SOUTH AFRICA NATIONAL GHG INVENTORY

2000 – 2020 REPORT

forestry, fisheries & the environment
Department: Forestry, Fisheries and the Environment
REPUBLIC OF SOUTH AFRICA

NATIONAL GHG INVENTORY REPORT

SOUTH AFRICA

2000 - 2020

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Acknowledgements

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Report compilation details

Report compilation: Luanne Stevens
Report reviewers: Jongikhaya Witi, Sindisiwe Mashele, Rumbidzai Damita Mhunduru

Lead sector compilers and technical contributors

Energy sector

Mamahloko Senatla Jaane (DFFE)

Hendrik Louw (DFFE)

IPPU sector

Farryn Bianca Sherman (DFFE)

AFOLU sector

Luanne Stevens (Gondwana Environmental Solutions)

Jared Lodder (Gondwana Environmental Solutions)

Elanie van Staden (Gondwana Environmental Solutions)

Sewela Malaka (DFFE)

Waste sector

Phindile Mangwana (DFFE)

Thulasizwe Masuku (DFFE)

Cross cutting contributors

Luanne Stevens (Gondwana Environmental Solutions)

Lindelwa Mngomezulu (DFFE)

Rumbidzai Damita Mhunduru (DFFE)

Thulasizwe Masuku (DFFE)

Adele Mhangani (DFFE)

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
BOD	Biological oxygen demand
BUR	Biennial Update Report
C_2F_4	Tetrafluoroethylene
C_2F_6	Carbon hexafluoroethane
CALC	Computer Automated Land Cover
CaO	Calcium oxide
$CaCO_3$	Calcium Carbonate
CF_4	Carbon tetrafluoromethane
CFC	Chlorofluorocarbons
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
COD	Chemical Oxygen Demand
CKD	Cement Kiln Dust
CRF	Common reporting format
CSP	Concentrated Solar Power
CSIR	Council for Scientific and Industrial Research
CTL	Coal to liquid
CWPB	Centre-Worked Prebake
DAFF	Department of Agriculture Affairs, Forestry and Fisheries
DALRRD	Department of Agriculture, Land Reform and Rural development
DEA	Department of Environmental Affairs
DEFF	Department of Environment, Forestry and Fisheries
DFFE	Department of Forestry, Fisheries and the Environment
DMR	Department of Mineral Resources
DMRE	Department of Mineral Resources and Energy
DOE	Department of Energy
DOM	Dead organic matter
DSM	Demand side management
DWAS	Department of Water and Sanitation
EAF	Electric Arc Furnace

EF	Emission factor
F-gases	Flourinated gases: e.g., HFC, PFC, SF_6 and NF_3
FOD	First order decay
FOLU	Forestry and Other Land Use
FSA	Forestry South Africa
FTOC	Foams Technical Options Committee
GDP	Gross domestic product
Gg	Gigagram
GHG	Greenhouse gas
GHGIP	Greenhouse Gas Improvement Programme
GIS	Geographical Information Systems
GIZ	Gesellschaft für Internationale Zusammenarbeit
GPG	Good Practice Guidance
GTL	Gas to liquid
GTI	GeoTerraImage
GWH	Gigawatt hour
GWP	Global warming potential
HC	Hydrocarbon
HCFC	Hydrochlorofluorocarbons
HFC	HydrofluorocarbonsHSS Horizontal Stud Søderberg
HWP	Harvested wood products
IEF	Implied emission factor
ITC	International Trade Centre
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
KCA	Key category analysis
LC	Land cover
LKD	Lime Kiln Dust
LPG	Liquefied petroleum gas
LTO	Landing/take off
LULUCF	Land Use, Land-Use Change and Forestry
MCF	Methane conversion factor
MDI	Metered dose inhalers
MODIS	Moderate Resolution Imaging Spectroradiometer
MSW	Municipal Solid Waste
MW	Megawatt
MWH	Megawatt hours
MWTP	Municipal wastewater treatment plant
N	Nitrogen
$NaCO_3$	Sodium carbonate

NAEIS	National Atmospheric Emissions Inventory System
N_2O	Nitrous oxide
NC	National Communications
NCV	Net calorific value
NDC	Nationally Determined Contribution
NE	Not estimated
NGERs	National Greenhouse Gas Emission Reporting Regulations
NFA	National Forests Act
NGHGIS	National Greenhouse Gas Inventory System
NH_3	Ammonia
NIC	National Inventory Co-ordinator
NIR	National Inventory Report
NMVOC	Non-methane volatile organic compound
NO	Not occurring
NOx	Nitrous Oxides
NTCSA	National Terrestrial Carbon Sinks Assessment
PFC	Perfluorocarbons
PRP	Pastures, rangelands and paddocks
QA	Quality assurance
QC	Quality control
RRL	Recover Release and Loss
RSA	Republic of South Africa
SAGERS	South African GHG Emissions Reporting System
SAMI	South African Minerals Industry
SANLC	South African National Land Cover
SAPA	South African Poultry Association
SAPIA	South African Petroleum Industry Association
SAIRAC	South African Institute of Refrigeration and Air Conditioning
SAR	Second Assessment ReportSARACCA South African Refrigeration & Air Conditioning Contractors' Association
SARDA	South African Refrigeration Distribution Association
SARS	South African Revenue Service
SF_6	Sulphur hexafluoride
SO_2	Sodium dioxide
SOC	Soil organic carbon
SSA	Sub Saharan Africa
SWDS	Solid Waste Disposal Site
SWPB	Side-Worked Prebake
TAR	Third Assessment Report (IPCC)
TiO_2	Titanium dioxide

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
VSS	Vertical Stud Søderberg

Executive summary

E.S.1. Background

E.S.1.1. Background information on greenhouse gas inventories

This report documents South Africa's submission of its national greenhouse gas inventory for the year 2020. It also reports on the greenhouse gas (GHG) trends for the period 2000 to 2020. It is compiled in accordance with the guidelines provided by the United Nations Framework Convention on Climate Change (UNFCCC) and follows the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National GHG Inventories (2006 IPCC Guidelines, IPCC, 2006), IPCC Good Practice Guidance (GPG) (IPCC, 2000; IPCC, 2003; IPCC, 2014) and the 2019 Refinement to the 2006 IPCC Guidelines (2019 Refinements, IPCC, 2019). This report provides an explanation of the methods (Tier 1, 2 and 3 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.

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 for 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), for 2013 to 2015 in 2019 (DEA, 2019), and 2017 in 2020 (DEFF, 2020).

E.S.1.2. Institutional arrangements for inventory preparation

The Department of Forestry, Fisheries and the Environment (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 ES 1 gives an overview of the institutional arrangements for the compilation of the 2000 – 2020 GHG emissions inventory.

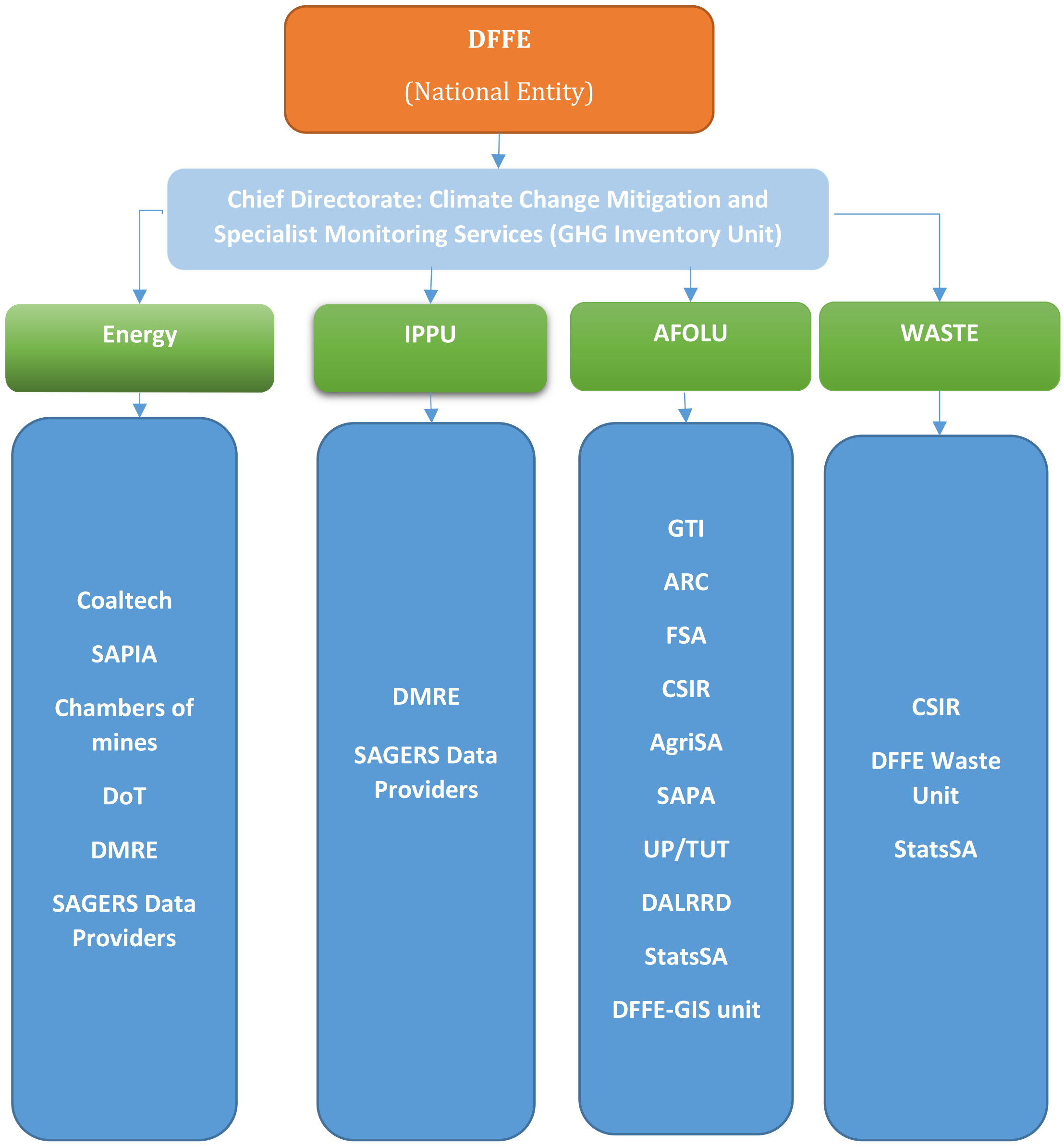


Figure ES 1: Institutional arrangements for the compilation of the 2000 – 2020 inventory for South Africa.

The Minister of DFFE promulgated the National Greenhouse Gas Emission Reporting Regulations, 2016 under Notice No. 275 in the Gazette No. 40762 of 03 April 2017 (NGERs). The purpose of the NGERs is to enable the DFFE to collate and publish GHG emissions data and information in an effective and efficient manner.

The NGERs were promulgated in fulfilment of the implementation of the regulatory framework to support the collection of the requisite activity and GHG emissions data necessary for the compilation of the National GHG emissions Inventory to improve the quality, sustainability, accuracy, completeness and consistency of the National GHG Inventories. The NEGRs came into effect on 03 April 2017. In accordance with regulation 7(1) of the NGERs the initial reporting cycle commenced on 31 March of 2018 requiring data providers to register and submit activity and GHG emissions data to the competent authority (DFFE).

As required in the 2011 White Paper (DEA, 2011), the DFFE has developed the South African Greenhouse Gas Emissions Reporting System (SAGERS) which is the GHG module of National Atmospheric Emissions Inventory System (NAEIS). The SAGERS module helps to facilitate the process of enabling Industry to meet its GHG reporting requirements in a web-based secure environment and facilitates the data collection process for energy related activities and IPPU.

E.S.1.3. 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, QA/QC process and uncertainty. 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.

E.S.2. Summary of national emission and removal trends

GWP

In this inventory the Second Assessment Report (SAR) (IPCC, 1996) Global Warming Potentials (GWPs) were applied. This is consistent with the previous inventory for 2017 (DEFF, 2020) 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) GWPs in other national regulations, the emissions based on TAR GWPs are also provided (Table ES 1) 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.

Table ES 1: Trends in national GHG emissions (excluding and including FOLU) between 2000 and 2020.

	SAR GWP		TAR GWP	
	Emissions (excl. FOLU)	Emissions (incl. FOLU)	Emissions (excl. FOLU)	Emissions (incl. FOLU)
Year	Gg CO_2e			
2000	464 980.2	445 884.9	469 704.95	450 734.65
2001	469 020.3	458 927.4	473 736.11	463 766.68
2002	481 452.8	473 627.2	486 148.10	478 444.26
2003	500 838.7	483 934.5	505 554.70	488 770.81
2004	515 101.4	507 629.3	519 802.98	512 449.62
2005	512 016.4	521 916.8	516 753.34	526 770.98
2006	508 202.2	515 672.0	512 942.23	520 527.63
2007	535 000.8	538 597.3	539 820.96	543 531.56
2008	532 397.2	546 991.0	537 287.23	551 993.56
2009	558 546.8	552 757.5	563 394.27	557 716.02
2010	526 195.7	526 987.2	531 117.42	532 018.37
2011	524 061.3	517 895.1	528 851.09	522 792.77
2012	535 793.2	529 487.2	540 744.05	534 544.41
2013	535 144.2	519 763.6	540 200.12	524 924.29
2014	513 877.4	503 710.4	518 954.50	508 890.75
2015	515 464.1	495 969.7	520 560.74	501 168.01
2016	512 663.5	479 366.4	517 722.88	484 525.90
2017	498 349.8	479 766.8	503 419.22	484 934.75
2018	507 047.0	490 451.2	512 068.39	495 569.61
2019	497 653.4	475 998.2	502 678.03	481 118.21
2020	468 811.7	442 125.1	473 958.75	447 365.98

E.S.3. Overview of source and sink category emission estimates and trends

E.S.3.1. Gas trends

Carbon dioxide

The gas contributing the most to South Africa's emissions (excl. FOLU) was CO_2, and this contribution has decreases from 84.8% to 83.6% between 2000 and 2020. The CO_2 emissions totalled 391 993 Gg CO_2 (excl. FOLU) and 363 677 Gg CO_2 (incl. FOLU) in 2020

(Table ES 2). The *Energy* sector is by far the largest contributor to CO_2 emissions in South Africa, contributing 94.7% in 2020. The categories *1A1 energy industries* (60.1%), and *1A3 Transport* (12%) were the major contributors to the CO_2 emissions in 2020. The *IPPU* sector contributed 4.9%, while the AFOLU sector (excl. FOLU) contributed 0.4%in 2020.

Methane

The contribution from methane (CH_4) has increased from 12.2% to 12.4% between 2000 and 2020 (Figure ES 2). National CH_4 emissions (excl. FOLU) increased from 56 522Gg CO_2e (2 692 Gg CH_4) in 2000 to 57 935 Gg CO_2e (2 759 Gg CH_4) in 2020. The *Livestock* and *SWD* sub-categories sectors were the major contributors, providing 49.6% and 31.5%, respectively, to the total CH_4 emissions in 2020, excl FOLU.

Nitrous oxide

Nitrous oxide (N_2O) contribution to the emissions (excl. FOLU) increased from 2.8% in 2000 to 3.0% in 2020 (Figure ES 2). The emissions (excl. FOLU) were 13 831 Gg CO_2e (44.6 Gg N_2O) in 2020 and 14 267 Gg CO_2e (46 Gg N_2O) including FOLU (Table ES 2). The category 3C *Aggregated and non-CO_2 sources on land* (which includes emissions from managed soils and biomass burning) contributed the most (50.9% excl. FOLU) to N_2O emissions. This was followed by 3A Livestock and 1A *Fuel Combustion* Activities at 18.8% and 17.9% excl. FOLU, respectively. Livestock manure, urine and dung inputs to managed soils provided the largest N_2O contribution (52.1%) in the AFOLU sector as this is closely linked to livestock population trends. N_2O emissions from IPPU declined by 82.2% between 2000 and 2017, but then increased again in 2018. The increase between 2018 and 2020 is due to improved data through the GHG Reporting Regulations.

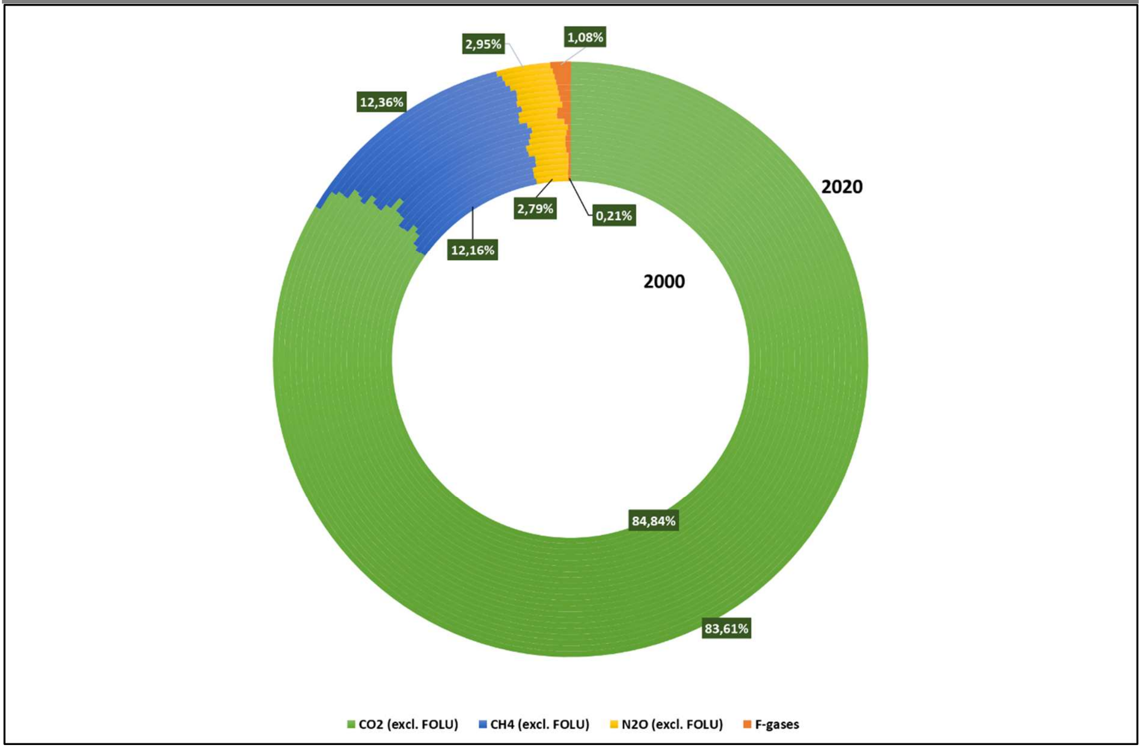


Figure ES 2: Gas contribution to South Africa's emissions (excl. FOLU) between 2000 and 2020.

