease of 19.6% in the *Manufacturing industries and construction* category and a 38.7% decline in *Other sector* emissions compared to the previous inventory.

In addition to the updated energy balance data, a recent parc model study (DFFE, 2020) was completed for the transport sector which provided consumption data based on vehicle kilometres travelled (VKT).

Fugitive emissions from fuels were 2.4% lower than estimates in the 2015 inventory. *Solid fuel* emissions were lower due to updated coal production data and in the *Other emissions from energy production* category the charcoal consumption data was corrected.

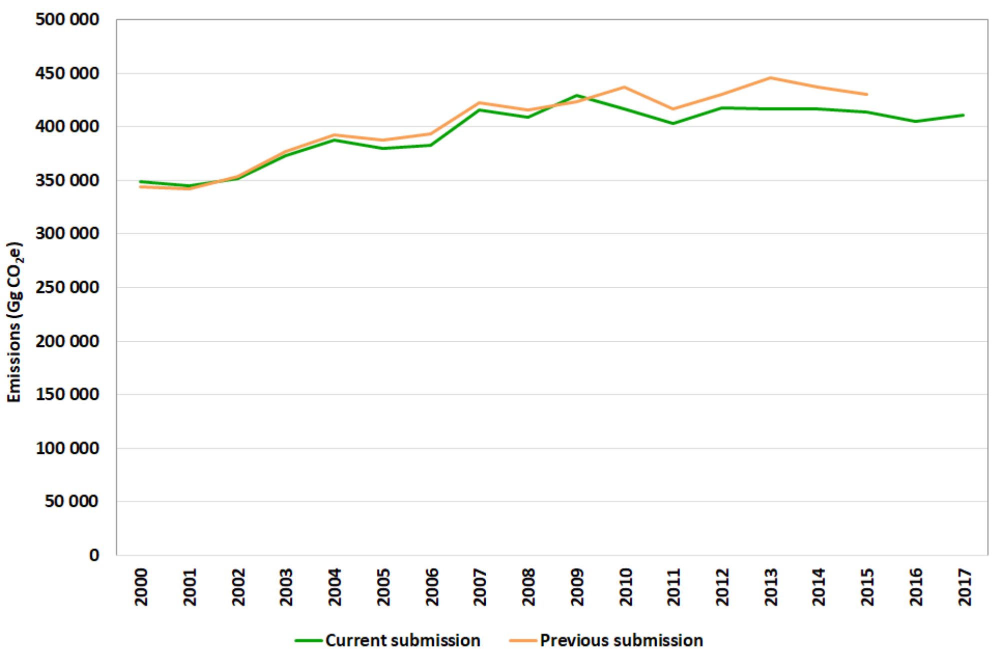

Figure 3.3: Recalculations for the Energy sector between 2000 and 2017.

3.1.5 Key categories in the energy sector

The key categories identified by the level (L) and trend (T) assessment (Tier 1) for the *Energy sector* 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 fuel)	CO_2	L1,T1
1A1a	Electricity and Heat Production	CO_2	T1
1A1b	Petroleum Refining (Gas)	CO_2	L1
1A1b	Petroleum Refining (Liquid)	CO_2	T1
1A1c	Manufacture of Solid Fuels and Other Energy Industries (Liquid fuel)	CO_2	L1,T1
1A2	Manufacturing Industries and Construction (Solid fuel)	CO_2	L1,T1
1A2	Manufacturing Industries and Construction (Liquid fuel)	CO_2	L1,T1
1A2	Manufacturing Industries and Construction (Gas)	CO_2	L1,T1
1A3a	Civil Aviation (Liquid)	CO_2	T1
1A3b	Road Transport (Liquid fuel)	CO_2	L1,T1
1A4a	Commercial/Institutional (Solid fuel)	CO_2	L1,T1
1A4a	Commercial/Institutional (Liquid fuel)	CO_2	L1
1A4b	Residential (Liquid fuel)	CO_2	L1,T1
1A4b	Residential (Solid fuel)	CO_2	T1
1A4c	Agriculture/Forestry/Fishing/Fish Farms (Liquid fuel)	CO_2	L1,T1
1A5a	Stationary (Solid fuel)	CO_2	L1,T1
1B3	Other Emissions from Energy Production	CO_2	L1,T1
1B3	Other Emissions from Energy Production	CH_4	L1,T1

3.1.6 Planned improvements

Improvements planned for the next inventory are:

1. There will be three instruments through which the data will be collected for the inventory in future (Figure 3.4). The first process will involve enhancement of the current direct communication between stakeholder and DFFE 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);

2. The other improvement will be data that will be generated through SAGERS. SAGERS was developed to improve the compilation of GHG emissions inventories by assisting DFFE and Category A[3] data providers to abide by the reporting NGER (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. In the next inventory data gathered through the NGER and SAGERS will be incorporated;

3. 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;

4. Fugitive emissions from coke production is currently accounted for under category 2C as part of process emissions, however it is planned that by the 2021 inventory these will be separated from process emissions and reported separately;

5. Re-evaluate reference versus sectoral data and methodology and include any improvements into the next inventory. In addition, provide further explanations for the differences; and

6. Country-specific uncertainty data will be sought and incorporated when available. This will be an ongoing improvement over the next few inventory cycles; and

7. Time-series will be extended back to 1990 over the next few years, but this will likely only be available in the 6th BUR (2021 inventory).

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.

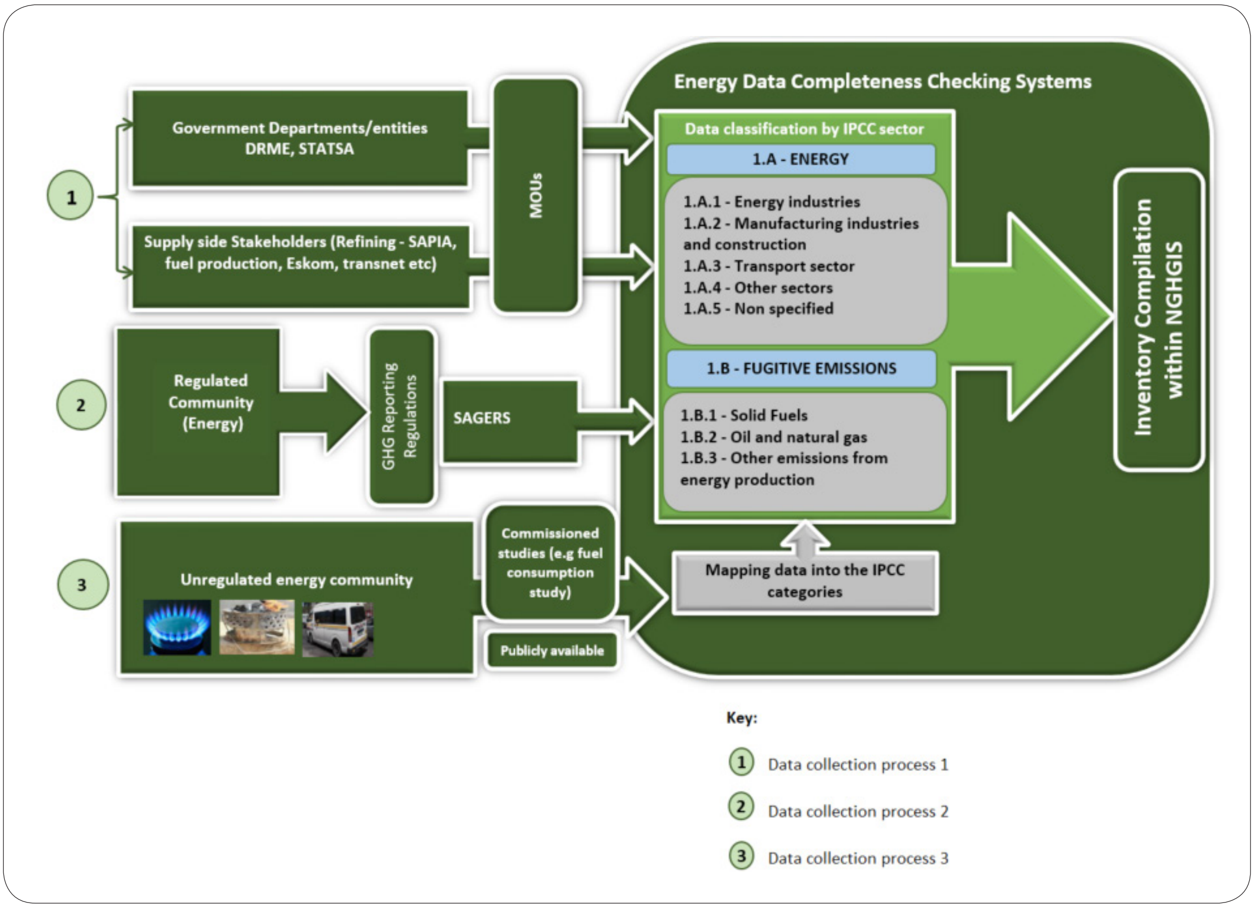

Figure 3.4: Data Collection Process for the Energy Sector.

3.2 SOURCE CATEGORY 1.A FUEL COMBUSTION

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* are 380 542 Gg CO_2e in 2017, equal to 92.7% of the *energy sector* emissions. *Energy industries* contributed 60.7% to the total fuel combustion activity emissions in 2017. CO_2 emissions constitute 98.4% of fuel activity emissions. CH_4 and N_2O emissions contributed 1.0% and 0.6% respectively.

2000 - 2017

Emissions are seen to increase from 2000 to 2009, decline to 2011 and then stabilise (Figure 3.5, Table 3.6). Further information on the trends, as well as methodologies, emission factors, uncertainty, and quality control and assurance are provided in the various sub-category sections below.

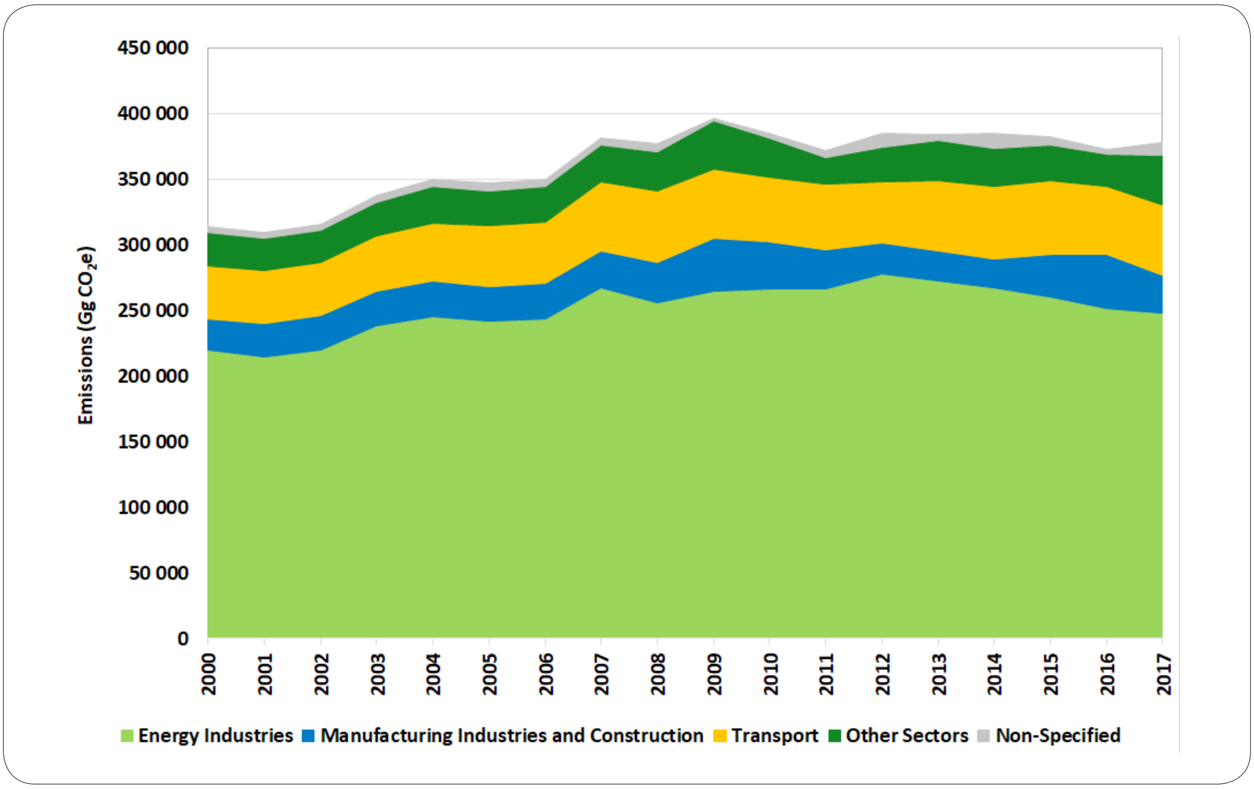

Figure 3.5: Trends and subcategory contributions to fuel combustion activity emissions in South Africa, 2000 – 2017.

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	24 413.4	41 062.9	26 123.3	4 257.0
2001	215 884.1	24 776.2	41 482.8	25 744.2	3 979.7
2002	221 177.2	25 646.2	41 733.1	25 504.2	3 920.7
2003	238 889.8	26 795.5	43 253.9	26 537.7	4 498.0
2004	246 680.0	27 003.4	45 275.4	28 262.6	5 610.5
2005	242 786.0	26 208.4	47 500.4	27 529.3	5 756.7
2006	244 834.0	26 838.2	47 448.2	27 655.3	5 587.2
2007	268 012.3	28 274.3	54 329.8	28 343.1	5 569.7
2008	257 213.4	30 804.3	55 155.1	30 408.4	6 279.6
2009	266 016.2	40 623.1	53 451.6	37 381.3	1 545.3
2010	267 845.3	35 984.3	50 162.3	29 774.0	3 517.4

	Energy Industries	Manufacturing Industries and Construction	Transport	Other Sectors	Non-Specified
	Gg CO_2e				
2011	267 890.2	29 758.8	50 529.0	20 758.8	5 217.0
2012	279 356.4	23 803.7	47 570.2	26 434.5	10 773.3
2013	273 764.4	23 036.4	54 365.8	31 309.3	4 179.8
2014	268 802.0	22 016.6	56 070.0	29 522.7	10 946.2
2015	261 127.6	32 843.1	57 369.7	27 808.0	5 782.5
2016	252 176.4	42 210.7	52 195.4	25 173.8	3 785.4
2017	249 333.7	28 765.5	54 694.5	38 022.3	9 726.1

Source category description

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:

$$(Emissions)_{ij} = Q_i \times EC_i \times EF_{ij} / 1000000 \quad \text{(Eq. 3. 1)}$$

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	19.8	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	

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)
Solid fuels	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	
	Derived gases	Gas works gas	44 400		1		0.1	
		Coke oven gas	44 400		1		0.1	
		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

Gas		Activity data uncertainty		Emission factor uncertainty	
		%	Source	%	Source
CH_4	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
	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 based on 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 2017 and the CO_2 emissions were always higher using the reference approach (Figure 3.6). The difference in CO_2 emissions using the reference and sectoral approach was 14.2%, 20.4% and 17.3% for the years 2015, 2016 and 2017, 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. There is a much smaller difference between the two approaches for liquid fuels, with some years having higher consumption with the reference approach and other years higher with the sectoral approach (Appendix 3.B, Figure 3.B.2). As with solid fuels, there is a large discrepancy in consumption between the two approaches, with consumption being consistently high 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.

In the next inventory the data and methodologies will be re-evaluated to determine if there are any further improvements that can be made to resolve some of the above-mentioned issues. In addition, further explanation for the discrepancies will be included.

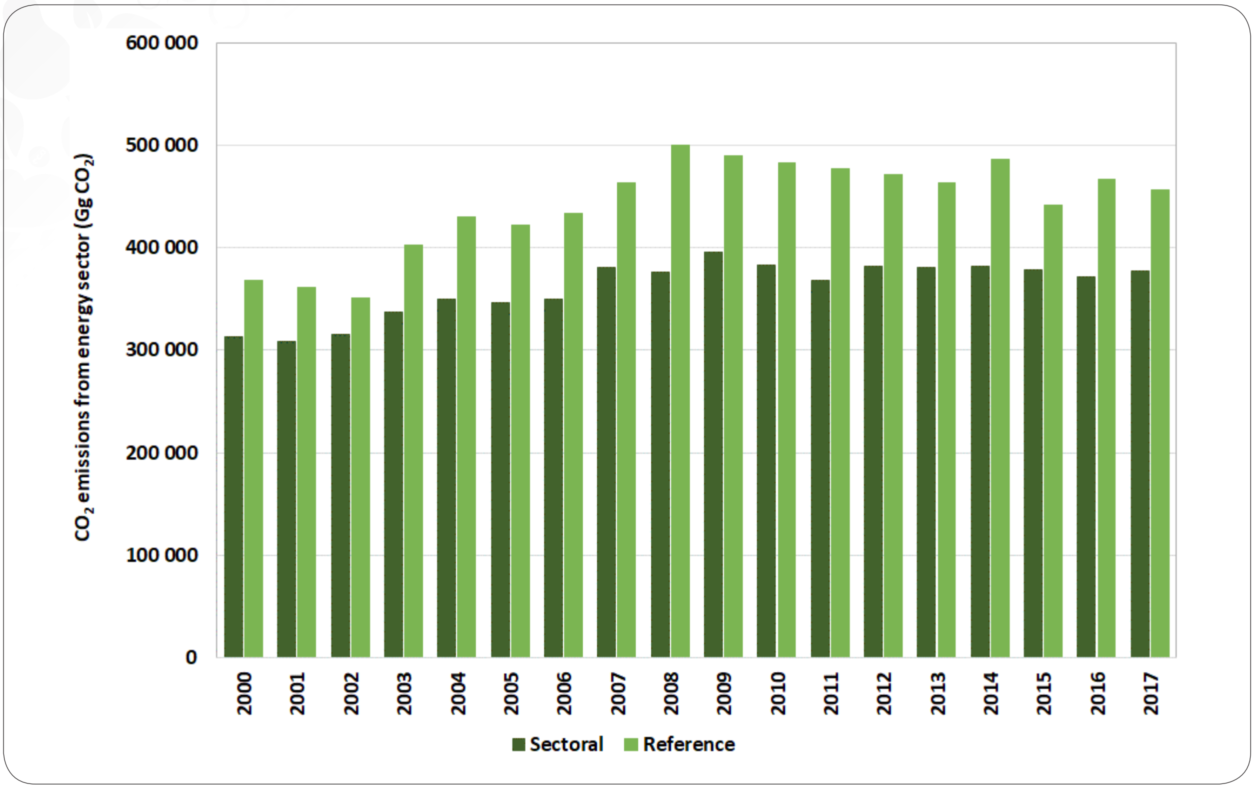

Figure 3.6: Comparisons between the reference and sectoral approach of determining the CO_2 emissions for the energy sector for South Africa, 2000 – 2017.

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 249 334 Gg CO_2e in 2017, which is 60.7% of the Energy sector emissions. Emissions were 28 747 Gg CO_2e (13%) 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 public electricity producer, however emissions have been showing a declining trend since 2013 (Table 3.11). Consumption increased by 13.3% over the 2000 - 2017 period, while emissions increased by 7.24%. 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% because 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 2013 (Table 3.11). Since 2013 there has been a 7.9% decline in electricity consumption, leading to an 9.7% 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. At the same time, Eskom's energy availability factor was reduced due to load shedding events that increased in intensity and frequency in both 2014 and 2015. The main contributor to load shedding for six months from November 2014 to May 2015 was the collapse of the Majuba Power station. The station has an installed capacity of 3600 MW and only came back in full capacity in May 2015. The Majuba incidence and other technical issues, resulted in the energy availability factor being 75.1% and 74% in 2014 and 2015, respectively. In the preceding years (2006 – 2012), the availability factor was between 77.7% and 88%. This translated to reduced consumption of coal in power stations.

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	173 858.0	1.8	2.7	185 961.7
2001	175 475.2	1.8	2.7	180 941.2
2002	181 307.0	1.9	2.8	187 186.1
2003	194 985.2	2.0	3.0	203 905.6
2004	204 689.9	2.1	3.2	211 946.8
2005	206 208.9	2.1	3.2	209 961.4
2006	207 464.6	2.2	3.2	212 345.6
2007	228 111.4	2.4	3.6	233 929.1
2008	218 542.6	2.3	3.4	223 521.0
2009	224 578.8	2.4	3.5	232 326.4
2010	231 405.0	2.4	3.6	234 759.2
2011	233 189.1	2.5	3.6	235 250.5
2012	243 497.4	2.6	3.8	245 912.9
2013	237 464.0	2.6	3.7	239 839.1
2014	232 114.6	2.5	3.6	234 492.0
2015	223 999.4	2.5	3.4	226 315.9
2016	217 118.2	2.3	3.4	218 418.5
2017	214 668.3	2.3	3.3	216 481.5

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 93.5% (10 442 Gg CO_2e) since 2000.

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	11 169.4	0.12	0.17	11 225.8
2001	4 557.0	0.05	0.07	4 580.0
2002	4 938.7	0.05	0.08	4 963.6
2003	7 896.0	0.08	0.12	7 935.8
2004	6 192.1	0.06	0.10	6 223.3
2005	2 697.7	0.03	0.04	2 711.4
2006	3 814.1	0.04	0.06	3 833.4
2007	4 642.5	0.05	0.07	4 665.9
2008	3 856.3	0.04	0.06	3 875.8
2009	6 581.6	0.07	0.10	6 614.9
2010	2 176.5	0.02	0.03	2 187.5
2011	882.0	0.01	0.01	886.5
2012	1 184.3	0.01	0.02	1 190.3
2013	1 176.1	0.01	0.02	1 182.1
2014	1 206.3	0.01	0.02	1 212.4
2015	1 188.9	0.01	0.02	1 194.9
2016	205.3	0.00	0.00	206.3
2017	727.8	0.01	0.01	731.5

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	4 042.6	0.10	0.02	4 049.5
2001	3 897.6	0.10	0.02	3 904.5
2002	3 384.6	0.08	0.01	3 390.0
2003	3 878.9	0.09	0.01	3 885.3
2004	3 563.0	0.08	0.01	3 568.6
2005	3 412.5	0.08	0.01	3 417.7
2006	3 669.0	0.09	0.01	3 674.9
2007	3 760.8	0.09	0.01	3 766.9
2008	3 867.8	0.09	0.01	3 874.0
2009	3 796.4	0.09	0.01	3 802.7
2010	3 545.6	0.08	0.01	3 551.3
2011	3 336.3	0.08	0.01	3 341.4
2012	3 379.0	0.08	0.01	3 384.2
2013	3 447.5	0.08	0.01	3 452.8
2014	3 417.6	0.08	0.01	3 422.9
2015	3 387.8	0.08	0.01	3 392.9
2016	3 357.9	0.08	0.01	3 363.0
2017	3 328.0	0.07	0.01	3 333.0

1A1c Manufacture of solid fuels and other energy industries

Emissions from *manufacture of solid fuels and other energy industries* totalled 29 519 Gg CO_2e in 2017, and these emissions have remained 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	30 454.7	0.10	0.02	30 575.7
2001	30 915.6	0.10	0.02	31 038.4
2002	30 479.8	0.08	0.01	30 601.1
2003	30 970.2	0.09	0.01	31 098.9
2004	31 041.6	0.08	0.01	31 164.6
2005	29 290.4	0.08	0.01	29 406.9
2006	28 698.9	0.09	0.01	28 813.5
2007	30 194.4	0.09	0.01	30 316.3
2008	29 699.2	0.09	0.01	29 818.4
2009	29 766.9	0.09	0.01	29 887.2
2010	29 415.2	0.08	0.01	29 534.8
2011	29 178.9	0.08	0.01	29 298.2
2012	29 903.3	0.08	0.01	30 059.3
2013	30 317.0	0.08	0.01	30 472.5
2014	30 723.9	0.08	0.01	30 887.1
2015	31 259.9	0.08	0.01	31 418.8
2016	30 237.6	0.08	0.01	30 394.9
2017	29 369.4	0.07	0.01	29 519.1

Changes in emissions since 2015

Emissions in this subsector decreased by 0.3% (1 313 Gg CO_2e) since 2015. This is due to a 6.1% (1 900 Gg CO_2e) decline in emissions from *manufacture of solid fuels and other energy industries*. Emissions from *electricity and heat production* decreased by 4% over this period, while *petroleum refining* emissions declined by 1.8% (60 Gg CO_2e). Emissions in the *manufacture of solid fuels and other energy industries* category decreased by 6% (1 900 Gg CO_2e) since 2015.

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	68 381	56 523
2010	2 406 936	22 613	52 520
2011	2 426 965	9 164	50 235
2012	2 537 365	12 305	51 049
2013	2 477 632	12 220	51 890
2014	2 423 731	12 533	51 504
2015	2 343 934	12 352	51 118
2016	2 259 087	2 133	50 731
2017	2 233 426	7 562	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. 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.

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.

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

Recalculations were performed from 2009 onwards because of activity data updates. For the main electricity provider, the jet kerosene consumption data for 2013 onwards was adjusted, which led to a very small (0.01%) lowering of emissions. Sub-bituminous coal consumption by auto-electricity providers was updated for 2009, 2010, and 2013 onwards. This produced a 54.8% higher and a 48.8% lower emission estimates for 2009 and 2010, respectively, while 2015 emissions were 34.6% higher in the current submission. Petroleum refining numbers from PetroSA were updated for 2013 onwards, leading to a 4.4% lower emission estimate for 2015.

Overall, these recalculations produced a 0.9%, 0.3%, 0.4% and 0.4% higher emission estimate in 2009, 2013, 2014, and 2015, respectively, in the current inventory compared to the 2015 submission.

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 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 28 766 Gg CO_2e in 2017, which is 7.0% of the Energy sector emissions. Emissions were 4 352 Gg CO_2e (17.8%) above the 2000 level. In 2010 GHG emissions from this category decreased by 11.0%, which might have been a result of the global economic crisis that started in late 2008. The emissions in this sector became stable since 2012 until they started increasing again in 2015 (Table 3.16). This was due to a decline in sub-bituminous coal and natural gas consumption (DoE, 2015). Emissions then increased again in 2014 to 22 017 Gg CO_2e and remained at these levels until 2017. Emissions in this subsector decreased by 4 078 GgCO_2e (12.4%) 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	24 304.3	0.3	0.3	24 413.4
2001	24 665.9	0.4	0.3	24 776.2
2002	25 532.3	0.4	0.3	25 646.2
2003	26 677.3	0.4	0.4	26 795.5
2004	26 884.8	0.4	0.4	27 003.4
2005	26 094.8	0.4	0.3	26 208.4
2006	26 722.0	0.4	0.3	26 838.2
2007	28 151.9	0.4	0.4	28 274.3
2008	30 671.4	0.5	0.4	30 804.3
2009	40 440.8	0.6	0.5	40 623.1
2010	35 825.6	0.5	0.5	35 984.3
2011	29 628.5	0.5	0.4	29 758.8
2012	23 702.5	0.4	0.3	23 803.7
2013	22 943.2	0.4	0.3	23 036.4
2014	21 930.0	0.4	0.3	22 016.6
2015	32 703.9	0.6	0.4	32 843.1
2016	42 021.5	0.6	0.6	42 210.7
2017	28 645.3	0.5	0.4	28 765.5

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) and from the fuel consumption study (DFFE, 2019). 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.

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.

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

	Other Kerosene	Gas/ Diesel Oil	Residual Fuel Oil	LPG	Bitumen	Sub-Bituminous Coal	Natural Gas
	(TJ)						
2000	698	28 234	194	109	5 053	202 749	39 532
2001	640	29 499	194	115	5 584	204 130	41 241
2002	606	30 955	187	113	6 161	210 505	43 048
2003	626	32 915	185	107	6 276	217 464	48 749
2004	649	34 769	199	108	6 382	217 134	50 361
2005	619	36 784	171	106	7 038	205 238	53 166
2006	601	36 015	166	116	7 245	210 508	56 038
2007	567	38 199	164	122	7 707	221 647	58 908
2008	433	50 628	164	118	7 475	236 878	61 778
2009	444	44 769	207	105	7 602	341 078	64 645
2010	469	39 725	219	111	8 044	294 415	68 406
2011	473	48 835	167	138	7 536	233 387	51 382
2012	383	52 164	198	126	9 807	171 402	44 518
2013	389	53 346	186	124	9 095	152 795	62 379
2014	365	62 475	186	126	9 384	134 189	63 799
2015	342	73 652	186	127	9 673	236 467	65 218
2016	318	46 981	186	128	9 963	352 754	66 637
2017	294	55 637	187	130	10 252	206 062	68 056

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

Recalculations were performed for the full time-series due to updated activity data (gas/diesel oil and sub-bituminous coal consumption) in the national energy balance. The recalculations for this category led to a reduction in the estimate compared to the previous submission. The estimates were lowered by an average of 26.6% between 2000 and 2010, with a 40% lower estimate in 2013 and 2014 and a 10.9% lower estimate for 2015.

Planned improvements and recommendations

In future, facility-level data needs to be sourced and country-specific emission factors must 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, and 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 (NOx, CO, SOx, NMVOCs, particulates, and trace components). Civil aviation data were sourced from both domestic and international aircrafts, including departures and arrivals. That also included civil commercial use of airplanes, scheduled and charter traffic for passengers and freight, air taxing, agricultural airplanes, private jets and helicopters. 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 generate 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

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

	Civil Aviation	Road Transport	Railways	Water-Borne Navigation	Total
	Gg CO_2e				
2000	698	28 234	194	109	5 053
2001	640	29 499	194	115	5 584
2002	606	30 955	187	113	6 161
2003	626	32 915	185	107	6 276
2004	649	34 769	199	108	6 382
2005	619	36 784	171	106	7 038
2006	601	36 015	166	116	7 245
2007	567	38 199	164	122	7 707
2008	433	50 628	164	118	7 475
2009	444	44 769	207	105	7 602
2010	469	39 725	219	111	8 044
2011	473	48 835	167	138	7 536
2012	383	52 164	198	126	9 807
2013	389	53 346	186	124	9 095
2014	365	62 475	186	126	9 384
2015	342	73 652	186	127	9 673
2016	318	46 981	186	128	9 963
2017	294	55 637	187	130	10 252

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 54 695 Gg CO_2e or 13.3% of the energy sector emissions. *Road transport* accounts for 95.7% of the transport emissions in 2017, while the contribution from *domestic aviation* and *railways* was small (2.8% and 0.9% 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 6 638 Gg CO_2e.

Emissions from *transport* increased from 41 063 Gg CO_2e in 2000 to 54 695 Gg CO_2e in 2017 (Table 3.18), which is a 33.2% increase. The major contributor to this subsector was *road transport* which increased by 37.8% between 2000 and 2017. *Domestic aviation* decreased by 730 Gg CO_2e over the same period. *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, increased from 12 060 Gg CO_2e in 2000 to 6 638 Gg CO_2e in 2017 (Table 3.19).

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	2 826.6	0.12	0.02	9 123.5	0.78	0.27
2001	2 665.5	0.11	0.02	8 874.6	0.76	0.26
2002	3 353.4	0.14	0.03	8 491.0	0.73	0.24
2003	3 551.2	0.15	0.03	8 265.6	0.72	0.23
2004	3 658.2	0.15	0.03	8 265.0	0.71	0.24
2005	3 916.8	0.16	0.03	8 375.8	0.72	0.24
2006	4 236.2	0.18	0.04	8 318.8	0.72	0.23
2007	4 461.2	0.19	0.04	8 250.6	0.72	0.23
2008	4 426.6	0.19	0.04	8 015.6	0.68	0.24
2009	4 337.3	0.18	0.04	6 973.7	0.57	0.22
2010	4 306.9	0.18	0.04	3 657.1	0.33	0.10
2011	4 482.0	0.19	0.04	2 564.6	0.23	0.07
2012	4 406.3	0.18	0.04	3 633.2	0.27	0.14
2013	4 645.0	0.19	0.04	2 018.4	0.18	0.06
2014	4 675.4	0.20	0.04	1 752.7	0.16	0.05
2015	4 731.2	0.20	0.04	1 757.8	0.16	0.05
2016	4 777.1	0.20	0.04	1 684.1	0.15	0.04
2017	4 929.1	0.21	0.04	1 674.4	0.15	0.04

Change in emissions since 2015

Transport emissions increased by 4.7% (2 675 Gg CO_2e) between 2015 and 2017 due to increase fuel consumption in the *road transport* subsector. *Road transport* increased by 4.7% (2 574 Gg CO_2e), and *domestic aviation* by 1.5% (22 Gg CO_2e). *Railway* and *Water-borne navigation* emissions declined by 121 Gg CO_2e and 2 Gg CO_2e respectively.

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, 2019), 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, 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:

$$Q_i = VKT_{vc} \times FE_{vc} \times N_{vc} \quad \text{(Eq. 3.2)}$$

Where;

Qi 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 (94% 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 3.7). This can be attributed to the efficiency and affordability of diesel compared with motor gasoline.