F-gases

Flourinated gas (F-gas) emission estimates varied annually and contributed 1.1% to overall emissions (excl. FOLU) in 2020 (Figure ES 2). Emissions increase from 2011 due to the addition of Hydrofluorocarbons (HFC) emissions from *air conditioning*, *foam blowing agents*, *fire protection* and *aerosols*. There is no data prior to 2005 so this time-series is not consistent. The elevated F-gas emissions are therefore not necessarily due to an increase in emissions but rather due to the incorporation of new categories.

Perfluorocarbons (PFC) emissions were estimated at 983 Gg CO_2e in 2000. This increased to 1 979 Gg CO_2e in 2012, then declined to 120 Gg CO_2e in 2020. This increase is, however, due mostly to the incorporation of new sources at intervals across this time series as opposed to a true increase. PFCs are produced during the production of aluminium. In 2000 only PFC's were estimated, and in 2005 HFC emissions from Ozone Depleting Substances (ODS) were included. From 2011 onwards the HFC emissions from *mobile air conditioning*, *fire protection*, *foam blowing agents* and *aerosols* were also incorporated. In 2020 HFCs contributed 97.6% to the total F-gas emissions. HFCs increased from 842 Gg CO_2e in 2005 to 4 933 Gg CO_2e in 2020, and the largest contributor is HFC-134a.

Table ES 2: Trend in gas emissions between 2000 and 2020 including FOLU.

	Emissions					
	CO_2 (incl. FOLU)	CH_4 (incl. FOLU)		N_2O (incl. FOLU)		F-gases
	Gg CO_2	Gg CO_2e	Gg CH_4	Gg CO_2e	Gg N_2O	Gg CO_2e
2000	373 220.0	58 109.7	2 767.1	13 572.0	43.8	983.2
2001	385 322.5	58 339.9	2 778.1	14 257.3	46.0	1 007.7
2002	399 823.8	58 231.1	2 772.9	14 675.2	47.3	897.1
2003	411 391.1	57 964.8	2 760.2	13 682.4	44.1	896.2
2004	434 861.7	57 922.0	2 758.2	13 956.1	45.0	889.4
2005	446 110.1	58 861.6	2 802.9	15 231.8	49.1	1 713.4
2006	440 127.3	58 294.1	2 775.9	15 269.7	49.3	1 980.9
2007	462 709.3	59 304.2	2 824.0	14 549.8	46.9	2 034.1
2008	471 786.0	59 502.1	2 833.4	14 129.3	45.6	1 573.6
2009	478 488.0	58 873.6	2 803.5	14 295.7	46.1	1 100.3
2010	452 107.9	59 055.7	2 812.2	13 619.9	43.9	2 203.7
2011	440 571.0	59 064.5	2 812.6	13 574.3	43.8	4 685.2
2012	450 816.4	60 366.7	2 874.6	13 797.4	44.5	4 506.8
2013	442 971.8	59 870.6	2 851.0	14 068.6	45.4	2 852.5
2014	426 224.6	60 031.5	2 858.6	14 166.2	45.7	3 288.2
2015	419 449.9	59 472.7	2 832.0	13 344.4	43.0	3 702.7
2016	403 895.9	58 644.2	2 792.6	12 940.6	41.7	3 885.7
2017	403 112.7	58 817.9	2 800.9	13 688.4	44.2	4 148.0
2018	412 669.2	58 566.0	2 788.9	14 760.2	47.6	4 455.9
2019	398 415.3	58 253.0	2 774.0	14 559.2	47.0	4 770.8
2020	363 676.9	59 127.5	2 815.6	14 267.2	46.0	5 053.5

E.S.3.2. GHG precursors

Carbon monoxide (CO), nitrogen oxides (NOx) and non-methane volatile organic compounds (NMVOCs) were estimated from biomass burning only. CO emissions varied between 1 313 Gg CO to 1 094 Gg CO between 2000 and 2020. The NOx emissions were between 25 Gg NOx and 77 Gg NOx, while NMVOCs were between 30 Gg NMVOCs and 85 Gg NMVOCs over the period 2000 to 2020. There is annual variability because the emissions include wildfires as well as controlled fires.

E.S.3.3. Sectoral trends

Energy

2020

Total emissions from the *Energy* sector for 2020 were estimated to be 379 505 Gg CO_2e (Table ES 3) which is 81.0% of the total emissions (excl. FOLU) for South Africa (Figure ES 2). *Energy industries* were the main contributor, accounting for 62.4% of emissions from the *Energy* sector. This was followed by *Transport* (12.7%) and *Manufacturing industries and construction* (8.8%).

Table ES 3: Sectoral trends in emissions for South Africa between 2000 and 2020.

	Energy	IPPU	AFOLU (excl. FOLU)	AFOLU (incl. FOLU)	Waste
	Emissions (Gg CO_2e)				
2000	371 344.6	32 955.2	42 439.1	23 343.8	18 241.2
2001	374 140.0	33 220.9	43 315.8	33 223.0	18 343.6
2002	384 308.9	35 204.1	43 373.4	35 547.7	18 566.4
2003	405 170.8	34 506.9	42 357.8	25 453.6	18 803.2
2004	419 521.7	34 617.1	42 103.8	34 631.7	18 858.8
2005	411 995.4	37 825.5	43 109.9	53 010.3	19 085.5
2006	407 032.8	38 900.2	42 973.3	50 443.0	19 295.9
2007	434 434.7	37 239.4	43 824.9	47 421.4	19 501.8
2008	432 848.2	35 441.5	44 365.4	58 959.2	19 742.1
2009	461 135.5	33 612.5	44 066.5	38 277.3	19 732.3
2010	426 504.9	35 928.4	43 755.3	44 546.9	20 007.0
2011	420 764.5	39 510.4	43 672.5	37 506.3	20 113.9
2012	432 091.1	38 654.1	44 741.1	38 435.1	20 306.9
2013	432 562.8	38 213.3	43 876.9	28 496.3	20 491.1
2014	409 532.8	39 097.3	44 587.0	34 420.0	20 660.4
2015	410 240.7	41 402.0	42 925.1	23 430.7	20 896.3
2016	409 456.8	40 120.7	41 962.6	8 665.5	21 123.4
2017	401 901.4	32 261.0	42 488.1	23 905.1	21 699.3
2018	413 151.3	30 104.6	41 802.0	25 206.3	21 989.0
2019	407 382.7	27 040.8	40 930.6	19 275.3	22 299.3
2020	379 505.2	25 486.1	40 774.6	14 088.0	23 045.8

2000 - 2020

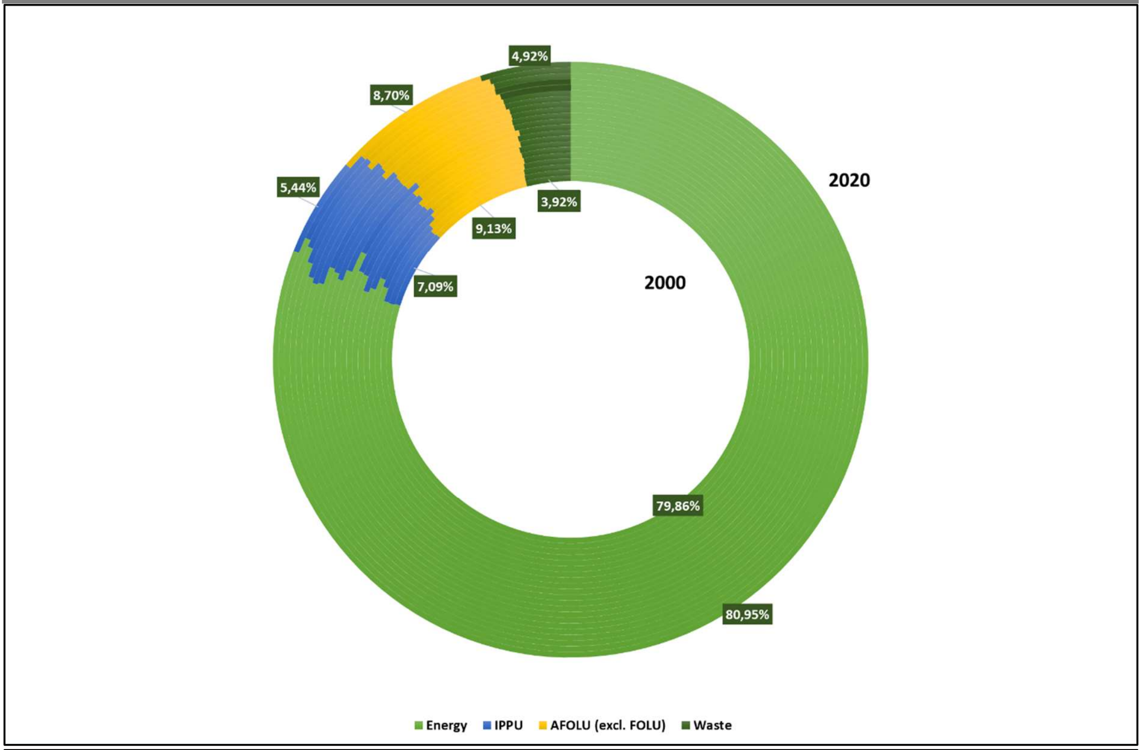
Energy sector emissions increased by 2.2% between 2000 and 2020. The emissions increased between 2000 and 2009, then declined to 2014 after which total emissions were stable until 2019. Emissions declined by 6.8% in 2020. The main contributor to the decline is a 19.7% reduction in emissions from *Other sectors* and a 13.7% reduction in *Transport* emissions. These reductions can be attributed to the reduced travel and trading during the COVID-19 lockdown restrictions.

2017 - 2020

Energy emissions declined by 5.6% since 2017 (Table ES 4). The main contributors to decrease were the *energy industries and transport* which decreased by 5.1% (12 679 Gg CO_2e) and 10.4% (5 590 Gg CO_2e) respectively. The *Other sectors* and *Non-specified* sectors collectively decreased by 18%. The decrease in *Other sectors* is due to the change in allocation of fuel, of which the most is sub-bituminous coal. The *Fugitive emissions* sector emissions decreased by 0.06%.

Table ES 4: Change in sector emissions since 2000 and 2017.

	Emissions (Gg CO_2e)			Change 2000 to 2020		Change 2017 to 2020	
	2000	2017	2020	Gg CO_2e	%	Gg CO_2e	%
Energy	371 344.6	401 901.4	379 505.2	8 160.5	2.2	-22 396.3	-5.6
IPPU	32 955.2	32 261.0	25 486.1	-7 469.1	-22.7	-6 774.9	-21.0
AFOLU (excl. FOLU)	42 439.1	42 488.1	40 774.6	-1 664.5	-3.9	-1 713.5	-4.0
AFOLU (incl. FOLU)	23 343.8	23 905.1	14 088.0	-9 255.8	-39.7	-9 817.1	-41.1
Waste	18 241.2	21 699.3	23 045.8	4 804.6	26.3	1 346.5	6.2



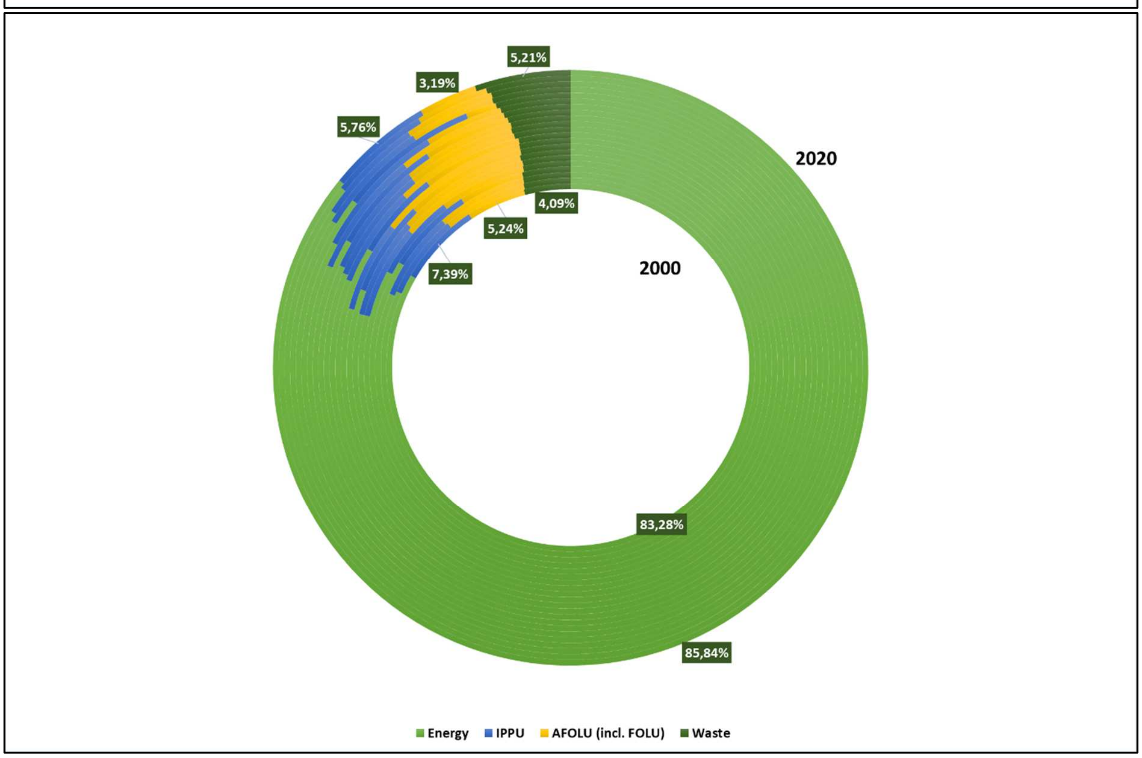


Figure ES 3: Sector contribution to total emissions excluding FOLU (top) and including FOLU (bottom) in South Africa between 2000 and 2020.

Industrial processes and product use (IPPU)

2020

In 2020 the IPPU sector produced 25 486 Gg CO_2e, which is 5.4 % of South Africa's emission (excluding FOLU) (Table ES 4, Figure ES 3). The largest source category is the metal industry category, which contributes 48% 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 3 853 Gg CO_2 (31.5%) and 7 069 Gg CO_2 (57.8%), respectively, to the total metal industry CO_2 emissions.

The *mineral industry* and the *Product used as substitutes for ozone depleting substances* subsectors contribute 18.7% and 19.4%, respectively, to the IPPU sector emissions.

Carbide production, *carbon black production*, *iron and steel production*, *ferroalloy production* and *ammonia production* produce 576 Gg CO_2e of CH_4, while *chemical industries* are estimated to produce 836 Gg CO_2e of N_2O.

2000 - 2020

Estimated emissions from the IPPU sector are 7 469 Gg CO_2e (22.7%) lower than the emissions in 2000. There was a decline in *cement production*, *iron and steel production* and *paraffin wax usage* in 2020 compared to 2019. An increase in production was observed in *ferroalloy production* since 2019. There was an overall decrease in IPPU emissions in 2020 due to a decrease in the *mineral industry* of 18.4% since 2019. Emissions also decreased by 1.9% in the *metal industry* and 34.3% in subsector *non-energy products from fuels and solvent use*.

IPPU emissions increased by 18.0% between 2000 and 2006, after which there was a 13.6% decline to 2009. This decrease was mainly due to the global economic recession and the electricity crisis that occurred in South Africa during this period. In 2010 emissions increased by 6.9% due to an increase in the *metal industry* and *products used as substitutes for ozone depleting substances* subsectors. The economy was beginning to recover from the global recession. Another reason for the increase in GHG emissions in 2010 was that South Africa hosted the 2010 FIFA World Cup and as a result an increase in demand for commodities was experienced.

Emissions increased between 2010 and 2016 mainly due to an increase in production in the mineral and metal industries. There was an increase of 8.9% during this time within the *mineral industry* and an increase of 2.5% within the *metal industry*. The overall increase between 2010 and 2016 was 11.7%. Emissions decreased by 19.6% between 2016 and 2017 as demand in the chemical and metal industry dropped.

2017 – 2020

Emissions within the sector decreased further from 2017 to 2020 by 21% due to lower production demands in the *mineral*, *chemica*l and *metal industry*. The economy in 2020 was further strained due to the COVID-19 pandemic and stringent lockdown regulations within South Africa. The *mineral industry* emissions decreased by 23.7% (1 483 Gg CO_2e) since 2017, and the *metal industry* showed an overall decrease of 40.0% (8 150 Gg CO_2e).

Agriculture, forestry and other land use change (AFOLU)

2020

The overall AFOLU emissions totalled 14 088 Gg CO_2e (incl. FOLU) in 2020, and 40 775 Gg CO_2e excluding FOLU (Table ES 4). Livestock contributed 31 372 Gg CO_2e (76.9% of total excl. FOLU). *Aggregated and non-CO_2 emissions on land* contributed 23.1% to the AFOLU (excl. FOLU) emissions in 2020, and the largest contributor to this category is *Direct N_2O from managed soils* (56.1%). Nitrogen inputs from urine and dung contributed 14.9% to *direct N_2O emissions*, while 57.5% comes from crop residues and 19% from inorganic fertilisers.

For the Land category the largest contributor to the sink is *Forest land* (24 575 GgCO_2e), followed by *Grasslands* (11 084 GgCO_2e). *Other land* (6 125 GgCO_2e) is the main contributor to the source in the Land category.

2000 - 2020

There was a 3.9% decline in emissions (excl. FOLU) and a 39.7% decline in emissions including FOLU between 2000 and 2020. *Enteric fermentation* emissions have shown a steady decline throughout the time series following the livestock population trend. The other cattle population has declined by 12.5% since 2014 which contributes to the decline in emissions to 2020. Other cattle and sheep were the largest contributors to the *Enteric fermentation* emissions. Emissions from manure management increased by 11.8% between 2000 and 2020 and this is because most managed manure is on dairy, pig and poultry farms and these livestock have been increasing in numbers over this period. Emissions from *Aggregated and non-CO_2 emissions on land* have shown a steady increase between 2000 and 2020.

The Land sector sink declined between 2000 and 2008, after which it increased to 2020. The sink was largest in 2016 due to increasing forest land and reduced losses through fuelwood collection and biomass burning. The sink declined in 2017 and 2018 but increased again thereafter.

2017 - 2020

AFOLU emissions (excl. FOLU) declined by 4.0% between 2017 and 2020 (Table ES 4), due to a 4.6% and 2.2% decline in *Livestock* and *Aggregated and non-CO_2 emissions on land*. On the other hand, *AFOLU* emissions (incl. FOLU) declined by 41.1% over the same period due to a 51.8% increase in the land sink over this time.

Waste

2020

In South Africa the total *Waste* sector emissions for 2020 were 23 046 Gg CO_2e (Table ES 4). Most of these emissions are from *Solid waste disposal* contributing 18 253 Gg CO_2e (79.2%) of the total *Waste* sector emissions. *Wastewater treatment and discharge* contributed a further 4 458 Gg CO_2e (19.3%) of waste emissions while *open burning* of waste contributed 335 Gg CO_2e (1.5%). Emissions from *biological treatment of solid waste were estimated to be insignificant* (0.0011) Gg CO_2e.

2000 - 2020

Solid waste disposal emissions have increased 34.1% since 2000. *Incineration and open burning of waste* emissions increased by 90.2% since 2000, while emissions from *Wastewater treatment and discharge* remained stable throughout the time series. This is largely driven by increases of 42.6% in *Domestic wastewater treatment* emissions, whilst there was a 54.2% decline in *Industrial wastewater treatment and discharge* emissions.

2017 - 2020

The *Waste* sector emissions increased by 6.2% between 2017 and 2020 (Table ES 3) due to a 6.2% increase in *Solid waste disposal* emissions, 33.6% increase in *Open burning of waste* and a 4.5% increase in *Wastewater treatment and discharge* emissions.

E.S.4. Improvements and recalculations

Improvements introduced in the current inventory

Energy

Updated consumption data in the *Road transport, Manufacturing industries and construction, Other sectors and Non-specified emissions from energy production* categories was included, particularly for coal, diesel, natural gas and gas works gas. This was because the energy balance data from Department of Mineral Resources and Energy (DMRE) updated the fuel allocation in these sectors. In addition, new data became available from a fuel consumption study done by DFFE under the GHG improvement programme. This 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. Lastly, DMRE had updated coal statistics in its South Africa's Mineral Industry (SAMI) report series.

IPPU

Through the introduction of the South African GHG Emissions Reporting System (SAGERS), the GHG reporting tool, there have been various additions to the inventory. In the Mineral industry the category *Other process uses of carbonates* was added from 2018, and dolomitic lime was added from 2019 to *Lime production*. In the Chemical industry *Silicon carbide production* was added in 2019 and an error was corrected in the *Titanium dioxide production* category. Emissions from three new categories were added, namely the *Soda ash production* from 2019, *Hydrogen production* from 2018 and *Other chemical processes* from 2020. Lastly, the Metal industry saw the change in activity from primary production to the treatment of secondary raw material under *Lead production*.

AFOLU

In the livestock category Tier 2 data for enteric fermentation and manure management emission factor calculations for cattle, goats and sheep were incorporated based on a study by Agricultural Research Council (ARC) (2020). This also led to changes in the livestock categorisation and an update of manure management data.

In the *Land* category various updates were made which include the incorporation of the 1990-2018 land change matrix, inclusion of updated biomass and DOM data from the National Terrestrial Carbon sinks assessment (DEFF, 2020) and various scientific publications, incorporation of new Biomass Conversion and Expansion Factor (BCEF) for plantations, inclusion of country specific Soil Organic Carbon (SOC) reference and stock change data, inclusion of mortality, inclusion of charcoal production and finally the inclusion of CO_2, CH_4 and N_2O from mineral inlands wetlands.

Aggregated and non-CO_2 emissions on land category were improved through the updated livestock category data as these have nitrogen inputs to this category. In addition, Moderate Resolution Imaging Spectroradiometer (MODIS) burnt area data was updated to Collection 6 data.

Country specific data was included in the Harvested Wood Products (HWP) calculations.

Waste

In the Waste sector the waste generation rate per person was adjusted to bring it in to alignment with data in IPCC 2019 refinement values. Waste generation rate per Gross Domestic Product (GDP) value was also adjusted along with the amount of waste sent to Solid Waste Disposal Site (SWDS) as Municipal Solid Waste (MSW) and Industrial waste.

Recalculations

Recalculations due to improvements led to higher emissions than previous estimates in the period 2000 to 2013, after which the estimates were lower than previous estimates (Figure ES 4).

For 2017, improvements led to a 2.8% and a 0.5% decrease in emission estimates excluding and including FOLU, respectively. The highest change in the emissions, for 2017, was a 32.8 % increase for the LULUCF sector and a 12.7 % decrease in emissions for the Agriculture sector. Recalculations resulted in a 2.1 % decrease in emissions for the Energy sector, a 2.1 % increase for the Waste sector and a 0.5 % increase in IPPU emissions for 2017.

Figure ES 4: Changes in overall emission estimates due to recalculations.

E.S.5. Key category analysis

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. The key categories were then ranked according to their combined contribution to the level and trend assessments. In the previous inventory there were 44 key categories, while in this inventory there are 58. Table ES 5 shows the top 30 key categories.

Electricity and heat production moved from the second place in the previous inventory to the number one key category over *Road transport*. In the previous inventory solid fuels from the *Commercial/Institutional* category was third, whereas in 2020 this has moved down to 20th place. Its contribution has reduced significantly, and this could be a result of COVID-19 lockdown restrictions. *Solid waste disposal* has moved up from 7th place to 4th place. Forest land remaining forest land moved up from 4th place in the previous inventory to 3rd place in this inventory.

Table ES 5: **Key categories for South Africa for 2020 (including FOLU) and their ranking.**

Rank	IPCC Category code	IPCC Category	GHG#
1	1A1a	Electricity and Heat Production (solid)	CO_2
2	1A3b	Road Transport (liquid)	CO_2
3	3B1a	Forest land remaining forest land	CO_2
4	4A	Solid Waste Disposal	CH_4
5	1A5a	Stationary (solid)	CO_2
6	1B3	Other Emissions from Energy Production	CO_2
7	3A1a	Enteric fermentation - cattle	CH_4
8	1A1c	Manufacture of Solid Fuels and Other Energy Industries (liquid)	CO_2
9	1A2	Manufacturing Industries and Construction (solid)	CO_2
10	1A4c	Agriculture/Forestry/Fishing/Fish Farms (liquid)	CO_2
11	2C1	Iron and Steel Production	CO_2
12	2F1	Refrigeration and Air Conditioning	HFCs
13	1A2	Manufacturing Industries and Construction (liquid)	CO_2
14	1A1a	Electricity and Heat Production (liquid)	CO_2
15	2C2	Ferroalloys Production	CO_2
16	3C4	Direct N_2O emissions from managed soils	N_2O
17	3A1c	Enteric fermentation - sheep	CH_4
18	3B1b	Land converted to forest land	CO_2
19	1A3d	Water-Borne Navigation (liquid)	CO_2

20	1A4a	Commercial/Institutional (solid)	CO_2
21	1A2	Manufacturing Industries and Construction (gas)	CO_2
22	1A4b	Residential (solid)	CO_2
23	4D1	Domestic Wastewater Treatment and Discharge	CH_4
24	1A4b	Residential (liquid)	CO_2
25	1B1a	Coal mining and handling	CH_4
26	3B3b	Land converted to grassland	CO_2
27	1A1b	Petroleum Refining (gas)	CO_2
28	3B5a	Settlements remaining settlements	CO_2
29	3B2b	Land converted to cropland	CO_2
30	3D1	Harvested wood products	CO_2

E.S.6. Indicator trends

The carbon intensity of the population (i.e., total net emissions per capita) increased between 2000 and 2009 to a peak of 10.96 t CO_2e per capita, after which it declined to 7.42 t CO_2e per capita in 2020 (Figure ES 5). The carbon intensity of the economy has shown a declining trend and declined by 9.6% between 2000 and 2009. After this there was a sharp decline between 2009 and 2012, however, thereafter the carbon intensity has shown a steady decline to 2020. The carbon intensity of the energy supply (i.e., total net emissions per energy unit) shows a steady decline, between 2000 and 2020, of 31.4%.

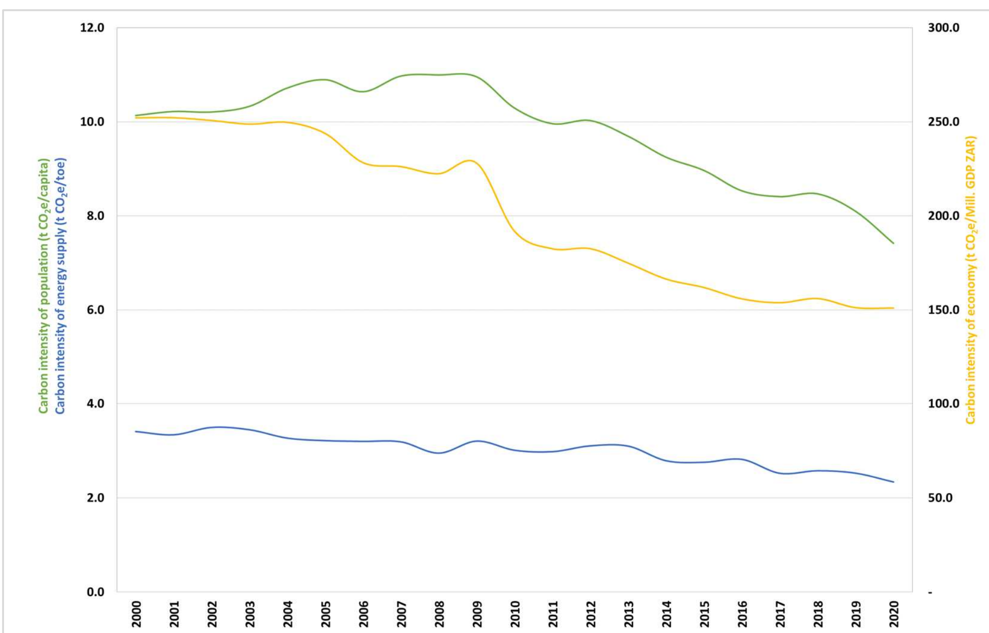


Figure ES 5: Trend in carbon intensity indicators for South Africa between 2000 and 2020.

E.S.7. Other information

General uncertainty evaluation

Uncertainty analysis is regarded by the IPPC Guidelines as an essential element of a complete and transparent inventory. The uncertainty information helps prioritizing efforts to improve the accuracy of future inventories and guide future decisions on methodological choice. Hence 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.

South Africa still makes use of numerous IPCC default uncertainties, but as data becomes available on country-specific uncertainties these values are improved. A trend uncertainty between the base year and 2020, 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 between 8.13% and 8.77% including FOLU, with a trend uncertainty of 6.71%. Excluding FOLU reduced the overall uncertainty to be between 6.64% and 7.32%, with the trend uncertainty dropping to 6.21%.

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 GHG 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. For the 2020 inventory quality assurance was completed through a public review process and the inventory was reviewed by the UNFCCC through an in-country QA workshop provided by the GHG support unit. 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 – 2020 is not complete, mainly due to the lack of sufficient data. Table ES 6 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 Appendix C). It is also noted that some precursor gases (sulphur dioxide and ammonia) and SF_6 have not yet been included in the inventory.

Table ES 6: Activities in the 2020 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	CO_2 emissions from Oil are included, but CH_4 emissions need to be included along with natural gas emissions. To 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 future inventories.
	1B1ai3	CH_4 emissions from *abandoned mines*.	New research work on sources of emissions from this category will be evaluated and emissions will be included in future inventories.
	1B3	N_2O from Other Emissions from Energy Production	Insufficient data to include.
	1C1	CO_2 transport	Insufficient data to include.
	1C2	Injection and storage	Insufficient data to include.
	2A	CH_4 emissions from cement production, lime production, glass production and OPUC	Insufficient data to include.
	2B1	N_2O from Ammonia production.	Insufficient data to include.
	2B2	CO_2 & CH_4 from nitric acid production	Insufficient data to include.
	2B5	N_2O from carbide production	Insufficient data to include.
	2B7	CH_4 & N_2O from Soda Ash production	Insufficient data to include.
	2B8	N_2O from petrochemical & carbon black production	Insufficient data to include.
	2C1	N_2O emissions from iron and steel production	Insufficient data to include.

NE, IE or NO	IPCC Category	Activity	Comments
	2C2	N_2O emissions from ferroalloy production	Insufficient data to include.
	2C3	CH_4 from Aluminium production	Insufficient data to include.
	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.
	2F1	CO_2 & PFCs from refrigeration & air conditioning	Insufficient data to include.
	2F2	CO_2 & PFCs from foam blowing agents	Insufficient data to include.
	2F3	CO_2 & PFCs from Fire protection	Insufficient data to include.
	2F4	PFCs from aerosols	Insufficient data to include.
	2F5	PFCs and HFCs from solvents	Insufficient data to include.
	2G1	PFCs from electrical equipment	Insufficient data to include.
	2G1	SF_6 emissions in the IPPU sector	Insufficient data. It is planned to include these in the next inventory.
	2G2	PFCs from other product uses	Insufficient data to include.
	2G3	N_2O from product uses	Insufficient data to include.
	2H1	CO_2 & CH_4 from Pulp & Paper industry	Insufficient data to include.
	2H2	CO_2 & CH_4 from Food & beverage industry	Insufficient data to include.
	3B	CO_2 from organic soils	This will be included in future inventories.
	3C4	N_2O from organic soils	Insufficient data to include.
	4C1	CO_2, CH_4 and N_2O from waste incineration	Insufficient data to include.
	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 in future inventories.
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.
	1A5b	CO_2, CH_4 and N_2O emissions from other mobile machinery	Included under Road transportation.
	1B1c	Solid fuel transformation	Included under sector specific categories

NE, IE or NO	IPCC Category	Activity	Comments
	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).
NO	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*	
	2B8a	Methanol production	
	2B8b	Ethylene production	
	2B8c	Ethylene dichloride & vinyl chloride monomer	
	2B8d	Ethylene oxide	
	2B8e	Acrylonitrile	
	2B9	HFCs, PFCs and SF_6 from *Fluorochemical production*	
	2C4	CO_2, HFCs, PFCs and SF_6 from *Magnesium production*	
	3A1	CH_4 emissions from buffalo and camels.	
	3A2	CH_4 and N_2O emissions from buffalo and camels.	
	3C1f	All emissions from *Other lands*	
	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 and Table summarize some of the projects that are under implementation as part of the GHGIP.

Table A: DFFE driven GHGIP projects

Sector	Baseline	Nature of methodological improvement	Partner	Completion date
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
Energy Sector	Gaps in Activity Data.	Fuel Consumption Survey, activity data improvement.	GIZ DOE	December 2020
Agriculture	Improving the parameters which are required to calculate the country specific EFs for Enteric fermentation and manure management	Improvement of Agricultural Greenhouse Gas Activity data in South Africa: Enteric Fermentation and Manure Management	WRI	December 2020

Table B: Donor funded GHGIP projects

Project	Partner	Objective	Outcome	Timelines	Status
Liquid Fuel Study	GIZ SAPIA	Development of CO_2 Emission Factors for Liquid and Gaseous Fuels in South Africa	Country Specific CO_2 emission factors developed to enable reporting of liquid fuels emissions using a tier 2 approach.	2022	Completed
Cement Sector Study	GIZ ACMP	Development of Country-Specific CO_2 Emission Factors for Alternative Fuels used in the cement sector in South Africa	Country Specific CO_2 emission factors developed to enable reporting of alternative fuels emissions using a tier 2 approach.	2022	Completed
Transport Sector Study	GIZ DOT	Development of Country-Specific Emission Factors (Methane and Nitrous Oxides) for transport sector	Shift towards an IPCC Tier 2 approach	2023	Not Started
Refrigeration and Conditioning Sector Study.	GIZ	HFC Survey in the Refrigeration Sector and Air Conditioning Sector.	Improvement of activity data for the sector.	2023	Not Started

Solid Fuels Study	GIZ	Development of CO_2 Emission Factors for Solid Fuels in South Africa	Country Specific CO_2 emission factors developed to enable reporting of solid fuels emissions using a tier 2 approach.	2023	In Progress

GHG regulation reporting

DFFE has modified the National Atmospheric Emissions Inventory System (NAEIS) to meet the requirements of the National Greenhouse Gas Emission Reporting Regulations (NGERs), (DEA, 2016). The 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 as further data is collected.

E.S.8. Conclusions and recommendations

The 2000 to 2020 GHG emissions results revealed emissions have increased since 2000 from the *Energy* and *Waste* sectors, with a decrease in the *IPPU* and *AFOLU* sector. These declines are due to improved data in the *IPPU* sector, as well as a reduction in emissions in 2020 partly due to the impacts of the COVID19 pandemic on industry and transport. In the *AFOLU* sector the decline is due to an increasing Land sink. There was an annual average increase of 2.4% in the total net emissions between 2000 and 2009, and then emissions stabilised and declined with an average annual decline of 2.0% between 2010 and 2020.