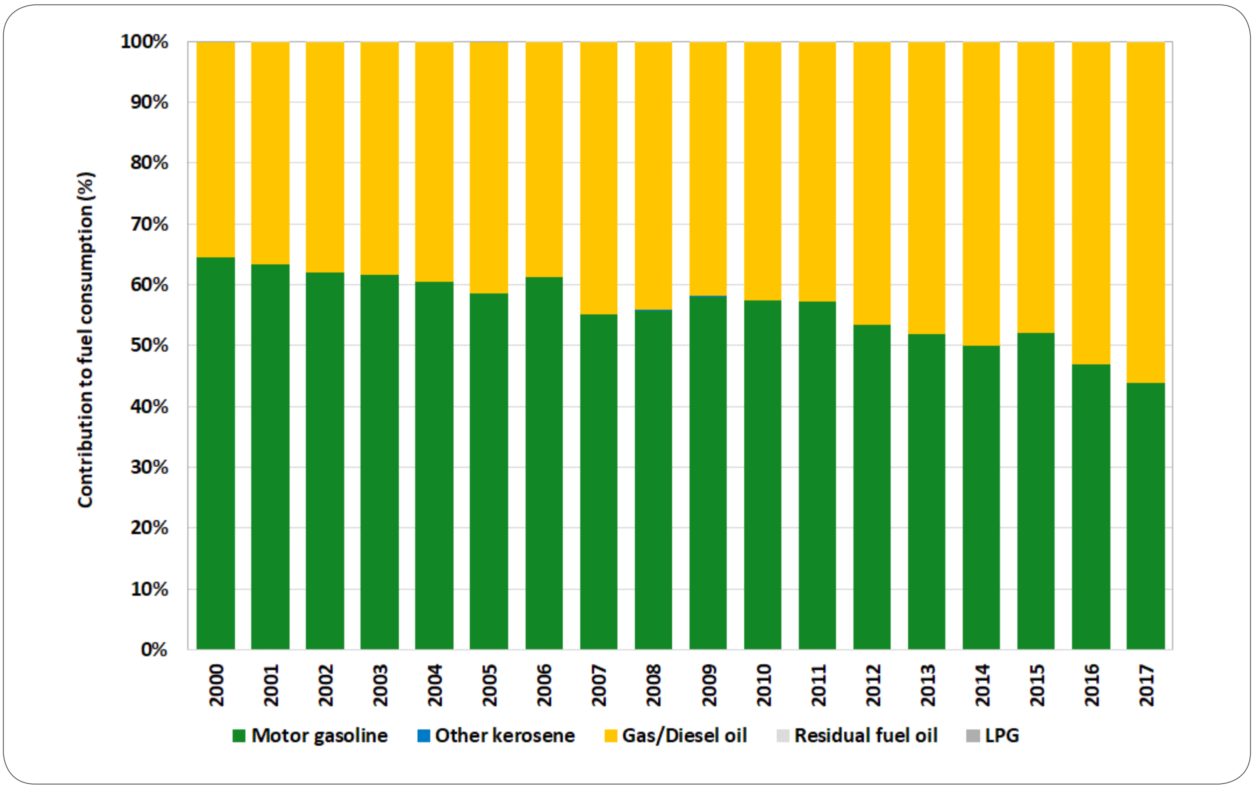

Figure 3.7: Percentage contribution of the various fuel types to fuel consumption in the road transport category (1A3b), 2000 – 2017.

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 DFFE 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 the 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 range 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 fuel consumption data. For Civil aviation, the jet kerosene data was updated for all years, while for Road transport it was the gas/diesel oil data and for Water-borne navigation the fuel oil consumption. These updates produced a transport emission estimate that was on average 8.5% higher than in the previous submission (Figure 3.8).

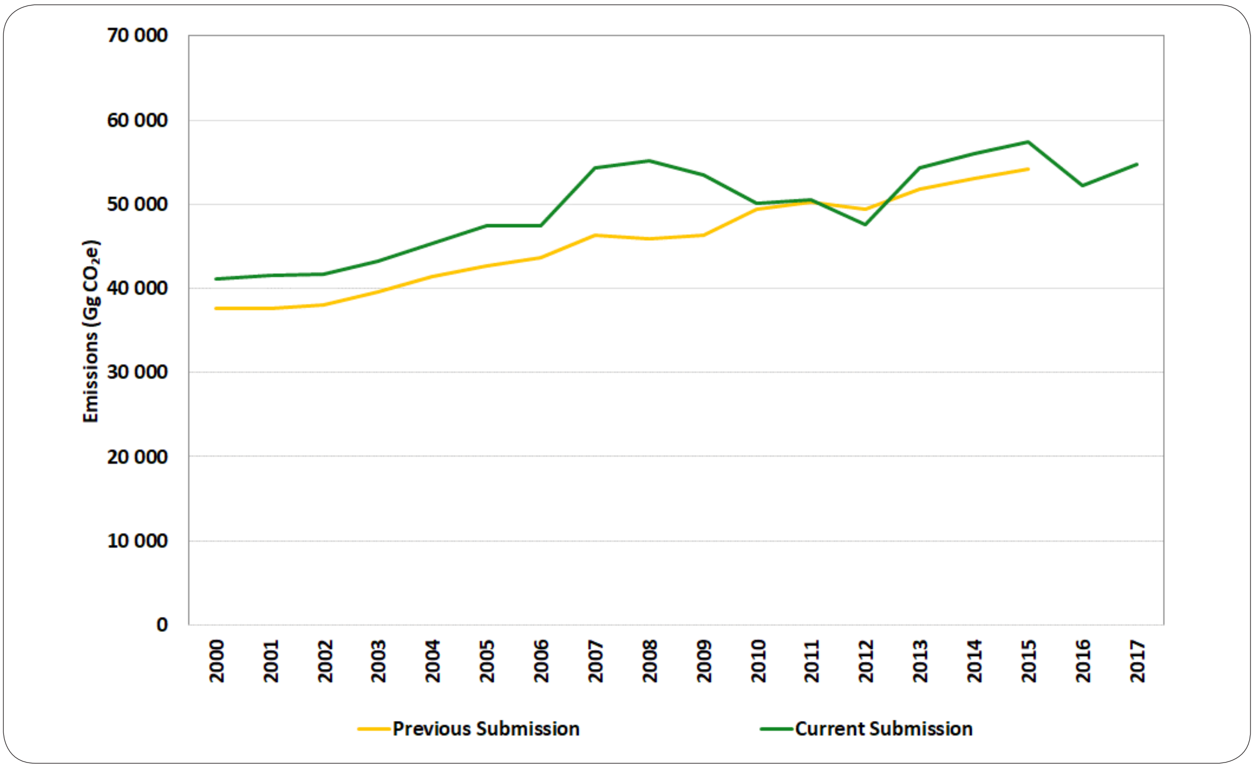

Figure 3.8: Recalculated transport emissions for 2000 to 2017, compared to 2015 submission estimates.

Emission factors

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. 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.

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

	Commercial/ Institutional	Residential	Agriculture/ Forestry/ Fishing/ Fish farms	Total
	Gg CO_2e			
2000	16 604.2	7 103.0	2 416.1	26 123.3
2001	14 010.0	9 231.2	2 503.0	25 744.2
2002	11 789.7	11 114.1	2 600.4	25 504.2
2003	11 501.8	12 309.4	2 726.4	26 537.7
2004	11 465.3	13 990.5	2 806.8	28 262.6
2005	9 714.5	15 023.0	2 791.9	27 529.3
2006	7 327.9	17 444.4	2 883.0	27 655.3
2007	3 815.8	21 389.9	3 137.4	28 343.1
2008	4 450.1	22 832.5	3 125.8	30 408.4
2009	9 853.9	24 283.5	3 244.0	37 381.3
2010	15 718.6	10 436.2	3 619.2	29 774.0
2011	4 841.9	12 075.2	3 841.7	20 758.8
2012	6 341.5	16 406.3	3 686.8	26 434.5
2013	8 178.3	19 247.5	3 883.6	31 309.3
2014	22 206.2	3 379.5	3 937.0	29 522.7
2015	20 560.6	3 236.5	4 010.9	27 808.0
2016	18 060.1	3 006.6	4 107.1	25 173.8
2017	30 209.8	3 533.0	4 279.5	38 022.3

Overview of shares and trends in emissions

2000 - 2017

The other sectors were estimated to produce 38 022 Gg CO_2e in 2017, which is 9.3% of the energy sector emissions. The largest contributor to this category was the commercial sector emissions (79.5%) followed by 11.2% from Agriculture/Forestry/ sector (Table 3.20). Total other sector emissions were 11 899 Gg CO_2e above the 2000 level of 26 123 Gg CO_2e (Table 3.20).

Change in emissions since 2015

Emissions in this subsector increased by 36.7% (10 214 Gg CO_2e) since 2015 due to a 46.9%, 9.2% and 6.7% increase in the *Commercial/institutional, Residential and Agriculture/ fishing/forestry/ fish farms* categories respectively.

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 3.9). Liquid fuels contributed the most to the fuel consumption in this sector.

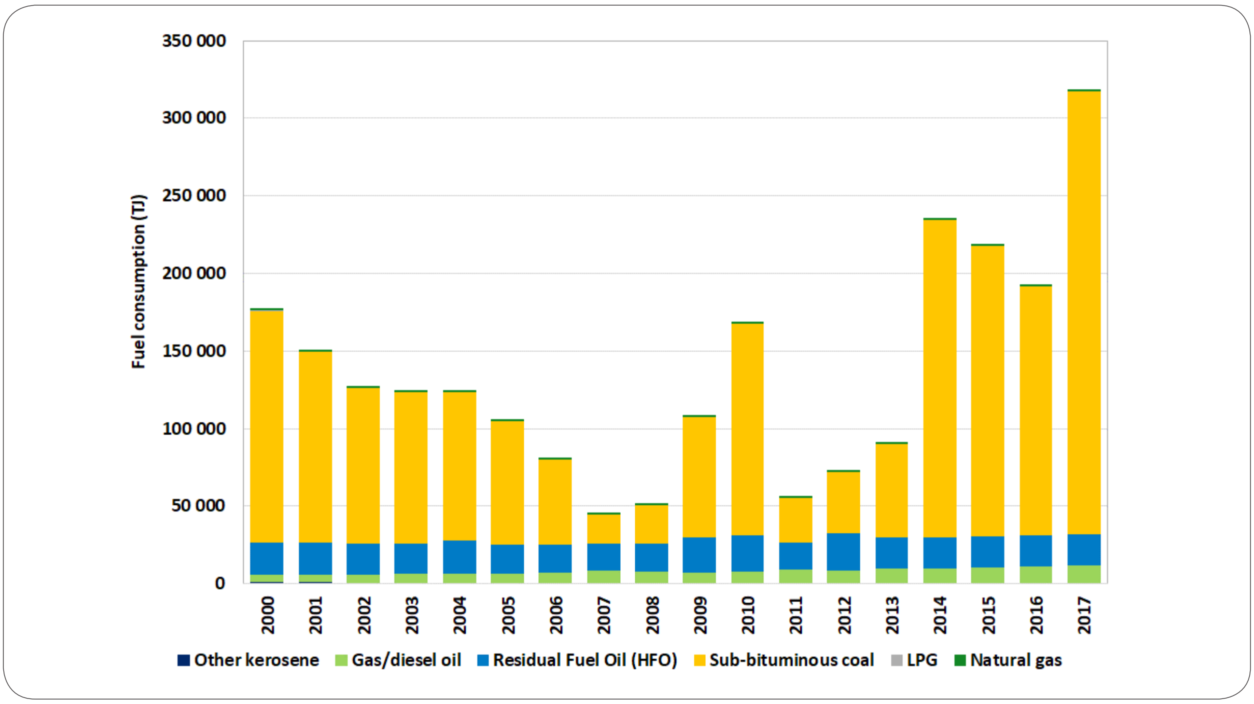

Figure 3.9: Fuel consumption in the commercial/institutional category, 2000 – 2017.

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), Fuel Consumption Study (DFFE,2019), 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 3.10) therefore the biomass fuel source declined. Domestic coal consumption increases over the time-series; however, the increase has slowed in the last 5 years.

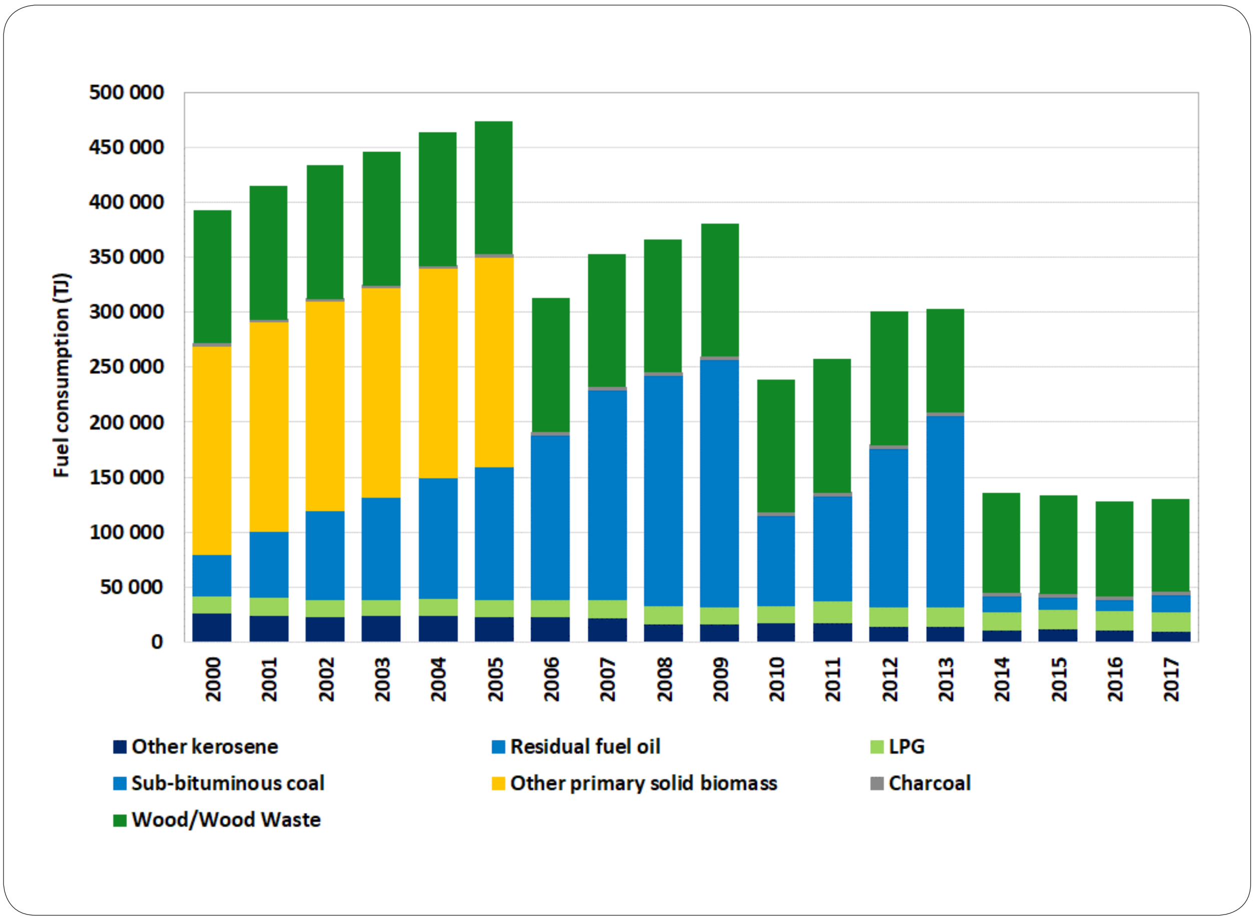

Figure 3.10: Trend in fuel consumption in the residential category, 2000 – 2017.

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 3.11).

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

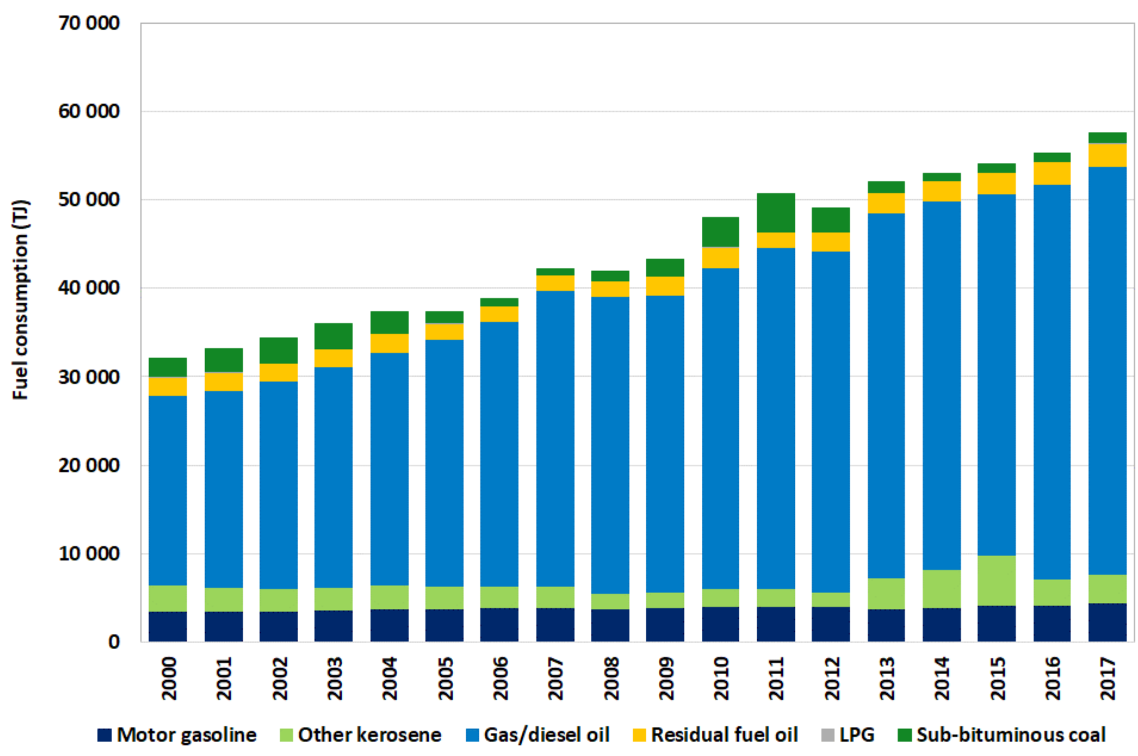

Figure 3.11: Trend in fuel consumption in the agriculture/forestry/fishing category, 2000 – 2017.

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, gas/diesel oil and sub-bituminous coal consumption data from the energy balance sheets. In addition, the LPG emission factors were corrected to IPCC defaults. These changes produced estimates for the Other sectors category that were on average 22% lower than in the previous submission.

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. Three fuels were reported under this category – namely motor gasoline, diesel, and coal.

Overview of shares and trends in emissions

2000 - 2017

The non-specified subsector was estimated to produce 9 726 Gg CO_2e in 2017, and these were 128% (5 469 Gg CO_2e) up from the 2000 level (4 257 Gg CO_2e). This category has shown a steady increase since 2000.

Change in emissions since 2015

Emissions in this subsector increased by 68% (3 944 Gg CO_2e) since 2015. The increase was due to more coal being attributed to this sector. During the same time coal usage tripled.

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. The coal consumption was taken from SAMI Reports (Department of Mineral Resources, 2017) while the diesel consumption was taken from the Department of Mineral Resources and Energy's energy balances.

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

Recalculations were performed for the entire time-series as gas diesel and sub-bituminous coal data was added to this category. These additions meant that emission estimates were on average 4 385 Gg CO_2e higher than the previous submission estimates.

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)

Overview of shares and trends in emissions

Total estimated *fugitive emissions* for 2017 were 30 143 Gg CO_2e. Net *solid fuel* emissions contributed 5.2% (1 571 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 92.7%.*

2000 - 2017

Overall *fugitive emissions* decreased by 8.6% (2 512 Gg CO_2e) between 2000 and 2017 (Figure 3.12, Table 3.21). There was a peak of emissions in 2004 (34 357 Gg CO_2e) due to an increase in *other emissions from energy production*, with an 11.2% decrease in 2005 (Figure 3.12). Emissions declined slightly until 2011, after which they increased to 2017.

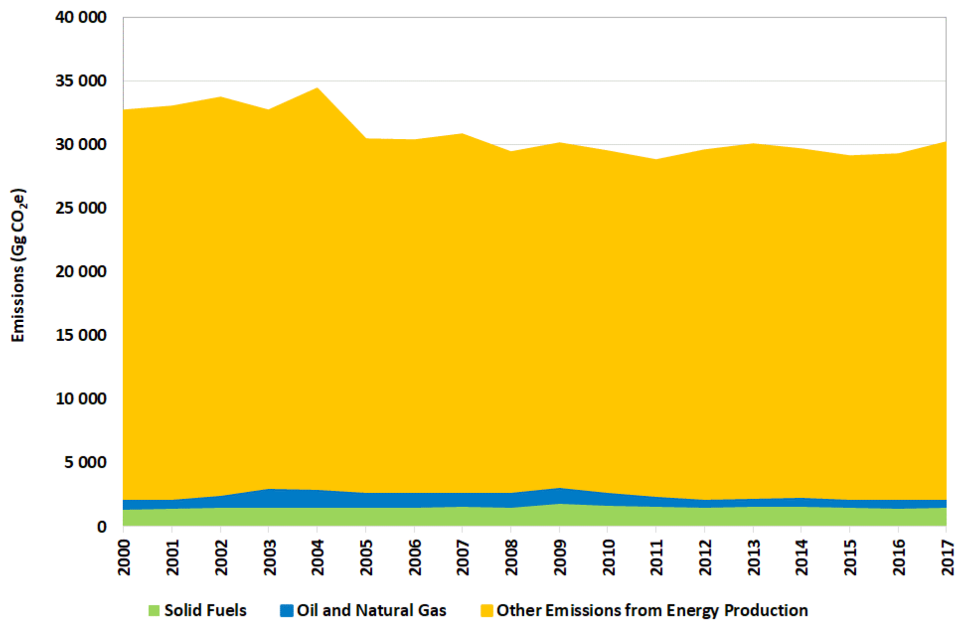

Figure 3.12: Trends in fugitive emissions from fuels, 2000 – 2017.

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

	Solid Fuels	Oil and Natural Gas	Other Emissions from Energy Production	Total
	Gg CO_2e			
2000	1 438.9	752.0	30 465.2	32 656.1
2001	1 475.2	752.9	30 690.9	32 919.0
2002	1 562.5	955.1	30 690.9	33 208.6
2003	1 577.5	1 458.0	29 589.0	32 624.5
2004	1 591.8	1 378.9	31 387.2	34 357.9
2005	1 590.5	1 160.1	27 662.5	30 413.1
2006	1 609.3	1 133.2	27 524.7	30 267.2
2007	1 641.8	1 132.7	27 973.6	30 748.1
2008	1 616.9	1 138.2	26 609.5	29 364.6
2009	1 915.4	1 243.4	26 912.9	30 071.7
2010	1 777.0	964.2	26 704.5	29 445.7
2011	1 630.6	785.8	26 319.8	28 736.2
2012	1 608.0	641.8	27 298.7	29 548.4
2013	1 635.9	641.8	27 705.1	29 982.8
2014	1 690.5	641.8	27 266.8	29 599.1
2015	1 573.9	641.8	26 826.6	29 042.3
2016	1 537.3	641.8	27 032.6	29 211.8
2017	1 571.0	641.8	27 930.4	30 143.1

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.

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.

Table 3.22: Data sources for the fugitive emissions subsector.

Sub-category	Activity data	Data source
Coal mining and handling	Coal production	SAMI (2015)
Oil and natural gas (flaring)	Production	CoalTech, SAMI (2009) – SAMI (2017)
Other emissions from energy production	Production	Refineries

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

3.3.2 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 1 571 Gg CO_2e in 2017, which is 0.4% of the energy sector emissions. Emissions were 132 Gg CO_2e (39%) higher than the 2000 estimate. Emissions increased by 23.5% between 2000 and 2010, then there was an 8.0% and 1.4% decrease to 2011 and 2012, respectively (Table 3.24). After 2012 emission levels remained constant to 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	17.9	67.7	1 438.9
2001	18.4	69.4	1 475.2
2002	19.4	73.5	1 562.5
2003	19.6	74.2	1 577.5
2004	19.8	74.9	1 591.8
2005	19.8	74.8	1 590.5
2006	20.0	75.7	1 609.3
2007	20.4	77.2	1 641.8
2008	20.1	76.0	1 616.9
2009	23.8	90.1	1 915.4
2010	22.1	83.6	1 777.0
2011	20.3	76.7	1 630.6
2012	20.0	75.6	1 608.0
2013	20.4	76.9	1 635.9
2014	21.0	79.5	1 690.5
2015	19.6	74.0	1 573.9
2016	19.1	72.3	1 537.3
2017	19.5	73.9	1 571.0

Change in emissions since 2015

Emissions in this subsector decreased by 3 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 (average of 62.20% surface mining and 37.8% underground mining) was based on the SAMI reports from 2009 to 2017 ((Department of Mineral Resources, 2017) for 2013. The split changed slightly from year to year from 2009 to 2017. The average split was used for the years 2000 – 2008 as there was no actual split data in those years.

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

	Underground	Opencast
	Coal produced (tonne)	
2000	106 308 704	174 918 853
2001	108 990 110	179 330 802
2002	115 444 975	189 951 547
2003	116 549 508	191 768 929
2004	117 605 558	193 506 539
2005	117 509 553	193 348 574
2006	118 901 619	195 639 060
2007	121 301 252	199 587 383
2008	119 464 910	196 565 890
2009	141 515 800	175 784 200
2010	131 286 250	186 213 750
2011	120 472 200	195 727 800
2012	118 800 000	211 200 000
2013	120 864 900	210 635 100
2014	124 900 360	213 399 640
2015	116 283 600	207 716 400
2016	113 583 645	205 516 355
2017	116 066 400	212 733 600

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).

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.

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

Table 3.26: Emission factors for coal mining and handling.

Mining method	Activity	GHG	Emission factor (m^3 $tonne^{-1}$)	
			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

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

Recalculations were completed for the full time-series due to updated coal production figures. These updates led to estimates that were on average 17.4% lower than previous estimates for 2000 to 2010 (Figure 3.13).

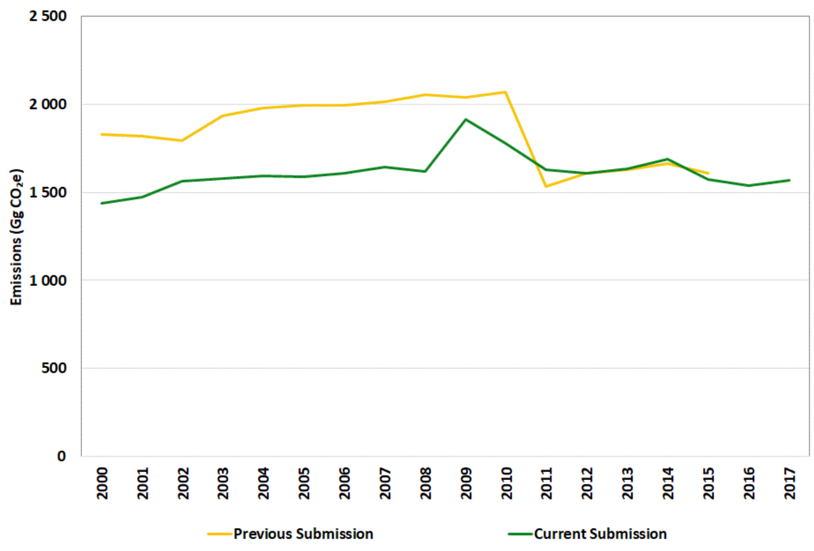

Figure 3.13: Recalculations for Solid fuels for 2000 to 2017.

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 2019 inventory these will be separated from process emissions and reported separately.

3.3.3 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 0.2% of the *energy* sector emissions. Emissions were 110 Gg CO_2e (14.7%) below the 2000 level (752 Gg CO_2e) (Table 3.27).

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 CH4 and formation CO2 (CO2 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.

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

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. In addition, IPCC splicing techniques for improving the extrapolation of activity data will be considered.

3.3.4 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 6.8% 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 entire time-series was undertaken due to the updated charcoal production data. Between 2000 and 2007 the recalculations resulted in a 0.1% increase in the estimates, while emission estimates were 1.1% lower than the previous submission for the years 2008 to 2012 (Figure 3.14). In 2013 the recalculated value was 12.1% 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 PetroSA.

Planned improvements and recommendations

No improvements are planned for this section.

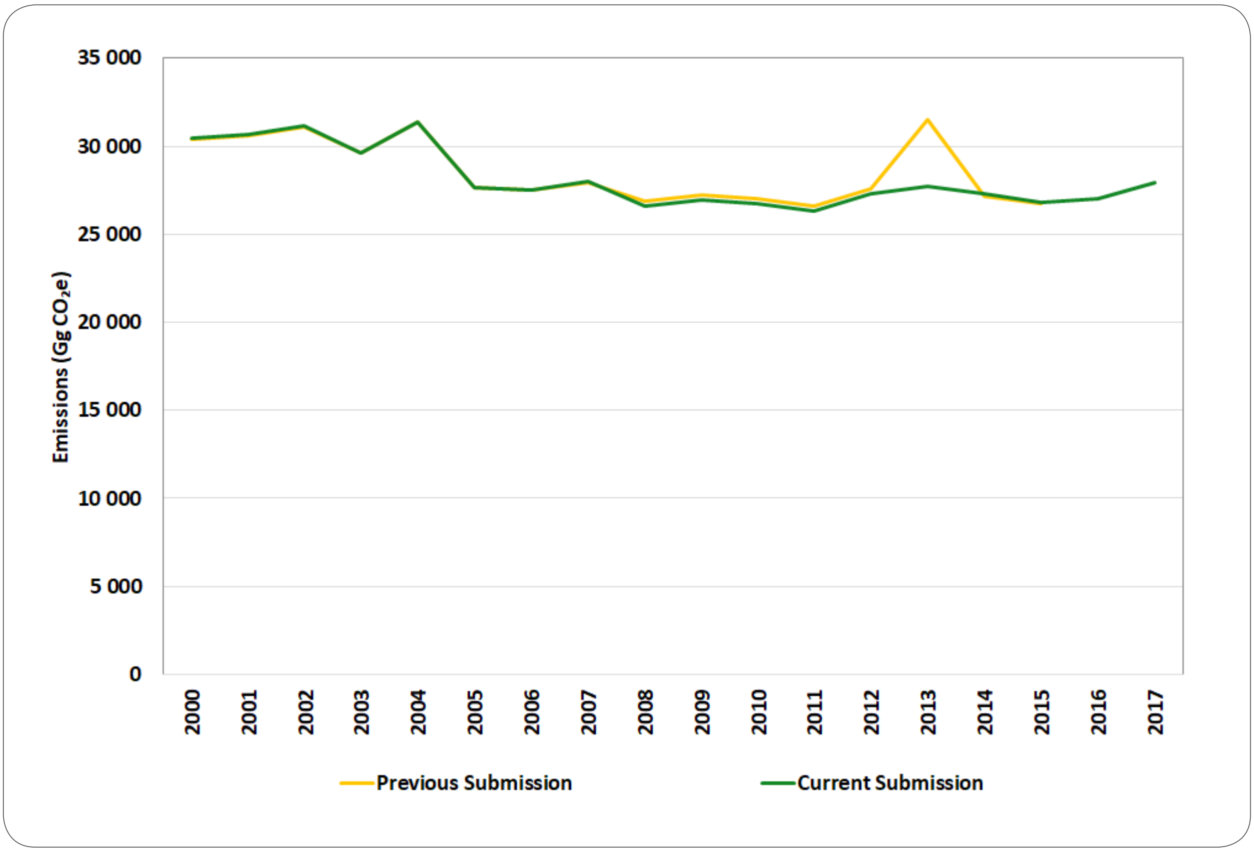

Figure 3.14: Recalculations for Other emissions from energy production for 2000 to 2017.