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 through the GHG Reporting Programme via the SAGERS. Increasing the amount of company level data will enhance the accuracy of emission estimates and help reduce uncertainty associated with the estimates. The mandatory GHG Reporting Programme, which is driven by the NGERs, will provide enhanced data for this sector. This data has been 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 2018 in most cases. These are issues which will be improved in future 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 is 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 a system for integrating various maps irrespective of the technologies used to develop the maps. It is recommended that carbon density maps be developed for multiple years and that these maps be integrated with the land mapping system so that South Africa can move towards a Tier 3 approach. A national forest inventory would also 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 solid waste 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.

Contents

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Chapter 1: Introduction

1.1 Background information

1.1.1 Background information on climate change

The UNFCCC was signed by South Africa in 1993 and ratified in 1997. All countries that ratified the Convention (the Parties) are required to address climate change, including monitoring trends in anthropogenic GHG 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.

1.1.2 Background information on GHG inventories

1.1.2.1 South Africa's National Greenhouse Gas Inventory

South Africa compiled its first National GHG Inventory in 1998 using activity data for the year 1990. This inventory utilised the 1996 IPCC Guidelines. Using the same methods, the second National GHG Inventory for the year 1994 was compiled and published in 2004. In 2009 the third National GHG Inventory for 2000 was completed and for this inventory the IPCC 2006 Guidelines were introduced in the Energy, IPPU and Waste sectors, but were only partially introduced in the AFOLU sector.

It was only in 2014 when South Africa started to present annual emissions and trends over a time-series instead of an individual year. The fourth National GHG Inventory included annual emission estimates for the period 2000 to 2010. The year 2000 was selected as the base year due to a lack of data, particularly in the Energy and IPPU sectors, prior to 2000. The inventory was then updated in 2016 for the period 2000 to 2012, in 2018 for the years 2000 to 2015, and again in 2021 for the period 2000 to 2017. In these inventories the IPCC 2006 Guidelines were implemented.

This 2020 NIR for South Africa provides estimates of South Africa's net GHG emissions for the period 2000 to 2020 and is South Africa's 8th inventory report. This report is to be submitted to UNFCCC to fulfil South Africa's reporting obligations under the UNFCCC. The

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Report has been compiled in accordance with the 2006 IPCC Guidelines, the *2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol* (IPCC, 2014a) and the 2019 Refinement. 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 NIR covers sources of GHG emissions, and removals by sinks, resulting from human (anthropogenic) activities for the major greenhouse gases: CO_2, CH_4, N_2O, PFCs, and HFCs. The indirect greenhouse gases, CO, NO_X and NMVOCs are also included for biomass burning. The gases are reported under four sectors: *Energy*; IPPU; AFOLU and *Waste*. Sulphur hexafluoride (SF_6) emissions have not yet been included due to a lack of data, however, DFFE has set a threshold for SF_6 in the new GHG reporting regulation so that companies will start reporting SF_6 data going forward. It has been noted that Eskom started to report SF_6 for the 2020 calendar so for this inventory there was insufficient data to include it, but further data is expected to be reported by the next inventory.

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.

1.1.3 Global warming potentials

As greenhouse gases vary in their radiative activity, and in their atmospheric residence time, converting emissions into carbon dioxide equivalents (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 CO_2e using the 100-year GWPs contained in the *IPCC* SAR (IPCC, 1996) (Table 1.1) so as to comply with international reporting requirements.

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

Greenhouse gas	Chemical formula	SAR GWP
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

1.2 Structure of the report

1.2.1 Overall structure

This NIR follows the format prescribed by the UNFCCC in the updated UNFCCC reporting guidelines on annual inventories (UNFCCC, 2013) following incorporation of the provisions of decision 14/CP.11 (FCCC/SBSTA/2006/9):

- **Chapter 1** is the introductory chapter which contains background information on climate change and GHG inventories, South Africa's inventory institutional arrangements, preparation and reporting process, key categories and uncertainty analysis, a description of the methodologies, activity data, emission factors, and the overall QA/QC process.
- **Chapter 2** provides an overview of the trends in aggregated GHG emissions and indicators, as well as an analysis and interpretation of the trends in emissions by gas (CO_2, CH_4, N_2O, F gases, indirect precursors) and by category (Energy, IPPU, AFOLU, Waste).
- **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, time-series consistency, QA/QC process, verification and planned improvements and recommendations.
- **References** are provided at the end of each chapter.
- The **Appendices** are found at the end of the report and contain the detailed key categories (Appendix A) and uncertainty analysis results (Appendix B), all summary tables in the IPCC prescribed format (Appendix C) and the energy sector reference and sectoral approach data (Appendix D).

1.2.2 Structure of sectoral chapters

In this submission the layout and structure of the detailed sectoral chapters (chapters 3 to 6) have been restructured slightly to improve the flow of the NIR. The following basic structure is followed in each chapter:

- **Sector overview** is at the beginning of each chapter, and this provides a detailed analysis of the emission trends and the drivers in the sector and the various sub-categories. In addition, this section provides an overview of the methodologies, completeness, improvements, recalculations, key categories, and planned improvements for the sector. This section in each chapter, therefore, highlights the main key points and take-home messages for each sector.
- **Category and sub-category sections** are provided below this, identified by the category name and number, and these provide the details on the methodologies, activity data, emission factors, uncertainties, time-series consistency, category specific recalculations, category specific QA/QC procedures and category specific planned improvements.

This is the overall structure followed throughout the chapters, although there are some variations in the chapters due to the different data in each sector, for example:

- In the Energy sector the Fuel combustion section has an overall, common methodology upfront with additional sections on the sectoral and reference approach, international bunkers, feedstocks, and CO_2 storage.
- The AFOLU sector has a section upfront in the Livestock category explaining the livestock population and manure management as this information is used in several sub-category sections.
- The AFOLU sector also has additional information at the beginning of the Land sub-category to provide details on the land representation and stratification that is used throughout the section.

1.3 National inventory arrangements

1.3.1 Overview of institutional, legal, and procedural arrangements

1.3.1.1 Single National Entity

In South Africa the DFFE is the central co-ordinating and policy-making authority with respect to environmental conservation. Following the announcement of the sixth administration in 2019, the forestry and fisheries functions were amalgamated into the previous Department of Environmental Affairs (DEA), which then became known as the Department of Environment, Forestry and Fisheries (DEFF). On the first of April 2021 (Government Gazette 44229, Notice No. 172) the name of the DEFF changed again to the DFFE.

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 National GHG Inventories. The branch responsible for the management and co-ordination of GHG inventories at the DFFE is the Climate Change and Air Quality branch (Figure 1.1), 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.

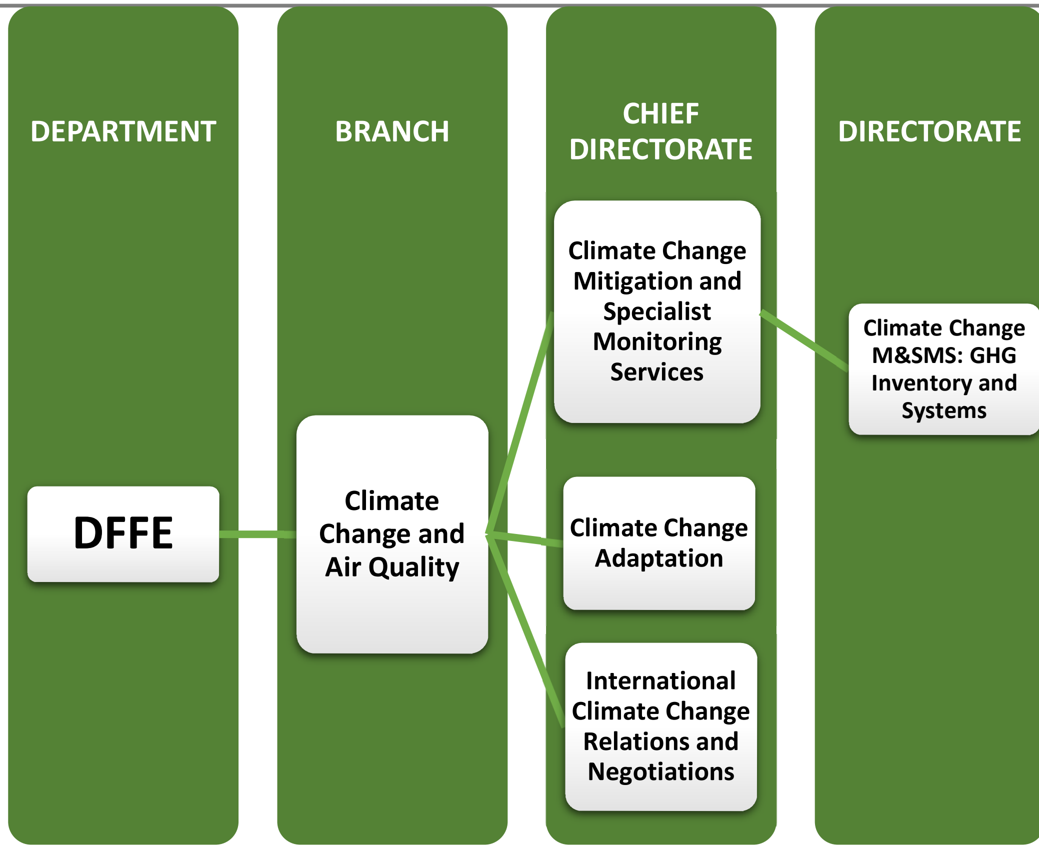

Figure 1.1: Organogram showing where the GHG Inventory compilation occurs within DFFE.

DFFE is currently responsible for managing all aspects of the National GHG Inventory development. The Director of the Climate Change M&E: GHG Inventory and Systems directorate is the National Inventory Co-ordinator (NIC) and the tasks of the coordinator include:

- Managing and supporting the National GHG Inventory staff, schedule, and budget 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 and internal DFFE technical staff 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 National Communications (NC) and/or Biennial Update Report (BUR).

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

1.3.1.2 Legal arrangements

Data is sourced from many institutes, associations, companies and ministerial branches. There are no formal agreements between the various government departments for the collection of data for the GHG Inventory. To aid in the collection of data from the energy sector and industries (including plantation industries and certain agricultural industries) the government published the NGERs, under Section 53(a), (o) and (p) read with section 12 of the National Environmental Management: Air Quality Act, 2004 (Act No. 39 of 2004), in the Government Gazette of the 3rd of April 2017. The purpose of the NGERs is to introduce a single national reporting system for the transparent reporting of GHG emissions, which will be used (a) to update and maintain a National GHG Inventory; (b) for the Republic of South Africa to meet its reporting obligations under the UNFCCC and instrument treaties to which it is bound; and (c) to inform the formulation and implementation of legislation and policy.

The NGERs were promulgated in fulfilment of the implementation of the regulatory framework to support the collection of the requisite activity and GHG emissions data necessary for the compilation of the National GHG emissions Inventory to improve the quality, sustainability, accuracy, completeness and consistency of the National GHG Inventories. In accordance with regulation 7(1) of the GHG Emission Reporting Regulations, 2016 the initial reporting cycle commenced on 31 March of 2018 requiring data providers to register and submit activity and GHG emissions data to the competent authority (DFFE).

As required in the 2011 White Paper (DEA, 2011), the DFFE has subsequently developed the South African Greenhouse Gas Emissions Reporting System (SAGERS) which is the GHG module of the National Atmospheric Emissions Inventory System (NAEIS). The SAGERS module helps to facilitate the process of enabling Industry to meet its GHG reporting requirements in a web-based secure environment and facilitates the data collection process for energy related activities and IPPU.

1.3.2 Overview of inventory planning, preparation and management

1.3.2.1 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, part of the Agriculture sub-sectors and Waste sector inventories, while remainder of the AFOLU sector is compiled by external consultants (Gondwana Environmental Solutions (GES)) who are appointed via a formal project-based contract with the GIZ Climate Support Programme. DFFE assists with the QC of the AFOLU sector. The consultants were also responsible for combining and compiling the overall inventory and providing the draft National Inventory Report to DFFE.

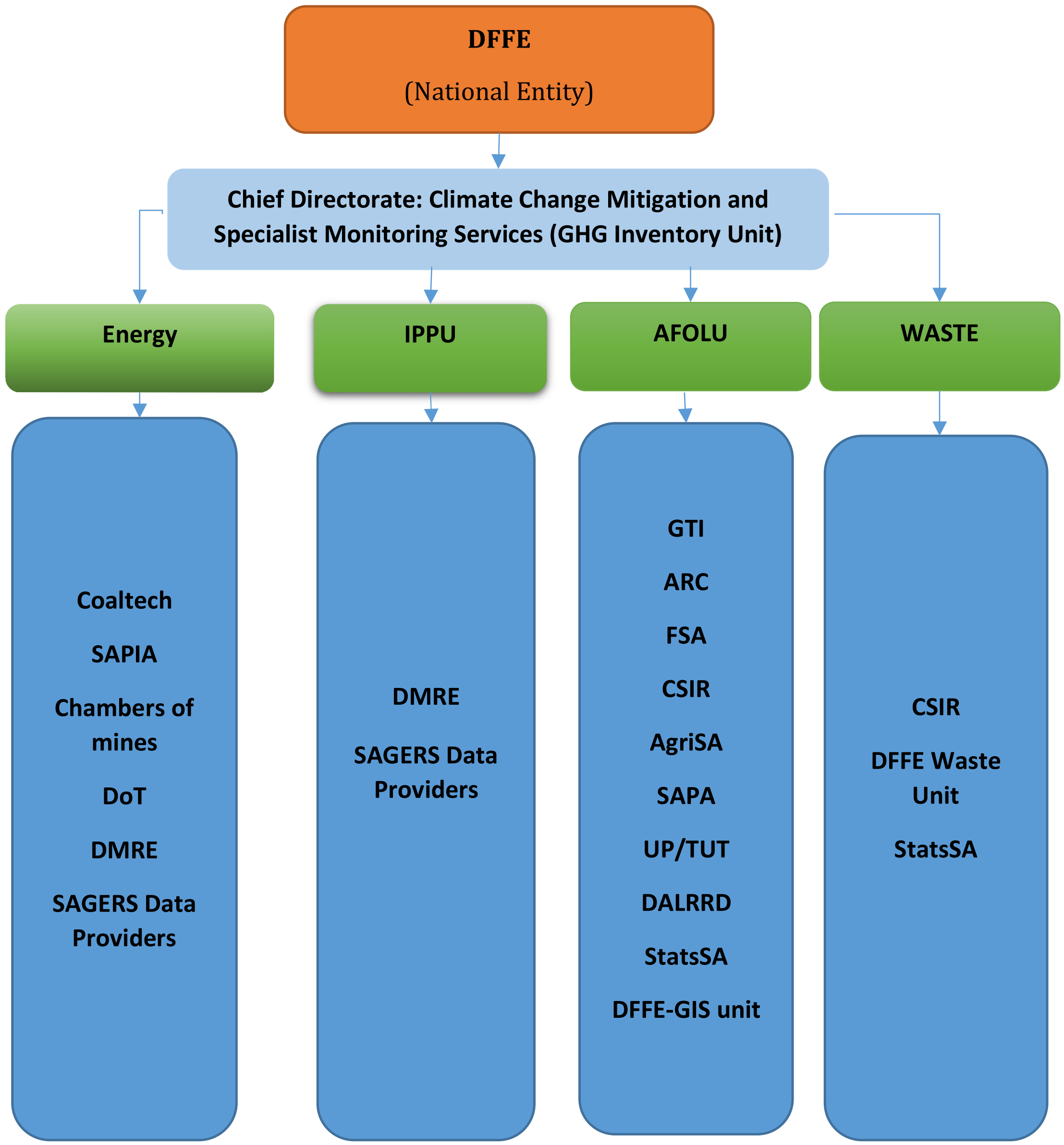

Figure 1.2: Institutional Arrangements Institutional arrangements for the compilation of the 2000 – 2020 inventory for South Africa.

1.3.2.2 Changes in the national inventory team since previous annual GHG inventory submission

The national arrangements have not changed but DFFE has enlarged the inventory team, by appointing additional officials, in preparation for the enhanced reporting requirements. Since the last inventory a new inventory co-ordinator was appointed, along with a new Energy, IPPU and Agriculture expert. In addition, an official proficient in statistics, was taken on board to assist with the improvement of the uncertainty analysis. All officials have undergone various IPCC training courses, including a course on uncertainty. The enlarged team also enabled a more in-depth QC process.

1.3.2.3 Inventory planning

A planning meeting was held in January 2021 to engage with the whole team and to plan the timelines for the inventory preparation process, from data collection to finalisation of the NIR. Since there were several new team members various training sessions (on inventory preparation, calculation files, QC procedures, time-series consistency, splicing techniques, and uncertainty analysis) were included in the inventory compilation plan. The planning phase also involved the preparation of files and templates for the inventory compilation.

1.3.2.4 Inventory preparation

After planning there are five main steps in the preparation of a National GHG Inventory:

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

The stages and activities undertaken in the inventory update and improvement process are shown in Figure 1.3.