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	**403 971.03**	**196.43**	**8.35**	**0.00**	**0.00**	**0.00**	**0.00**	**410 685.26**
1.A - Fuel Combustion Activities	377 563.19	18.55	8.35	0.00	0.00	0.00	0.00	380 542.11
1.A.1 - Energy Industries	248 093.63	2.72	3.82	0.00	0.00	0.00	0.00	249 333.65
1.A.1.a - Main Activity Electricity and Heat Production	215 396.16	2.27	3.35	NE	NE	NE	NE	216 481.54
1.A.1.a.i - Electricity Generation	215 396.16	2.27	3.35	NE	NE	NE	NE	216 481.54
1.A.1.a.ii - Combined Heat and Power Generation (CHP)	IE	IE	IE	NE	NE	NE	NE	0.00
1.A.1.a.iii - Heat Plants	NE	NE	NE	NE	NE	NE	NE	0.00
1.A.1.b - Petroleum Refining	3 328.03	0.07	0.01	NE	NE	NE	NE	3 332.99
1.A.1.c - Manufacture of Solid Fuels and Other Energy Industries	29 369.45	0.37	0.46	NE	NE	NE	NE	29 519.13
1.A.1.c.i - Manufacture of Solid Fuels	29 369.45	0.37	0.46	NE	NE	NE	NE	29 519.13
1.A.1.c.ii - Other Energy Industries	NE	NE	NE	NE	NE	NE	NE	NE
1.A.2 - Manufacturing Industries and Construction	28 645.29	0.47	0.36	0.00	0.00	0.00	0.00	28 765.51
1.A.2.a - Iron and Steel				NE	NE	NE	NE	0.00
1.A.2.b - Non-Ferrous Metals				NE	NE	NE	NE	0.00
1.A.2.c - Chemicals				NE	NE	NE	NE	0.00
1.A.2.d - Pulp, Paper and Print				NE	NE	NE	NE	0.00

Categories	Emissions (Gg)							Emissions
	CO_2	CH_4	N_2O	NOx	CO	NMVOCs	SO_2	(Gg CO_2e)
1.A.2.e - Food Processing, Beverages and Tobacco				NE	NE	NE	NE	0.00
1.A.2.f - Non-Metallic Minerals				NE	NE	NE	NE	0.00
1.A.2.g - Transport Equipment				NE	NE	NE	NE	0.00
1.A.2.h - Machinery				NE	NE	NE	NE	0.00
1.A.2.i - Mining (excluding fuels) and Quarrying				NE	NE	NE	NE	0.00
1.A.2.j - Wood and wood products				NE	NE	NE	NE	0.00
1.A.2.k - Construction				NE	NE	NE	NE	0.00
1.A.2.l - Textile and Leather				NE	NE	NE	NE	0.00
1.A.2.m - Non-specified Industry				NE	NE	NE	NE	0.00
1.A.3 - Transport	53 597.63	12.00	2.73	0.00	0.00	0.00	0.00	54 694.55
1.A.3.a - Civil Aviation	1 522.07	0.06	0.01	NE	NE	NE	NE	1 527.38
1.A.3.a.i - International Aviation (International Bunkers) (MEMO ITEM)	4 929.14	0.21	0.04	NE	NE	NE	NE	4 946.30
1.A.3.a.ii - Domestic Aviation	1 522.07	0.06	0.01	NE	NE	NE	NE	1 527.38
1.A.3.b - Road Transportation	51 277.12	11.88	2.55	NE	NE	NE	NE	52 318.43
1.A.3.b.i - Cars				NE	NE	NE	NE	0.00
1.A.3.b.i.1 - Passenger cars with 3-way catalysts				NE	NE	NE	NE	0.00
1.A.3.b.i.2 - Passenger cars without 3-way catalysts				NE	NE	NE	NE	0.00
1.A.3.b.ii - Light-duty trucks				NE	NE	NE	NE	0.00
1.A.3.b.ii.1 - Light-duty trucks with 3-way catalysts				NE	NE	NE	NE	0.00

Categories	Emissions (Gg)							Emissions
	CO_2	CH_4	N_2O	NOx	CO	NMVOCs	SO_2	(Gg CO_2e)
1.A.3.b.ii.2 - Light-duty trucks without 3-way catalysts				NE	NE	NE	NE	0.00
1.A.3.b.iii - Heavy-duty trucks and buses				NE	NE	NE	NE	0.00
1.A.3.b.iv - Motorcycles				NE	NE	NE	NE	0.00
1.A.3.b.v - Evaporative emissions from vehicles				NE	NE	NE	NE	0.00
1.A.3.b.vi - Urea-based catalysts				NE	NE	NE	NE	0.00
1.A.3.c - Railways	442.77	0.02	0.15	NE	NE	NE	NE	490.27
1.A.3.d - Water-borne Navigation	355.66	0.03	0.01	NE	NE	NE	NE	358.47
1.A.3.d.i - International water-borne navigation (International bunkers) (MEMO ITEM)	1 674.41	0.15	0.04	NE	NE	NE	NE	1 691.45
1.A.3.d.ii - Domestic Water-borne Navigation	355.66	0.03	0.01	NE	NE	NE	NE	358.47
1.A.3.e - Other Transportation				NE	NE	NE	NE	0.00
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	37 547.25	3.22	1.31	0.00	0.00	0.00	0.00	38 022.31
1.A.4.a - Commercial/ Institutional	29 930.40	0.38	0.88	NE	NE	NE	NE	30 209.82
1.A.4.b - Residential	3 352.40	2.66	0.40	NE	NE	NE	NE	3 532.98
1.A.4.c - Agriculture/ Forestry/Fishing/Fish Farms	4 264.45	0.17	0.04	NE	NE	NE	NE	4 279.51
1.A.4.c.i - Stationary	4 264.45	0.17	0.04	NE	NE	NE	NE	4 279.51
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	9 679.39	0.15	0.14	0.00	0.00	0.00	0.00	9 726.09

Categories	Emissions (Gg)							Emissions
	CO_2	CH_4	N_2O	NOx	CO	NMVOCs	SO_2	(Gg CO_2e)
1.A.5.a - Stationary	9 679.39	0.15	0.14	NE	NE	NE	NE	9 726.09
1.A.5.b - Mobile				NE	NE	NE	NE	0.00
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)								0.00
1.B - Fugitive emissions from fuels	**26 407.84**	**177.87**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**30 143.15**
1.B.1 - Solid Fuels	19.55	73.88		0.00	0.00	0.00	0.00	1 570.95
1.B.1.a - Coal mining and handling	19.55	73.88		NE	NE	NE	NE	1 570.95
1.B.1.a.i - Underground mines	19.55	73.88		NE	NE	NE	NE	1 570.95
1.B.1.a.i.1 - Mining	15.85	59.88		NE	NE	NE	NE	1 273.30
1.B.1.a.i.2 - Post-mining seam gas emissions	3.70	14.00		NE	NE	NE	NE	297.65
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	0.00	0.00		NE	NE	NE	NE	0.00
1.B.1.a.ii.1 - Mining	0.00	0.00		NE	NE	NE	NE	0.00
1.B.1.a.ii.2 - Post-mining seam gas emissions	0.00	0.00		NE	NE	NE	NE	0.00
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	641.83	0.00	0.00	0.00	0.00	0.00	0.00	641.83
1.B.2.a - Oil	641.83	0.00	0.00	NE	NE	NE	NE	641.83

Categories	Emissions (Gg)							Emissions
	CO_2	CH_4	N_2O	NOx	CO	NMVOCs	SO_2	(Gg CO_2e)
I.B.2.a.i - Venting	NE	NE		NE	NE	NE	NE	NE
I.B.2.a.ii - Flaring	641.83	NE		NE	NE	NE	NE	NE
I.B.2.a.iii - All Other				NE	NE	NE	NE	0.00
I.B.2.a.iii.1 - Exploration				NE	NE	NE	NE	0.00
I.B.2.a.iii.2 - Production and Upgrading				NE	NE	NE	NE	0.00
I.B.2.a.iii.3 - Transport				NE	NE	NE	NE	0.00
I.B.2.a.iii.4 - Refining				NE	NE	NE	NE	0.00
I.B.2.a.iii.5 - Distribution of oil products				NE	NE	NE	NE	0.00
I.B.2.a.iii.6 - Other				NE	NE	NE	NE	0.00
I.B.2.b - Natural Gas				NE	NE	NE	NE	0.00
I.B.2.b.i - Venting				NE	NE	NE	NE	0.00
I.B.2.b.ii - Flaring				NE	NE	NE	NE	0.00
I.B.2.b.iii - All Other				NE	NE	NE	NE	0.00
I.B.2.b.iii.1 - Exploration				NE	NE	NE	NE	0.00
I.B.2.b.iii.2 - Production				NE	NE	NE	NE	0.00
I.B.2.b.iii.3 - Processing				NE	NE	NE	NE	0.00
I.B.2.b.iii.4 - Transmission and Storage				NE	NE	NE	NE	0.00
I.B.2.b.iii.5 - Distribution				NE	NE	NE	NE	0.00
I.B.2.b.iii.6 - Other				NE	NE	NE	NE	0.00
I.B.3 - Other emissions from Energy Production	25 746.47	104.00	NE	NE	NE	NE	NE	NE
I.C - Carbon dioxide Transport and Storage	**0.00**			**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
I.C.1 - Transport of CO_2	0.00			0.00	0.00	0.00	0.00	0.00
I.C.1.a - Pipelines	NE			NE	NE	NE	NE	NE
I.C.1.b - Ships	NE			NE	NE	NE	NE	NE
I.C.1.c - Other (please specify)	NE			NE	NE	NE	NE	NE
I.C.2 - Injection and Storage	0.00			0.00	0.00	0.00	0.00	0.00

Categories	Emissions (Gg)							Emissions
	CO_2	CH_4	N_2O	NOx	CO	NMVOCs	SO_2	(Gg CO_2e)
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	0.00			0.00	0.00	0.00	0.00	0.00

APPENDIX 3.B REFERENCE AND SECTORAL FUEL CONSUMPTION

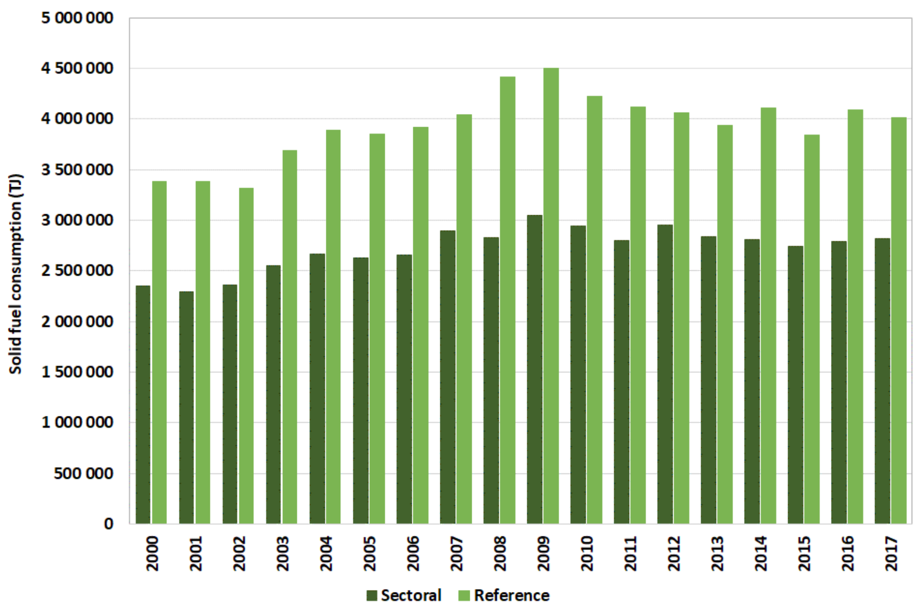

Figure 3.B.1: Comparisons between the solid fuel consumption determined by the reference and sectoral approaches, 2000 – 2017.

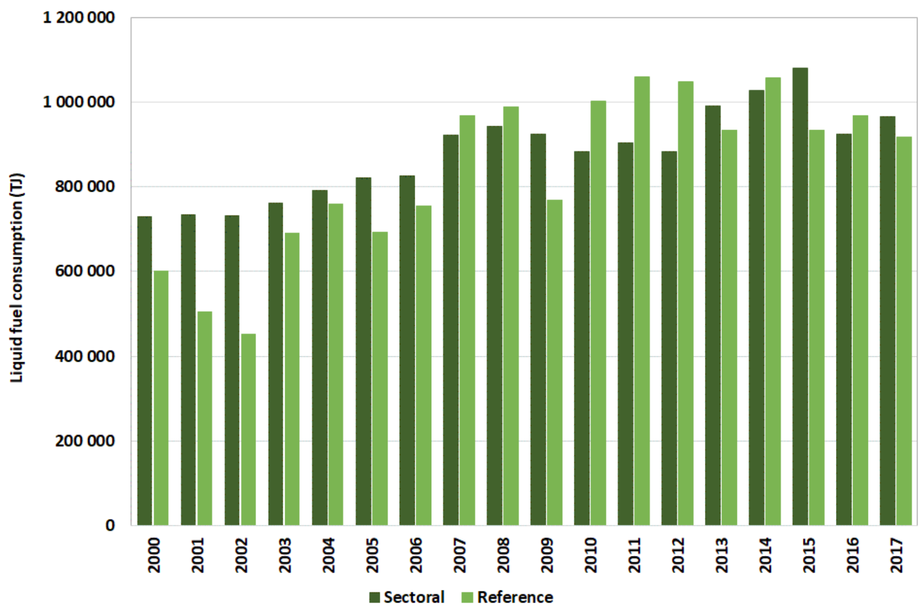

Figure 3.B.2: Comparisons between the liquid fuel consumption determined by the reference and sectoral approaches, 2000 – 2017.

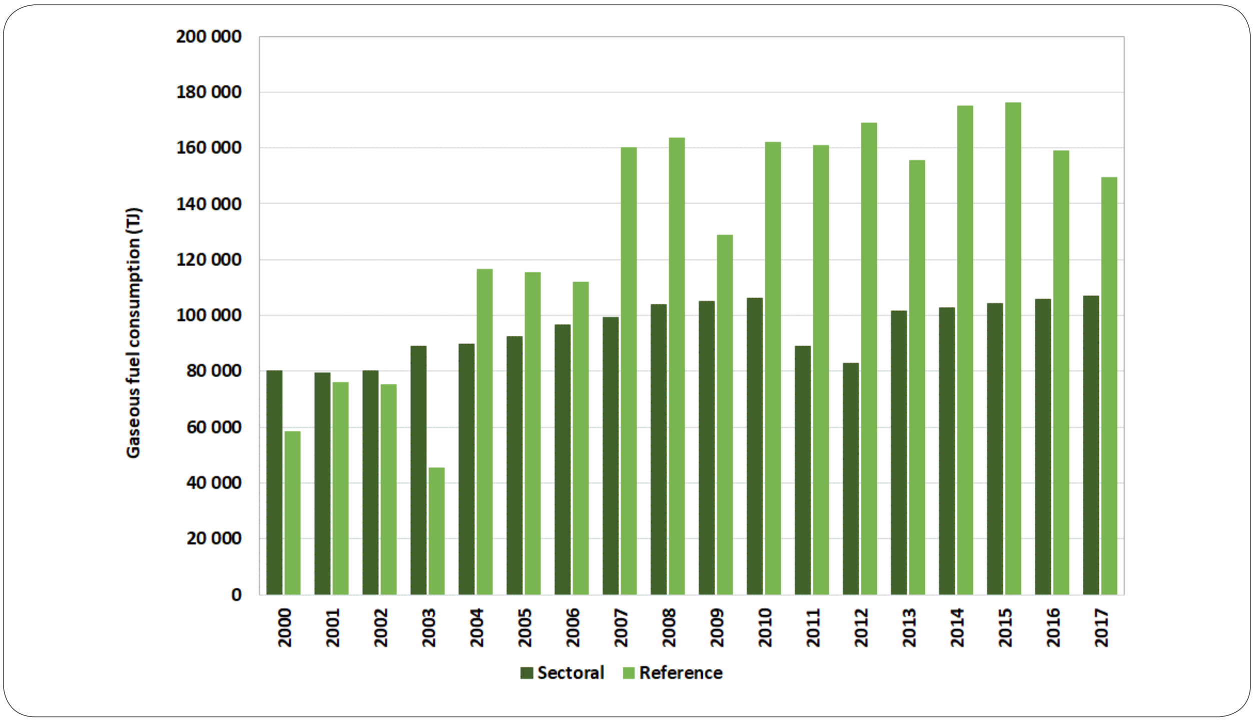

Figure 3.B.3: Comparisons between the gaseous fuel consumption determined by the reference and sectoral approaches, 2000 – 2017.

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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 many 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 (85.7%), fluorinated gases (12.9%) 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 2017 the IPPU sector produced 32 085 Gg CO_2e. The largest source category is the *metal industry* category, which contributes 63.5% 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 7 725 Gg CO_2 (24.1%) and 11 330 Gg CO_2 (35.3%) respectively to the total metal industry CO_2 emissions. The *mineral industry* and the *product uses as substitute ODS* subsectors contribute 19.5% and 12.5%, respectively, to the IPPU sector emissions (Table 4.1), with all the emissions from the product uses as substitute ODS being HFCs. *Ferroalloy production, carbon black production* and *ammonia production* produce a small amount (168 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_2	Gg	Gg CO_2e	Gg	Gg CO_2e	Gg CO_2e	Gg CO_2e	Gg CO_2e
2.IPPU	**27 496.0**	**8.0**	**168.4**	**0.9**	**292.6**	**4 014.5**	**113.1**	**32 084.6**
2.A Mineral industry	6 257.3	NE	NE	NE	NE	NE	NE	6 257.3
2.B Chemical industry	433.6	7.9	167.3	0.9	292.6	NE	NE	893.4
2.C Metal industry	20 274.5	0.1	1.1	NE	NE	NE	113.1	20 388.7
2.D Non-energy products from fuels and solvents	530.6	NE	NE	NE	NE	NA	NA	530.6
2.E Electronic industry	NE	NA	NA	NE	NE	NE	NE	NE
2.F Product uses as substitute ODS	NE	NA	NA	NA	NA	4 014.5	NE	4 014.5
2.G Other product manufacture and use	NE	NE	NE	NE	NE	NE	NE	NE
2.H Other	NE	NE	NE	NE	NE	NE	NE	NE

Numbers may not sum exactly due to rounding off.

2000 – 2017

Estimated emissions from the *IPPU* sector are 903 Gg CO_2e (2.7%) lower than the emissions in 2000 (Table 4.2). This was mainly due to the 20.5% decrease in the metal industry emissions and the 67.8% decrease in the *chemical industry* emissions (Table 4.3). In the metal industry *Ferroalloy production* increased by 3 247 Gg CO_2e while *Iron and steel production* emissions declined by 7 609 Gg CO_2e.

Table 4.2: Summary of the change in emissions in 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	**32 987.3**	**32 084.6**	**-902.7**	**-2.7**
2.A Mineral industry	4 379.0	6 257.3	1 878.3	42.9
2.B Chemical industry	2 773.6	893.4	-1 880.2	-67.8
2.C Metal industry	25 638.8	20 388.7	-5 250.1	-20.5
2.D Non-energy products from fuels and solvents	195.9	530.6	334.7	170.8
2.E Electronic industry	NE	NE	NE	NE
2.F Product uses as substitute ODS	NE	4 014.5	4 014.5	
2.G Other product manufacture and use	NE	NE	NE	NE
2.H Other	NE	NE	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 manufacture and use	Total
	Gg CO_2e							
2000	4 379.0	2 773.6	25 638.8	195.9	NE	0.0	NE	32 987.3
2001	4 286.1	2 715.1	26 010.2	226.0	NE	0.0	NE	33 237.4
2002	4 805.0	2 744.0	27 420.6	250.3	NE	0.0	NE	35 219.9
2003	5 075.9	2 169.1	27 026.1	248.6	NE	0.0	NE	34 519.7
2004	4 972.9	2 472.6	26 937.5	246.2	NE	0.0	NE	34 629.1
2005	5 713.1	2 973.6	27 842.7	467.9	NE	841.8	NE	37 839.0
2006	6 106.4	2 746.8	28 508.0	509.2	NE	1 045.4	NE	38 915.7
2007	6 041.8	1 969.0	27 664.5	5 773.5	NE	1 063.4	NE	42 512.2
2008	6 265.8	1 226.4	26 415.8	5 435.5	NE	1 026.0	NE	40 369.5
2009	6 550.6	1 068.2	24 486.6	5 733.9	NE	992.0	NE	38 831.4
2010	5 873.1	1 021.2	26 449.1	59.1	NE	2 065.8	NE	35 468.2
2011	5 674.3	1 070.9	29 964.8	543.4	NE	2 274.4	NE	39 527.8
2012	5 419.8	931.3	28 749.4	1 042.8	NE	2 527.6	NE	38 670.9
2013	5 655.5	1 152.2	30 020.9	524.8	NE	2 852.5	NE	40 205.9
2014	5 712.6	766.9	28 522.5	718.9	NE	3 065.6	NE	38 786.6
2015	6 119.1	1 071.8	28 005.0	2 495.4	NE	3 482.1	NE	41 173.3
2016	6 397.1	2 283.0	27 095.4	472.9	NE	3 715.1	NE	39 963.6
2017	6 257.3	893.4	20 388.7	530.6	NE	4 014.5	NE	32 084.6

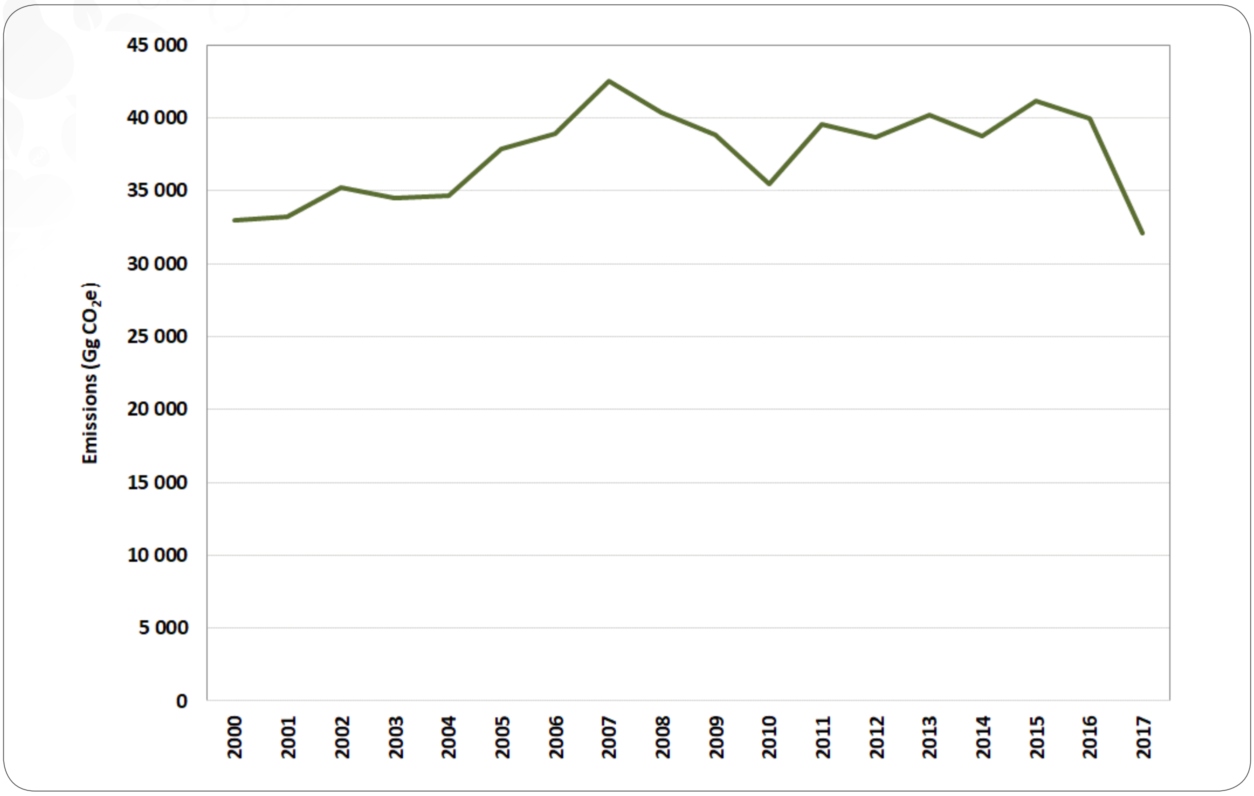


Figure 4.1: Trend in South Africa's IPPU sector emissions, 2000 – 2017.

Figure 4.1 shows that IPPU emissions increased by 28.9% between 2000 and 2007, after which there was a 16.6% decline to 2010. This decrease was mainly due to the global economic recession and the electricity crisis that occurred in South Africa during that period. In 2011 emissions increased again. The economy was beginning to recover from the global recession. Emissions stabilised between 2011 and 2016. Between 2016 and 2017 there is a 22.3% decline in emissions, and this is mostly due to a 42.8% decline in the pig iron production in the Iron and steel sub-category. In recent years companies have been reporting data through the SAGERS system due to the GHG regulation and this data is starting to be included in the inventory. In 2017 the Iron and steel industries showed a change in allocation of production data, with a much-reduced production from pig iron and direct reduced iron, but production data for sinter which was not previously report was included. The emission factor for sinter is much lower than for pig iron and direct reduced iron and hence the reduction in emissions in 2017.

2015 – 2017

IPPU emissions showed a decrease of 22.1% (9 088 Gg CO_2e) between 2015 and 2017. The main contributors to this decrease were the *Iron and steel production* and *Ferroalloy production* categories which decreased by 42.1% (5 609 Gg CO_2e) and 14.6% (1 942 Gg CO_2e) respectively, over this period. The *mineral industry* emissions increased by 2.3% (138 Gg CO_2e) between 2015 and 2017, and the *metal industry* showed an overall decrease of 27.2% (7 616 Gg CO_2e). Again, this reduction may not be a true reduction in emissions but is partly due to a change in the activity data source during this time.

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	T2	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	**Manufacturing industries and construction**										
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	T1	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	**Agriculture/Forestry/ Fishing/Fish farms**										
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	

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
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		T2a/ T2b	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

Recalculations were performed for the entire time-series. The emission estimates for the IPPU sector are lower than the previous estimates for the years 2000 to 2006 and 2010 onwards, whereas estimates were higher between 2007 and 2009 (Figure 4.2). These changes were due to the following recalculations:

- *Mineral Industry* showed a 0.6% reduction in emissions due to:
  - updated Cement production activity data; and
  - the application of the hydrated lime emission factor;
- *Chemical Industry* had an emission estimate that was 17.3% below the previous submission for 2014 and a 7.0% higher estimate for 2015 relative to the last submission and this was due to:
  - updated Carbide production activity data for 2014 onwards;
  - updated Titanium dioxide production activity data; and
  - updated Carbon black production activity data for 2015;
- *Metal Industry* showed a 2.7% to 4.4% lower emission estimate between 2000 and 2013, with a 10.4% and

9.5% reduction in the estimates for 2014 and 2015 respectively, due to:

- a correction in the direct reduced iron and sinter emission factors for Iron and steel production;
- an update the emission factor for emissions from the Corex process (included under the Other category for Steel and iron production);
- updated activity data for ferrosilicon 65% Si production for 2015 onwards;
- updated activity data for Aluminium production for 2014 onwards; and
- updated activity data for Lead and Zinc production for 2013 onwards;

- *Non-energy products from fuels and solvent use* showed a might higher emission estimate (by an average of 5 418 Gg CO_2e) between 2007 and 2009, and an average of 458 Gg CO_2e between 2011 and 2014 compared to previous submission due to:
  - improved energy balance activity data for lubricants and paraffin wax.

The specific details of the recalculations for the various sub-categories are provided in the sections below.

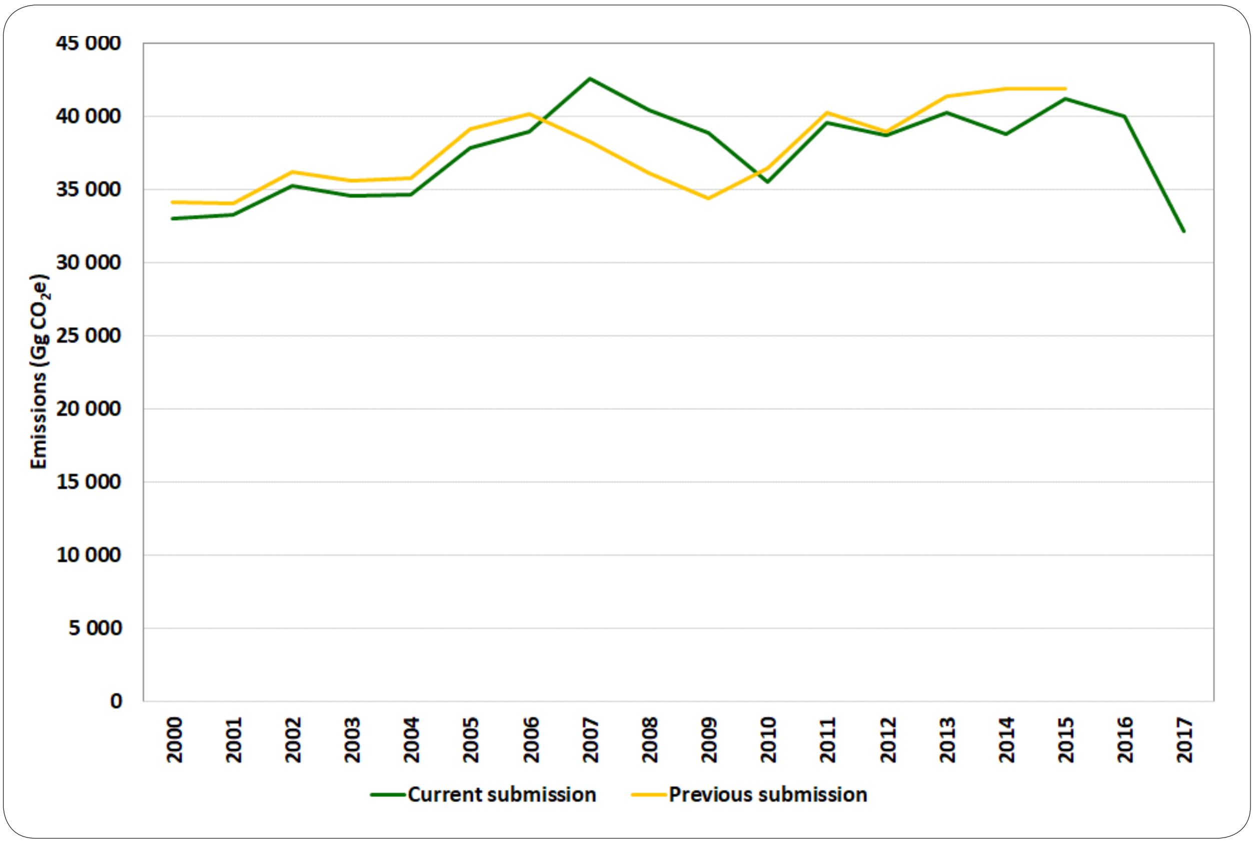


Figure 4.2: Recalculations for the IPPU sector since the 2015 submission.

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.

4.1.6 Planned improvements

Due to the recent introduction of the NGER companies will be reporting data and emissions through the SAGERS system. In this inventory data from the SAGERS has started to be incorporated, but further data will be included in the next inventory.

Table 4.5: Key categories identified in the IPPU sector.

IPCC Code	Category	GHG	Identification Criteria
2A1	Cement Production	CO_2	L1,T1
2A2	Lime Production	CO_2	T1
2B3	Nitric acid production	N_2O	T1
2B6	Titanium dioxide production	CO_2	T1
2C1	Iron and Steel Production	CO_2	L1,T1
2C2	Ferroalloys Production	CO_2	L1,T1
2C3	Aluminium Production	PFCs	T1
2F1	Refrigeration and Air Conditioning	HFCs	L1,T1

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 6 257 Gg CO_2, which is 19.5% of the IPPU sector emissions. *Cement production* accounted for 83.8% of these emissions. All the emissions in this category were CO_2 emissions.

2000 – 2017

The emissions were 42.9% (1 878 Gg CO_2) higher than the 4 386 Gg CO_2 in 2000. There was a 49.6% increase in the *mineral industry* emissions between 2000 and 2009, after which emissions declined by 17.3% to 1 131 Gg CO_2 in 2012 (Figure 4.3). The increase between 2000 and 2009 was due to increased emissions from *cement production* because 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 838 Gg CO_2 (15.5%) due mainly to increasing *cement production*.

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

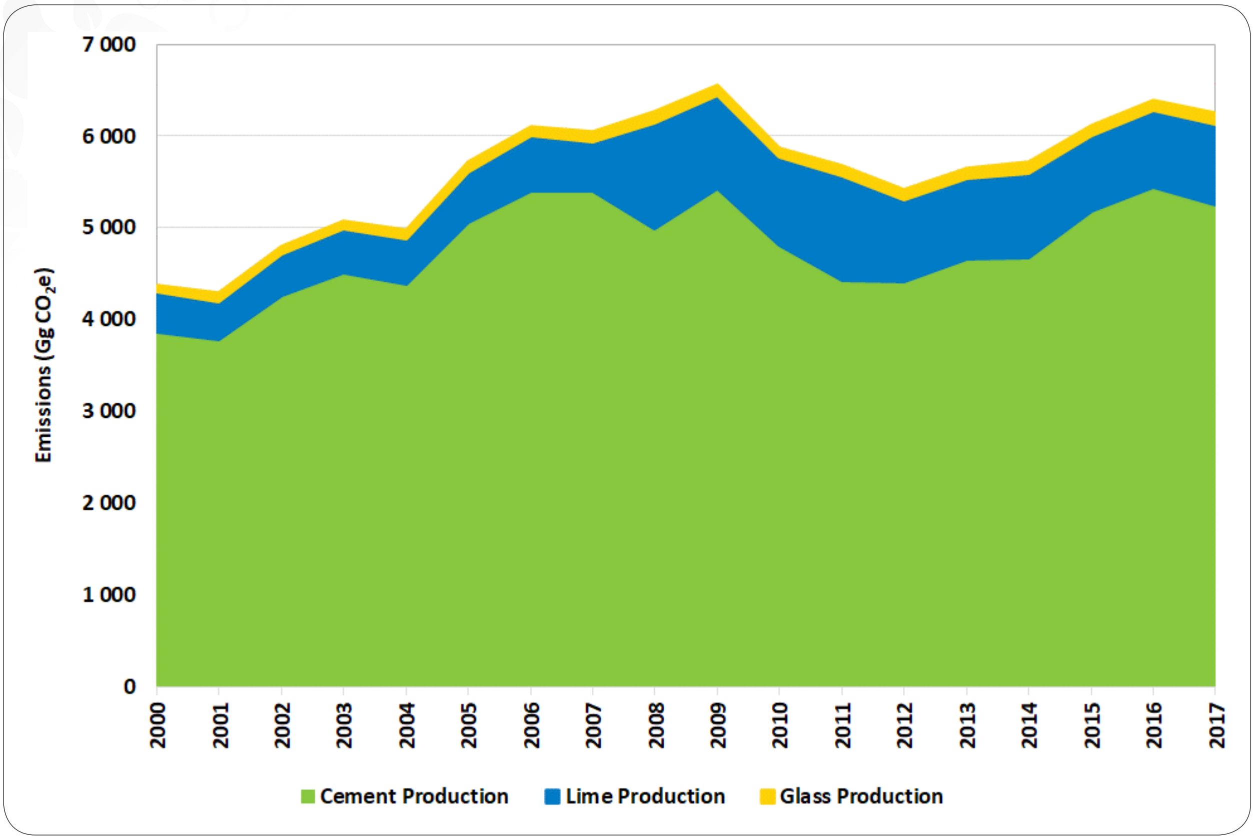


Figure 4.3: Category contribution and trend for the mineral subsector, 2000 – 2017.