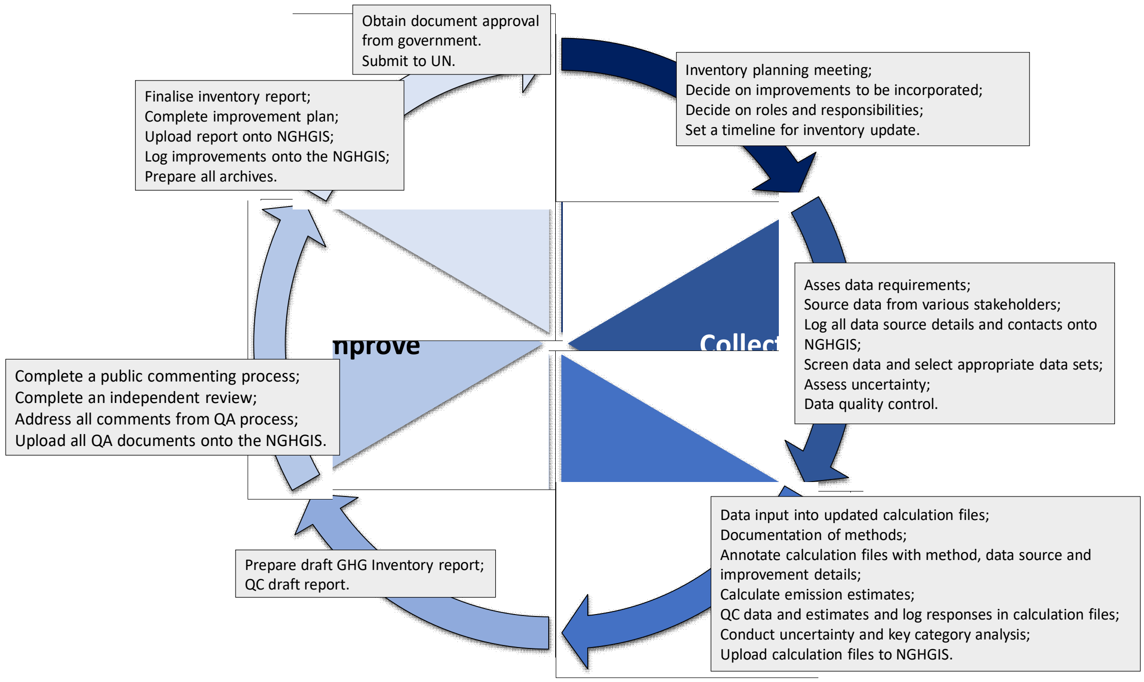

Figure 1.3: Overview of the phases of the GHG inventory compilation and improvement process undertaken for South Africa's 2020 GHG inventory.

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

The writing phase is where the draft inventory report is prepared, including all cross-cutting components (KCA, trends by gas and sector, etc.) and QC of the draft is completed. At the end of this component the draft document is subjected to a QA, or review process. The review is done by independent consultants and/or public commenting process. For the 2020 inventory only the public commenting process was utilised. 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.

1.4 Inventory preparation

1.4.1 GHG inventory

1.4.1.1 National inventory management system

South Africa recently developed a National GHG Inventory Management System (NGHGIS) to manage and simplify its climate change obligations to the UNFCCC process (Figure 1.4). 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:

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

The NGHGIS includes:

a) The formalization of a National Entity (the DFFE) responsible for the preparation, planning, management, review, implementation and improvement of the inventory;
b) Legal and collaborative arrangements between the National Entity and the institutions that are custodians of key source data;
c) A process and plan for implementing quality assurance and quality control procedures;
d) A process to ensure that the national inventory meets the standard inventory data quality indicators of accuracy, transparency, completeness, consistency, and comparability; and
e) A process for continual improvement of the national inventory.
f) A process of reviewing the GHG trends and analysis of the previous years.

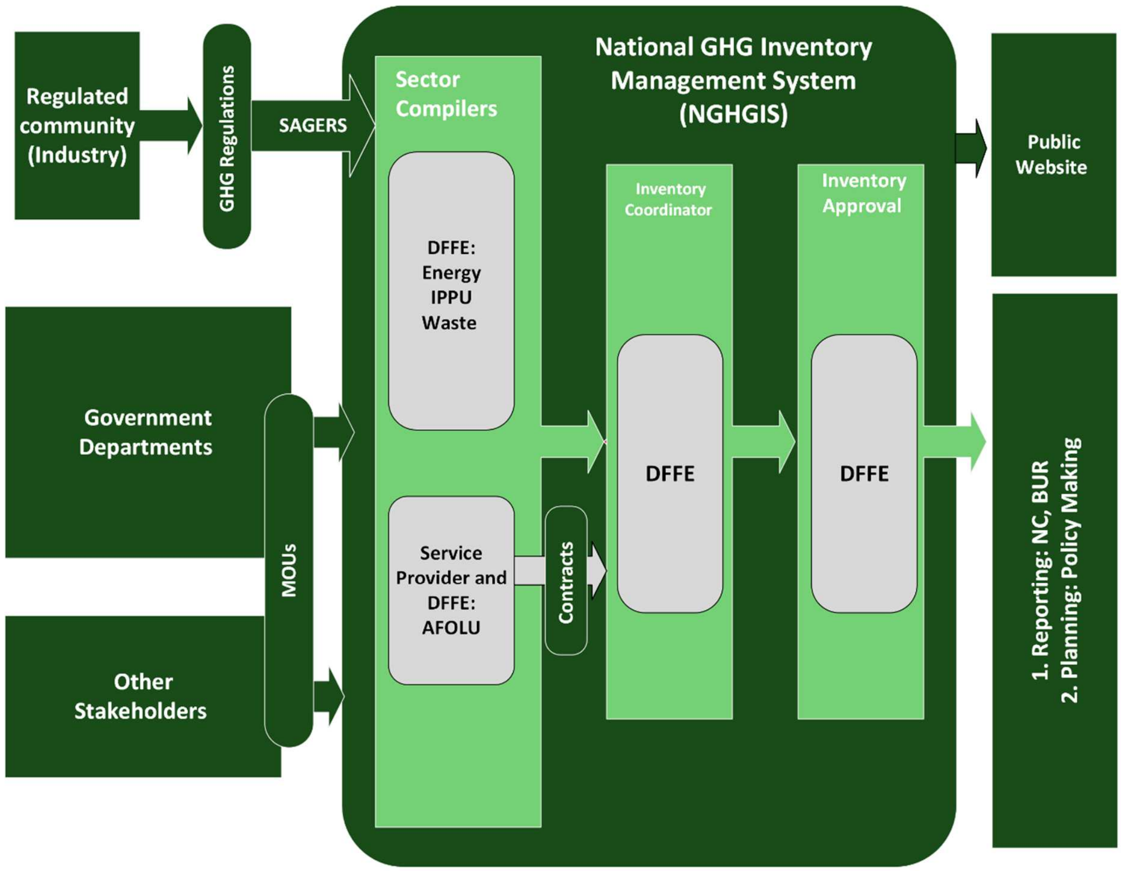

Figure 1.4: The inventory compilation process is co-ordinated through a central web-based inventory management system as depicted in this illustration.

1.4.1.2 Determination of key categories

A key category is one that is prioritised within the national inventory system because its estimate has a significant influence on a country's total inventory of greenhouse gases in terms of the absolute level, the trend, or the uncertainty in emissions and removals (IPCC, 2006). There are two approaches which can be used to determine the key categories: namely, the level approach and the trend approach. The former is used if only one year of data is available, while the latter can be used if there are two comparable years. The level assessment determines the contribution from the categories to the total national inventory. The trend assessment identifies categories that may not be large enough to be identified by the level assessment, but whose trend is significantly different from the trend of the overall inventory and should therefore receive particular attention. The trend can be an increase or a decrease in emissions. This inventory provides emissions for more than one year; therefore, both the level and trend assessments for key category analysis were performed.

The key categories have been assessed using the Approach 1 level (L1) and Approach 1 trend (T1) methodologies from the 2006 IPCC Guidelines (IPCC, 2006). The key category analysis identifies key categories of emissions and removals as those that sum to 95 per cent of the gross or net level of emissions and those that are within the top 95 per cent of the categories that contribute to the change between 2000 and 2020, or the trend of emissions.

1.4.1.3 Calculation and aggregation of uncertainties

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 the IPCC 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. Obtaining quantitative information on uncertainty remains a huge challenge for South Africa, and in many cases IPCC default uncertainties or expert judgement are still used. As improved uncertainty data becomes available it is included in the inventory.

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 B) are largely consistent with typical uncertainty ranges expected for each sector (IPCC, 2014; IPCC, 2006).

The IPCC good practice Tier 1 method was used to determine the overall aggregated uncertainty on South Africa's inventory estimate for 2020. More country specific uncertainty data will be required before South Africa can move to the Tier 2 approach.

1.4.2 Data collection, processing and storage

1.4.2.1 Data collection

Data collection and documentation take place under the responsibility of the relevant experts. One way of collecting data is to evaluate official statistics, association statistics, studies, periodicals and third-party research projects.

SAGERS

South Africa has started to move towards a more formalised data collection system for industry. DFFE has setup the National Atmospheric Emissions Inventory System (NAEIS), which is an online reporting platform for air quality and GHG emissions from companies to manage the mandatory reporting of GHG emissions. Emissions information including activity data from the NAEIS serves as input data during the national inventory compilation process.

DFFE has modified the NAEIS to meet the requirements of the NGERs (DEA, 2016). This component of the portal, the SAGERS, serves as a tool for the implementation of the online registration and reporting by industry in fulfilment of mandatory NGERs. 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.

Energy data

The main sources of data for the *Energy* sector are the energy balance data compiled by the DMRE, data supplied by the main electricity provider, Eskom, and petroleum companies, i.e., PetroSA and Sasol. Annual reports from South African Petroleum Industry Association (SAPIA) and Transnet are also considered. There are currently no formal processes in place for requesting or obtaining data from DMRE. Data from major companies are gathered via SAGERS, through the GHG Reporting Programme. The data collection process for the Energy sector is shown in Figure 1.5.

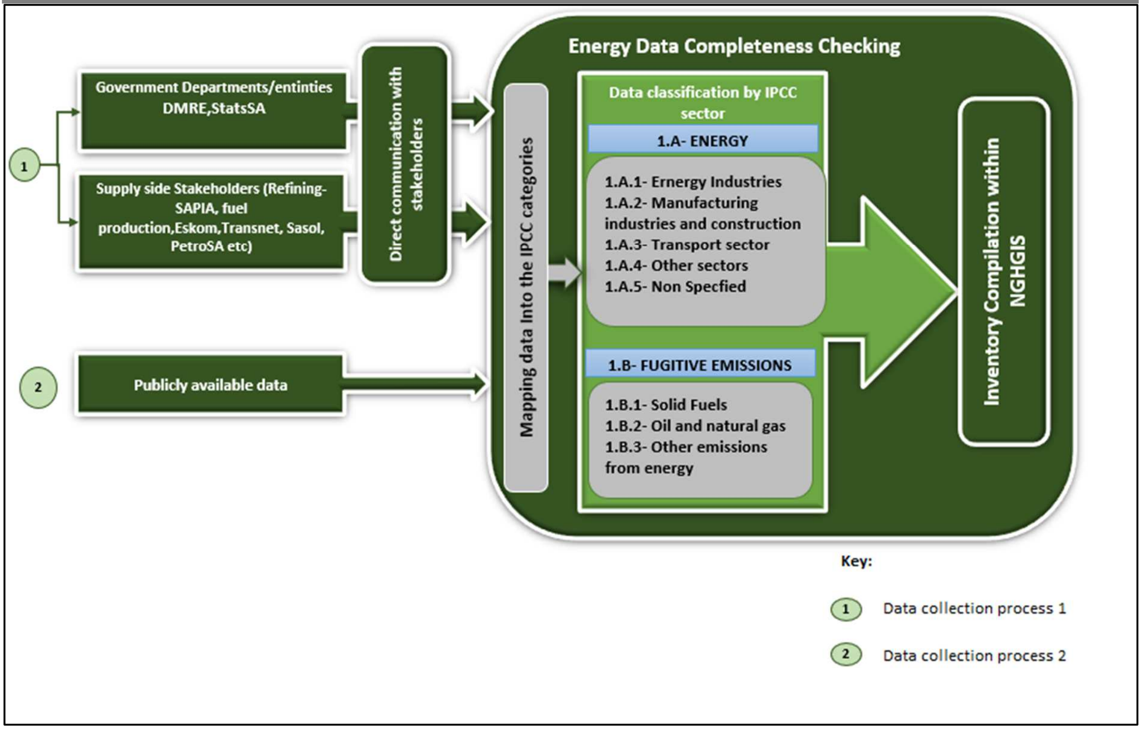

Figure 1.5: Data collection process for the 2020 Energy inventory.

Energy data sources are shown in Table 1.2.

Table 1.3: Principal data sources for the Energy sector inventory.

Sub-category	Activity data	Activity data sources
Electricity generation	Fuel consumption for public electricity generation	SAGERS
	Fuel consumption for auto electricity producers	SAGERS
	NCVs	SAGERS
Petroleum refining	Fuel consumption	Refineries
Manufacture of solid fuels and other energy industries	No activity data, only emission data - based on Mass Balance and measurement	SAGERS, Food and Agriculture Organisation of UN
Manufacturing industries and construction	Other kerosene, bitumen and natural gas consumption	Energy balance (DMRE)
	Gas/Diesel consumption	Energy balance (DMRE)
	Residual fuel oil consumption	Energy digest
	LPG consumption	SAMI report (DMRE)
Transport	Vehicle kilometres travelled for road transport	Fuel consumption study
	Domestic aviation gasoline consumption	Fuel consumption study
	Domestic aviation jet kerosene consumption	Fuel consumption study
	Road transport fuel consumption	Fuel consumption study

	Road transportation other kerosene consumption	Energy balance (DMRE)
	Railway fuel oil consumption	Energy balance (DMRE)
	Railway gas/diesel oil consumption	Energy balance (DMRE)
	Water-borne navigation fuel consumption	Energy balance (DMRE) / Fuel consumption study
	International aviation Jet Kerosene consumption	Energy balance (DMRE)
Commercial/institutional	Other kerosene, gas/diesel oil, gas works gas and natural gas consumption	Energy balance (DMRE)
	Sub-bituminous coal consumption	Energy balance (DMRE)
	Residual fuel oil consumption	Energy balance (DMRE)
Residential	Coal consumption	Energy balance (DMRE)
	LPG consumption	Energy balance (DMRE)
	Sub-bituminous coal consumption	Energy balance (DMRE)
	Other fuel consumption	Energy balance (DMRE)
Agriculture/forestry/fishing/fish farms	Other kerosene consumption	Energy balance (DMRE)
	Gas/diesel oil consumption	Energy balance (DMRE)
	Other fuel consumption	Energy balance (DMRE)
Stationary non-specified	Fuel consumption	Energy balance (DMRE)
Fugitive emissions	Solid fuels	SAGERS
	Oil and Natural Gas	SAGERS
	Other fugitive emissions	SAGERS / Fuel consumption study

IPPU data

Data for the IPPU sector is obtained mostly through the SAGERS system . The HFC and PFC data was supplied by the DFFE waste branch and supplemented with the 2016 5-year periodic survey conducted by DFFE (DEA, 2016). There is no formal data collection process in place for this.

Table 1.4: Principal data sources for the IPPU sector inventory.

Sub-category	Activity data	Data source
Cement production	Cement produced	SAGERS
	Clinker fraction	SAGERS
Lime production	Mass of lime produced	SAGERS
Glass production	Glass production	SAGERS
Other product uses of carbonates (OPUC)	Emissions from OPUC	SAGERS
Ammonia production	Emissions from ammonia production	SAGERS
Nitric acid production	Emissions from nitric acid production	SAGERS
Carbide production	Raw material (petroleum coke) consumption	SAGERS

Titanium dioxide production	Emissions from titanium dioxide production	SAGERS
Soda Ash production	Emissions from soda ash production	SAGERS
Carbon black production	Amount of carbon black produced	SAGERS
Hydrogen production	Emissions from hydrogen production	SAGERS
Other chemical processes	Emissions from other chemical processes	SAGERS
Iron and steel production	Production data	SAGERS
Ferroalloys production	Production data	SAGERS
Aluminium production	Production data	SAGERS
Lead production	Production data	SAGERS
Zinc Production	Production data	Extrapolated
Lubricant use	Lubricant consumption	Extrapolated
Paraffin wax use	Paraffin wax consumption	Extrapolated
Refrigeration and air conditioning	Existing, new and retired refrigerators	HFC Survey, DEA 2016; Stats SA
	Annual data on stationary air conditioning units	HFC Survey, DEA 2016; BSRIA
	Existing, new and retired refrigeration trucks	HFC study (GIZ, 2014); SARDA
	Existing. New and retired vehicles	eNaTIS; NAAMSA
Foam blowing agents	Total HFC used in foam manufacturing in a year	HFC Survey (DEA, 2016)
Fire protection	Bank of agent in fire protection equipment in a year	HFC Survey (DEA, 2016)

AFOLU data

AFOLU data is obtained from various sources as indicated in. The DFFE employs consultants to process the satellite imagery to generate land cover datasets used to determine land cover change for the *AFOLU* sector. This is usually done on a project-by-project basis. To improve the consistency and frequency of the land cover data, DFFE has developed a Computer Automated Land Cover (CALC) model which can generate land cover maps based on Sentinel 2 data and these maps can be developed from 2016 onwards, however the first map developed is for 2018. The aim is to generate a map every two years. All South African National Land Cover (SANLC) data (including the CALC data) can be obtained from https://egis.environment.gov.za/gis_data_downloads. DFFE is also investigating a new land mapping system which will be able to incorporate and combine various types of land maps to generate a consistent time series since 1990.

Other spatial land data, such as the carbon density maps, are obtained from https://catalogue.saeon.ac.za/. These products are also developed on a project-by-project basis.

There are no formal data collection processes in place for all the other land and agriculture data. Data is obtained from available government reports, statistics databases, and the literature. Plantation data is supplied by Forestry SA, and the cropland data is supplied by Department of Agriculture, Land Reform and Rural development (DALRRD). Burnt area data is obtained from the MODIS burnt area product which is processed by Gondwana Environmental Solutions. Fertiliser and liming data is sourced 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. Plantation data will also be reported to DFFE through the SAGERS system (DEFF, 2020) and so this data could be utilised in future inventories.