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	434.1	74.4
2001	3 783.0	418.7	84.4
2002	4 258.4	458.3	88.3
2003	4 514.6	470.0	91.3
2004	4 390.1	486.9	95.9
2005	5 061.5	549.2	102.4
2006	5 399.8	604.8	101.8
2007	5 407.7	529.1	105.0
2008	4 988.6	1 159.9	117.4
2009	5 432.1	1 008.7	109.8
2010	4 819.0	950.2	103.9
2011	4 432.8	1 135.4	106.1
2012	4 414.5	891.4	113.9
2013	4 665.0	876.6	113.9
2014	4 678.2	920.5	113.9
2015	5 181.1	824.0	113.9
2016	5 447.3	830.5	119.2
2017	5 246.4	890.0	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.

IPCC Code	Category	GHG
Cement production	Cement produced	SAMI Report from DMR (2019)
	Clinker fraction	Cement industries
Lime production	Mass of lime produced	SAMI Report from DMR (2019)
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 (tonnes CO_2/ tonne product)	Source
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

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

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.

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 CO2 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 CO2 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 5 246 Gg CO_2e in 2017, which is 16.4% of the *IPPU* sector emissions. Emissions were 1 376 Gg CO_2e (35.5%) above the 2000 level (3 871 Gg CO_2e).

Change in emissions since 2015

Emissions in this subsector showed a 1.3% increase (65 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, 2019) 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	13 053 000	1 091 000	100 000	1 095 264
2014	13 099 000	1 111 579	148 760	1 095 264
2015	14 456 000	1 026 591	92 623	1 095 264
2016	15 182 000	1 035 000	93 000	1 146 296
2017	14 622 000	1 112 000	96 000	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

Recalculations were performed for this category for the 2013 and 2015 period as updated sales information became available in the SAMI (2019) report. Current emission estimates are 0.1% higher than previous estimates for 2013, no change in 2014 and the 2015 estimates are 0.5% lower than in the previous submission.

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, 2019). 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. Quciklime sales for both pyromettalurgical uses and chemical uses both increased in 2017 (DMR, 2019). Demand for hydrated lime for water purification purposes decreased from 2016 to 2017, while demand for sales for chemical applications increased during the same time period (DMR, 2019).

Overview of shares and trends in emissions

2000 - 2017

Lime production was estimated to produce 890 Gg CO_2 in 2017, which is 2.77% of the IPPU sector emissions. Emissions were 456 Gg CO_2 (105.0%) above the 2000 level (434 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. For the data prior to 2008 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 due to emissions but also due to a change in the activity data. In the 2019 inventory this inconsistency will be reviewed to determine whether the data can be improved so as to maintain consistency across the time-series.

Change in emissions since 2015

Emissions in this subsector increased by 8.0% (66 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, 2019).

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, 2019). 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, 2019) were used (Table 4.10). It was assumed that all quicklime is high calcium lime. No dolomitic lime is included in this report.

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. The 2006 IPCC default emission factor for hydrated lime (0.59 tonnes CO_2 per tonne lime) was applied to hydrated lime.

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. The numbers in the DMR report are actually the total amount of lime (quicklime and hydrated lime) sold locally so may produce slightly overestimated values if not all lime is produced in South Africa or during that year.

Recalculations

Recalculations were undertaken for the whole time series due to the corrected default emission factor for hydrated lime. In the previous inventory only the quicklime emission factor was applied. This change led to a 39.8% reduction in hydrated lime emissions and an overall 4.2% reduction in emissions from Lime production in 2015.

Planned improvements

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

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 0.4% of the IPPU sector emissions. Emissions were 46.5 Gg CO_2e (63.5%) 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 893 Gg CO_2e in 2017, which is 2.8% 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 1 880 Gg CO_2e (67.8%) since 2000 (2 774 Gg CO_2e). Emissions from this subsector fluctuated considerably over the 17-year period (Figure 4.4). Between 2000 and 2006 emissions fluctuated between 2 169 Gg CO_2e and 2 974 Gg CO_2e (Figure 4.4), 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.

Methodology

Many of the chemical industries determine their own emissions and provide these emission estimates to DFFE. 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.

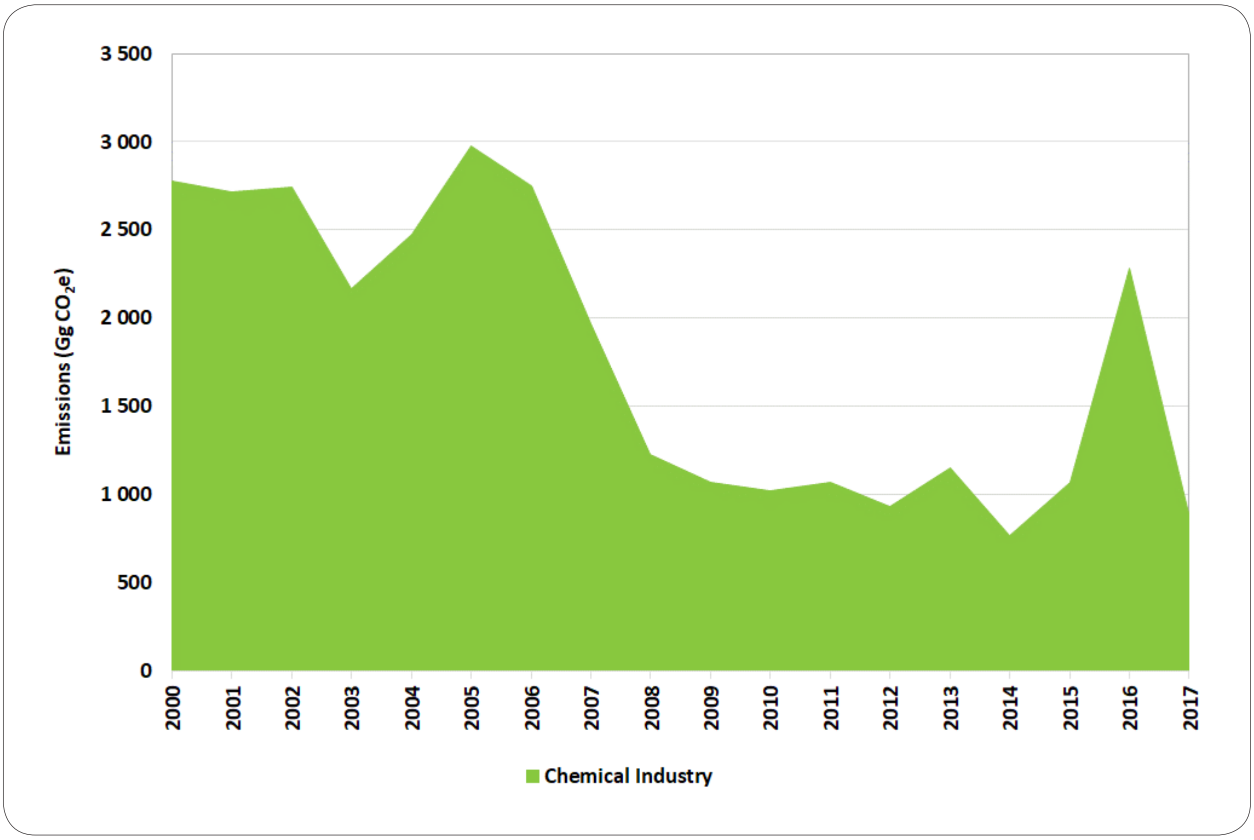


Figure 4.4: Trend in chemical industry emissions in South Africa, 2000 – 2017.

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 (reported in SAGERS)
Carbide production	Raw material (petroleum coke) consumption	SAMI Report (DMRE, 2019); Carbide production plants (reported in SAGERS)
Titanium dioxide production	Emissions from titanium dioxide production	SAMI Report (DMRE, 2019); Titanium dioxide production plants (reported in SAGERS)
Carbon black production	Amount of carbon black produced	Orion Engineered Carbons (Pty) Ltd (reported in SAGERS)

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.

Uncertainty and time-series consistency

Companies have recently started to report their emissions via the SAGERS and this updated data was available, in most cases, from 2014 onwards. For Carbide production the updated data showed an increase compared to the data prior to 2014, while for Titanium dioxide production the opposite was true. The reasons for the inconsistencies will be looked at in more detail in the next inventory.

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

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

Sub-category	Activity data	Data source	Source
	(tonnes CO_2/tonne product)	(kg CH_4/tonne product)	
Carbide production	1.09		IPCC 2006
Carbon black production – furnace black production	2.62	0.06	IPCC 2006
Carbide production	0.12		IPCC 2006

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

Gas	Sub-category	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 NOx control and the NOx abatement system may or may not reduce the N_2O concentration of the treated gas. The uncertainty measures of default emission factors are +/-2%. The IPCC guidelines suggest that where uncertainty values are not available from other sources, as is the case for this inventory, this default value of ±2 percent should be applied to the activity data (IPCC 2006, vol 3, chpt 3, pg 3.25). For emission factors the default uncertainty range between 10% and 40% for a tier 2 approach (IPCC 2006, vol 3, chpt 3, 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. Recent data (since 2014) was obtained from the SAGERS reporting system.

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. There seems to be an inconsistency in the time-series with the updated data from 2014 being much higher that the data from previous years. This inconsistency will be investigated further in the 2019 inventory.

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

Recalculations were undertaken for 2014 onwards as more accurate activity data from the production plants became available. The production data was double what it was in the previous inventory in 2014 and for 2015 production increased from 3 659 t to 121 587 t which led to a large increase in the Carbide production emission estimate.

Planned improvements

There are no subcategory specific planned improvements, but any further 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. Data for recent years (2014 onwards) was obtained from the SAGERS reporting system.

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. As with Carbide production, there seems to be an inconsistency in the time-series data as the updated data from 2014 is much lower than the data from the previous years. This inconsistency will be investigated further in the 2019 inventory.

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

Recalculations were undertaken for 2014 onwards as more accurate activity data from the production plants became available. This led to a decline of 161 Gg CO2e which is a decline of 99% in 2015 compared to the previous submission.

Planned improvements

There are no subcategory specific planned improvements, but any further 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. In 2016 production data for acetylene black process became available so this was added only for 2016 and 2017. The 2015 to 2017 data was sourced from the SAGERS reporting system. In 2016 and 2017 data for the acetylene black process was added as new data was available.

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).

Uncertainty and time-series consistency

Due to the new data for the acetylene black process there is an inconsistency in the time-series as this data is only available for 2016 and 2017. 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

Recalculations were undertaken for 2015 onwards as more accurate activity data from production plants became available. This produced a 76.5% increase in emissions in 2015.

Planned improvements

There are no subcategory specific planned improvements, but any further 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 20 389 Gg CO_2e in 2017, which is 63.5% of the IPPU sector emissions. The largest contribution comes from *ferroalloy production* (11 330 Gg CO_2e or 56.0%), followed by *iron and steel production* (7 725 Gg CO_2e or 37.9%)

2000 – 2017

Emissions from the *metal industry* decreased by 5 250 g CO_2e (20.5%) below the 2000 emissions of 25 639 Gg CO_2e. Figure 4.5 shows that emissions from the *metal industries* increased slowly (11.2%) between 2000 and 2006, after which there was a 14.1% decline to 24 487 Gg CO_2e in 2009. This decrease was evident in the *iron and steel production* emissions (26.1%), *aluminium production* emissions (40.6%) and *zinc production* emissions (17.6%).

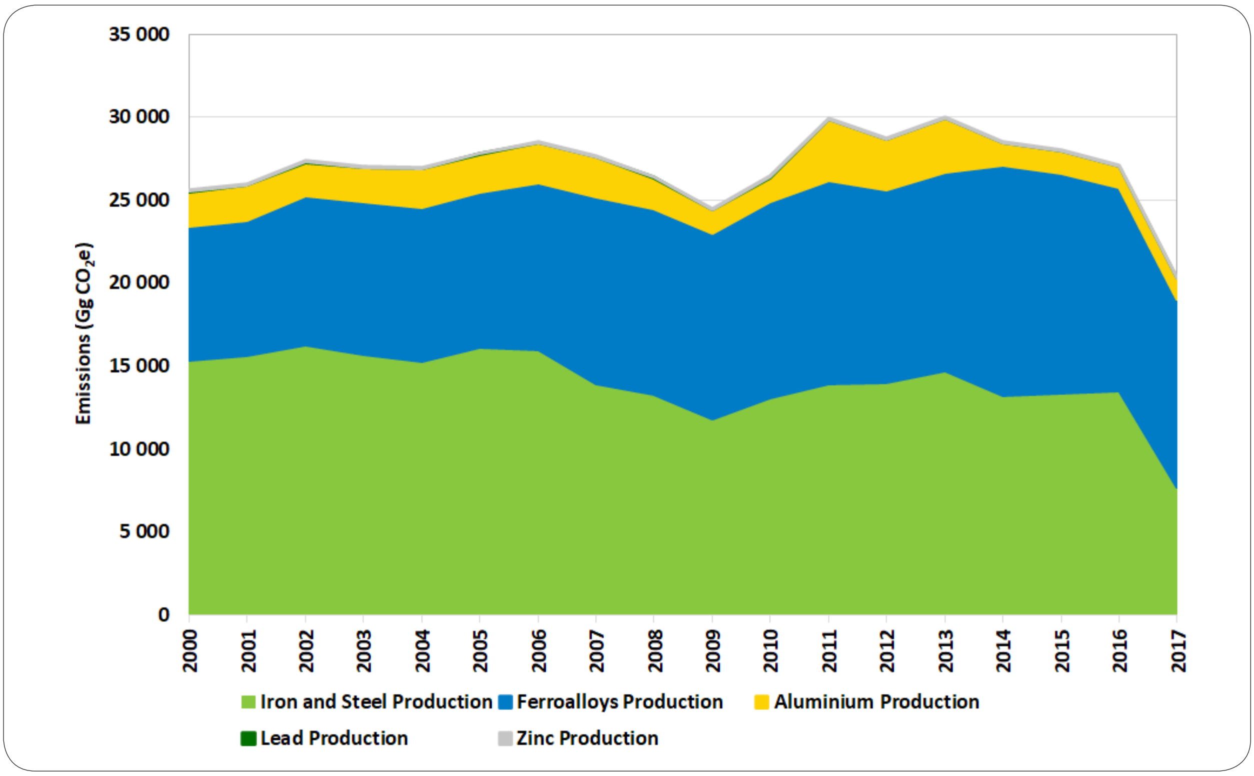


Figure 4.5: Trend and category contribution to emissions from the metal industries, 2000 – 2017.

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	15 334.4	8 082.4	2 074.4	39.2	108.4
2001	15 608.1	8 199.2	2 071.1	26.9	104.9
2002	16 274.7	8 974.3	2 035.8	25.7	110.1
2003	15 719.3	9 160.5	2 055.0	20.7	70.5
2004	15 291.0	9 286.9	2 285.0	19.5	55.0
2005	16 103.5	9 388.0	2 274.1	21.9	55.0
2006	15 986.3	10 068.3	2 369.7	25.1	58.5
2007	13 919.5	11 250.1	2 419.7	21.8	53.3
2008	13 313.9	11 179.5	1 848.4	24.1	49.9
2009	11 813.9	11 192.7	1 406.3	25.5	48.2
2010	13 106.8	11 822.1	1 432.0	26.3	61.9
2011	13 921.3	12 241.2	3 710.4	28.3	63.6
2012	13 985.2	11 627.2	3 046.1	27.3	63.6
2013	14 684.9	11 964.8	3 297.6	21.8	51.8
2014	13 203.9	13 897.4	1 361.0	15.3	45.0
2015	13 334.1	13 271.5	1 331.5	18.0	49.9
2016	13 506.5	12 257.7	1 264.8	20.5	45.9
2017	7 725.0	11 329.5	1 256.2	25.0	52.9

Aluminium production emissions more than doubled between 2010 and 2011 due to increased PFC emissions (Figure 4.5; 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 C2F4 and CF4 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 9.0%.

Iron and steel production emissions decreased by 1 828 GgCO_2e (11.9%) between 2000 and 2016, and then declined a further 42.8% (5 782 Gg CO_2e) between 2016 and 2017. This reduction was due to a further disaggregation of the iron and steel production data, where production of pig iron and direct reduced iron declined but sinter production was added. The emission factors for sinter production are much lower than for pig iron and direct reduced iron, hence the reduction in emissions.

Ferroalloy industry emissions increased steadily by 64.2% (5 189 GgCO_2e) between 2000 and 2015, with a slight decline of 14.6% (1 940 Gg CO_2e) between 2015 and 2017. Overall, though there is still an increase of 3 249 Gg CO_2e (40.2%) since 2000.

Methodology

A Tier 1 approach was used for all subcategories. 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.

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 4.15: 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); Iron and Steel production plants (reported via SAGERS 205 onwards)
Ferroalloys production	Production data	South African Minerals Industry (SAMI) Report produced by DMR (2019)
Lead production	Production data	Aluminium industries (2000 – 2017) (data from 2014 reported through SAGERS)
Zinc production	Production data	SAMI Report produced by DMR (2019)
Carbon black production	Production data	SAMI Report produced by DMR (2019)

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	0.7		IPCC 2006
Sinter	0.2		IPCC 2006
*Other**	1.06		DEA Technical Guidelines (2017)
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

Sub-category	CO_2 EF	CH_4 EF	Source
	(tonnes CO_2/ tonne product)	(kg CH_4/ tonne product)	
Aluminium production			
Prebake	1.6		IPCC 2006
Soderberg	1.7		IPCC 2006
Lead production	0.52		IPCC 2006
Zinc production	1.72		IPCC 2006

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

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

Activity data

There are inconsistencies in the time-series as company data was sourced through SAGERS for 2014 onwards and this showed some changes in activity data and process allocation compared to data for earlier years.

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

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 7 717 Gg CO_2e in 2017, which is 24.1% of the IPPU sector emissions. Emissions were 8 694 Gg CO_2e (53.0%) below the 2000 level (16 411 Gg CO_2e) (Table 4.14).

Change in emissions since 2015

Emissions in this subsector decreased by 45.2% (6 377 Gg CO_2e) since 2015.

Methodology

A Tier 1 approach (country-specific emission factors) was applied to calculate the emissions from *iron and steel production* for the different process types in 2017. Default IPCC emission factors were used for the calculation of GHG emissions from basic oxygen furnace, electric arc furnace and pig iron production, 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* between 2000 and 2016 (Table 4.18). In 2017 the data was obtained from SAGERS. It seems that in the company reporting in SAGERS there is a different disaggregation, with a reduction in production from pig iron and direct reduced iron and the addition of sinter production. The updated disaggregation is utilised for 2017 but does create an inconsistency in the time-series which can be evaluated further I the next inventory.

Emission factors

IPCC default emission factors were applied for the calculation of emissions from *iron and steel production*. 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 *Other* category values were based solely on production by the Corex process. Production companies supplied a value of 1.06 t CO_2/t production, and this is the average value provided in the DEA Technical Guidelines (DEA, 2017).

Uncertainty and time-series consistency

Data was not consistent throughout the time series as the data was provided by a different source for 2017. The company data in SAGERS showed a different production allocation than reported for previous years and sinter production was included in 2017 only as no data sinter data is available for previous years.

The Tier 1 approach for metal production emission estimates generates several 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

Recalculations were performed for the entire time-series as the emission factor for direct reduced iron and sinter were corrected to the IPCC default factors. The previous

Table 4.18: Production data for the iron and steel industry, 2000 – 2017.

	Basic oxygen furnace	Electric arc	Pig iron	Direct reduced iron	Sinter	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	4 242 431	1 153 047	101 115	660 605	3 631 445	107 153

inventory provided different emission factors; however, the source of these emission factors was not documented, therefore default values were applied for the entire time-series. In addition, the emission factor for emissions from the Corex process (included under the *Other* category for *iron and steel production*) was updated to 1.06 t CO_2/t which is an emission factor sourced from the production plant and is the average value provided in the Technical Guidelines (DEA, 2017). This value was applied to the complete time-series. These updates produced a 5% to 8% decrease in emissions from *Iron and steel production* across the time-series.

Planned improvements

There are no subcategory specific planned improvements, but any further 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 11 330 Gg CO_2e in 2017 (Table 4.14), which is 35.3% of the IPPU sector emissions. Emissions were 3 247 Gg CO_2e (40.2%) above the 2000 level (8 082 Gg CO_2e). In this subcategory 1.1 Gg CO_2e of the *ferroalloys production* total was from CH_4.

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	34 100
2014	3 719 000	814 263	194 737	87 700	47 200
2015	3 685 000	492 000	123 000	91 800	46 300
2016	3 524 000	296 000	74 000	73 200	26 600
2017	3 268 000	354 400	88 600	48 200	4 700

Change in emissions since 2015

Emissions in this subcategory declined by 14.6% (1 942 Gg CO_2e) since 2015.

Methodology

Ferrochromium production emissions are based on a Tier 2 approach, 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, 2019) 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. A drop in silicon metal production was observed in 2017 due to the closure of most furnaces because of low demand and high electricity tariffs (DMR, 2019).

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

Recalculations were performed for 2015 as updated activity data for ferrosilicon 65% Si production became available and this produced a 1.1% decline in emissions in 2015 compared to the previous submission.

Planned improvements

There are no subcategory specific planned improvements, but any further 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 1 256 Gg CO_2e in 2017, which is 3.9% of the IPPU sector emissions. Emissions were 818 Gg CO_2e (39.4%) below 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 decreased by 5.7% (73.5 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 2000-2019 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* were the aluminium production plants. For PFCs the industry provided emission data for 2000 to 2017, therefore activity and emission factor data were 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

Recalculations were performed for 2013 onwards as updated activity data was obtained from the production plants for these years. This led to a 12.4%, 61.3% and 60.4% decline in emissions compared to the previous submission for 2013, 2014 and 2015, respectively.

Planned improvements

There are no subcategory specific planned improvements, but any further 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 to produce 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 25 Gg CO_2e in 2017, which is 0.09% of the IPPU sector emissions. Emissions were 14 Gg CO_2e (36.1%) below the 2000 level (39 Gg CO_2e). *Zinc production* was estimated to produce 53 Gg CO_2e in 2017, which is 0.2% of the IPPU sector emissions. Emissions were 55 Gg CO_2e (50.9%) 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 7 Gg CO_2e (39.3%) since 2015. Zinc production emissions increased by 3Gg CO_2e (6.0%) 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, 2019). 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	41 848	30 145
2014	29 348	26 141
2015	34 573	29 040
2016	39 344	26 695
2017	48 150	30 778

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

Recalculations were performed for Lead and Zinc production from 2013 to 2015 as more accurate production data had become available in the SAMI report (DMRE, 2019). For Lead production this produced a 30.8% decline in emissions for 2014, but only a 1.2% decline for 2015. For Zinc production recalculations produced a 0.5% increase in emission estimates for 2013 and a 0.1% increase in 2015.

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.

SOURCE CATEGORY 2.D NON-ENERGY PRODUCTS FROM FUELS AND SOLVENT USE

4.5

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* category was estimated to produce 531 Gg CO_2e in 2017, which is 1.7% of the IPPU sector emissions. The largest contribution comes from lubricant use (424 Gg CO_2e or 79.8%).

2000 – 2017

Emissions from the *non-energy products from fuels and solvent use* category were 335 Gg CO_2e (170.8%) higher than the 2000 level of 196 Gg CO_2e. Emissions fluctuated a lot with there being a peak in emissions between 2007 and 2009 (Figure 4.6). In 2010 there was a decline in emissions to 59 Gg CO_2e. The use of paraffin wax spiked in 2015 leading to increased emissions. These then declined again in 2016 and 2017.

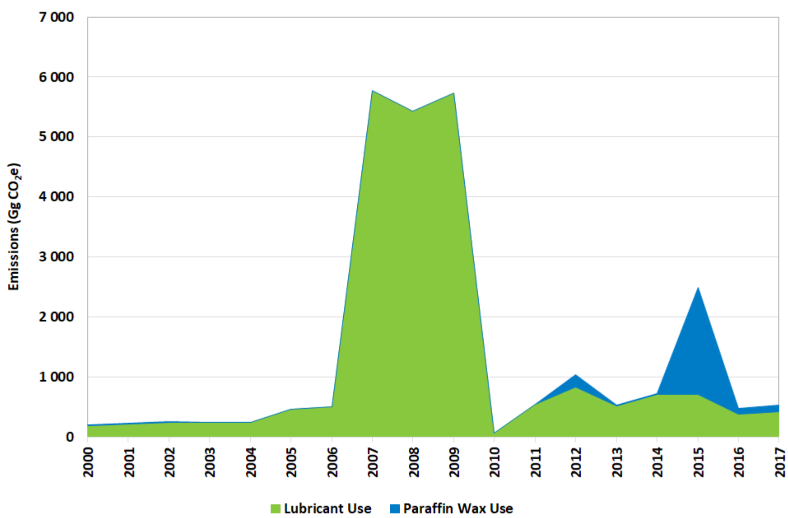


Figure 4.6: Trend and category contribution in the emissions from non-energy products from fuels and solvents, 2000 – 2017.

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	393 505	141
2008	370 423	182
2009	390 719	231
2010	4 000	28
2011	37 000	53
2012	57 160	13 939
2013	35 574	207
2014	48 652	366
2015	48 531	121 608
2016	25 490	6 756
2017	28 940	7 240

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.

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.

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 424 Gg CO_2e in 2017, which is 1.3% of the IPPU sector emissions. Emissions were 236 Gg CO_2e (125.5%) above the 2000 level (188 Gg CO_2e). There was a huge peak in emissions between 2007 and 2009, with emissions increasing by 5 267 Gg CO_2e between 2006 and 2007 and dropping again

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

Sub-category	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

by 5 672 Gg CO_2e between 2009 and 2010. This peak may need to be investigated further in the next inventory.

Change in emissions since 2015

Emissions in this subsector decreased by 40.4% (287Gg 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

Recalculations were completed for 2007 onwards due to an improvement in the energy balance activity data. The emission estimates were much higher in this inventory than in the previous inventory for all recalculated year except 2010 which showed a 74% lower emission estimate.

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 106 Gg CO_2e in 2017. Emissions were 99 Gg CO_2e above the 2000 level (7 Gg CO_2e). There was a spike in emissions of 1 783 Gg CO_2e in 2015. This peak will be investigated further in the next inventory.

Change in emissions since 2015

Emissions in this subsector decreased by 94.0% since 2015, but this is because of the spike in emissions in 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

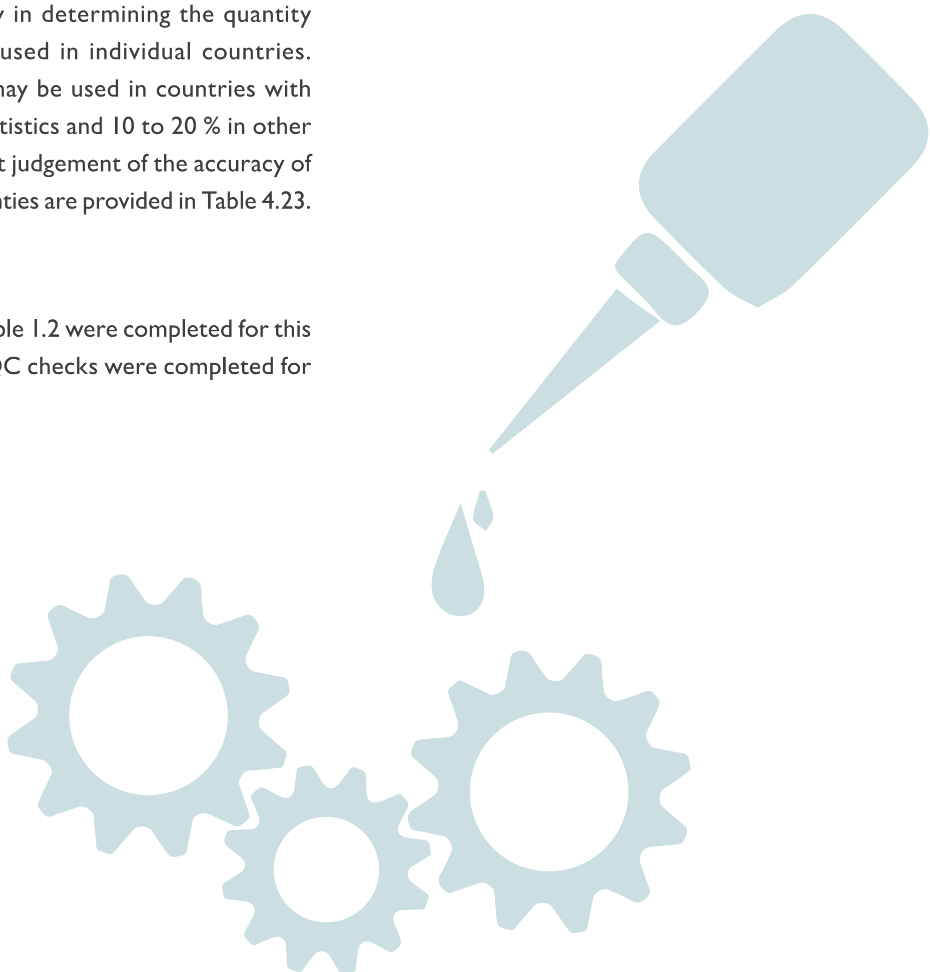
All general QC listed in Table 1.2 were completed for this category and no specific QC checks were completed for this sub-category.

Recalculations

Recalculations were completed for 2007 onwards due to improvements in the energy balance activity data. These updates led to an increase in emission estimates from 3 Gg CO_2e to 1 783 Gg CO_2e in 2015. Emission estimates in 2012 were also higher, however estimates were 87.9% and 79.8% lower in 2010 and 2011.

Planned improvements

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



SOURCE CATEGORY 2.E ELECTRONICS INDUSTRY 4.6

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

SOURCE CATEGORY 2.F PRODUCT USES AS SUBSTITUTES FOR OZONE DEPLETING SUBSTANCES (ODS) 4.7

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 12.5% 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 4.7) 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.

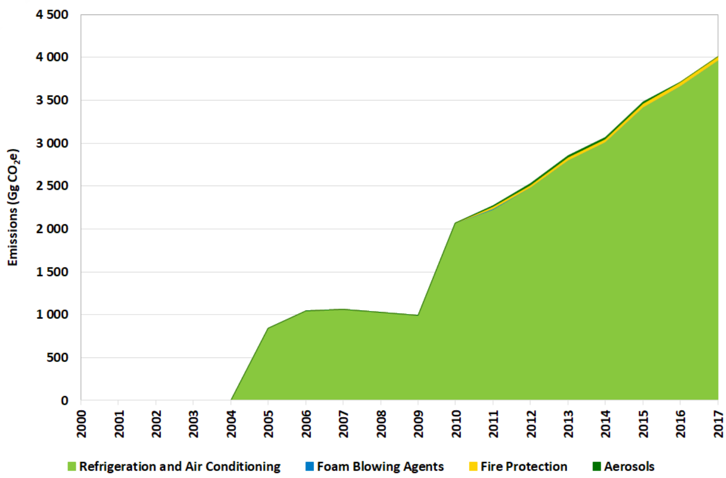


Figure 4.7: Trend and category contribution to the product uses as substitutes for ODS emissions, 2000 – 2017.

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	NE	NE	NE	NE
2001	NE	NE	NE	NE
2002	NE	NE	NE	NE
2003	NE	NE	NE	NE
2004	NE	NE	NE	NE
2005	841.8	NE	NE	NE
2006	1 045.4	NE	NE	NE
2007	1 063.4	NE	NE	NE
2008	1 026.0	NE	NE	NE
2009	992.0	NE	NE	NE
2010	2 065.8	NE	NE	NE
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.

Emission factors

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

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 DFFE
Foam blowing agents	Total HFC used in foam manufacturing in a year	HFC Survey DFFE
Fire protection	Bank of agent in fire protection equipment in a year	HFC Survey DFFE
Aerosols		HFC Survey DFFE

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	10	Years	IPCC 2006
from installed base	15	%	IPCC 2006
% of HFC destroyed at End-of-Life	25	%	IPCC 2006
Foam blowing agents			
Product life	34	Years	(UNEP, 2005, IPCC, 2006)
First year loss	14	%	
Annual loss	0.66	%	
Landfilling loss	16	%	
Landfill annual loss	0.75	%	
Fire protection	4	%	IPCC 2006
Aerosols (HFC-134a)	0,50	Fraction	IPCC 2006

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

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

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 98.7% 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.

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 DFFE'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.

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.

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 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).

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

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.

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.