The main sources of data for agriculture are the DALRRD and ARC. Data from the ARC is also completed on a project-by-project basis and is not a consistent, sustainable data source. The SAGERS has recently introduced small components of data for agriculture, such as data from poultry farms. Reporting has only just started, but the SAGERS will be a mechanism to collect some data for the agriculture sector.

Table 1.5: Principal data sources for the AFOLU sector inventory.

Category	Principal data source	Principal data collection mechanism
3A Livestock	DALRRD	DFFE is in the process of developing an MOU with DALRRD
	FAO	Statistics available on FAO Stats website (unofficial)
	South African Poultry Association (SAPA)	Information obtained through direct contact. No formal mechanism is in place.
	ARC, Tshwane University of Technology (TUT) and University of Pretoria	Data is available through scientific publications.
3B Land	DALRRD	Statistical data is released annually and is freely available. DFFE is in the process of developing an MOU with DALRRD
	Forestry South Africa	Data obtained through direct request, no formal mechanism in place. Data is also freely available on their website.
	DFFE	Data and land maps are developed (usually by GTI) or funded through DFFE and are freely available on the EGIS website.
	ARC	DFFE is in the process of developing an MOU with ARC.
	SAEON/DFFE	Spatial data from the National Terrestrial Carbon Sinks Assessment is stored on the SAEON data portal and is freely accessible. This data has been updated once but is only done if funding is available.
3C Aggregated & non-CO_2 emissions from land	South African Mineral Industry Report compiled by DMRE	No formal mechanism is in place, but data is currently publicly available.
	MODIS burnt area data	No formal process for obtaining this data.
	FAO	Statistics available on FAO Stats website
	ARC	DFFE is in the process of developing an MOU with DALRRD.
	Statistics SA	Agricultural census data are available from Statistics SA. No formal mechanism is in place.
	Fertilizer Association of SA	Annual nitrogen application data for crops

	SARS	Provides annual import data for urea
	ISRIC	SOC ref data
3D Harvested wood products	FSA	Forestry SA (2018). This data is updated annually.

Waste data

Waste data is collected from various data reports, statistics and global data sets. As with the AFOLU sector there is no formal data collection process in this sector. The main data providers for the Waste sector are Statistics SA, DFFE, Department of Water and Sanitation (DWS) and the United Nations (UN). In time it may be possible to collect some of the Waste data through the SAGERS system.

Table 1.6: Principal data sources for the Waste sector inventory.

Sub-category	Activity data	Data source
Solid waste disposal	Population data	Statistics SA (2015);
		UN (2012)
	Waste composition	IPCC 2006, and 2019 IPCC Refinement
	Waste generation rate for each component	State of Waste Report (2018)
	GDP	World bank
Biological treatment of solid waste	Mass of organic waste by biological treatment type	SAWIC, DFFE (wastewater treatment and biological treatment of solid waste study)
Open burning of waste	Population data	Statistics SA (2015);
		UN (2012)
	Fraction of population burning waste	Assumption based on population without access to waste collection services.
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, DWS
	Per capita nitrogen generation rate	IPCC 2006

1.4.2.2 Data preparation and emission calculation

The process of data preparation and emissions calculation comprises the following steps:

a) Data entry,
b) Data preparation (model formation, disaggregation, aggregation)
c) Calculation of emissions,
d) Preparation of report sections (texts), and
e) Approval by the relevant experts.

Report texts are prepared along with the time series for activity data, emission factors, uncertainties, and emissions. As a result, the term "data" is understood in a broad sense. In addition to number data, time series, etc., it also includes contextual information such as the sources for time series, and descriptions of calculation methods, and it also refers to preparation of report sections for the NIR and documentation of recalculations.

After all checks have been carried out, and the relevant parties have been consulted where necessary, the emissions are calculated in excel by each sector lead based on the following principle:

activity data * emission factor = emission

As much of the data as possible is included in the calculation files, but where larger data sets are referred to these are stored in the NGHGIS.

Following complete preparation of data, report sections and QC/QA checklists by the responsible experts, and transmission of those materials to the Single National Entity, the materials are reviewed by category-specific, specialised contact persons at the Single National Entity, on the basis of a QC checklist. The results of this review are then provided to the relevant responsible experts, to enable these experts to revise their contributions (if necessary, following suitable consultation) accordingly.

1.4.2.3 Report preparation

Report preparation includes the following steps:

a) Aggregation of emissions data for the national trend tables and reporting formats, preparation of data tables for the NIR,
b) Compilation of submitted report texts to form a report draft (NIR), and editing of the complete NIR,
c) Internal review of the draft (national trend tables and NIR) by DFFE,
d) Public commenting process,
e) External review by 3rd party,
f) Finalisation of report,
g) Approval by DFFE Minister,
h) Submission to UNFCCC, and
i) Archiving.

1.4.2.4 Data storage and archiving

The NGHGIS for South Africa assists in managing and storing the inventory compilation related documents and processes. The NGHGIS, amongst other things, keeps 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) QC Tools
(g) QC Analysis Tags
(h) Methods and data sources
(i) 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
(j) Calculation and supporting files
(k) Key references
(l) Key categories; and
(m) 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 1.7. The NGHGIS is used to archive inventory data.

1.5 General description of methodologies

The guiding documents in the inventory's preparation are the 2006 Guidelines*.* 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.

1.5.1.1 Energy

Emissions for the *Energy* sector were estimated with a sectoral approach. A mix of T1, T2 and T3 methods area applied (details provided in Table 3.7 in chapter 3):

a) Category 1A1 – T1/T2/T3
b) Category 1A2 – T1/T2
c) Category 1A3 – T1/T2
d) Category 1A4 – T1/T2/T3
e) Category 1A5 – T1/T2
f) Category 1B1 – T2
g) Category 1B2 – T3
h) Category 1B3 – T1/T3

1.5.1.2 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 (details provided in Table 4. 3 in Chapter 4):

a) Category 2A – T1/T2/T3
b) Category 2B – T1/T2/T3
c) Category 2C – T1/T3
d) Category 2D – T1
e) Category 2F – T1/T2

1.5.1.3 AFOLU

Activity data in the AFOU 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 (details provided in Table 4. 3 in Chapter 5):

a) Category 3A – T1/T2

b) Category 3B – T1/T2

c) Category 3C – T1/T2

d) Category 3D – T2

1.5.1.4 Waste

Waste sector activity data are derived from different sources. Tier 1 method was used for all emissions estimates in the waste sector. Solid waste is determined with the IPCC first order decay model. Details are provided in Table 4. 34 in Chapter 6.

a) Category 4A – Tier 1
b) Category 4B – Tier 1
c) Category 4C – Tier 1
d) Category 4D – Tier 1

1.6 Brief description of key categories

1.6.1 Methodology

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 2020, or the trend of emissions. This includes both source and sink categories. The level assessment was conducted on the base year (2000) and the current year (2020), while the trend assessment utilised the base year 2000 and 2020.

1.6.2 Summary of key categories

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 FOLU. The key categories identified in 2020, along with their ranking, are summarised in Table 1.7. The full key category analysis (level and trend, including and excluding FOLU) is provided in Appendix A.

Table 1.7: **Key categories for South Africa for 2020 (including FOLU) and their ranking.**

Rank	IPCC Category code	IPCC Category	GHG#
1	1A1a	Electricity and Heat Production (solid)	CO_2
2	1A3b	Road Transport (liquid)	CO_2
3	3B1a	Forest land remaining forest land	CO_2
4	4A	Solid Waste Disposal	CH_4
5	1A5a	Stationary (solid)	CO_2
6	1B3	Other Emissions from Energy Production	CO_2
7	3A1a	Enteric fermentation - cattle	CH_4
8	1A1c	Manufacture of Solid Fuels and Other Energy Industries (liquid)	CO_2
9	1A2	Manufacturing Industries and Construction (solid)	CO_2
10	1A4c	Agriculture/Forestry/Fishing/Fish Farms (liquid)	CO_2
11	2C1	Iron and Steel Production	CO_2
12	2F1	Refrigeration and Air Conditioning	HFCs
13	1A2	Manufacturing Industries and Construction (liquid)	CO_2
14	1A1a	Electricity and Heat Production (liquid)	CO_2
15	2C2	Ferroalloys Production	CO_2
16	3C4	Direct N_2O emissions from managed soils	N_2O
17	3A1c	Enteric fermentation - sheep	CH_4
18	3B1b	Land converted to forest land	CO_2
19	1A3d	Water-Borne Navigation (liquid)	CO_2

20	1A4a	Commercial/Institutional (solid)	CO_2
21	1A2	Manufacturing Industries and Construction (gas)	CO_2
22	1A4b	Residential (solid)	CO_2
23	4D1	Domestic Wastewater Treatment and Discharge	CH_4
24	1A4b	Residential (liquid)	CO_2
25	1B1a	Coal mining and handling	CH_4
26	3B3b	Land converted to grassland	CO_2
27	1A1b	Petroleum Refining (gas)	CO_2
28	3B5a	Settlements remaining settlements	CO_2
29	3B2b	Land converted to cropland	CO_2
30	3D1	Harvested wood products	CO_2
31	3B4	Wetland	CH_4
32	1A3a	Civil Aviation (liquid)	CO_2
33	3C2	Liming	CO_2
34	2B	Chemical industry	C
35	3A1d	Enteric fermentation - goats	CH_4
36	1A5a	Stationary (liquid)	CO_2
37	3A2i	Manure management - poultry	N_2O
38	1A1b	Petroleum Refining (liquid)	CO_2
39	1A4a	Commercial/Institutional (liquid)	CO_2
40	1A4a	Commercial/Institutional (gas)	CO_2
41	3B2a	Cropland remaining cropland	CO_2
42	3A2a	Manure management - cattle	N_2O
43	3B6b	Land converted to other lands	CO_2
44	2D2	Paraffin Wax Use	CO_2
45	2D1	Lubricant Use	CO_2
46	1B3	Other Emissions from Energy Production	CH_4
47	2B	Chemical industry	C
48	2A2	Lime Production	CO_2
49	1A1a	Electricity and Heat Production (solid)	N_2O
50	2C2	Ferroalloys Production	CH_4
51	4D1	Domestic Wastewater Treatment and Discharge	N_2O
52	2A1	Cement Production	CO_2
53	3C3	Urea application	CO_2
54	1A3b	Road Transport (liquid)	N_2O
55	2C3	Aluminium Production	CO_2
56	2C3	Aluminium Production	PFCs
57	3B3a	Grassland remaining grassland	CO_2
58	1B2a	Oil	CO_2

#C=Confidential

1.6.3 Changes in key categories since the 2017 submission

In the level assessment of emissions (excl. FOLU) there are a few new key categories in this submission which are *Electricity and heat production (*liquid fuels; CO_2), *Coal mining and handling* (CH_4), *Water-borne-navigation* (liquid fuel; CO_2), *Manure management* emissions from cattle (N_2O), *Enteric fermentation* from goats (CH_4) and *Aluminium production* (CO_2). These categories are in the bottom half of the key category list. There were two categories that moved off the list and these are *Commercial/Institutional* (solid fuels; CO_2) and *Indirect N_2O from managed soils*. *Commercial/institutional* (solid fuels) contribution was 5.4% in the previous submission, so this is a significant change. There is a large drop in emissions in this sector in 2020 and this is likely due to the COVID-19 lockdown restrictions.

Considering the main differences in contribution of each category to the current submission and the 2017 submission, *Road transport* (liquid fuels, CO_2) decreased its contribution from 9.9% to 9.4% and *Electricity and heat production* (solid fuels, CO_2) increased its contribution from 41.8% to 42.9% (Figure 1.6). *Direct N_2O emissions from managed soils* declined from 3.3% to 1.1% but this is likely due to the updated emission factor which was much lower than in the previous inventory. The *Ferroalloys production* and *Iron and Steel production* decreased their contribution, and this could be attributed to COVID-19 lockdown restrictions. The top five key categories have shifted in that *Other emissions from Energy Production* moved up from 5th place in the 2017 inventory to 4th place. Additionally, *Commercial/Institutional* (solid fuels, CO_2) moved off the list and was replaced by *Enteric fermentation from cattle* taking 5th place in the 2020 inventory.

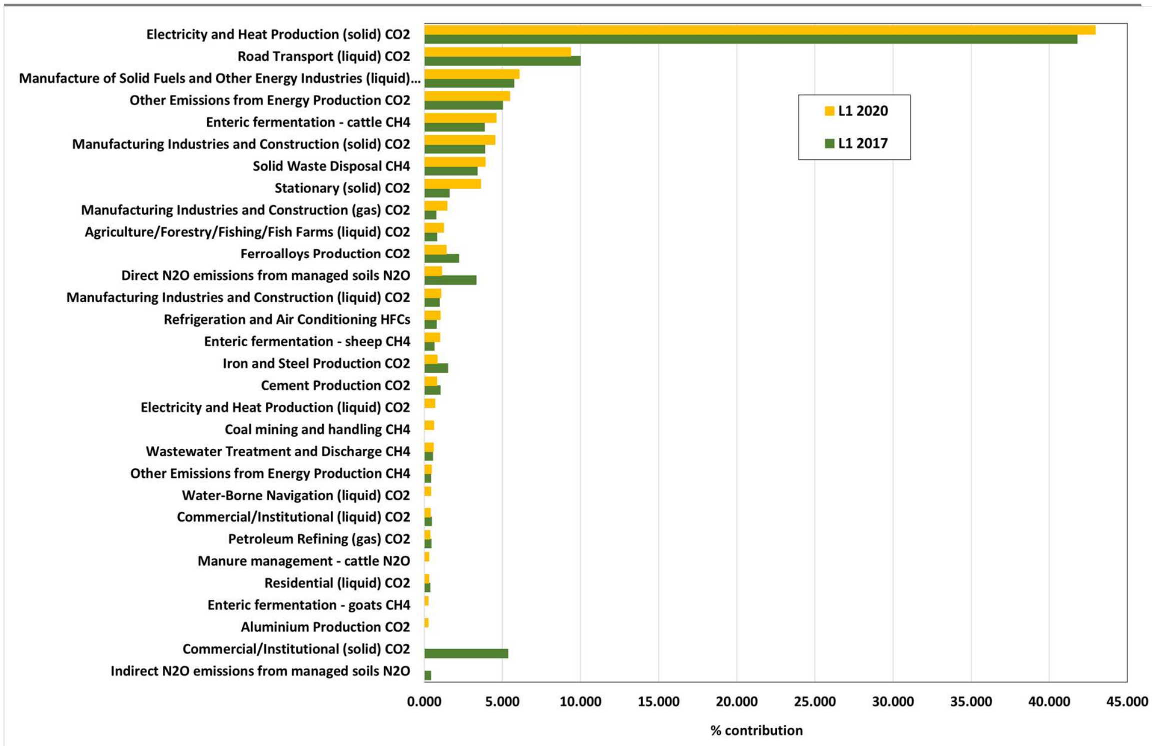

Figure 1.6: Difference in contribution to the level assessment (excl. FOLU) key category analysis between the current submission and the 2017 submission.

In the level assessment of emissions (incl. FOLU) there were several additional land key categories, namely *Land converted to forest land*(CO_2), *Forest land remaining forest land* (CO_2), *Land converted to grassland* (CO_2), *Land converted to other lands* (CO_2), *Land converted to cropland* (CO_2), *Settlements remaining settlements* (CO_2), Cropland *remaining cropland* (CO_2), *Wetland* (CH_4) and *Grassland remaining grassland* (CO_2) (Figure 1.7). The *Wetland* category CH_4 and *Cropland remaining cropland* (CO_2) emissions were added to the key categories list in this inventory. The *Forest land remaining forest land* and *Grassland remaining grassland* contributions declined but these changes are due to updates as opposed to be actual changes.

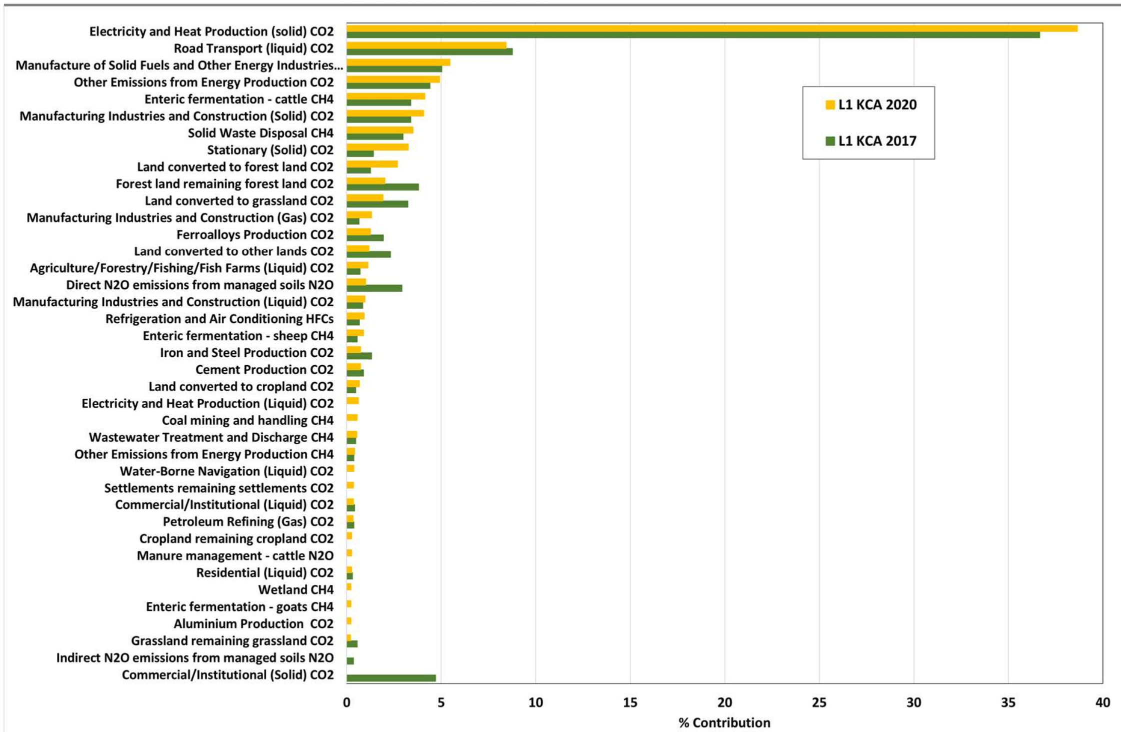

Figure 1.7: Comparison of level assessment key categories and their contribution to emissions (incl. FOLU) in the current and previous 2017 submission.