SUMMARY TABLE OF IPPU EMISSIONS IN 2017

APPENDIX 4.A

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	**27 496.0**	**8.0**	**0.9**	**4 014.5**	**113.1**	**NE**	**NE**	**NE**	**NE**	**NE**	**32 084.6**
2.A - Mineral Industry	6 257.3	NE	NE	NE	NE	NE	NE	NE	NE	NE	6 257.3
2.A.1 - Cement production	5 246.4	NE					NE	NE	NE	NE	5 246.4
2.A.2 - Lime production	890.0	NE					NE	NE	NE	NE	890.0
2.A.3 - Glass Production	120.9	NE					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)	NE						NE	NE	NE	NE	NE
2.A.5 - Other (please specify)							NE	NE	NE	NE	NE
2.B - Chemical Industry	433.6	8.0	0.9	NE	NE	NE	NE	NE	NE	NE	893.4
2.B.1 - Ammonia Production	C	C	NE	NE			NE	NE	NE	NE	C
2.B.2 - Nitric Acid Production	NE	NE	C				NE	NE	NE	NE	C
2.B.3 - Adipic Acid Production	NO	NO	NO				NO	NO	NO	NO	NO

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.B.4 - Caprolactam, Glyoxal and Glyoxylic Acid Production	NO	NO	NO				NO	NO	NO	NO	NO
2.B.5 - Carbide Production	C	NE	NE				NE	NE	NE	NE	C
2.B.6 - Titanium Dioxide Production	C	NE	NE				NE	NE	NE	NE	C
2.B.7 - Soda Ash Production	NE	NE	NE				NE	NE	NE	NE	NE
2.B.8 - Petrochemical and Carbon Black Production	C	C	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				NE			NE	NE	NE	NE	NE
2.B.9.b - Fugitive Emissions							NE	NE	NE	NE	0.0
2.B.10 - Other (Please specify)							NE	NE	NE	NE	0.0
2.C - Metal Industry	20 274.5	0.1	NE	NE	113.1	NE	NE	NE	NE	NE	20 388.7
2.C.1 - Iron and Steel Production	7 725.0	0.0	NE				NE	NE	NE	NE	7 725.0

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.C.2 - Ferroalloys Production	11 328.4	0.1	NE				NE	NE	NE	NE	11 329.5
2.C.3 - Aluminium production	1 143.1	NE			113.1		NE	NE	NE	NE	1 256.2
2.C.4 - Magnesium production	NO					NO	NO	NO	NO	NO	NO
2.C.5 - Lead Production	25.0						NE	NE	NE	NE	25.0
2.C.6 - Zinc Production	52.9						NE	NE	NE	NE	52.9
2.C.7 - Other (please specify)	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	0.0
2.D - Non-Energy Products from Fuels and Solvent Use	530.6	NE	NE	NA	NA	NA	NE	NE	NE	NE	530.6
2.D.1 - Lubricant Use	424.5						NE	NE	NE	NE	424.5
2.D.2 - Paraffin Wax Use	106.2	NE	NE				NE	NE	NE	NE	106.2
2.D.3 - Solvent Use							NE	NE	NE	NE	0.0
2.D.4 - Other (please specify)							NE	NE	NE	NE	0.0
2.E - Electronics Industry	NA	NA	NA	NE	NE	NE	NE	NE	NE	0.0	0.0
2.E.1 - Integrated Circuit or Semiconductor				NE	NE	NE	NE	NE	NE	NE	NE
2.E.2 - TFT Flat Panel Display					NE	NE	NE	NE	NE	NE	NE
2.E.3 - Photovoltaics					NE		NE	NE	NE	NE	NE
2.E.4 - Heat Transfer Fluid					NE		NE	NE	NE	NE	NE
2.E.5 - Other (please specify)							NE	NE	NE	NE	NE

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.F - Product Uses as Substitutes for Ozone Depleting Substances	NE	NA	NA	4 014.5	NE	NE	NE	NE	NE	NE	4 014.5
2.F.1 - Refrigeration and Air Conditioning	NE			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	NE			0.0	NE		NE	NE	NE	NE	0.0
2.F.3 - Fire Protection	NE			51.1	NE		NE	NE	NE	NE	51.1
2.F.4 - Aerosols				0.0	NE		NE	NE	NE	NE	0.0
2.F.5 - Solvents				NE	NE		NE	NE	NE	NE	NE
2.F.6 - Other Applications (please specify)				NO	NO		NO	NO	NO	NO	NO
2.G - Other Product Manufacture and Use	NA	NA	NE	NA	NE	NE	NE	NE	NE	NE	NE
2.G.1 - Electrical Equipment					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

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.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)					NE	NE	NE	NE	NE	NE	NE
2.G.3 - N_2O from Product Uses			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)			NE				NE	NE	NE	NE	NE
2.G.4 - Other (Please specify)							NE	NE	NE	NE	NE
2.H - Other	NE	NE	NA	NA	NA	NA	NE	NE	NE	NE	NE
2.H.1 - Pulp and Paper Industry	NE	NE					NE	NE	NE	NE	0.0
2.H.2 - Food and Beverages Industry	NE	NE					NE	NE	NE	NE	0.0
2.H.3 - Other (please specify)							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.

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. DFFE 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.

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

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)	**-29 409.2**	**1 224.4**	**70.0**	**528.8**	**21.4**	**31.1**	**17 997.5**
3. AFOLU (excl. FOLU)	**1 901.7**	**1 192.7**	**70.0**	**528.8**	**21.4**	**31.1**	**48 641.8**
3.A Livestock	NA	1 172.8	5.3	NA	NA	NA	26 272.2
3.B Land	-30 534.0	31.7	NE	NA	NA	NA	-29 867.4
3.C Aggregated and non-CO_2 sources	1 901.7	19.9	64.7	528.8	21.4	31.1	22 369.5
3.D Other	-776.9	NA	NA	NA	NA	NA	-776.9

** Totals may not sum exactly due to rounding off. Total does not include NOx, CO and NMVOCs*

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 17 997 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 (52.8%) to the AFOLU (excl. FOLU) emissions, with N_2O contributing 44.6%. *Enteric fermentation* contributed 95.8% of the CH_4 emissions. *Direct N_2O emissions from managed soils* was the largest contributor (78.6%) to the N_2O emission in this sector. Indirect emissions of NOx, CO and NMVOCs were estimated for biomass burning.

2000 – 2017

The AFOLU (excl. FOLU) emissions declined by 8.6% (4 587 Gg CO_2e) between 2000 and 2017, while AFOLU (incl. FOLU) declined by 56.2% (23 091 Gg CO_2e) (Table 5.3). This large decline is due to a 18 017 Gg CO_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).

The GHG emissions from *Livestock* declined due mainly to the decreasing cattle, sheep and goat populations. The other cattle[5] population has declined by 5.4% since 2000, leading to a decline in other cattle emissions which is the largest contributor to *Enteric fermentation*. *Livestock* contributed 54.0% 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

5 All cattle except dairy cows and lactating heifers.

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 to the Grassland category. *Croplands* were a source of CO_2 due to conversions to croplands.

The sink remained fairly constant (between 1 500 Gg CO_2 and 1 800 Gg CO_2) over the time-series. *Croplands remaining croplands* were a sink, while *Land converted to croplands* produced emissions of 2 756 Gg CO_2e in 2017. The majority of the emissions were from the conversion of forest land to cropland.

Other lands provide a constant source of emissions (13 513 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 9.2% 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 46.0% 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).

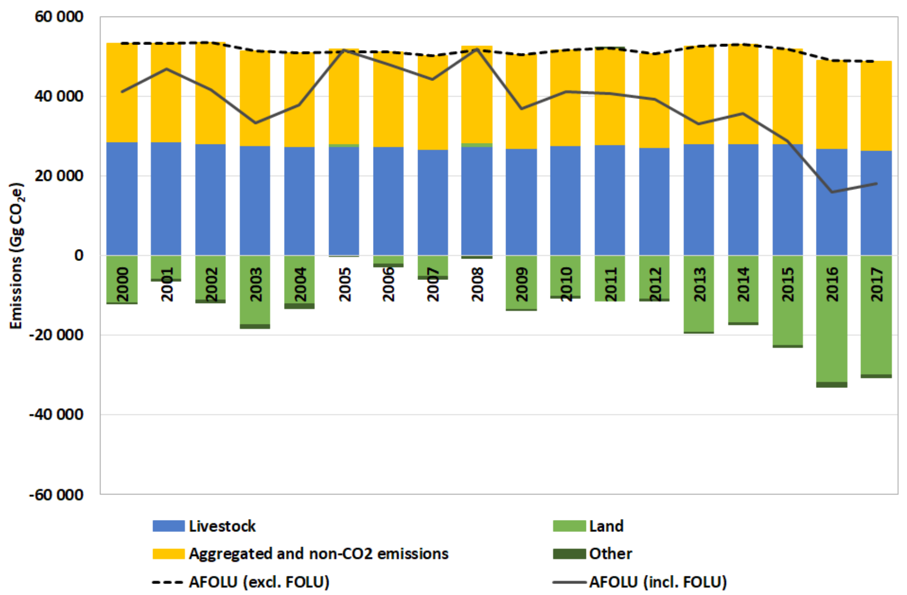


Figure 5.1: Emission trends for South Africa's AFOLU sector, 2000 – 2017.

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	28 604.3	-11 850.3	24 625.1	-290.4	41 088.7	53 229.4
2001	28 439.0	-5 872.9	24 764.1	-557.0	46 773.2	53 203.1
2002	28 158.3	-11 148.8	25 420.6	-735.5	41 694.6	53 578.9
2003	27 538.0	-17 294.0	23 847.0	-893.1	33 198.0	51 385.0
2004	27 384.3	-12 062.3	23 504.9	-1 151.0	37 675.8	50 889.2
2005	27 326.6	740.8	23 672.7	-251.7	51 488.4	50 999.3
2006	27 258.0	-2 073.0	23 765.8	-869.1	48 081.6	51 023.8
2007	26 600.1	-5 295.7	23 512.7	-629.0	44 188.1	50 112.8
2008	27 439.7	804.7	24 252.4	-792.3	51 704.5	51 692.1
2009	26 868.0	-13 472.1	23 516.5	-119.1	36 793.3	50 384.5
2010	27 664.4	-10 123.2	23 986.8	-513.1	41 014.8	51 651.2
2011	27 801.5	-11 382.7	24 215.6	57.2	40 691.7	52 017.1
2012	27 190.8	-10 946.6	23 466.8	-441.4	39 269.6	50 657.6
2013	28 125.4	-19 145.1	24 452.7	-282.9	33 150.1	52 578.2
2014	28 132.1	-16 775.9	24 798.2	-535.4	35 619.0	52 930.3
2015	28 022.6	-22 534.9	23 781.7	-608.3	28 661.2	51 804.3
2016	26 770.5	-31 943.3	22 214.1	-1 091.1	15 950.1	48 984.6
2017	26 272.3	-29 867.4	22 369.5	-776.9	17 997.5	48 641.8

2015 – 2017

There was a 6.0% (3 163 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 37.2% (10 663.7 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 1 412 Gg CO_2e (5.9%), 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 Agriculture/Forestry/ Fishing/Fish farms**							
	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, 2015)
		Soil: T1	Soil: DF					Mineral soils only, Organic soils NE

GHG Source and sink category		CO_2		CH_4		N_2O		Details
		Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	
3B LAND	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, 2015)
		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, 2015)
		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, 2015)
		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, 2015)
		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, 2015)
		Soil: T1	Soil: DF					Mineral soils only, Organic soils NE

	GHG Source and sink category	CO_2 Method applied	CO_2 Emission factor	CH_4 Method applied	CH_4 Emission factor	N_2O Method applied	N_2O Emission factor	Details
3B LAND	**4 Wetland**							
3B LAND	a. Wetland remaining wetland	NE		T1	DF	NE		
3B LAND	b. Land converted to wetland	NE		NE		NE		
3B LAND	**5 Settlements**							
3B LAND	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, 2015)
		Soil: T1	Soil: DF					Mineral soils only, Organic soils NE
3B LAND	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, 2015)
		Soil: T1	Soil: DF					Mineral soils only, Organic soils NE
3B LAND	**6 Other land**							
3B LAND	a. Other land remaining other land	Biomass: NE						
		Soil: T1	Soil: DF					
3B LAND	b. Land converted to other land	Biomass: T2	Biomass: CS					CS activity data and EF are applied (see data sources table)
		Soil: T1	Soil: DF					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 (DEAT, 2009; DAFF, 2010)
3C AGGREGATED SOURCES AND NON-CO_2 EMISSIONS ON LAND	**2 Liming**	T1	DF	NA		NA		
3C AGGREGATED SOURCES AND NON-CO_2 EMISSIONS ON LAND	**3 Urea application**	T1	DF	NA		NA		
3C AGGREGATED SOURCES AND NON-CO_2 EMISSIONS ON LAND	**4 Direct emissions from managed soils**							
3C AGGREGATED SOURCES AND NON-CO_2 EMISSIONS ON LAND	Synthetic fertilizers	NA		NA		T1	DF	
3C AGGREGATED SOURCES AND NON-CO_2 EMISSIONS ON LAND	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)

GHG Source and sink category		CO_2 Method applied	CO_2 Emission factor	CH_4 Method applied	CH_4 Emission factor	N_2O Method applied	N_2O Emission factor	Details
3C AGGREGATED SOURCES AND NON-CO_2 EMISSIONS ON LAND	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 (2018)
			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)
			Du Toit *et al.* (2013a-c)

Category	Sub-category	Activity data	Data source
3A LIVESTOCK	**Manure management**	Manure management data	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, 2015)
		Burnt area data	MODIS burnt area product – collection 5 and 6 (2019)
	Forest land	Plantation data	Forestry South Africa Industry facts (FSA, 2019)
			Du Toit *et al.* (2016)
			Alembong (2015)
			Timber Statistics reports (DAFF, 2018a)
		Natural forests and woodland carbon stock data	National Terrestrial Carbon Sinks Assessment (DEA, 2015)
		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, 2015)
	Grassland	Biomass carbon stock data and growth rates	National Terrestrial Carbon Sinks Assessment (DEA, 2015)
		Grassland management data	Fairbanks *et al.* (2000)
			Matsika (2007)

Category	Sub-category	Activity data	Data source
3B LAND	Settlements	Management data	Fairbanks *et al.* (2000)
			GTI (2015)
	Other lands	Soil carbon stock data	IPCC (2006)
3C AGGREGATED AND NON-CO2 EMISSIONS ON LAND	Biomass burning		MODIS burnt area product – collection 5 and 6 (2019)
			2000 NIR (DEAT, 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 (FASA, 2019); SAMI Reports (DMR, 2018)
	Urea application	Urea import data	SARS (2018)
	Synthetic fertilizers	Total N fertilizer consumption	Fertilizer Association of SA (FASA, 2019)
		N content of fertilizers	Grain SA Report (2011)
	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 (2018)
		Crop yield data	Moeletsi *et al.* (2015)
			Tongwane *et al.* (2016)
			FAOStats (2018)
		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 (2018)

2015 – 2017

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 1.2% lower and a 12.1% increase in the 2015 estimates for *Livestock* and *Aggregated and non-CO_2 emissions on land*, respectively. The *Land* category showed a 17.1% decrease in the sink in 2015, however in some years the estimates showed an increase 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 4.6% increase in emission estimates for 2015, while the AFOLU sector emissions including FOLU were 36.1% higher than in the previous submission.

Figure 5.2: Change in AFOLU emission estimates due to recalculations since 2015 submission.

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	-325.6
Manure management (CH_4)	Adjusted herd composition for cattle; Updated manure management data	70.1
Manure management (N_2O)	Adjusted herd composition for cattle; Updated manure management data; Country specific N excretion rates for poultry and swine	589.8
Forest land	Area adjustment for 20-year transition period; Updated biomass, litter and soil ref data; Updated wood removal data	10 875.6
Cropland	Area adjustment for 20-year transition period; Updated biomass, litter and soil ref data; Improved disturbance data	-1 975.8
Grassland	Area adjustment for 20-year transition period; Updated biomass, litter and soil ref data; Improved disturbance data	-12 280.8
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	-3 151.5
Other lands	Area adjustment for 20-year transition period; Include Tier 1 assumption that soil carbon becomes zero after 20 years	11 142.2
Biomass burning	Improved burnt area data; Updated fuel load and combustion factor data	-84.2
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	2 461.2
Indirect N_2O from managed soils	Adjusted herd composition data for cattle; Updated manure management data; Improved crop residue calculations	49.9
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	-175.9
Harvested wood products	Updated import and export data from FAOStat	51.8
Total change (incl. FOLU)		7 601.3

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	Improvement/ update	GHG	Identification Criteria
3A1a	Enteric fermentation - cattle	CH_4	L1, T1
3A1c	Enteric fermentation - sheep	CH_4	L1,T1
3B1a	Forest land remaining forest land	CO_2	L1,T1
3B1b	Land converted to forest land	CO_2	L1,T1
3B2b	Land converted to cropland	CO_2	L1
3B3a	Grassland remaining grassland	CO_2	L1,T1
3B3b	Land converted to grassland	CO_2	L1,T1
3B5a	Settlements remaining settlements	CO_2	T1
3B6b	Land converted to other lands	CO_2	L1,T1
3C1c	Biomass burning in grasslands	N_2O	T1
3C1c	Biomass burning in grasslands	CH_4	T1
3C2	Liming	CO_2	T1
3C4	Direct N_2O emissions from managed soils	N_2O	L1,T1
3C5	Indirect N_2O emissions from managed soils	N_2O	L1,T1
3D1	Harvested wood products	CO_2	L1,T1

SOURCE CATEGORY 3.A.1 ENTERIC FERMENTATION

5.2

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 5.4% 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 2007, but returned to similar levels by 2017. Dairy cattle contribution to the overall *Enteric fermentation* emissions increased by 6.4% 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 23 884 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.

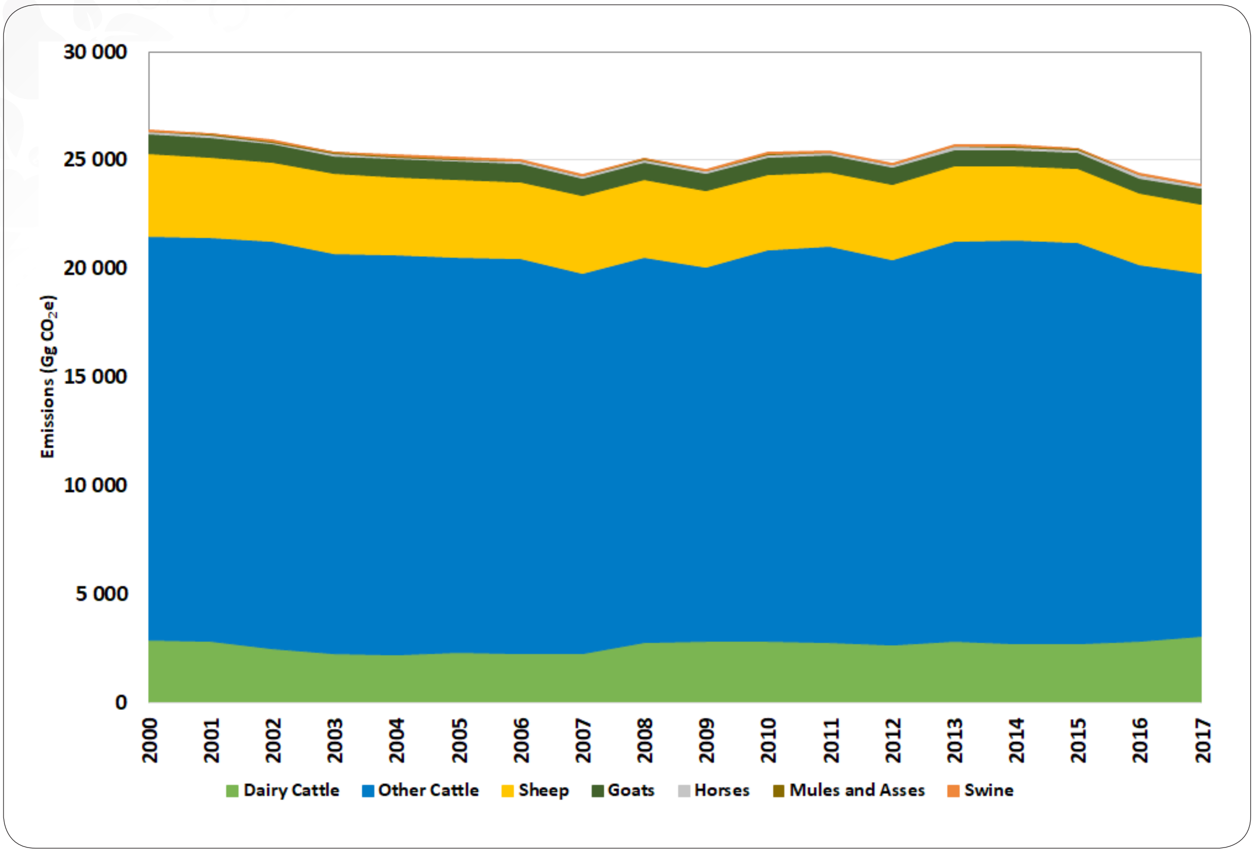


Figure 5.3: *Enteric fermentation* emission trends, 2000 – 2017.

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	18 654.3	18 212.6	18 056.2	18 283.6	17 796.2	18 413.2	18 631.4	18 499.5	17 348.0	16 734.2
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	26 389.7	25 124.3	25 338.8	25 430.4	24 856.3	25 699.1	25 692.7	25 555.0	24 386.5	23 883.7

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[4]	2 848.6	2 327.7	2 837.4	2 734.2	2 633.1	2 839.5
Other cattle	18 654.3	18 212.6	18 056.2	18 283.6	17 796.2	18 413.2
Buffalo	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
Goats	906.2	822.0	789.6	782.3	780.4	771.6
Camels	NO	NO	NO	NO	NO	NO
Horses	102.1	102.1	113.4	115.3	116.4	117.2
Mules & asses	34.4	34.4	34.9	35.1	35.1	35.8
Swine	43.5	43.6	42.1	41.9	41.7	41.6
Other	NO	NO	NO	NO	NO	NO
Total	26 389.7	25 124.3	25 338.8	25 430.4	24 856.3	25 699.1

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.

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.

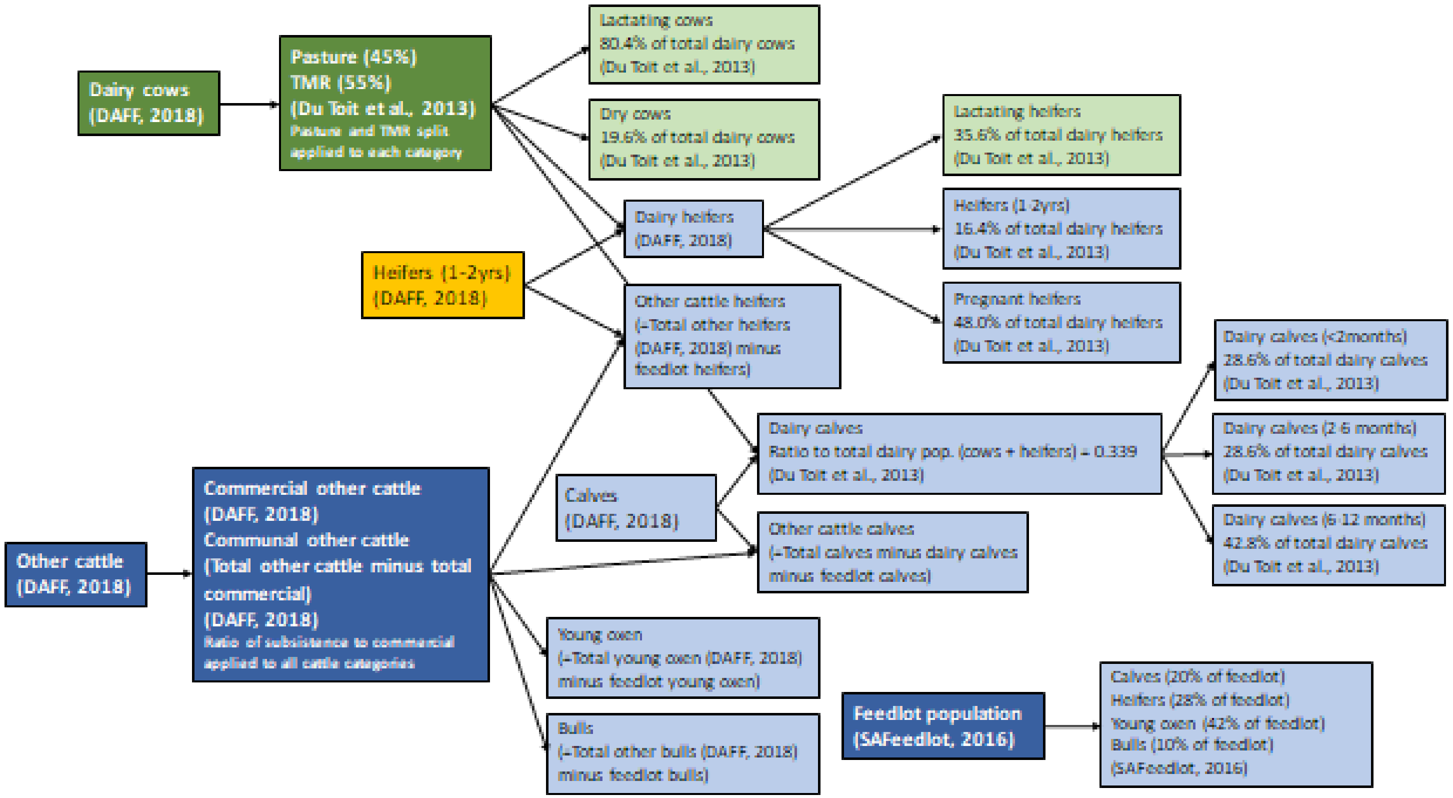


Figure 5.4: Diagram illustrating how the cattle population data was split into the more detailed sex and age classes. Green blocks reflect what is included under Dairy cattle, while blue shows the Other cattle category.

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)

W0 = 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)

kl = 0.60 efficiency of use of ME for milk production (SCA, 1990)

qm = metabolizability of the diet (i.e. ME/GE). Calculated using the equation of Minson & McDonald (1987)

qm = 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 (2018) 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

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.

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:

$$MA = (LC \times FA) + ((I - LC) \times I)$$

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 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 x 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	145 521	150 607	73 017	134 609	120 013	128 823	149 606	132 836	83.8
	Calves	1 323 890	1 437 597	1 395 769	1 067 767	1 115 380	970 464	1 812 295	1 739 815	40.9
	Cows	2 710 027	2 574 164	1 583 733	2 620 215	2 496 023	2 584 797	2 656 419	2 639 632	73.1
	Heifers	725 750	754 502	1 036 889	654 339	660 708	642 855	684 537	501 892	62.5
	Oxen	154 599	413 705	157 064	549 089	731 917	710 109	107 429	263 963	72.6
	Young oxen	420 213	189 425	403 528	653 982	535 960	542 951	69 714	21 863	41.6
	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

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
	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

Livestock category		Population								Enteric fermentation EF
		2010	2011	2012	2013	2014	2015	2016	2017	(kg CH_4/head)
Subsistence sheep	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
	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
	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

Livestock category		Population								Enteric fermentation EF
		2010	2011	2012	2013	2014	2015	2016	2017	(kg CH_4/head)
Subsistence sheep	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.

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

Livestock category		Population								Enteric fermentation EF
		2010	2011	2012	2013	2014	2015	2016	2017	(kg CH_4/head)
Subsistence goats	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

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.

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
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

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

In addition implied emission factors (IEFs)[9] have been compared to the IPCC defaults as well as those reported in the Australian National Inventory Report (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 swine IEFs are generally consistent with the IPCC defaults and the values provided for Australia.

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 1.26% lower 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.

9 An implied emission factor is defined as emissions divided by the relevant measure of activity: IEF = Emissions / Activity data

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 7.9% between 2000 and 2017 (Table 5.19). CH_4 emissions declined (Table 5.20), while N_2O emissions increased (Table 5.21).

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. Managed manure from non-dairy cattle and piggeries contributed the most to the CH_4 emissions (32.9% and 58.9% respectively); while the largest contributors to the N_2O emissions were non-dairy cattle (50.2%) and poultry (39.0%).

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	762.9	744.2	-18.7	-2.5	34.4	31.2
Nitrous oxide	1 451.7	1 644.4	192.7	13.3	65.6	68.8
Total manure management	2 214.6	2 388.6	174.0	7.9	100	100

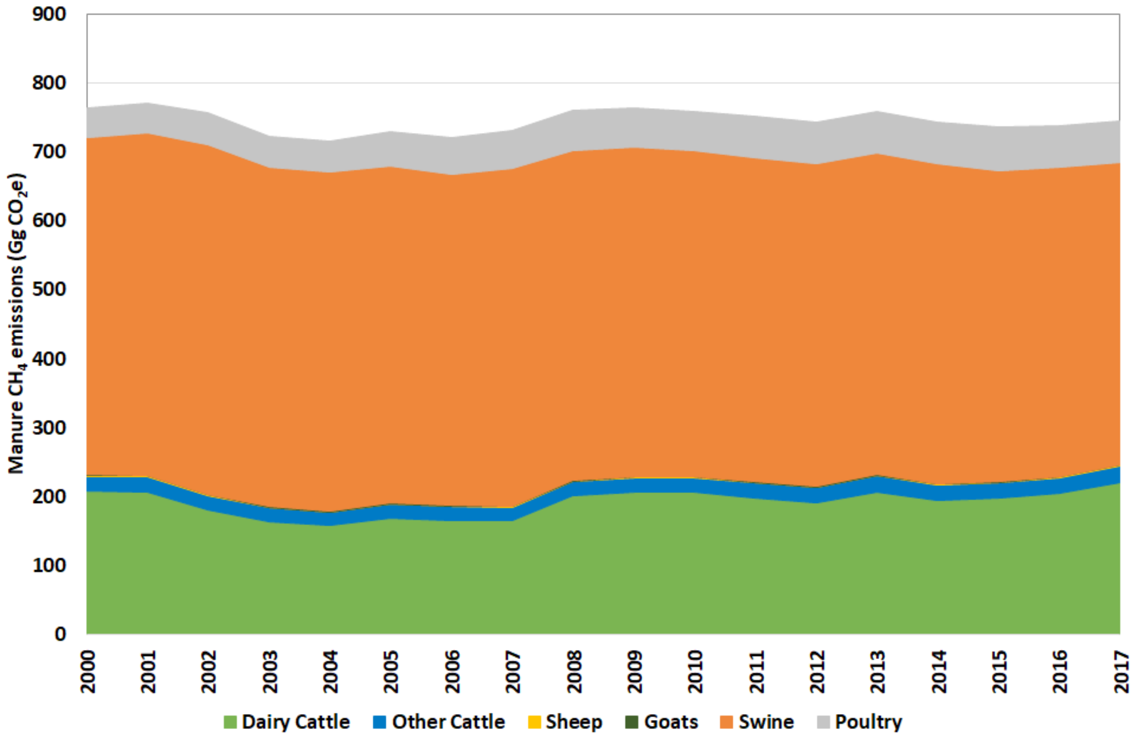


Figure 5.5: *Trend in manure management CH4 emissions from livestock, 2000 – 2017.*

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]	22.0	19.5	20.9	21.4	21.6	23.3	22.5	22.5	23.0	24.3
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
Total	762.9	729.0	758.9	750.8	743.8	757.9	743.7	736.5	737.3	744.2

Note: Numbers may not add exactly due to rounding off.

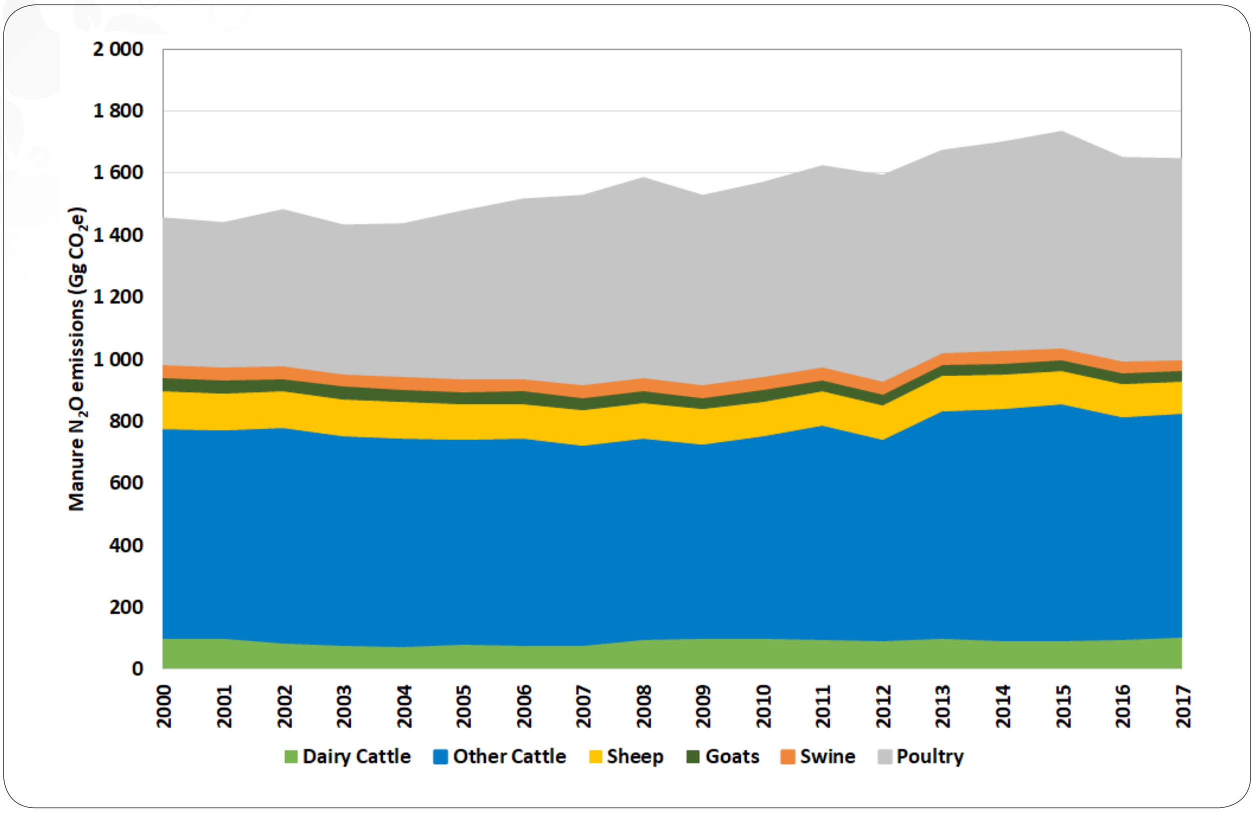


Figure 5.6: Trend in manure management N_2O emissions from livestock, 2000 – 2017.

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]	672.3	658.2	651.7	688.0	645.9	732.7	744.7	756.4	713.6	716.3
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
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	1 451.7	1 473.3	1 566.7	1 620.3	1 590.7	1 668.4	1 695.7	1 731.0	1 646.7	1 644.4

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 (1.4×10^{-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:

Bo = 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 (kg)	Manure CH_4 emission factor (kg CH_4 head^{-1} yr^{-1})	Annual N excretion rate (kg N (animal mass)$^{-1}$ yr^{-1})	Weighted N_2O emission factor (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 x 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, 2009) 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 (B0) 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.

<table>
<tr><th colspan="2" rowspan="2">Livestock subcategory</th><th>Typical animal mass</th><th>Manure CH_4 emission factor</th><th>Annual N excretion rate</th><th>Weighted N_2O emission factor</th></tr>
<tr><th>(kg)</th><th>(kg CH_4 head^{-1} yr^{-1})</th><th>(kg N (animal mass)$^{-1}$ yr^{-1})</th><th>(kg N_2O-N (kg Nex)$^{-1}$)</th></tr>
<tr><td rowspan="7">Commercial cattle</td><td>Bulls</td><td>733</td><td>0.022</td><td>168.6</td><td rowspan="3">0.0007</td></tr>
<tr><td>Calves</td><td>190</td><td>0.012</td><td>43.7</td></tr>
<tr><td>Cows</td><td>475</td><td>0.018</td><td>109.2</td></tr>
<tr><td>Feedlot</td><td>286</td><td>0.87</td><td>65.8</td><td>0.0164</td></tr>
<tr><td>Heifers</td><td>365</td><td>0.016</td><td>83.9</td><td rowspan="3">0.0007</td></tr>
<tr><td>Oxen</td><td>430</td><td>0.018</td><td>98.9</td></tr>
<tr><td>Young oxen</td><td>193</td><td>0.012</td><td>44.4</td></tr>
<tr><td rowspan="6">Subsistence cattle</td><td>Bulls</td><td>462</td><td>0.017</td><td>106.2</td><td rowspan="6">0.0015</td></tr>
<tr><td>Calves</td><td>152</td><td>0.01</td><td>35.0</td></tr>
<tr><td>Cows</td><td>360</td><td>0.015</td><td>82.8</td></tr>
<tr><td>Heifers</td><td>292</td><td>0.013</td><td>67.2</td></tr>
<tr><td>Oxen</td><td>344</td><td>0.015</td><td>79.1</td></tr>
<tr><td>Young oxen</td><td>154</td><td>0.01</td><td>35.4</td></tr>
</table>

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 x 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	0.0031
	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	

Livestock subcategory		Typical animal mass (kg)	Manure CH_4 emission factor (kg CH_4 head^{-1} yr^{-1})	Annual N excretion rate (kg N (animal mass)$^{-1}$ yr^{-1})	Weighted N_2O emission factor (kg N_2O-N (kg Nex)$^{-1}$)
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.

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.

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	

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.

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.

Table 5.27: Manure CH_4 emission factors and typical animal mass for horses, mules and asses.

Livestock subcategory	Typical animal mass	Manure CH_4 emission factor
	(kg)	(kg CH_4 head^{-1} yr^{-1})
Horses	595	0.013
Mules and asses	250	0.0045

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)

Bo = 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/m³).

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 CH_4/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_o, 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.

<table>
<tr><th rowspan="2">Livestock category</th><th colspan="4">CH_4 emission factor ($kg\ CH_4\ head^{-1}\ yr^{-1}$)</th><th colspan="2">Annual N excretion ($kg\ N\ (animal\ mass)^{-1}\ yr^{-1}$)</th><th colspan="2">Typical animal (kg)</th></tr>
<tr><th>Du Toit et al. (2013)#</th><th>Moeletsi & Tongwane (2015)</th><th>IPCC Africa default</th><th>IPCC Oceania default</th><th>Current inventory</th><th>Moeletsi & Tongwane (2015)</th><th>Current inventory</th><th>Moeletsi & Tongwane (2015)</th></tr>
<tr><td colspan="9">Dairy cattle</td></tr>
<tr><td>Lactating cow (pasture)</td><td>5.0</td><td rowspan="2">40.98</td><td rowspan="4">1</td><td rowspan="4">29</td><td>118.3</td><td rowspan="2">80.0</td><td>540</td><td rowspan="2">498</td></tr>
<tr><td>Lactating cow (TMR)</td><td>14.8</td><td>129.2</td><td>590</td></tr>
<tr><td>Lactating heifer (pasture)</td><td>4.8</td><td rowspan="2">1.85</td><td>95.9</td><td rowspan="2">63.9</td><td>438</td><td rowspan="2">355</td></tr>
<tr><td>Lactating heifer (TMR)</td><td>14.7</td><td>110.2</td><td>503</td></tr>
</table>

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)
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	
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

Table 5.30: parison 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

Implied emission factors

Implied emission factors were compared to the IPCC defaults as well as those reported in the Australian National Inventory Report (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.

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;

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	1 451.7	476.1	48.8
2010	Manure CH_4	687.2	758.9	71.7	10.4
	Manure N_2O	1 015.2	1 566.7	551.5	54.3
2015	Manure CH_4	666.5	736.5	70.0	10.5
	Manure N_2O	1 141.3	1 731.0	589.7	51.7

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 10.5% increase in the manure CH_4 emissions and a 51.6% increase in the manure N_2O emissions for 2015 (Table 5.31).

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.

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

Land class	1990		2014		% change
	1000 ha	% of total area	1000 ha	% of total area	
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.

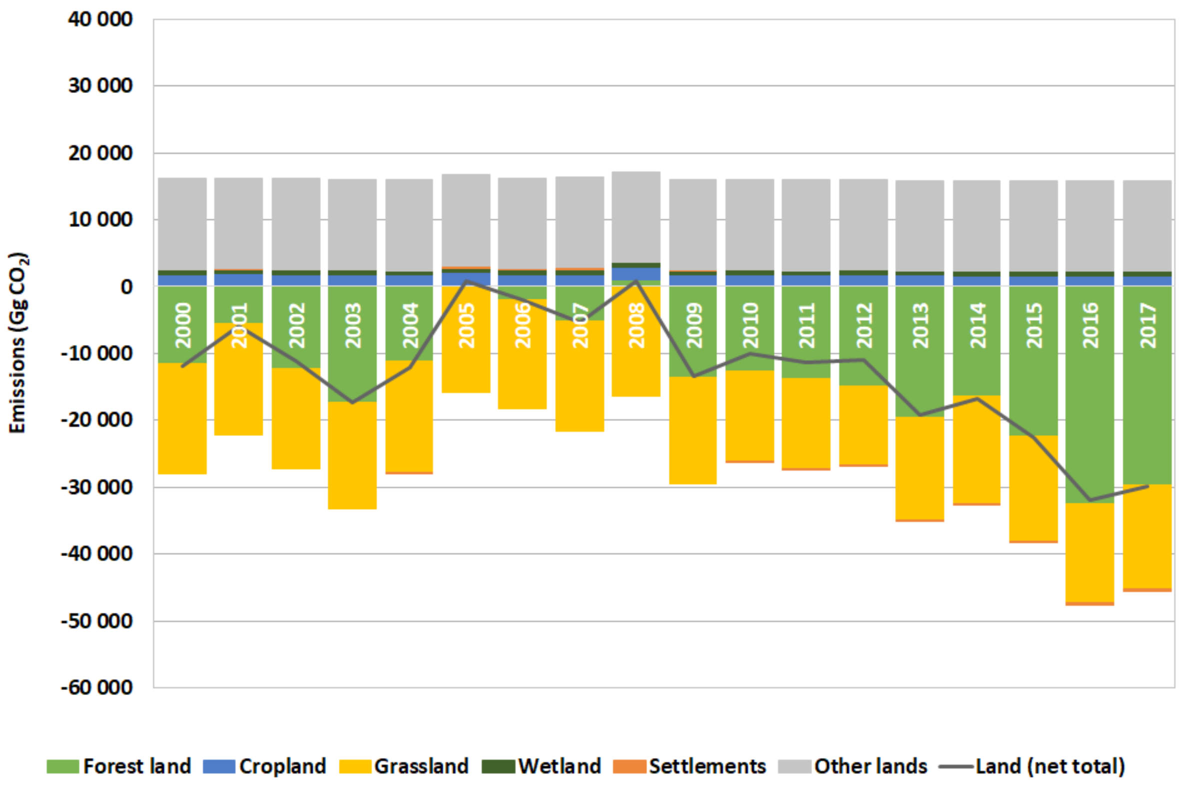


Figure 5.7: Time series for GHG emissions and removals (Gg CO_2) in the Land sector in South Africa.

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.

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	-11 595.2	1 820.8	-16 363.7	666.6	108.3	13 512.9
2001	-5 601.5	1 905.0	-16 523.4	666.6	167.5	13 512.9
2002	-12 239.9	1 824.7	-15 022.1	666.6	95.4	13 512.9
2003	-17 265.4	1 819.1	-16 027.4	666.6	19.6	13 512.9
2004	-11 153.3	1 711.7	-16 702.2	666.6	-85.5	13 512.9
2005	268.2	1 823.3	-15 939.0	666.6	381.4	13 512.9
2006	-1 953.9	1 753.5	-16 318.7	666.6	277.1	13 512.9
2007	-5 137.6	1 836.9	-16 524.8	666.6	355.0	13 512.9
2008	1 015.4	1 892.1	-16 323.0	666.6	42.4	13 512.9
2009	-13 611.8	1 684.5	-15 875.2	666.6	144.4	13 512.9
2010	-12 604.5	1 778.6	-13 481.3	666.6	-9.8	13 512.9
2011	-13 698.7	1 742.8	-13 457.9	666.6	-149.0	13 512.9
2012	-14 815.9	1 803.1	-11 961.7	666.6	-158.5	13 512.9
2013	-19 577.5	1 693.6	-15 282.3	666.6	-136.2	13 512.9
2014	-16 337.1	1 642.4	-16 127.6	666.6	-122.0	13 512.9
2015	-22 439.5	1 615.3	-15 643.6	666.6	-246.5	13 512.9
2016	-32 421.1	1 596.2	-14 905.1	666.6	-392.8	13 512.9
2017	-29 616.9	1 580.8	-15 596.5	666.6	-397.0	13 512.9

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.

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

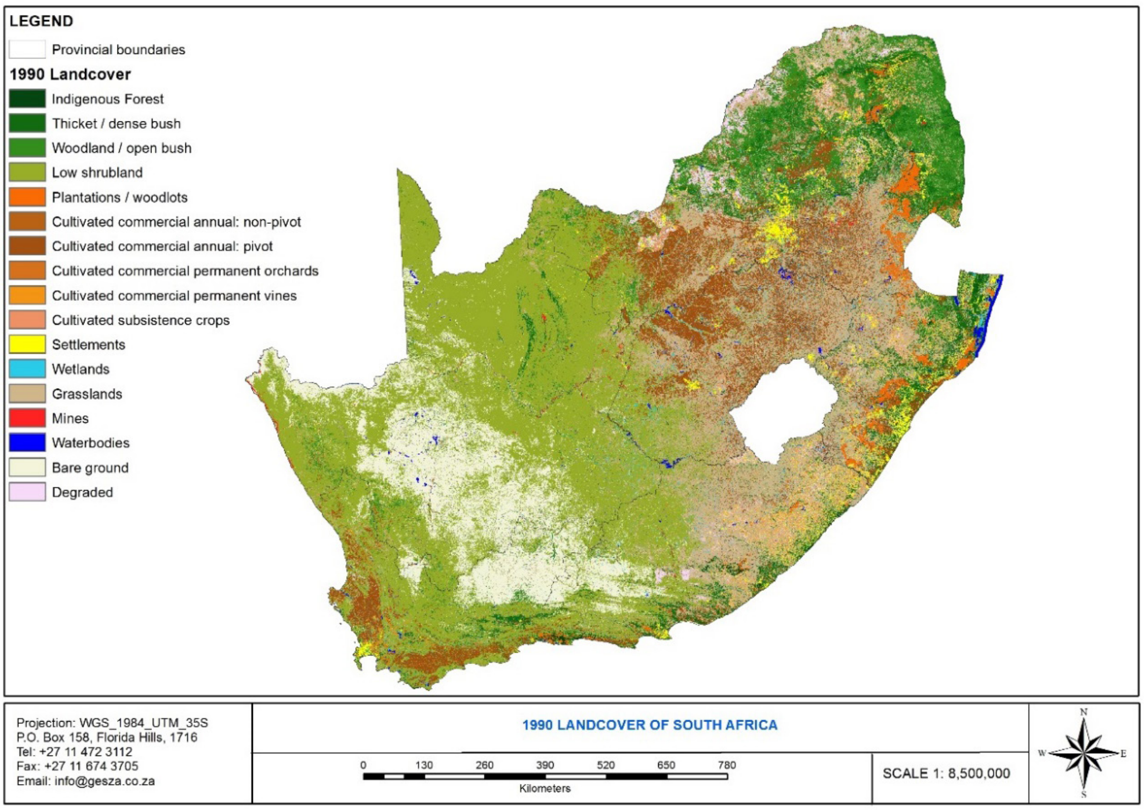


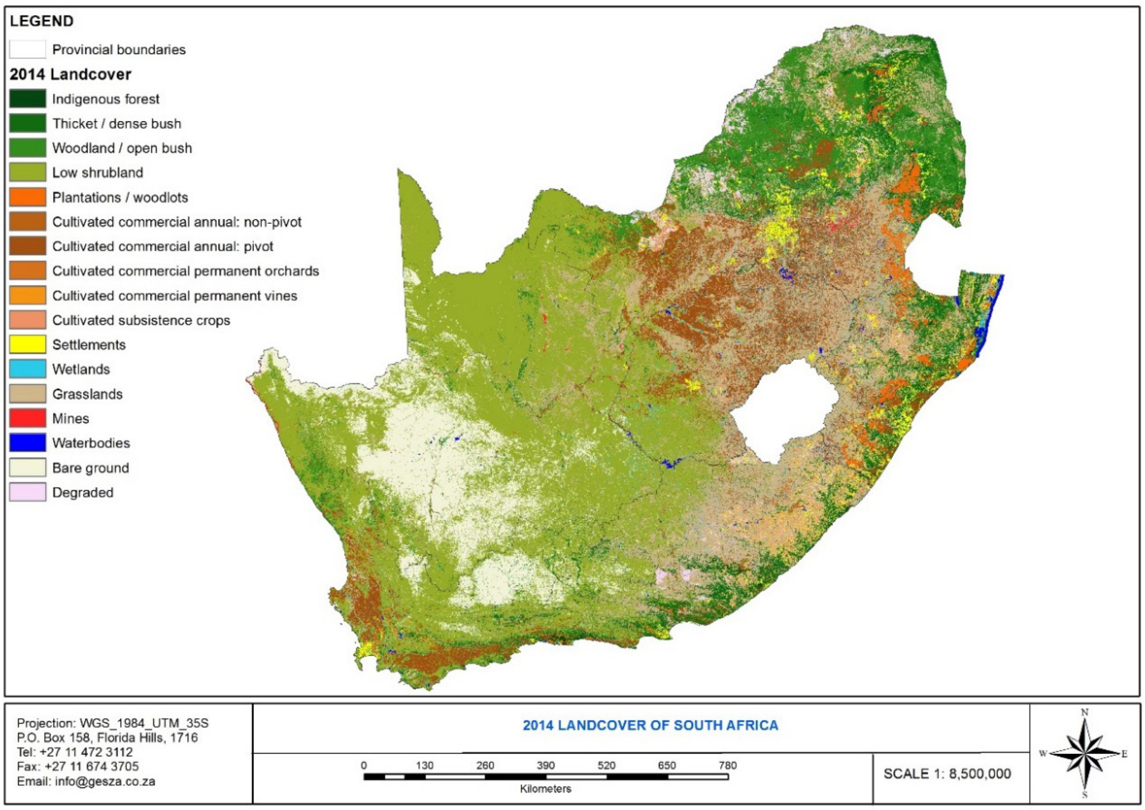
Figure 5.8: Land cover maps for South Africa for 1990 (left) and 2014 (right) (Source: GTI, 2014; 2015).

10 The term 'land cover' is used loosely here as the classes are a combination of land cover and land use.

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	

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.

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.

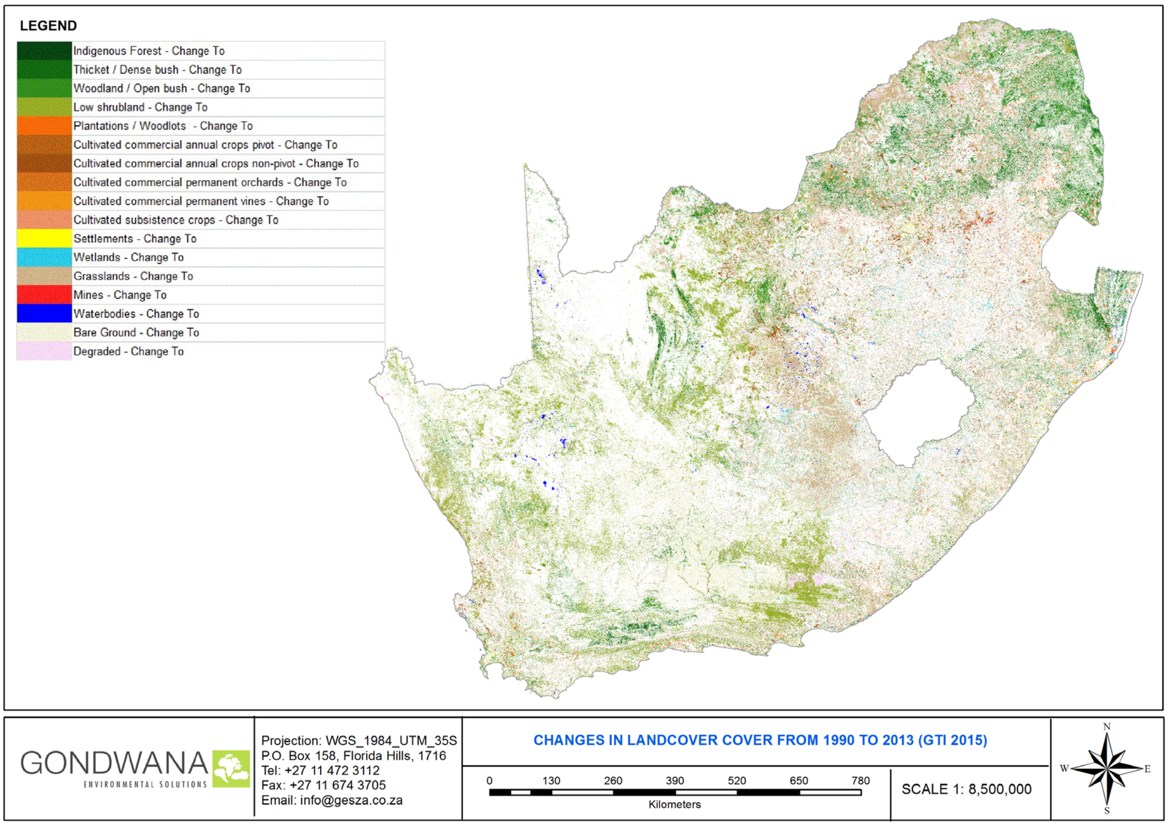


Figure 5.9: Land cover change in South Africa between 1990 and 2014.

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.

Land change area corrections for natural land classes

A 2018 South African National Land Cover Assessment was completed as part of the 2018 land cover mapping project to verify the natural land class changes between

11 Forestry SA reports on "Area converted out of plantation".

1990/2014/2018. This assessment (DFFE, 2020) showed that most of the land changes between the natural classes were not real changes. It only indicated that there may be some loss of indigenous forest to grassland, loss of thicket to woodland (although hard to detect due to extent of area), and thicket to shrubland. This information was incorporated into the land change data by making some assumptions. The conversion areas where no conversion is considered to occur were reverted back to the 2014 land remaining land class. Based on the assessment the conversion from shrubland to grassland could be real, therefore this change was left as given in the change map. In the conversions there were pockets of real change were considered to occur (indigenous forest to grassland, thicket to woodland, thicket to shrubland) it was assumed that a quarter of the actual reported change occurs.

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:

$$LC_{i\ 1990} = ALC_{i\ 1990} * 20\ yrs$$

$$LRL_{i\ 1990} = A_{i\ 1990} - LC_{i\ 1990}$$

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;

LCi_{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;

$ALCi_{(t-20)}$ = 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.

	Livestock category	2014																
		Indigenous Forest	Thicket/ dense bush	Woodland/ open bush	Low s hrubland	Plantations/ woodlots	Commercial Annual crop: non-pivot	Commercial Annual crop: pivot	Permanent orchards	Permanent vines	Cultivated subsistence crops	Settlements	Wetlands	Grasslands	Mines	Waterbodies	Bare ground	Degraded
1990	Indigenous Forest		0	0	0	0	35	1	28	0	41	84	0	70	11	1	23	0
	Thicket/ dense bush	0		13 320	3 978	0	4 225	375	981	161	2 132	1 970	0	0	357	435	888	0
	Woodland/ open bush	0	0		0	0	4 021	1 424	484	71	2 945	3 384	0	0	637	481	6 666	0
	Low shrubland	0	0	0		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	0	0	0	0	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).

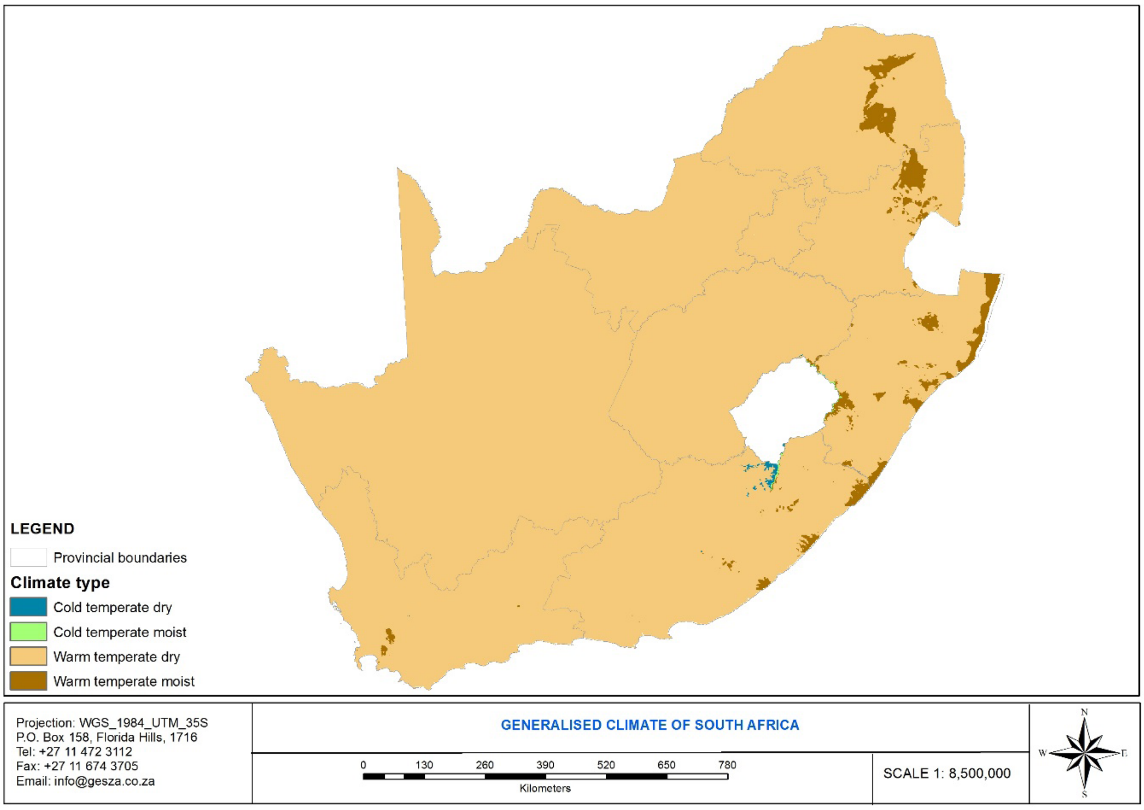


Figure 5.10: South Africa's long term climate map classified into the IPCC climate classes (Source: Moeletsi *et al.*, 2015).

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).

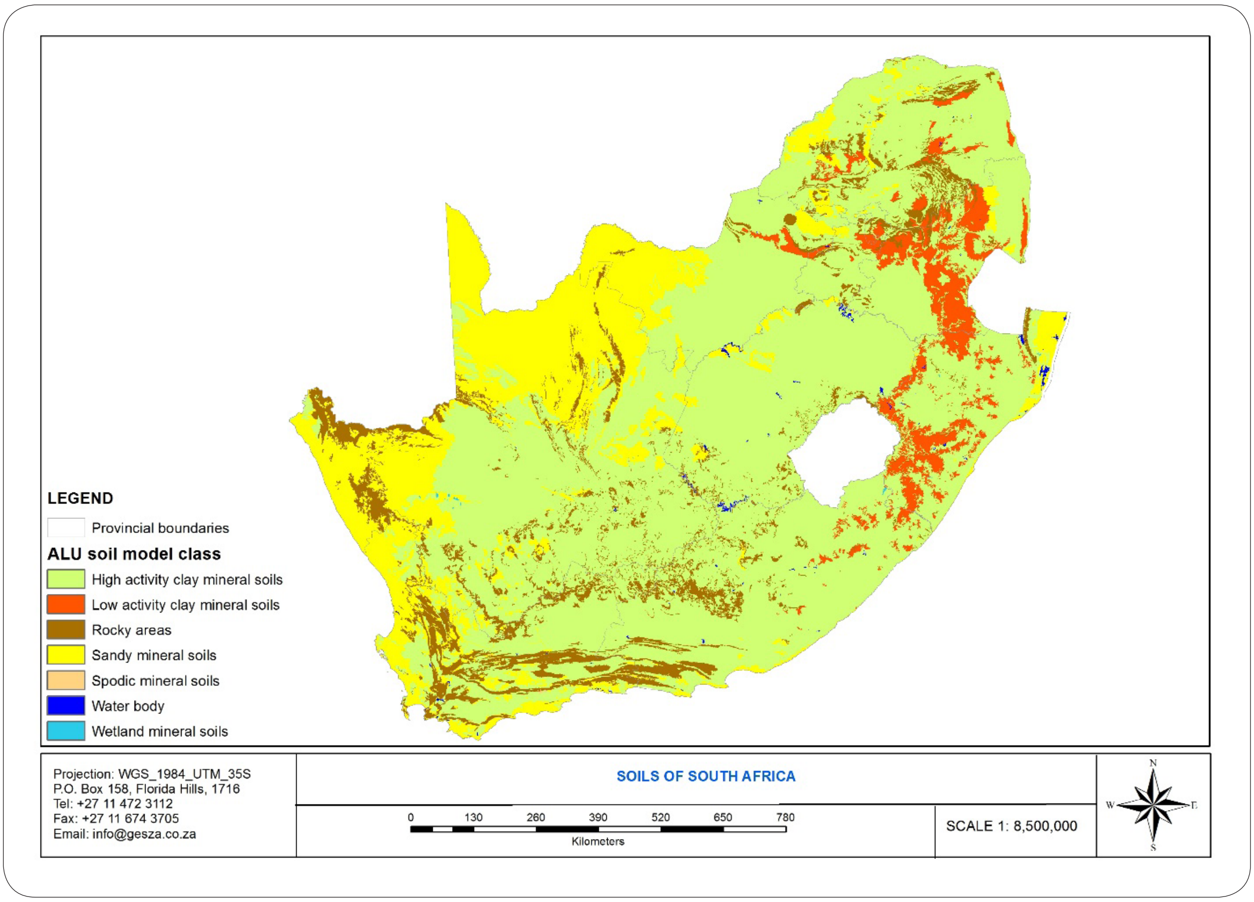


Figure 5.11: South African soils classified into the IPCC classes (Moeletsi *et al*., 2015).

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 (AG + BG)	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 forests	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	4.2[1]				1.03[3]
Other land	0				0

1 NTCSA report (DEA, 2015)
2 Alembong (2015)
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 (DEAT, 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, 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:

$$\Delta C_B = \Delta C_G - \Delta C_L \quad \text{(Eq. 5. 1)}$$

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:

$$\Delta C_B = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L \quad \text{(Eq. 5. 2)}$$

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),

$$\Delta C_{CONVERSION} = \sum\{(B_{AFTERi} - B_{BEFOREi}) * \Delta A_{TO\_OTHERSi}\} * CF \quad \text{(Eq. 5. 3)}$$

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:

$$\Delta C_{DOM} = \{(C_n - C_o) * A_{on}\}/T_{on} \quad \text{(Eq. 5.4)}$$

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):

$$\Delta C_{Mineral} = [\sum[\{(SOC_{REF} * F_{LU} * F_{MG} * F_I)_0 - (SOC_{REF} * F_{LU} * F_{MG} * F_I)_{(0-T)}\} * A]]/D \quad \text{(Eq. 5.5)}$$

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;
  - Land change area corrections for natural vegetation classes;
  - 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 17.1% lower 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).

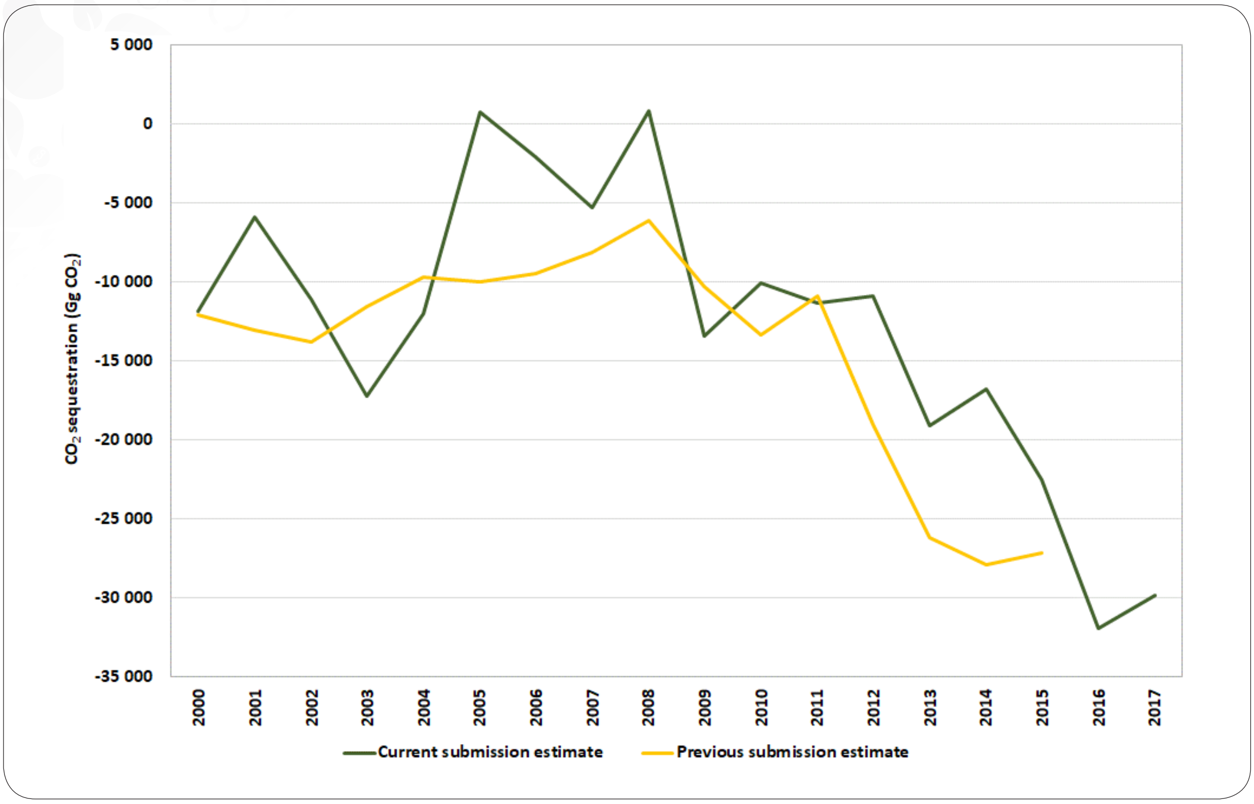


Figure 5.12: Recalculated Land category emissions compared to 2015 submission data, 2000 – 2017.

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 2005 to 2008. The source is due to increased biomass losses in these years. Harvested wood removals increased between 2002 and 2006, slowly declined to 2010 after which it stabilised to 2017. Losses dues to disturbances increased between 2005 and 2008. These two factors contribute to the sink in 2005 to 2008.

The *Forest land* sink increased between 2008 and 2017 due to the increase in forest area, mainly woodlands and thickets, combined with reduced disturbance losses. Disturbance losses declined significantly between 2014 and 2017, contributing to the increased sink during these years. Fuelwood removal decline over the time-series and are also a contributing factor to the increasing sink. 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. There are also 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.

Grasslands converted to *forest lands* are the largest sink component in the converted lands category. Biomass is the dominant carbon pool (Table 5.37).

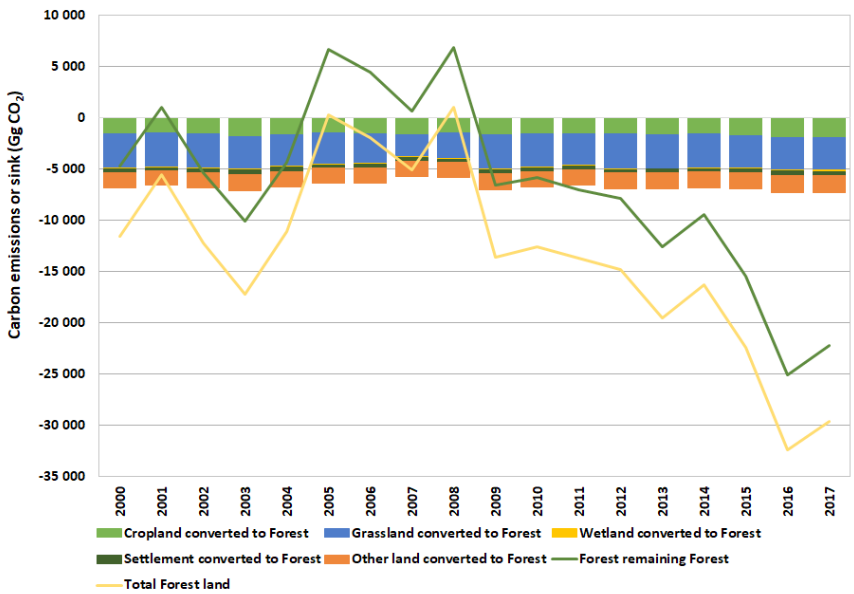


Figure 5.13: CO_2 emissions and removals (Gg CO_2) due to changes in carbon stocks between 2000 and 2017 for South Africa's Forest land.