With the trend analysis on emissions (excl. FOLU) there were several additional key categories, namely, *Stationary* (liquid fuels; CO_2), *Water-borne navigation* (liquid fuels, CO_2), *Industrial wastewater treatment and discharge* (CH_4), *Domestic wastewater treatment and discharge* (CH_4), *Lubricant use* (CO_2), *Coal mining and handling* (CH_4), *Ferroalloy production* (CH_4) and *Paraffin wax use* (CO_2). There were also several categories moving off the list as can be seen in Figure 1.8. Even though *Commercial/Institutional* (solid fuels, CO_2) dropped off the level assessment key category list it increased its contribution from 11.2% to 16.1% in the trend assessment. This is likely because of the very large decrease in emissions shown in 2020. The contribution from *Electricity and heat production* (solid fuels, CO_2) increased from 2.9% to 13.6%. The contributions from *Other emissions from energy production*, and *Manufacture of solid fuels and other energy industries* dropped significantly and this could be due to reduction in consumption during the COVID-19 lockdown. Cattle *enteric fermentation* and *Direct N_2O emissions from managed soils* also showed significant declines, with the N_2O emissions being due to an updated emission factor and not necessarily because emissions declined.

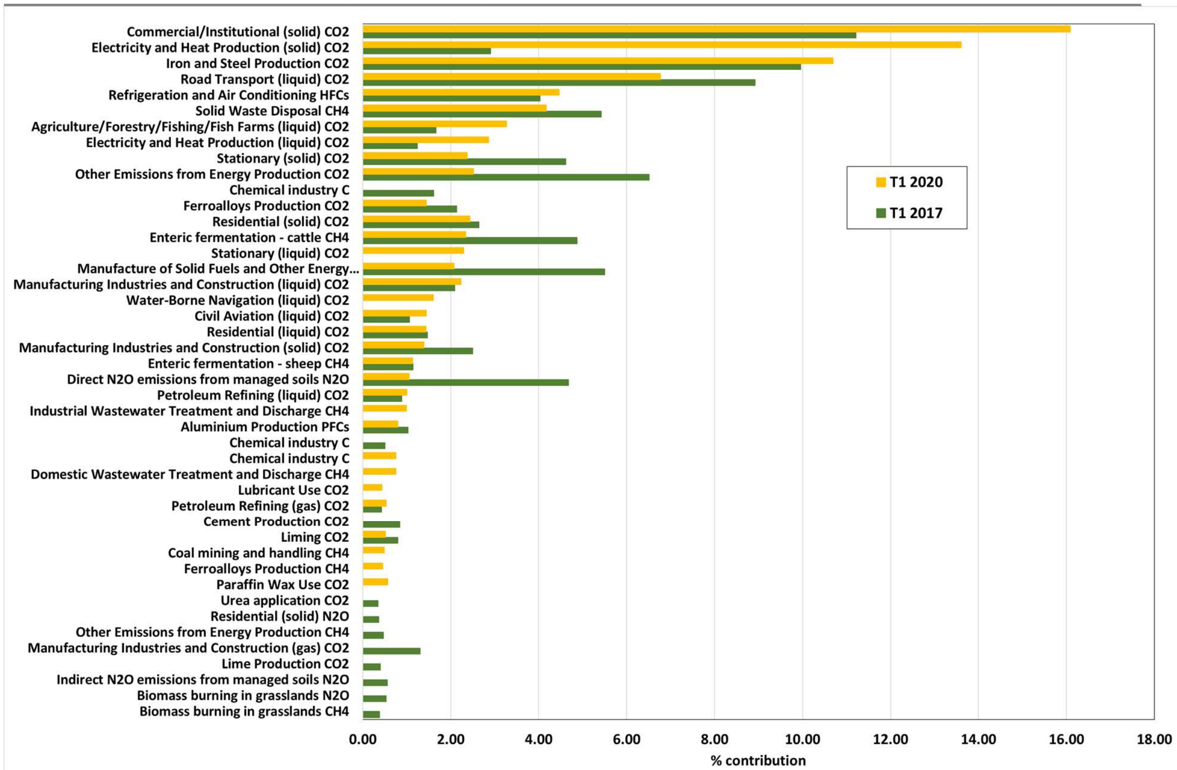

Figure 1.8: Difference in contribution to the trend assessment (excl. FOLU) key category analysis between the current submission and the 2017 submission.

Including FOLU in the trend analysis led to the inclusion of the land category *Wetlands* (CH_4) (Figure 1.9). The categories *Land converted to other lands* (CO_2), *Land converted to grasslands* (CO_2) and *Grassland remaining grassland* (CO_2) were no longer on the trend key category list.

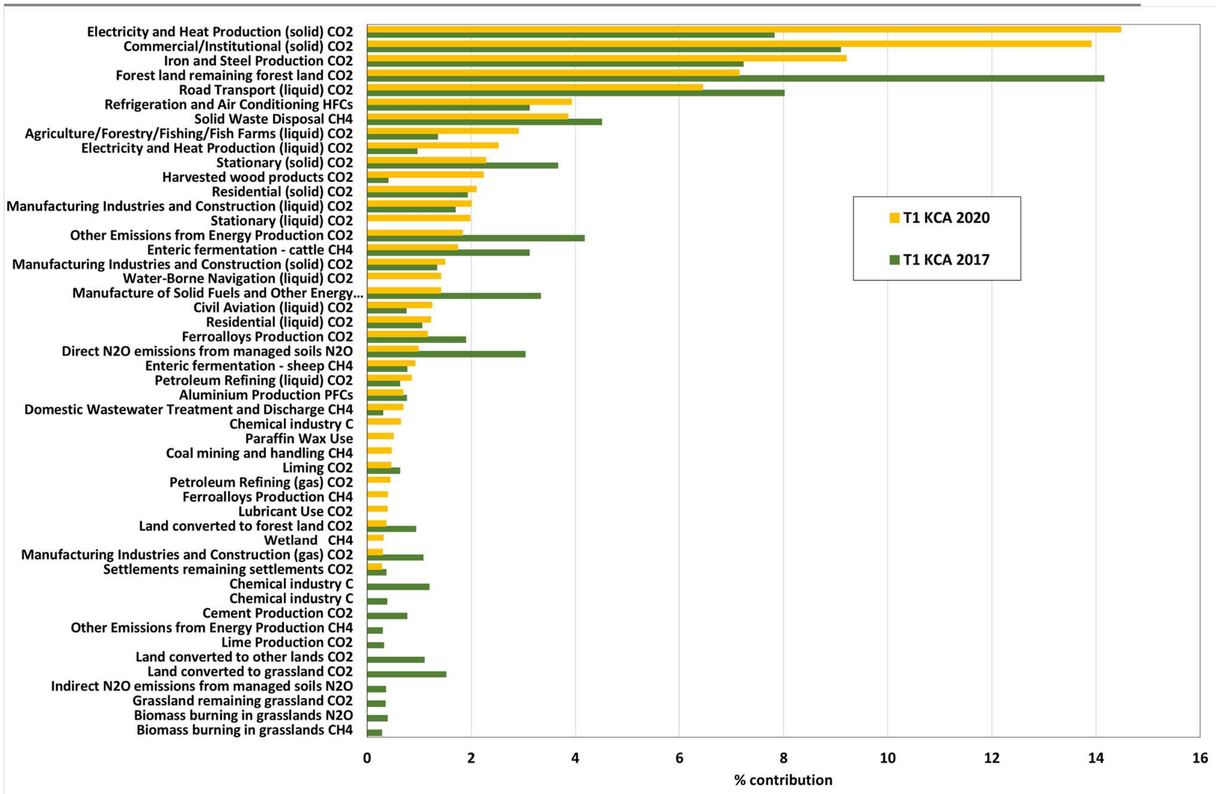

Figure 1.9: Comparison of trend assessment key categories and their contribution to emissions (incl. FOLU) in the current and previous 2017 submission.

1.7 Quality assurance, quality control and verification plans and procedures

1.7.1 Quality assurance and quality control procedures

1.7.1.1 QA/QC plan and procedures

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. In this inventory the relatively new team was provided with QA/QC training and each team member was assigned to a sector. Each quality controller went through the sector calculation files and provided comments. A programme, QA Analyst, assisted with the process of tracking the comments by keeping a log in the front of each file.

1.7.1.2 General QC procedures

The 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 2020 inventory are provided in Table 1.8.

Table 1.8: Quality control checks carried out on South Africa's 2020 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
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

ID	Type of check	Description	Level
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 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 have 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

ID	Type of check	Description	Level
QC051	Complete uncertainty check	Check that the uncertainty analysis is complete.	Draft NIR
QC052	Consistency in methodology	Check that there is consistency in the methodology across the time series	Calculation file
QC053	Data gaps	Is there sufficient documentation of data gaps?	Sector report
QC054	Steering committee review	Has the draft NIR been approved by the steering committee? Was there public consultation?	Draft NIR
QC055	Check calorific values	Have the correct net calorific values been used? Are they consistent between sectors? Are they documented?	Calculation file
QC056	Check carbon content	Have the correct carbon content values been used? Are they consistent between sectors? Are they documented?	Calculation file
QC057	Supplied emission check	If emissions are supplied by industry have they been calculated using international standards? Have the methods been adequately described?	Sector report
QC058	Livestock population checks	Have the livestock population data been checked against the FAO database?	Calculation file
QC059	Land area consistency	Do the land areas for the land classes add up to the total land area for South Africa?	Calculation file
QC060	Biomass data checks	Have the biomass factors been compared to IPCC default values or the EFDB?	Calculation file
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

1.7.1.3 Workshops

Several workshops and training sessions between the team and the wider group at the DFFE were held during the preparation of this inventory. An initial planning meeting started the process off, followed by several team meetings to share data and queries. This was something new in this round and proved to be very useful. Everyone had a chance to understand other sectors and it also improved the cross linkages. This should continue in future inventories.

1.7.1.4 Review process

Quality Assurance, as defined in the *IPCC Good Practice Guidanc*e, comprises a "planned system of review procedures conducted by personnel not directly involved in the inventory compilation and development process." The quality assurance process includes both expert review and a general public review (Figure 1.10). 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 NIR or reflected in the inventory estimates.

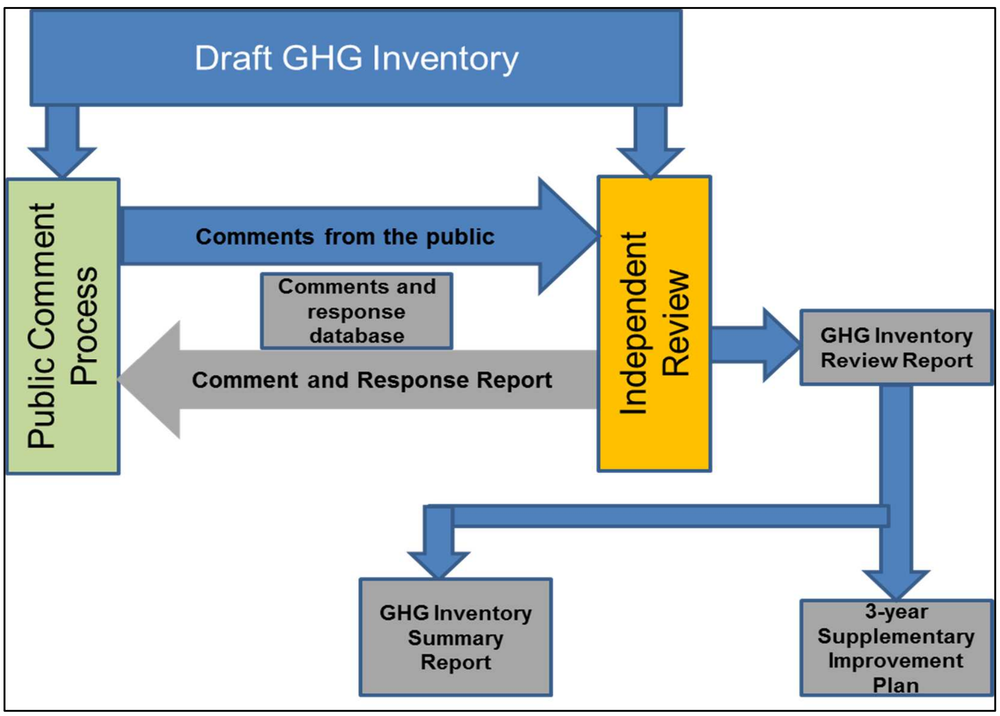

Figure 1.10: The independent review process for the 2000 – 2020 inventory.

1.7.2 Verification activities

Emission and activity data are verified by comparing them with other available data compiled independently of the GHG inventory system where available. These include national statistics, 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.

1.8 General uncertainty evaluation

1.8.1 Procedures for determining uncertainty

Uncertainty estimates are an essential element of a complete and transparent emissions inventory. Uncertainty information is not intended to challenge the validity of inventory estimates, but to help prioritize efforts to improve the accuracy of future inventories and guide future decisions on methodological choice. 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 Guidelines 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. South Africa still lacks data in terms of country specific uncertainty for all sectors. As data becomes available it is incorporated but there is a general need to build capacity and develop projects to assess the uncertainty in each sector.

The identified uncertainties are associated with activity data, emission factor and emissions. The individual uncertainties are combined to provide uncertainty estimates. Hence tier 1 methodology was applied for the 2020 inventory uncertainty.

1.8.2 Results of uncertainty assessment

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 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 2020. A trend uncertainty between the base year and 2020, 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 between 8.13% and 8.77%, with a trend uncertainty of 6.71%. Excluding FOLU reduces the overall uncertainty to be between 6.64% and 7.32%, with the trend uncertainty dropping to 6.21%. The full uncertainty assessment is provided in Appendix B.

1.9 General assessment of completeness

The South African GHG emission inventory for the period 2000 – 2020 is not complete, mainly due to the lack of sufficient data. Table 1.9 identifies the sources in the 2006 Guidelines which were not estimated or included elsewhere in this inventory and the reason for their omission is discussed further in the appropriate chapters. The table also indicates which activities do not occur in South Africa.

Table 1.9: Activities in the 2020 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	CO_2 emissions from Oil are included, but CH_4 emissions need to be included along with natural gas emissions. To 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 future inventories.
	1B1ai3	CH_4 emissions from *abandoned mines*.	New research work on sources of emissions from this category will be evaluated and emissions will be included in future inventories.
	1B3	N_2O from Other Emissions from Energy Production	Insufficient data to include.
	1C1	CO_2 transport	Insufficient data to include.
	1C2	Injection and storage	Insufficient data to include.
	2A	CH_4 emissions from cement production, lime production, glass production and OPUC	Insufficient data to include.

NE, IE or NO	IPCC Category	Activity	Comments
	2B1	N2O from Ammonia production.	Insufficient data to include.
	2B2	CO_2 & CH_4 from nitric acid production	Insufficient data to include.
	2B5	N_2O from carbide production	Insufficient data to include.
	2B7	CH_4 & N_2O from Soda Ash production	Insufficient data to include.
	2B8	N_2O from petrochemical & carbon black production	Insufficient data to include.
	2C1	N_2O emissions from iron and steel production	Insufficient data to include.
	2C2	N_2O emissions from ferroalloy production	Insufficient data to include.
	2C3	CH_4 from Aluminium production	Insufficient data to include.
	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.
	2F1	CO_2 & PFCs from refrigeration & air condiitioning	Insufficient data to include.
	2F2	CO_2 & PFCs from foam blowing agents	Insufficient data to include.
	2F3	CO_2 & PFCs from Fire protection	Insufficient data to include.
	2F4	PFCs from aerosols	Insufficient data to include.
	2F5	PFCs and HFCs from solvents	Insufficient data to include.
	2G1	PFCs from electrical equipment	Insufficient data to include.
	2G1	SF_6 emissions in the IPPU sector	Insufficient data. It is planned to include these in the next inventory.
	2G2	PFCs from other product uses	Insufficient data to include.
	2G3	N_2O from product uses	Insufficient data to include.
	2H1	CO_2 & CH_4 from Pulp & Paper industry	Insufficient data to include.
	2H2	CO_2 & CH_4 from Food & beverage industry	Insufficient data to include.
	3B	CO_2 from organic soils	This will be included in future inventories.
	3C4	N_2O from organic soils	Insufficient data to include.
	4C1	CO_2, CH_4 and N_2O from waste incineration	Insufficient data to include.

NE, IE or NO	IPCC Category	Activity	Comments
	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 in future inventories.
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.
	1A5b	CO_2, CH_4 and N_2O emissions from other mobile machinery	Included under Road transportation.
	1B1c	Solid fuel transformation	Included under sector specific categories
	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).
NO	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*	
	2B8a	Methanol production	
	2B8b	Ethylene production	
	2B8c	Ethylene dichloride & vinyl chloride monomer	
	2B8d	Ethylene oxide	
	2B8e	Acrylonitrile	
	2B9	HFCs, PFCs and SF_6 from *Fluorochemical production*	
	2C4	CO_2, HFCs, PFCs and SF_6 from *Magnesium production*	
	3A1	CH_4 emissions from buffalo and camels.	
	3A2	CH_4 and N_2O emissions from buffalo and camels.	
	3C1f	All emissions from *Other lands*	
	3C7	Rice cultivation	

1.10 Improvements introduced

1.10.1 Energy

Updated consumption data in the *Road transport, Manufacturing industries and construction, Other sectors and Non-specified emissions from energy production* categories was included, particularly for coal, diesel, natural gas and gas works gas. This was because the energy balance data from DMRE updated the fuel allocation in these sectors. In addition, new data became available from a fuel consumption study done by DFFE under the GHG improvement programme. This was completed for the transport sector which provided consumption data based on VKT. In this inventory the petrol, diesel and natural gas consumption data for *Road transport* was updated. Lastly the DMRE had updated coal statistics in its SAMI report series.