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	-4 715.0	5.9	0.0	-4 599.0	-254.0	-2 033.0
2001	1 029.2	5.9	0.0	-4 349.6	-254.0	-2 033.0
2002	-5 408.2	5.9	0.0	-4 550.5	-254.0	-2 033.0
2003	-10 122.0	5.9	0.0	-4 862.2	-254.0	-2 033.0
2004	-4 348.5	5.9	0.0	-4 523.7	-254.0	-2 033.0
2005	6 641.5	5.9	0.0	-4 092.0	-254.0	-2 033.0
2006	4 426.3	5.9	0.0	-4 099.0	-254.0	-2 033.0
2007	626.3	5.9	0.0	-3 482.8	-254.0	-2 033.0
2008	6 857.2	5.9	0.0	-3 560.6	-254.0	-2 033.0
2009	-6 604.4	5.9	0.0	-4 726.2	-254.0	-2 033.0
2010	-5 859.7	5.9	0.0	-4 463.6	-254.0	-2 033.0
2011	-7 104.9	5.9	0.0	-4 312.6	-254.0	-2 033.0
2012	-7 897.7	5.9	0.0	-4 637.0	-254.0	-2 033.0
2013	-12 600.9	5.9	0.0	-4 695.3	-254.0	-2 033.0
2014	-9 510.7	5.9	0.0	-4 545.3	-254.0	-2 033.0
2015	-15 475.7	5.9	0.0	-4 682.6	-254.0	-2 033.0
2016	-25 090.0	5.9	0.0	-5 049.9	-254.0	-2 033.0
2017	-22 255.6	5.9	0.0	-5 080.0	-254.0	-2 033.0

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:

$$\Delta C = \Delta C_G - L_{wood-removals} - L_{fuelwood} - L_{disturba}N_{ces}$$

(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):

$$\Delta CG = \sum (A_i * G_{TOTALi} * CF_i)$$

(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):

$$L_{wood\text{-}removals} = [H * BCEF_R * (1+R) * CF \quad \text{(Eq. 5.8)}$$

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 (FSA, 2019; DAFF, 2018a) 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):

$$L_{fuelwood} = [FG_{trees} * BCEF_R * (1+R) + FG_{part} * D] * CF \quad \text{(Eq. 5.9)}$$

Where:

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

FGpart = 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 (FSA, 2019; DAFF, 2018a) 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, 2019). 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:

$$L_{disturbances} = A_{disturbance} * BW * (1+R) * CF * fd \quad \text{(Eq. 5.10)}$$

Where:

$A_{disturbaNce}$ = area affected by disturbances (ha yr^{-1})

BW = 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 (FSA, 2019; DAFF, 2018a) 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 (BW) 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 BBEFORE is determined from the biomass data provided in Table 5.36.

Dead organic matter

Forest land remaining forest land

The Tier I 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 I 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) and total forest land carbon stock data was compared to the outputs of the National Terrestrial Carbon Sinks Assessment (DEA, 2015). In addition, during the NDC update process a LULUCF model for estimating projections for the sector was compiled. This model recreated the LULUCF sector emission profile using a slightly more simplistic approach. The data outputs from this model were compared to the inventory outputs and the comparison enabled the detection and correction of calculation errors in both the model and the inventory calculations.

Source specific planned improvements

No specific improvements are currently 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 small change in the area of crops. The soil carbon pool is the dominant contributor to the source (Table 5.38).

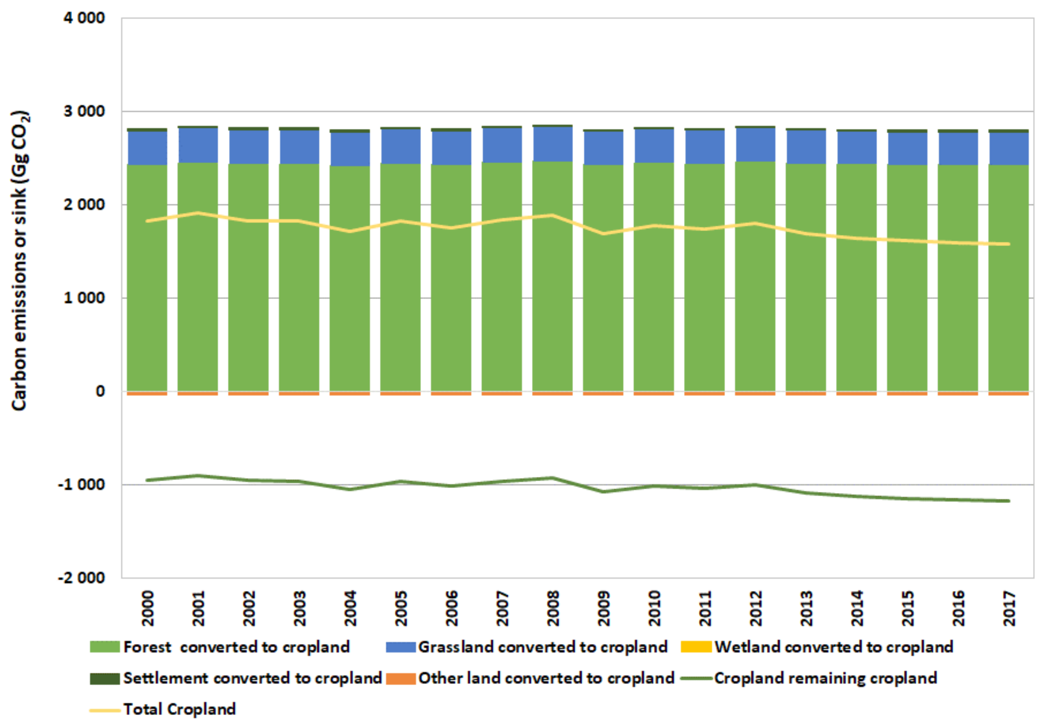


Figure 5.14: CO_2 emissions and removals (Gg CO_2) due to changes in carbon stocks between 2000 and 2017 for South Africa's Cropland.

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	-797.2	-166.0	11.7	1 827.9	-868.9	1 813.3
2001	-737.9	-169.3	11.7	1 857.6	-870.4	1 813.3
2002	-795.6	-172.6	11.7	1 839.7	-871.9	1 813.3
2003	-798.6	-175.8	11.7	1 841.8	-873.4	1 813.3
2004	-877.8	-179.1	11.7	1 843.2	-874.9	1 813.3
2005	-795.5	-182.3	11.7	1 852.5	-876.3	1 813.3
2006	-844.2	-185.6	11.7	1 836.1	-877.8	1 813.3
2007	-784.6	-188.8	11.7	1 864.6	-879.3	1 813.3
2008	-743.8	-192.1	11.7	1 883.8	-880.8	1 813.3
2009	-895.1	-195.3	11.7	1 832.2	-882.3	1 813.3
2010	-824.0	-198.6	11.7	1 860.0	-883.8	1 813.3
2011	-844.9	-201.9	11.7	1 849.8	-885.3	1 813.3
2012	-805.4	-205.1	11.7	1 875.3	-886.8	1 813.3
2013	-885.6	-208.4	11.7	1 850.8	-888.3	1 813.3
2014	-924.4	-211.6	11.7	1 843.2	-889.8	1 813.3
2015	-940.5	-214.9	11.7	1 836.9	-891.3	1 813.3
2016	-954.7	-218.1	11.7	1 836.8	-892.8	1 813.3
2017	-965.5	-221.4	11.7	1 836.9	-894.3	1 813.3

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:

$$\Delta C_B = A * (\Delta C_G - \Delta C_L)$$

(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, 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.

Table 5.39: Stock change factors for the various crop types in South Africa.

Land class	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.

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 (2018), CGA (2016), national statistics (Stats SA, 2007), Crop Estimates Committee, SATI (2016), SAWI (2016) and FAO (FAOStats, 2018). 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 were 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.

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). In addition, during the NDC update process a LULUCF model for estimating projections for the sector was compiled. This model recreated the LULUCF sector emission profile using a slightly more simplistic approach. The data outputs from this model were compared to the inventory outputs and the comparison enabled the detection and correction of calculation errors in both the model and the inventory calculations.

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;
- Incorporate, where possible, recent stock change data from the updated National Terrestrial Carbon Sinks Assessment; 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 source of CO_2 (Figure 5.15) and this is because of the inclusion of degraded grasslands. *Land converted to grassland* are a large sink, with *Other land converted to grasslands* being the dominant contributor. 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).

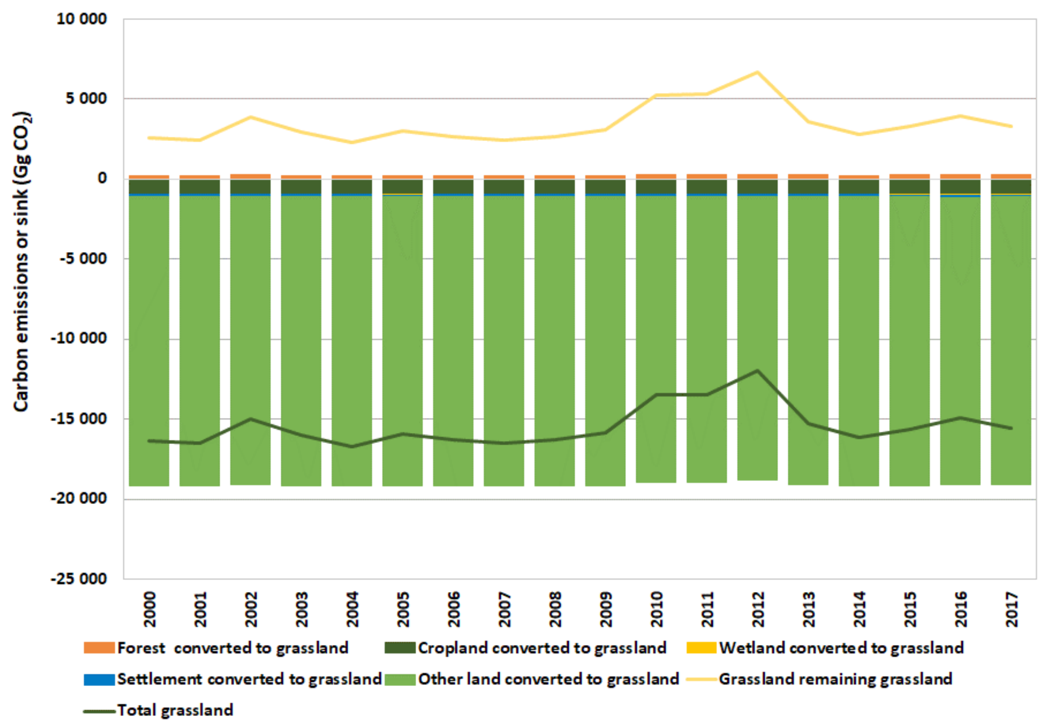


Figure 5.15: CO_2 emissions and removals (Gg CO_2) due to changes in carbon stocks between 2000 and 2017 for South Africa's Grassland.

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	114.5	462.9	2 015.9	-1 128.6	-1 472.0	-16 356.4
2001	-39.5	462.9	2 015.9	-1 134.3	-1 472.0	-16 356.4
2002	1 352.7	462.9	2 015.9	-1 011.7	-1 472.0	-16 356.4
2003	408.0	462.9	2 015.9	-1 105.1	-1 472.0	-16 356.4
2004	-199.7	462.9	2 015.9	-1 165.5	-1 472.0	-16 356.4
2005	518.2	462.9	2 015.9	-1 080.2	-1 472.0	-16 356.4
2006	140.9	462.9	2 015.9	-1 120.8	-1 472.0	-16 356.4
2007	-40.2	462.9	2 015.9	-1 139.7	-1 472.0	-16 356.4
2008	151.0	462.9	2 015.9	-1 126.1	-1 472.0	-16 356.4
2009	566.9	462.9	2 015.9	-1 086.1	-1 472.0	-16 356.4
2010	2 777.2	462.9	2 015.9	-894.6	-1 472.0	-16 356.4
2011	2 784.7	462.9	2 015.9	-892.4	-1 472.0	-16 356.4
2012	4 168.0	462.9	2 015.9	-773.2	-1 472.0	-16 356.4
2013	1 088.1	462.9	2 015.9	-1 043.1	-1 472.0	-16 356.4
2014	326.6	462.9	2 015.9	-1 115.6	-1 472.0	-16 356.4
2015	790.1	462.9	2 015.9	-1 084.1	-1 472.0	-16 356.4
2016	1 477.2	462.9	2 015.9	-1 032.7	-1 472.0	-16 356.4
2017	827.4	462.9	2 015.9	-1 091.6	-1 472.0	-16 356.4

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.

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 (FI)
		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.

Stock change factors for *Forest land, Croplands, Wetlands, Settlements* and *Other lands* are provided in the specific land category sections of this report.

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). In addition, during the NDC update process a LULUCF model for estimating projections for the sector was compiled. This model recreated the LULUCF sector emission profile using a slightly more simplistic approach. The data outputs from this model were compared to the inventory outputs and the comparison enabled the detection and correction of calculation errors in both the model and the inventory calculations.

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:

$$CH_4\ emissions_{WWFlood} = P * E(CH_4)_{diff} * A * 10^{-6} \quad \text{(Eq. 5.12)}$$

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 2010, but this turned to a small sink between 2011 and 2017. *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 contributing the most to this source. Conversion to settlements from all land types except *Other lands* leads to a loss of carbon. With conversion of Other lands, 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. The biomass and soil pools are the larger contributors to the overall emissions in Settlements (Table 5.42).

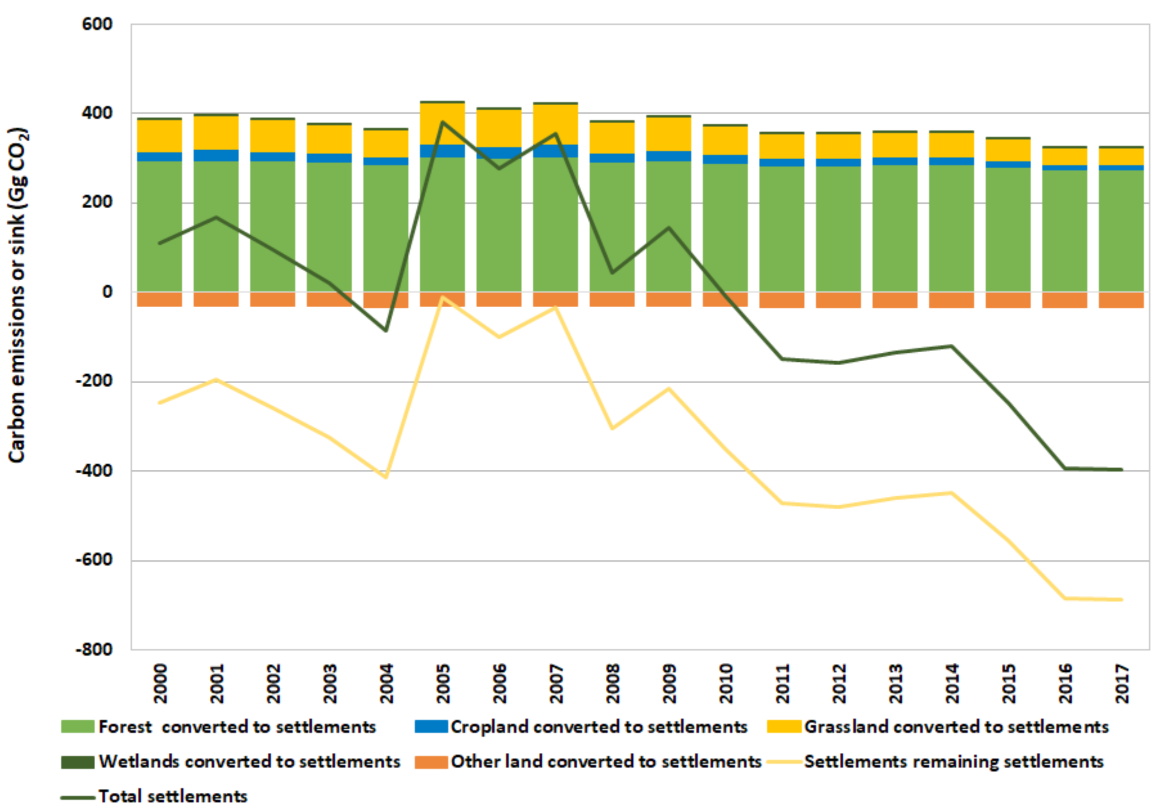


Figure 5.16: CO_2 emissions and removals (Gg CO_2) due to changes in carbon stocks between 2000 and 2017 for South Africa's Settlements.

Table 5.42: South Africa's net carbon stock change (Gg CO_2) by carbon pool for Settlements, 2000 – 2017.

	Settlements remaining settlements			Land converted to settlements		
	Biomass	Litter	Mineral soil	Biomass	Litter	Mineral soil
2000	-246.5	-0.4	0.2	242.3	-88.8	201.5
2001	-195.4	-0.4	0.2	250.4	-88.8	201.5
2002	-257.8	-0.4	0.2	240.8	-88.8	201.5
2003	-323.6	-0.4	0.2	230.7	-88.8	201.5
2004	-414.6	-0.4	0.2	216.7	-88.8	201.5
2005	-10.4	-0.4	0.2	279.3	-88.8	201.5
2006	-100.7	-0.4	0.2	265.4	-88.8	201.5
2007	-33.2	-0.4	0.2	275.8	-88.8	201.5
2008	-304.3	-0.4	0.2	234.2	-88.8	201.5
2009	-215.9	-0.4	0.2	247.9	-88.8	201.5
2010	-349.8	-0.4	0.2	227.5	-88.8	201.5
2011	-470.7	-0.4	0.2	209.2	-88.8	201.5
2012	-479.1	-0.4	0.2	208.1	-88.8	201.5
2013	-459.9	-0.4	0.2	211.2	-88.8	201.5
2014	-447.7	-0.4	0.2	213.2	-88.8	201.5
2015	-556.0	-0.4	0.2	197.0	-88.8	201.5
2016	-683.3	-0.4	0.2	178.1	-88.8	201.5
2017	-687.2	-0.4	0.2	177.7	-88.8	201.5

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 (FI)
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. In addition, during the NDC update process a LULUCF model for estimating projections for the sector was compiled. This model recreated the LULUCF sector emission profile using a slightly more simplistic approach. The data outputs from this model were compared to the inventory outputs and the comparison enabled the detection and correction of calculation errors in both the model and the inventory calculations.

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).

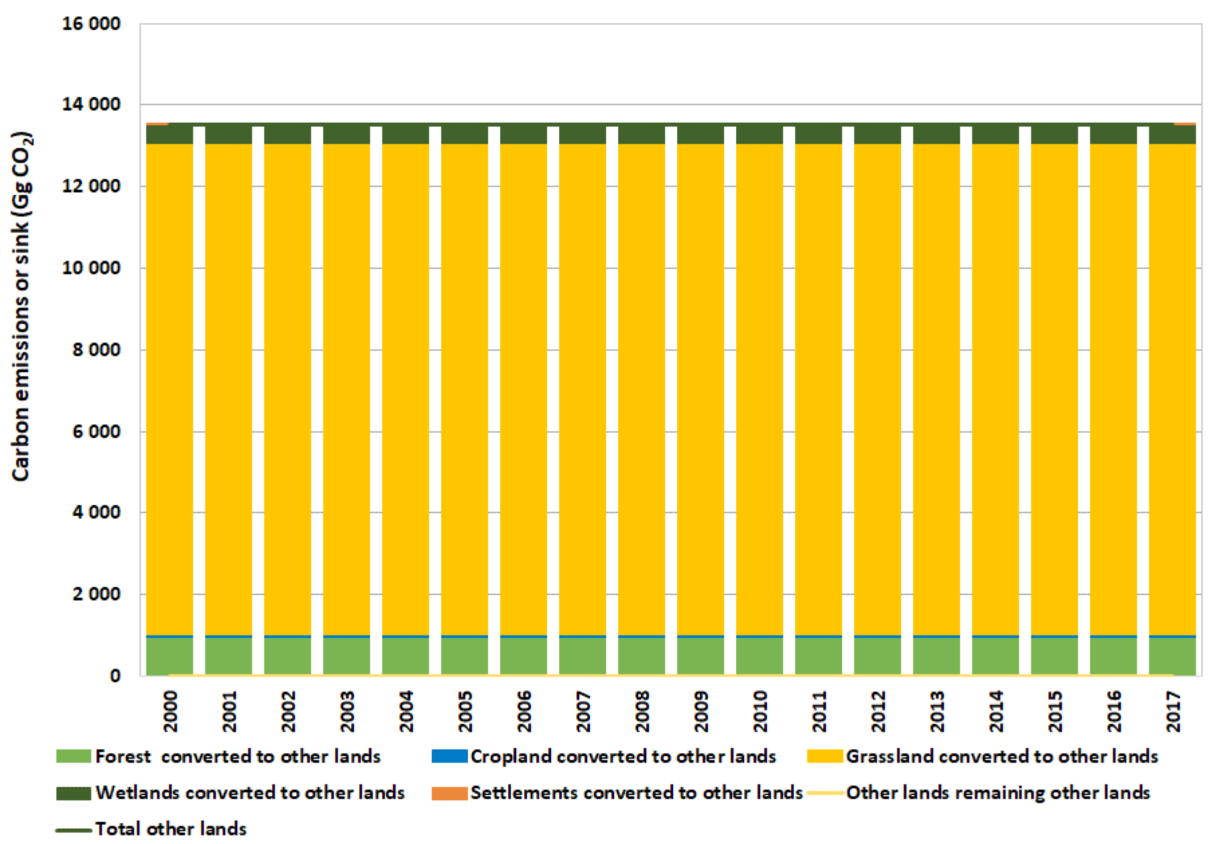


Figure 5.17: CO_2 emissions and removals (Gg CO_2) due to changes in carbon stocks between 2000 and 2017 for South Africa's Other lands.

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	1 292	1 047	11 174
2001	1 292	1 047	11 174
2002	1 292	1 047	11 174
2003	1 292	1 047	11 174
2004	1 292	1 047	11 174
2005	1 292	1 047	11 174
2006	1 292	1 047	11 174
2007	1 292	1 047	11 174
2008	1 292	1 047	11 174
2009	1 292	1 047	11 174
2010	1 292	1 047	11 174
2011	1 292	1 047	11 174
2012	1 292	1 047	11 174
2013	1 292	1 047	11 174
2014	1 292	1 047	11 174
2015	1 292	1 047	11 174
2016	1 292	1 047	11 174
2017	1 292	1 047	11 174

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. In addition, during the NDC update process a LULUCF model for estimating projections for the sector was compiled. This model recreated the LULUCF sector emission profile using a slightly more simplistic approach. The data outputs from this model were compared to the inventory outputs and the comparison enabled the detection and correction of calculation errors in both the model and the inventory calculations.

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.

SOURCE CATEGORY 3.C AGGREGATED SOURCES AND NON-CO_2 EMISSIONS ON LAND

5.5

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	2 242.3	827.5	-1 414.8	-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	19 067.5	17 049.3	-2 018.3	-10.6
Indirect N_2O from managed soils	2 342.4	2 126.3	-216.1	-9.2
Indirect N_2O from manure management	404.1	464.9	60.8	15.0
Total	**24 738.6**	**22 369.6**	**-2 368.0**	**-9.6**

Note: Numbers may not sum exactly due to rounding off.

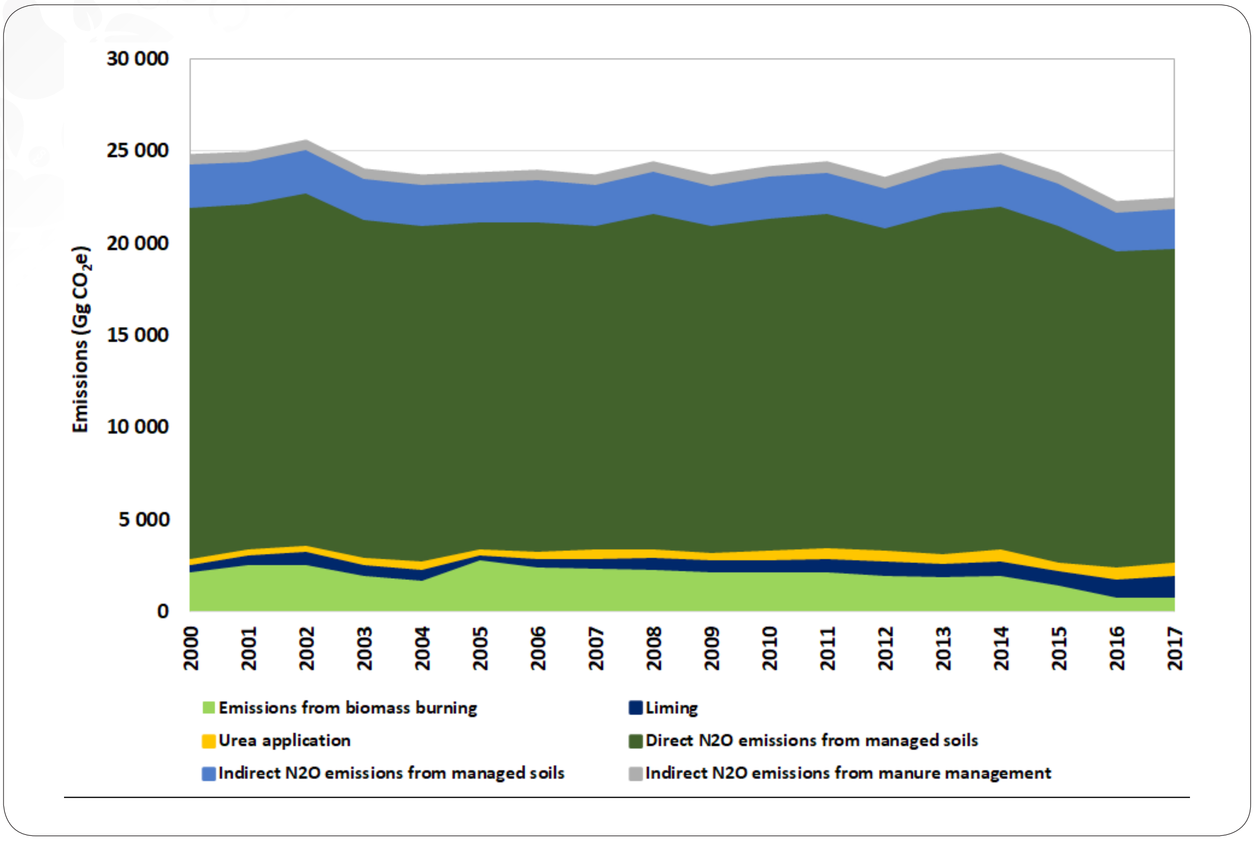


Figure 5.18: Trends in aggregated and non-CO_2 emissions on land, 2000 – 2017.

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 5.4% reduction in the emission estimates for 2015 compared to the previous submission., 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 FSOM which was not previously estimated;
- All of these changes meant that emission estimates for 2015 were 15.6% 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 2.24% higher than previously estimated;
- Indirect N_2O from manure management:
  - Updated manure management and livestock population data also impacted indirect emissions;
  - Emission estimates were 27.7% lower than the 2015 estimates in the previous inventory.

Overall the recalculated estimates for *Aggregated and non-CO_2 emissions on land* were 12.1% higher than the estimates in the previous submission (Figure 5.19).

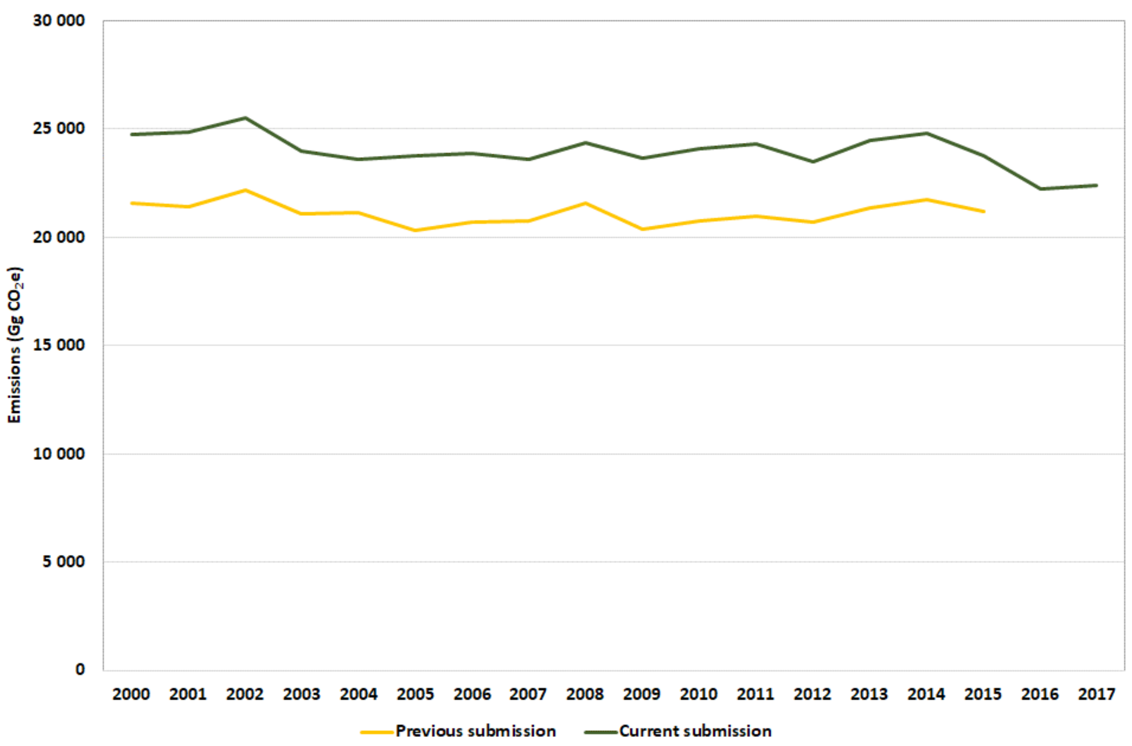


Figure 5.19: Recalculated emissions for the aggregated and non-CO_2 emissions on land.

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.

Table 5.46: Trends and changes in biomass burning emissions between 2000 and 2017.

Category	Emissions (Gg CO_2e)		Change (2000 – 2017)	
	2000	2017	Diff	%
Forest lands	698.2	274.2	-424.0	-60.7
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]	**2 242.3**	**827.5**	**-1 414.8**	**-63.1**

a Numbers may not sum exactly due to rounding off.

Overview of shares and trends in emissions

2000 - 2017

Biomass burning contributed 827.5 Gg CO_2e in 2017, which is a 63.1% 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 NO_x and CO from biomass burning were also estimated and are provided in Table 5.47.

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):

$$L_{fire} = A * M_B * C_f * G_{ef} * 10^{-3} \quad \text{(Eq. 3.2)}$$

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})

C_f = combustion factor (dimensionless)

G_{ef} = emission factor (g kg^{-1} dm burnt)

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	NO_x	CO
	Gg CH_4	Gg N_2O	Gg CO_2e		Gg CO_2e	Gg NOx	Gg CO
2000	52.6	3.7	1 103.7	1 138.5	2 242.3	68.1	1 479.4
2001	61.7	4.3	1 295.2	1 348.0	2 643.2	80.0	1 710.6
2002	61.9	4.3	1 300.4	1 328.8	2 629.2	79.1	1 722.5
2003	48.6	3.3	1 021.2	1 017.8	2 039.1	59.6	1 338.1
2004	42.4	3.0	891.0	914.8	1 805.8	54.3	1 178.6
2005	68.1	4.7	1 429.4	1 448.2	2 877.6	86.8	1 895.5
2006	59.6	4.1	1 251.8	1 263.6	2 515.4	76.7	1 672.3
2007	58.8	3.9	1 235.0	1 217.6	2 452.6	70.2	1 596.3
2008	54.8	3.8	1 150.1	1 180.4	2 330.5	69.1	1 507.8
2009	52.0	3.6	1 091.3	1 108.5	2 199.7	65.6	1 436.8
2010	53.2	3.6	1 117.0	1 122.5	2 239.5	65.6	1 462.9
2011	52.4	3.6	1 100.6	1 111.8	2 212.4	64.8	1 442.8
2012	48.1	3.2	1 010.9	1 003.3	2 014.2	56.3	1 295.2
2013	45.6	3.2	956.7	981.0	1 937.6	57.3	1 254.4
2014	48.8	3.3	1 024.2	1 029.4	2 053.6	59.3	1 331.1
2015	35.4	2.4	742.8	748.3	1 491.1	42.5	957.8
2016	21.4	1.4	448.5	435.5	884.0	23.4	562.5
2017	19.9	1.3	418.8	408.7	827.5	22.3	528.8

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 (MB) and the combustion factor (Cf)

The values for fuel density were sourced from various sources (Table 5.48). A weighted average for fuel density and the combustion factor (Cf) was determined for low shrublands. According to the 2013/2014 land cover map report (GTI, 2015) low shrublands are mainly karoo type vegetation. Also included in this category is a portion of fynbos (13% according to the 2013/2014 land cover map). The karoo vegetation classes have similar fuel densities and Cf values, but these are very different for fynbos (Table 5.48). A weighted average fuel density and Cf value was calculated from these numbers for the low shrubland category in this inventory. Wetlands were assumed to have the same values as grasslands as done in the earlier inventories (DEAT, 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	0.91c	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, 2009). 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

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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

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.

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, 2018) 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.

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

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	Dolomite consumption
	(t)	(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, 2018) 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.

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 FOS (N from managed organic soils) was assumed to be minimal and was therefore excluded from the calculations. DFFE 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 N2O emissions from soils is therefore as follows:

$$N_2O_{Direct}\text{-}N = N_2O\text{-}N_{N\ inputs} + N_2O\text{-}N_{PRP} \quad \text{(Eq. 5.13)}$$

Where:

$$N_2O\text{-}N_{N\ inputs} = [(F_{SN} + F_{ON} + F_{CR} + F_{SOM}) * EF_1] \quad \text{(Eq. 5.14)}$$

$$N_2O\text{-}N_{PRP} = [(F_{PRP,CPP} * EF_{3PRP,CPP}) + (F_{PRP,SO} * EF_{3PRP,SO})] \quad \text{(Eq. 5.15)}$$

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)	1 767.0	1 823.4	56.4	3.2
Crop residues	1 296.9	1 034.6	-262.4	-20.2
Urine and dung deposits	12 509.1	10 677.8	-1 831.3	-14.6
N mineralisation from loss of SOC	1 355.8	1 355.9	0.0	0.0
Total direct N_2O from managed soils	**18 955.0**	**17 049.2**	**-1 905.8**	**-10.05**

Note: Numbers may not sum exactly due to rounding off.

Where:

N_2O_{Direct}-N = annual direct N_2O-N emissions produced from managed soils (kg N_2O-N yr^{-1});

N_2O-NN_iN_{puts} = 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_I = 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. FSOM is calculated as per IPCC equation 11.8. The loss of soil carbon required for this equation was obtained from the Land sector file.

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

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.

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.

EF1 (Table 5.55) was used to estimate direct N_2O-N emissions from F_{SN} inputs.

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 (FracLossMS). IPCC 2006 default values were used here (Table 10.23, Chapter 10, Volume 4, IPCC 2006);

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

- 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 FAM 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 (FPRP; kg N yr^{-1}) was calculated using Equation 11.5 in the IPCC 2006 Guidelines (Chapter 11, Volume 4):

$$F_{PRP} = \sum[(N_{(T)} * Nex_{(T)}) * MS_{(T, PRP)}] \quad \text{(Eq. 5.17)}$$

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 EF3PRP (Table 5.55) was used to estimate direct N2O-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 N2O, 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:

$$F_{CR} = \sum\{Crop_{(T)} * (Area_{(T)} - Area\ burnt_{(T)} * C_f) * Frac_{ReNew(T)} * [R_{AG(T)} * N_{AG(T)} * (1 - Frac_{Remove(T)}) + R_{BG(T)} * N_{BG(T)}]\} \quad \text{(Eq. 5. 18)}$$

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-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, 2018), 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.

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 (FSOM) 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%

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] (kg dm ha^{-1})	Fraction burnt[d,e]	RAG(T)[f,g] (kg dm (kg dm)$^{-1}$)	NAG(T)[f,g] (kg N (kg dm)$^{-1}$)	Fraction removed[d,e]	RBG(T)[f,g] (kg dm (kg dm)$^{-1}$)	NBG(T)[f,g] (kg N (kg dm)$^{-1}$)
Barley	3 403	0.20	1.15	0.007	0.62	0.474	0.014
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	0.01
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	0.007
Potato	7 942	0.00	0.23	0.019	0.00	0.247	0.014
Sorghum	1 294	0.00	1.91	0.007	0.88	0.000	0.006
Soyabean	1 343	0.08	1.94	0.008	0.56	0.558	0.008
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	0.009
Oats	1 443	0.00	1.53	0.007	0.80	0.632	0.009

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)

(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 2 126 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 90.1% of the indirect N_2O, and these emissions declined by 9.9% 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 2.6%. The contribution from fertilisers (both inorganic and organic) increased between 2000 and 2017, while the contribution from crop residues declined.

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

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	**2 342.3**	**2 126.3**	**-216.0**	**-9.2**
Indirect N_2O from deposition of volatilized N	***2 127.3***	***1 916.8***	***-210.5***	***-9.9***
Inorganic fertilizers	202.6	215.8	13.1	6.5
Organic fertilizers	353.4	364.7	11.3	3.2
Urine and dung deposits	1 571.3	1 336.4	-234.9	-14.9
Indirect N_2O from leaching/ runoff	***215.1***	***209.4***	***-5.7***	***-2.6***
Inorganic fertilizers	67.6	71.2	3.6	5.3
Organic fertilizers	59.0	60.2	1.2	2.0
Crop residues	43.3	33.4	-9.9	-22.9
Urine and dung deposits	NO	NO		
N mineralisation from SOC losses	45.2	44.7	-0.5	-1.1

Note: Numbers may not sum exactly due to rounding off.

($N_2O_{(ATD)}$-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 FracLEACH-(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 465 Gg CO_2e in 2017, which is an 15.0% increase from the 404 Gg CO_2e produced in 2000. Losses due to volatilisation accounted for 78.6% 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.

SOURCE CATEGORY 3.D OTHER

5.6

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.

$$f_{IRW}(i) = (IRW_P(i) - IRW_{EX}(i)) / (IRW_P(i) + IRW_{IM}(i) - IRW_{EX}(i)) \quad \text{(Eq. 5.19)}$$

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}).

$$f_{PULP}(i) = (PULP_P(i) - PULP_{EX}(i)) / (PULP_P(i) + PULP_{IM}(i) - PULP_{EX}(i)) \quad \text{(Eq. 5.20)}$$

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.

$$HWP_j(i) = HWP_P(i) * fD_P(i) * f_j(i) \quad \text{(Eq. 5.21)}$$

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:

$$C(i+1) = e^{-k} * C(i) + ((1 - e^{-k})/k) * Inflow(i) \quad \text{(Eq. 5.22)}$$

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:

$$Inflow_{average} = (\sum_{i=t0}^{t4} Inflow(i))/5 \qquad \text{(Eq. 5.24)}$$

$C(t_0)$ 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

Country specific data will be considered for inclusion in the next inventory if there is a long enough time-series.

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	NO_x	CO	NMVOCs	
3 - Agriculture, Forestry, and Other Land Use	**-29 409.2**	**1 224.4**	**70.0**	**528.8**	**21.4**	**31.1**	**17 997.5**
3 - AFOLU (excluding FOLU)	**1 901.7**	**1 192.7**	**70.0**	**528.8**	**21.4**	**31.1**	**48 641.8**
3.A - Livestock	**NA**	**1 172.8**	**5.3**	**NA**	**NA**	**NA**	**26 272.3**
3.A.1 - Enteric Fermentation	NA	1 137.3	NA	NA	NA	NA	23 883.7
3.A.1.a - Cattle		941.2					19 764.6
3.A.1.a.i - Dairy Cows		144.3					3 030.4
3.A.1.a.ii - Other Cattle		796.9					16 734.2
3.A.1.b - Buffalo		IE					IE
3.A.1.c - Sheep		153.1					3 214.6
3.A.1.d - Goats		33.8					709.2
3.A.1.e - Camels		NO					NO
3.A.1.f - Horses		5.8					122.0
3.A.1.g - Mules and Asses		1.6					34.2
3.A.1.h - Swine		1.9					39.1
3.A.1.j – Other		NO					NO
3.A.2 - Manure Management	NA	35.4	5.3	NA	NA	NA	2 388.6
3.A.2.a - Cattle		11.6	2.7				1 070.7
3.A.2.a.i - Dairy cows		10.5	0.4				330.1
3.A.2.a.ii - Other cattle		1.2	2.3				740.6
3.A.2.b - Buffalo		IE	IE				IE
3.A.2.c - Sheep		0.0	0.3				0.9
3.A.2.d - Goats		0.0	0.1				0.8
3.A.2.e - Camels		NO	NO				NO
3.A.2.f - Horses		0.0	0.0				0.1
3.A.2.g - Mules and Asses		0.0	0.0				0.0

	Net CO_2 emissions / removals	Emissions					Total emissions
	(Gg)						(Gg CO_2e)
	CO_2	CH_4	N_2O	NO_x	CO	NMVOCs	
3.A.2.h - Swine		20.9	0.1				438.6
3.A.2.i - Poultry		2.8	2.1				59.2
3.A.2.j – Other		NO	NO				NO
3.B - Land	**-30 534.0**	**31.7**	**IE**	**IE**	**IE**	**IE**	**-29 867.4**
3.B.1 - Forest land	-29 616.9	IE	IE	IE	IE	IE	-29 616.9
3.B.1.a - Forest land Remaining Forest land	-22 249.8	IE	IE	IE	IE	IE	-22 249.8
3.B.1.b - Land Converted to Forest land	-7 367.1	IE	IE	IE	IE	IE	-7 367.1
3.B.1.b.i - Cropland converted to Forest Land	-1 970.6	IE	IE	IE	IE	IE	-1 970.6
3.B.1.b.ii - Grassland converted to Forest Land	-3 175.4	IE	IE	IE	IE	IE	-3 175.4
3.B.1.b.iii - Wetlands converted to Forest Land	-111.4	IE	IE	IE	IE	IE	-111.4
3.B.1.b.iv - Settlements converted to Forest Land	-448.6	IE	IE	IE	IE	IE	-448.6
3.B.1.b.v - Other Land converted to Forest Land	-1 661.0	IE	IE	IE	IE	IE	-1 661.0
3.B.2 - Cropland	1 580.8	IE	IE	IE	IE	IE	1 580.8
3.B.2.a - Cropland Remaining Cropland	-1 175.2	IE	IE	IE	IE	IE	-1 175.2
3.B.2.b - Land Converted to Cropland	2 756.0	IE	IE	IE	IE	IE	2 756.0
3.B.2.b.i - Forest Land converted to Cropland	2 423.2	IE	IE	IE	IE	IE	2 423.2
3.B.2.b.ii - Grassland converted to Cropland	352.5	IE	IE	IE	IE	IE	352.5
3.B.2.b.iii - Wetlands converted to Cropland	0.7	IE	IE	IE	IE	IE	0.7
3.B.2.b.iv - Settlements converted to Cropland	17.3	IE	IE	IE	IE	IE	17.3
3.B.2.b.v - Other Land converted to Cropland	-37.7	IE	IE	IE	IE	IE	-37.7

	Net CO_2 emissions / removals	Emissions					Total emissions
	(Gg)						(Gg CO_2e)
	CO_2	CH_4	N_2O	NO_x	CO	NMVOCs	
3.B.3 - Grassland	-15 613.8	IE	IE	IE	IE	IE	-15 613.8
3.B.3.a - Grassland Remaining Grassland	3 306.2	IE	IE	IE	IE	IE	3 306.2
3.B.3.b - Land Converted to Grassland	-18 920.1	IE	IE	IE	IE	IE	-18 920.1
3.B.3.b.i - Forest Land converted to Grassland	223.5	IE	IE	IE	IE	IE	223.5
3.B.3.b.ii - Cropland converted to Grassland	-992.0	IE	IE	IE	IE	IE	-992.0
3.B.3.b.iii - Wetlands converted to Grassland	-26.7	IE	IE	IE	IE	IE	-26.7
3.B.3.b.iv - Settlements converted to Grassland	-133.5	IE	IE	IE	IE	IE	-133.5
3.B.3.b.v - Other Land converted to Grassland	-17 991.4	IE	IE	IE	IE	IE	-17 991.4
3.B.4 - Wetlands	0.0	31.7	IE	IE	IE	IE	666.6
3.B.4.a - Wetlands Remaining Wetlands	0.0	31.7	IE	IE	IE	IE	666.6
3.B.5 - Settlements	-397.0	IE	IE	IE	IE	IE	-397.0
3.B.5.a - Settlements Remaining Settlements	-687.5	IE	IE	IE	IE	IE	-687.5

	Net CO_2 emissions / removals	Emissions					Total emissions
	(Gg)						(Gg CO_2e)
	CO_2	CH_4	N_2O	NO_x	CO	NMVOCs	
3.B.5.b - Land Converted to Settlements	290.4	IE	IE	IE	IE	IE	290.4
3.B.5.b.i - Forest Land converted to Settlements	274.6	IE	IE	IE	IE	IE	274.6
3.B.5.b.ii - Cropland converted to Settlements	11.7	IE	IE	IE	IE	IE	11.7
3.B.5.b.iii - Grassland converted to Settlements	36.9	IE	IE	IE	IE	IE	36.9
3.B.5.b.iv - Wetlands converted to Settlements	0.6	IE	IE	IE	IE	IE	0.6
3.B.5.b.v - Other Land converted to Settlements	-33.3	IE	IE	IE	IE	IE	-33.3
3.B.6 - Other Land	13 512.9	IE	IE	IE	IE	IE	13 512.9
3.B.6.a - Other land Remaining Other land	0.0	IE	IE	IE	IE	IE	0.0
3.B.6.b - Land Converted to Other land	13 512.9	IE	IE	IE	IE	IE	13 512.9
3.B.6.b.i - Forest Land converted to Other Land	944.4	IE	IE	IE	IE	IE	944.4
3.B.6.b.ii - Cropland converted to Other Land	69.8	IE	IE	IE	IE	IE	69.8

	Net CO_2 emissions / removals	Emissions					Total emissions
	(Gg)						(Gg CO_2e)
	CO_2	CH_4	N_2O	NO_x	CO	NMVOCs	
3.B.6.b.iii - Grassland converted to Other Land	12 043.3	IE	IE	IE	IE	IE	12 043.3
3.B.6.b.iv - Wetlands converted to Other Land	446.6	IE	IE	IE	IE	IE	446.6
3.B.6.b.v - Settlements converted to Other Land	8.8	IE	IE	IE	IE	IE	8.8
3.C - Aggregate sources and non-CO_2 emissions sources on land	**1 901.7**	**19.9**	**64.7**	**528.8**	**21.4**	**31.1**	**22 369.5**
3.C.1 - Emissions from biomass burning	IE	19.9	1.3	528.8	21.4	31.1	827.5
3.C.1.a - Biomass burning in forest lands	IE	6.9	0.4	162.5	5.4	14.1	274.2
3.C.1.b - Biomass burning in croplands	IE	2.7	0.1	92.8	2.5	0.0	79.1
3.C.1.c - Biomass burning in grasslands	IE	9.8	0.8	257.7	13.4	16.2	446.6
3.C.1.d - Biomass burning in wetlands	IE	0.5	0.0	13.7	0.0	0.7	24.0

	Net CO_2 emissions / removals	Emissions					Total emissions
	(Gg)						(Gg CO_2e)
	CO_2	CH_4	N_2O	NO_x	CO	NMVOCs	
3.C.1.e - Biomass burning in settlements	IE	0.1	0.0	2.1	0.1	0.1	3.7
3.C.1.f - Biomass burning in other lands	IE	0.0	0.0	0.0	0.0	0.0	0.0
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			55.0				17 049.1
3.C.5 - Indirect N_2O Emissions from managed soils			6.9				2 126.3
3.C.6 - Indirect N_2O Emissions from manure management			1.5				464.9
3.C.7 - Rice cultivations	NO	NO	NO				NO
3.C.8 - Other (please specify)							0.0
3.D - Other	**-776.9**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**-776.9**
3.D.1 - Harvested Wood Products	-776.9						-776.9
3.D.2 - Other (please specify)							0.0

Table 5A.1: Summary table of emissions from the AFOLU sector in 2017.

Categories	Activity Data		Net carbon stock change and CO_2 emissions									Net CO_2 emissions ($Gg\ CO_2$)
			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**	**22 188.6**	**-14 772.6**	**IE**	**7 114.5**	**0.0**	**IE**	**385.9**	**520.4**	**0.0**	**-30 534.0**
3.B.1 - Forest land	**22 439 346**	**0**	**21 134.1**	**-13 678.9**	**IE**	**7 455.2**	**IE**	**IE**	**67.7**	**554.5**	**0.0**	**-29 616.9**
3.B.1.a - Forest land Remaining Forest land	21 345 193	NE	19 523.7	-13 454.0		6 069.7			-1.6	0.0	NE	-22 249.8
3.B.1.b - Land Converted to Forest land	1 094 153	NE	1 610.4	-224.9	IE	1 385.5	IE	IE	69.3	554.5	NE	-7 367.1
3.B.1.b.i - Cropland converted to Forest Land	515 244	NE	357.7	-41.0		316.7	IE		16.2	204.6	NE	-1 970.6
3.B.1.b.ii - Grassland converted to Forest Land	192 704	NE	969.0	-155.2		813.8	IE		18.3	33.9	NE	-3 175.4
3.B.1.b.iii - Wetlands converted to Forest Land	34 369	NE	29.5	-2.9		26.6	IE		3.8	0.0	NE	-111.4
3.B.1.b.iv - Settlements converted to Forest Land	109 910	NE	92.1	-12.6		79.5	IE		10.9	32.0	NE	-448.6
3.B.1.b.v - Other Land converted to Forest Land	241 927	NE	162.0	-13.1		148.9	IE		20.1	284.0	NE	-1 661.0
3.B.2 - Cropland	**13 793 331**	**0**	**407.5**	**-645.1**	**IE**	**-237.7**	**0.0**	**IE**	**304.3**	**-1 324.6**	**0.0**	**1 580.8**

Categories	Activity Data		Net carbon stock change and CO_2 emissions									Net CO_2 emissions ($Gg\ CO_2$)
			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.2.a - Cropland Remaining Cropland	12 112 976	NE	305.3	-42.0		263.3			60.4	-3.2	NE	-1 175.2
3.B.2.b - Land Converted to Cropland	1 680 355	NE	102.1	-603.1	IE	-501.0	IE	IE	243.9	-1 321.4	NE	2 756.0
3.B.2.b.i - Forest Land converted to Cropland	544 741	NE	73.1	-583.2		-510.2	IE		82.6	-233.3	NE	2 423.2
3.B.2.b.ii - Grassland converted to Cropland	1 081 003	NE	27.0	-18.1		8.9	IE		155.0	-260.0	NE	352.5
3.B.2.b.iii - Wetlands converted to Cropland	4 337	NE	0.3	0.7		1.0	IE		0.7	-1.9	NE	0.7
3.B.2.b.iv - Settlements converted to Cropland	43 357	NE	0.7	-3.1		-2.3	IE		3.6	-6.0	NE	17.3
3.B.2.b.v - Other Land converted to Cropland	6 918	NE	1.1	0.6		1.7	IE		1.9	6.7	NE	-37.7
3.B.3 - Grassland	**68 146 456**	**0**	**411.8**	**0.0**	**IE**	**297.7**	**0.0**	**IE**	**275.2**	**3 911.0**	**0.0**	**-15 613.8**
3.B.3.a - Grassland Remaining Grassland	63 669 214	NE	0.0	-225.7		-225.7			-126.3	-549.8	NE	3 306.2
3.B.3.b - Land Converted to Grassland	4 477 242	NE	411.8	-114.1	IE	297.7	IE	IE	401.5	4 460.8	NE	-18 920.1

Categories	Activity Data		Net carbon stock change and CO_2 emissions									Net CO_2 emissions ($Gg CO_2$)
			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.3.b.i - Forest Land converted to Grassland	80 962	NE	9.6	-79.8		-70.2	IE		9.5	-0.2	NE	223.5
3.B.3.b.ii - Cropland converted to Grassland	1 109 796	NE	43.0	-38.6		4.5	IE		-14.1	280.2	NE	-992.0
3.B.3.b.iii - Wetlands converted to Grassland	52 194	NE	2.8	5.9		8.7	IE		4.4	-5.9	NE	-26.7
3.B.3.b.iv - Settlements converted to Grassland	147 879	NE	2.8	7.7		10.5	IE		5.1	20.8	NE	-133.5
3.B.3.b.v - Other Land converted to Grassland	3 086 411	NE	353.6	-9.3		344.3	IE		396.5	4 166.0	NE	-17 991.4
3.B.4 - Wetlands	**2 445 103**	**NE**	**0.0**	**0.0**	**IE**	**NE**	**IE**	**IE**	**NE**	**NE**	**NE**	**NE**
3.B.5 - Settlements	**3 243 421**	**0**	**235.3**	**-96.3**	**IE**	**-48.5**	**0.0**	**IE**	**24.3**	**-55.0**	**0.0**	**-397.0**
3.B.5.a - Settlements Remaining Settlements	2 785 592	NE	206.7	-19.2		187.4			0.1	-0.1	NE	-687.5
3.B.5.b - Land Converted to Settlements	457 829	NE	28.6	-77.1	IE	-48.5	IE	IE	24.2	-55.0	NE	290.4
3.B.5.b.i - Forest Land converted to Settlements	128 889	NE	8.8	-55.0		-46.2	IE		7.1	-35.8	NE	274.6

Categories	Activity Data		Net carbon stock change and CO_2 emissions									Net CO_2 emissions ($Gg\ CO_2$)
			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.5.b.ii - Cropland converted to Settlements	65 503	NE	2.6	-8.4		-5.8	IE		-1.1	3.7	NE	11.7
3.B.5.b.iii - Grassland converted to Settlements	257 853	NE	16.8	-13.6		3.2	IE		17.7	-31.0	NE	36.9
3.B.5.b.iv - Wetlands converted to Settlements	1 068	NE	0.1	0.0		0.1	IE		0.1	-0.3	NE	0.6
3.B.5.b.v - Other Land converted to Settlements	4 516	NE	0.3	0.0		0.3	IE		0.4	8.4	NE	-33.3
3.B.6 - Other Land	**12 450 349**	**0**	**0.0**	**-352.2**	**IE**	**-352.2**	**0.0**	**IE**	**-285.6**	**-3 047.6**	**0.0**	**13 512.9**
3.B.6.a - Other land Remaining Other land	9 932 899	NE								0.0	NE	0.0
3.B.6.b - Land Converted to Other land	2 517 450	NE	0.0	-352.2	IE	-352.2	0.0	IE	-285.6	-3 047.6	NE	13 512.9
3.B.6.b.i - Forest Land converted to Other Land	151 522	NE	0.0	-56.4		-56.4			-10.5	-190.6	NE	944.4
3.B.6.b.ii - Cropland converted to Other Land	13 688	NE	0.0	-2.5		-2.5			-1.7	-14.8	NE	69.8
3.B.6.b.iii - Grassland converted to Other Land	2 273 833	NE	0.0	-292.8		-292.8			-273.0	-2 718.8	NE	12 043.3

Categories	Activity Data		Net carbon stock change and CO_2 emissions									Net CO_2 emissions ($Gg\ CO_2$)
			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.6.b.iv - Wetlands converted to Other Land	73 546	NE	0.0	0.0		0.0			0.0	-121.8	NE	446.6
3.B.6.b.v - Settlements converted to Other Land	4 862	NE	0.0	-0.6		-0.6			-0.3	-1.5	NE	8.8

CH_4 emissions	Gg CH_4	Gg CO_2e
3.B.4 - Wetlands	**31.7**	**666.6**

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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 Solid 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 each 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.

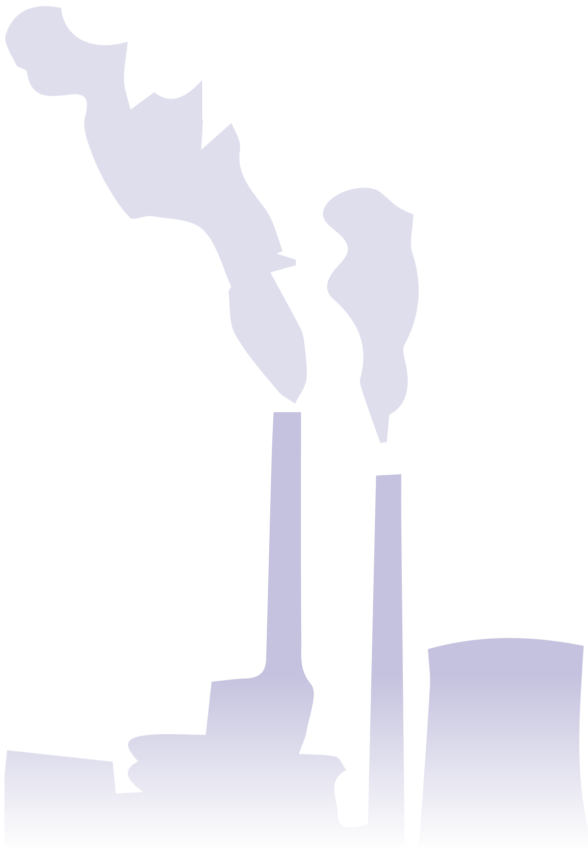

Table 6.2: GHG emissions from South Africa's Waste sector between 2000 and 2017.

Greenhouse gas source categories	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 Wastewater treatment and discharge	2 743.4	3 522.8	779.4	0.3

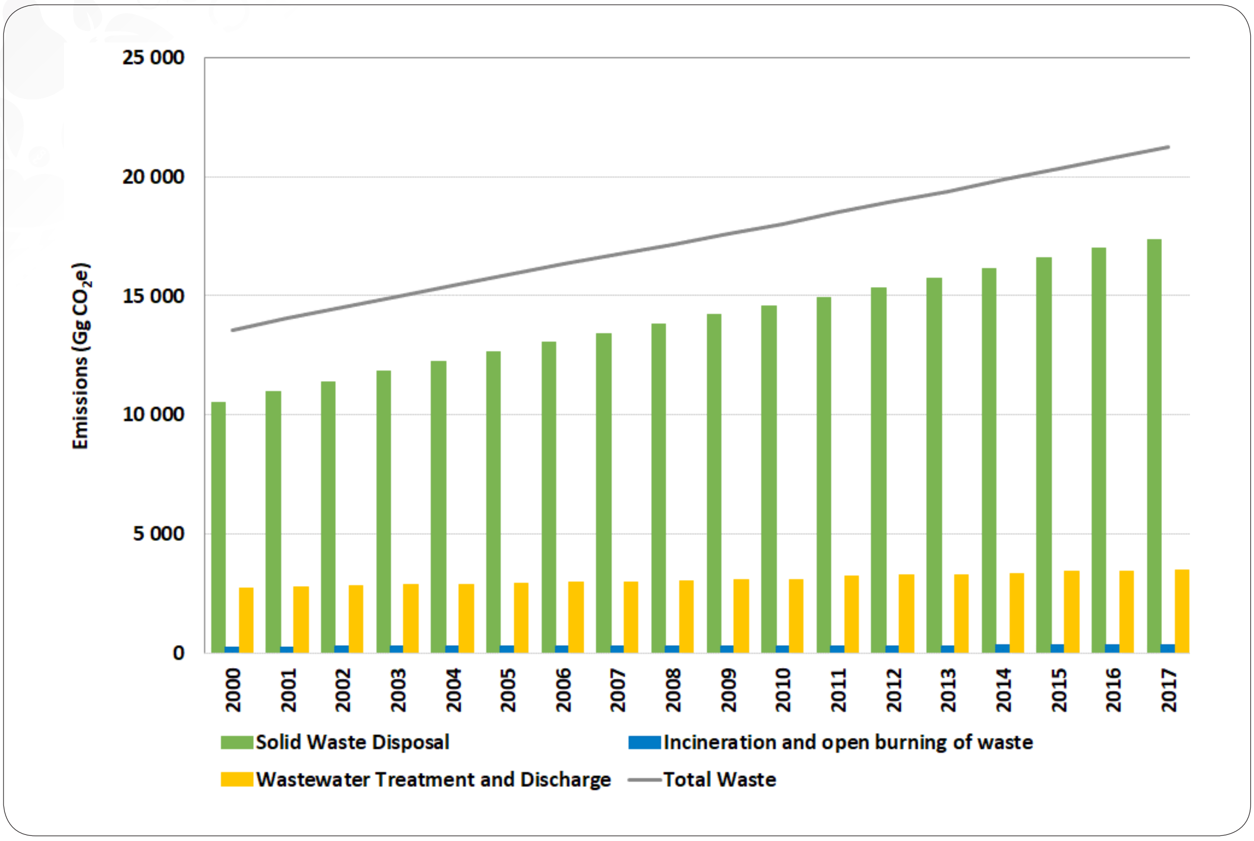

Figure 6.1: Trend in emissions from Waste sector, 2000 - 2017.

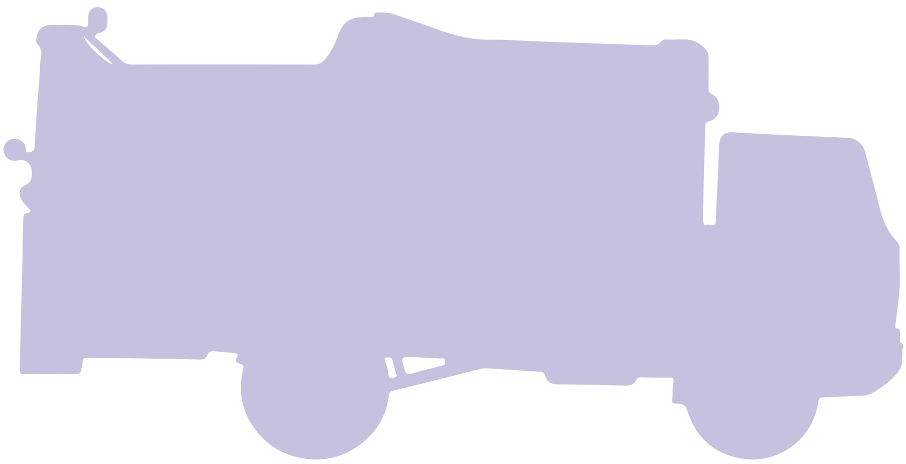

Table 6.3: Trend in Waste sector category emissions between 2000 and 2017.

	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 data 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.

Data sources

The main data sources for the Waste sector are provided in Table 6.5.

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	NA		T1	DF	NA		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	

Table 6.5: Main data sources for the Waste sector emission calculations.

Details	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	Expert judgement
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 are shown in Table 6.6.

Table 6.6: Key categories identified in the Waste sector.

IPCC Code	Category	GHG	Identification Criteria
4A	Solid Waste Disposal	CH_4	L1,T1
4D1	Wastewater Treatment and Discharge	CH_4	L1, T1

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.

The DFFE has recently undertaken a study to collect actual activity data for this category for the period 2000 – 2017 for the waste streams listed below:

- 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

This data is currently being used to recalculate emissions from the waste sector for the entire time series and will be reported in the 2000 – 2019 GHG inventory.

South Africa has also 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.

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 6.7).

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.

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.

Table 6.7: 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	
		0.06	
Methane correction factor (MCF)	Unmanaged, shallow	0.4	Dimensionless
	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	Dimensionless

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

Table 6.8: 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	
	DOCf	±20	
	MCF	±10	
	Fraction of CH4 in generated landfill gas	±5	
	Methane recovery	±50	

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 6.8.

Time series consistency

The FOD methodology for estimating methane emissions from solid waste requires a minimum of 48 years' worth of historical waste disposal data. However, in South Africa, waste disposal statistics are not available. In addition, periodic waste baseline studies do not build time-series data. Hence, population statistics sourced from the UN secretariat provided consistent time-series activity data for solid waste disposal.

6.2.4 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

According to the 2006 IPCC guidelines, open burning of waste is defined as combustion of unwanted combustible materials, typically domestic waste such as paper, wood, plastics, textiles, rubber, waste oils and other debris in nature (open-air) or in open dumps, where smoke and other emissions are released directly into the air without passing through a chimney or stack. With open burning of waste, the three key gasses that are emitted include CO_2, methane (CH_4) and nitrous oxide (N_2O).

In this source category only the emissions from *Open burning of waste* have been included. Emissions from Incineration of waste are to be considered in the 2000 – 2019 GHG inventory as in the current inventory cycle there were challenges with accessing the activity data needed for this activity.

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) which is assumed to be the fraction of population without access to formal waste collection services. It is therefore assumed that 9% of the population openly burns its waste. In addition, a correction factor of 2% (Expert Judgement) was added to the calculation to account for open burning that occurs at managed Solid Waste Disposal Sites.as means of managing waste. Table 6.8 provides the default IPCC parameters used to estimate emissions from open burning of waste. CO_2 emissions were calculated for the different waste types using the IPCC default breakdown, with biogenic CO_2 subtracted from organic waste streams.

Emission factors

Emission factors are shown in Table 6.9.

6.3.3 Uncertainty and time series consistency

Uncertainty

Activity data uncertainty are provided in Table 6.8. 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

Table 6.9: Emission factors for estimating emissions from open burning of waste.

Sub-category	Value	Unit	Source
Dry matter content		fraction	IPCC 2006
Food	*0.4*		
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

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

The DFFE has implemented a study to collect data on the actual quantities of waste that are openly burnt in the country and this will allow for the move away from using population as a driver to estimate emissions from Open Burning of waste. These revised estimates will be included in the next inventory cycle (2000 – 2019).

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

Table 6.10: Emission factors for different wastewater treatment and discharge systems (Source: DEAT, 2009).

Activity data and emission factors	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

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 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 6.10) as was the data on distribution and utilization of different treatment and discharge systems (Table 6.11).

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.

Table 6.11: 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 (kg CH_4/kg BOD)	Degree of utilization (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

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.

SUMMARY TABLE OF WASTE SECTOR EMISSIONS IN 2015

APPENDIX 6.A

Categories	Emissions (Gg)							Emissions
	CO_2	CH_4	N_2O	NO_x	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	NA	827.0	NE	NE	NE	NE	NE	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	NA	NE	NE	NE	NE	NE	NE	NE
4.C - Incineration and Open Burning of Waste	37.5	11.5	0.3	NE	NE	NE	NE	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	NA	131.1	2.5	NE	NE	NE	NE	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	IE	NE	NE	NE	NE	NE
4.E - Other (please specify)				0.0	0.0	0.0	0.0	0.0

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