1.10.2 IPPU

Through the introduction of the SAGERS, the GHG reporting tool, there have been various additions to the inventory as well as recalculations and these are:

- *Mineral Industry:*
    - The addition of *Other Process Uses of Carbonates* category from 2018.
    - Activity data for 2018 and 2019 were extrapolated for quicklime due to lack of activity data.
    - The addition of dolomitic lime from 2019.
- *Chemical Industry:*
    - Addition of silicon *carbide production* in 2019 has led to increased carbide production emissions through the estimation of CH_4 emissions.
    - *Titanium dioxide production* saw an error corrected from 2014 onwards resulting in higher but accurate emissions
    - Addition of *Soda ash production* category from 2019.
    - Addition of *Hydrogen production* from 2018.
    - Addition of *Other Chemical Processes* from 2020.
- *Metal Industry:*
    - The addition of Treatment of secondary raw material under *Lead production,* which has led to a change throughout the time series where the emission factor was changed from 0.52 to 0.2 from 2000 – 2020.

1.10.3 AFOLU

1.10.3.1 Livestock

In the livestock category Tier 2 data for enteric fermentation and manure management emission factor calculations for cattle, goats and sheep were incorporated based on a recent study by ARC (2020). This also led to changes in the livestock categorisation and an update of manure management data.

1.10.3.2 Land

In the *Land* category several updates were made:

- Incorporation of the 1990-2018 land change matrix;
- Updated biomass, DOM and litter data from the NTCSA (DEFF, 2020) and scientific publications were incorporated;
- DOM included deadwood;
- Biomass accumulation rates were updated and forests were divided into primary and secondary forests to accommodate different growth rates;
- Mortality was included in forest biomass;
- Charcoal consumption was included in fuelwood collection data;
- New BCEF factors for plantations were included;
- Country specific SOC reference values and stock change factors were utilised; and
- CO_2 for mineral wetland soils was included, along with CH_4 and N_2O emissions.

1.10.3.3 Aggregated and non-CO_2 sources on land

This category was improved firstly by the changes in the livestock category as these have an input to this category. In addition, MODIS burnt area data was updated to Collection 6 data.

1.10.3.4 Other (HWP)

Country specific data was included in this category.

1.10.4 Waste

Various improvements were incorporated into the Waste sector:

- Waste generation rate per person was adjusted from 578 kg/cap/yr in previous submissions to 398 kg/cap/yr in the current submission and this is consistent with the waste generation rates per capita provided in the 2019 refinement to the 2006 IPCC guidelines.

- Amount sent to SWDS adjusted to 76% for MSW and 85% for Industrial waste to reflect changes in penetration of recycling and the evolution of other forms of waste management and/or treatment.

1.11 Improvement plan

Table 1.10 shows planned improvements and the timelines for these improvements.

Table 1.10: List of planned improvements for South Africa's GHG inventory.

Sector	Improvement	Priority	Reason	Status	Completion timeframe	Barriers and constraints
Completed tasks						
Cross-cutting	Incorporate data from SAGERS into inventory (data reported due to NGERs)	High	Accuracy	Completed	5th BUR (2020 inventory)	Data will continue to be incorporated into the future.
	Set up MOUs with key data providers, e.g. DMRE, SAPIA	High	Transparency	Resolved	NA	This has proved to be difficult and is not working, therefore regulatory processes (NGERs) and the GHGIP are being used for data gathering instead.
	Improve understanding of difference between reference and sectoral approach	Medium	Key category; Transparency	Resolved	5th BUR (2020 inventory)	Updates were made to the Energy balance data and the actual methodology and calculation file for the reference approach was reassessed. Data was incorporated into the energy sector calculation file.
Energy	Develop EFs, carbon content of fuels and NCVs of liquid fuels	High	Key category; Accuracy	Completed	1st BTR (Next inventory)	Study was completed in 2022 for most used liquid fuels. Developed parameters to be used in the next inventory.

Sector	Improvement	Priority	Reason	Status	Completion timeframe	Barriers and constraints
IPPU	Calculate CH_4 emissions from Iron and steel production	High	Key category; Completeness	Completed	5th BUR (2020 inventory)	Completed.
	Estimate emissions from OPUC category using currently available data	Medium	Completeness	Completed	5th BUR (2020 inventory)	Completed for ceramics, soda ash usage and dolomite usage.
AFOLU	Update HWP with country specific data	Low	Accuracy	Completed	5th BUR (2020 inventory)	Completed.
	Incorporate all background data and equations for the Tier 2 calculations of enteric fermentation	High	Key category; Accuracy; Transparency	Completed	5th BUR (2020 inventory)	Completed.
Waste	Include information on population distribution in rural and urban areas as a function of income	Medium	Key category; Accuracy	Completed	5th BUR (2020 inventory)	Study was completed in March 2020 and data is included in the 2020 inventory.
Tasks in progress						
	Improve transparency in reporting by including	High	Transparency	In progress	5th BUR	Transparency in the Energy and IPPU sectors were enhanced, however this is

Sector	Improvement	Priority	Reason	Status	Completion timeframe	Barriers and constraints
Cross-cutting	more detailed description of methodologies and activity data, particularly in energy and IPPU sectors.				(2020 inventory)	an ongoing activity and further updates will be made in the next inventory.
	Improve the improvement plan by incorporating all review activities not addressed in current inventory.	High	Transparency	In progress	5th BUR (2020 inventory)	Partly resolved. Challenges around inclusion of further improvements into the improvement plan are limited resources and process management. The DFFE inventory team has increased in size, but it is still taking time to completely address all the issues. The review outputs are included in this report as a reminder of what still needs to be completed.
	Incorporate NOx, CO, NMVOC, and SOx emissions	High	Completeness	In Progress	5th BUR (2020 inventory)	Partly resolved. NOx, CO and NMVOCs emissions from Biomass Burning were estimated.
Energy	CO_2 and CH_4 fugitive emissions from oil and natural gas operations	Medium	Completeness	In progress	5th BUR (2020 inventory)	Partly resolved. CO_2 emissions from Oil are included. Further gases from this source category will be added in the next

Sector	Improvement	Priority	Reason	Status	Completion timeframe	Barriers and constraints
						inventory as information will be obtained through NGERs.
	Improve explanation of large changes in trends	High	Transparency	In progress	5th BUR (2020 inventory)	Partly resolved. Additional explanations have been provided, but there are still areas where this can be improved further. Ongoing process.
AFOLU	Incorporate updated National Terrestrial Carbon Sinks Assessment (NTCSA) data to improve estimates, particularly for soils	High	Key category; Accuracy	In progress	5th BUR (2020 inventory)	Partly resolved. The NTCSA above-ground woody, above round herbaceous and DOM were included or used as validation data, but not as a Tier 3 approach due to there only being 1 year of data for woody biomass. A QGIS plugin was developed with the last update, and this is currently being explored to determine whether the sinks data can be updated for the additional years to allow for the use of the stock difference approach. A study needs to be undertaken to fully incorporate the carbon sinks data and to conduct an uncertainty assessment on the data. This could be a project for the GHGIP.

Sector	Improvement	Priority	Reason	Status	Completion timeframe	Barriers and constraints
	Include deadwood in the DOM pool for all land categories	Low	Completeness	In progress	1st BTR (Next inventory)	Partly resolved. Deadwood was included for forest land categories.
	Include CO_2 estimates for wetlands	Low	Completeness	In progress	Future inventories	Partly resolved. Wetlands were assumed to be mineral inland wetlands and CO_2 estimates were incorporated on this basis. The data from the Blue Carbon study should however be used to update this in future inventories and include other wetlands and mangroves.
	Include 2018 and 2020 SANLC maps	High	Key category; Completeness; Accuracy	In progress	1st BTR (Next inventory)	Partly resolved. The 2018 and 2020 SANLC maps were developed using Sentinel 2 data as opposed to the Landsat data that was used for 1990 and 2014. This posed some challenges as there was some reclassification of the land types which led to large area changes. The 2018 map was degraded to compare with the 1990 and 2014 maps and an assessment of the natural land change classes was completed. In this inventory the 1990-2018 matrix was applied with some assumptions based on the land change data assessment. At this stage

Sector	Improvement	Priority	Reason	Status	Completion timeframe	Barriers and constraints
						the 2020 data has not been included as it needs to be assessed in terms of the reclassifications, particularly for the natural land classes, but it will be included in the next inventory. DFFE is currently trying to obtain annual maps of the 8 natural land classes to be able to assist in separating out actual change from natural seasonal change. This is a high priority.
Waste	Data collection on quantities of waste disposed of into managed and unmanaged landfills		Key category; Accuracy	In progress	1st BTR (Next inventory)	Project is completed some of the results will be incorporated in the next inventory.
Tasks outstanding						
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.

Sector	Improvement	Priority	Reason	Status	Completion timeframe	Barriers and constraints
	Extend time-series back to 1990 for energy, IPPU and waste sectors.	Medium	Completeness	Proposed	Future inventories	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 to 1990 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	Future inventories	Not resolved. Various methods were compared but give varying results. Alternative data sources have not yet been found, but it may be possible to collect further data through the SAGERS system in future.
	Improve QA/QC process by addressing all issues in external review	High	Transparency	In progress	1st BTR (Next 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. There are still many issues not resolved but the inventory team is

Sector	Improvement	Priority	Reason	Status	Completion timeframe	Barriers and constraints
						working through them. It is an ongoing process.
Energy	CO_2, CH_4 and N_2O from spontaneous combustion of coal seams.	Low	Completeness	Planned	1st BTR (Next inventory)	New research work on sources of emissions from this category are evaluated and used to report emissions in future inventories.
	CH_4 emissions from abandoned mines	Low	Completeness	Proposed	Future inventories	New research work on sources of emissions from this category are evaluated and used to report emissions in future inventories.
	Fugitive emissions from coke production to be reported separately from 2C process emissions	Low	Transparency	Planned	Future inventories	Progress on this has been slow but reporting through the NGER will allow this activity to be incorporated in the next inventory.
	Incorporate emissions from biogas	Low	Completeness	Proposed	Future inventories	This would require a study and so should be recommended as a project under the GHGIP.
	CO_2 transport and storage	Low	Completeness	Proposed	Future inventories	Proposed but nothing planned.
	CO_2, CH_4 and N_2O emissions from combined	Medium	Completeness	Proposed	Future inventories	Proposed but nothing planned.

Sector	Improvement	Priority	Reason	Status	Completion timeframe	Barriers and constraints
	heat and power (CHP) combustion systems					
IPPU	Development of country specific EF for ferroalloy industry	Medium	Key category; Accuracy	Proposed	Future inventories	Resources and funding are required to complete this study so it will be incorporated into the GHGIP.
	Include emissions from electronics industry	Medium	Completeness	Planned	Future inventories	A study needs to be undertaken to understand emissions from this source so it should be highlighted as a project for the GHGIP.
	Incorporate emissions SF_6 emissions	Medium	Completeness	In progress	1st BTR (Next inventory)	Lack of data is still a challenge.
	Investigate historical data for the imports and exports of clinker	Medium	Completeness	Proposed	Future inventories	TBC
	Undertake a completeness assessment to determine if non-marketed lime is reported	Medium	Completeness	Proposed	Future inventories	TBC

Sector	Improvement	Priority	Reason	Status	Completion timeframe	Barriers and constraints
	Disaggregate the cullet ratio by facility.	Medium	Completeness	Proposed	Future inventories	TBC
	Investigate the availability of the historical data (2B6)	Medium	Completeness	Proposed	Future inventories	TBC
	Investigate the air quality database for those data providers that trigger reporting under Lead Battery processing	Medium	Completeness	Proposed	Future inventories	TBC
	Investigate if secondary zinc production occurs in South Africa Investigate the air quality database regarding pyrometallurgical process involving the use of an imperial smelting furnace is used for combined zinc and lead production.	Medium	Completeness	Proposed	Future inventories	TBC
	South Africa to undertake a desktop study regarding two-stroke engines and	Medium	Completeness	Proposed	Future inventories	TBC

Sector	Improvement	Priority	Reason	Status	Completion timeframe	Barriers and constraints
	the use of blended lubricant.					
AFOLU	Improve manure management data, including biogas digesters as a management system	Medium	Accuracy	Proposed	Future inventories	Proposed project as there is a high variability in this dataset.
	Incorporate organic soils study to include emissions from organic soils	Medium	Completeness	Planned	Future inventories	Not resolved. Due to the other more pressing issues relating to land this was not a priority and will be incorporated once the land mapping system is running.
	Complete an assessment of crop types and areas and investigate discrepancies between crop statistics and NLC data	Medium	Consistency; Comparability	Planned	Future inventories	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.
	Improve HWP model by incorporating further country specific data and by comparing the	Medium	Key category; Accuracy	Proposed	Future inventories	Proposed project that could be considered under the GHGIP.

Sector	Improvement	Priority	Reason	Status	Completion timeframe	Barriers and constraints
	production method to the atmospheric model.					
	Complete a full uncertainty analysis for the Land sector, including area bias corrections	High	Key category; Accuracy	Proposed	Future inventories	Proposed to conduct a study to complete an uncertainty analysis for the Land sector, include all spatial data. This could be a project for the NGHGIP.
Waste	Improve MCF and rate constants		Key category; Accuracy	Proposed	To be considered as a long-term project.	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	Future inventories	
	Include HWP in solid waste	Medium	Key category; Completeness	Proposed	To be considered as a long-term.	Insufficient data.
	Obtain data on waste streams and the bucket system		Accuracy	In progress	Future inventories	
	CO_2, CH_4 and N_2O from waste incineration	High	Completeness	Proposed	Future inventories	

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Chapter 2: Trends in GHG emissions

2.1 Description and interpretation of trends for aggregated GHG 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 2020 are provided in Appendix C.

2.1.1 National trends

2.1.1.1 Overall emissions (excluding FOLU)

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

2000 - 2020

South Africa's GHG emissions excl. FOLU were 464 980Gg CO_2e in 2000 and these increased by 0.8% by 2020 (Table 2.1). Emissions (excl. FOLU) in 2020 were estimated at 468 812 Gg CO_2e. The *Energy* sector was the main contributor to the increasing emissions.

Emissions excl. FOLU increased slowly between 2000 and 2009 reaching a peak of 558 547 Gg CO_2e. There was a decline in emissions in 2010 with a slight increase to 2012. Emissions were then estimated to decrease to 2020 (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 increased. The annual growth rate was 2.1% between 2000 and 2009, however between 2010 and 2020 there is an average annual decline of 1.5% excl. FOLU. This shows that the emissions are stabilising and even moving towards a declining trend.

Table 2.1: Changes in South Africa's emissions excluding and including FOLU between 2000, 2017 and 2020.

	Emissions ($Gg CO_2e$)			Change between 2000 and 2020		Change between 2017 and 2020	
	2000	2017	2020	$Gg CO_2e$	%	$Gg CO_2e$	%
Emissions (excl. FOLU)	464 980.2	498 349.8	468 811.7	3 831.5	0.8	29 538.1	-5.9
Emissions (incl. FOLU)	445 884.9	479 766.8	442 125.1	-3 759.8	-0.8	37 641.8	-7.8

2017 - 2020

Emissions (excl. FOLU) decreased by 5.9% between 2017 and 2020 (Table 2.1), while emissions (incl. FOLU) decreased by 7.8%. The decrease in the emissions excluding FOLU were mainly due to a decrease in emissions in the *Energy* and *IPPU* sectors, while the FOLU sector also contributed to the decline in the emissions when FOLU was included.

2020

The *Energy* sector was the largest contributor to South Africa's gross emissions (excl. FOLU) in 2020, comprising 81% of total emissions. This was followed by the *AFOLU* sector (excl. FOLU) (8.7%), *IPPU* sector (5.4%) and the *Waste* sector (4.9%).

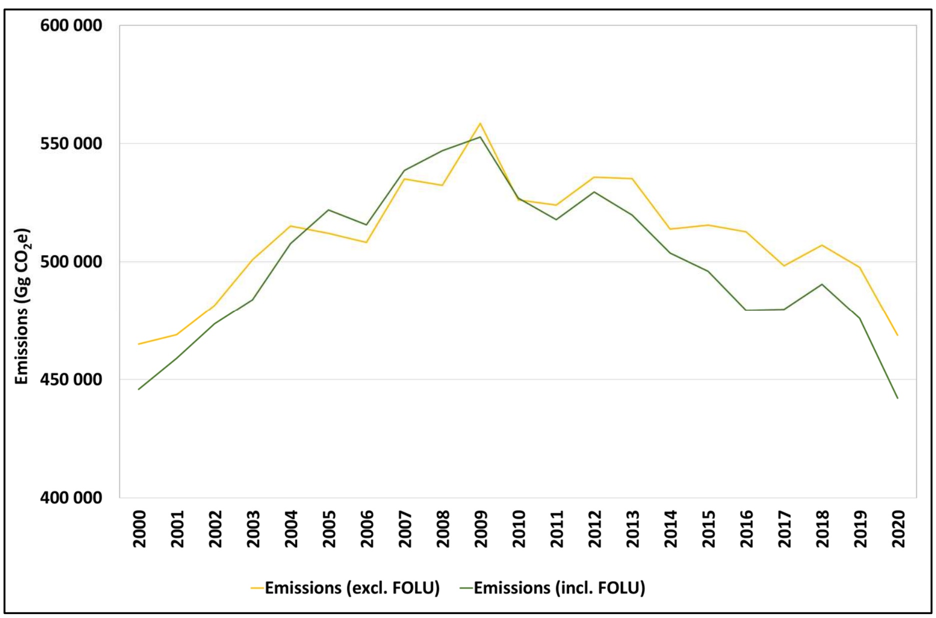


Figure 2.1: National GHG emissions (excluding and including FOLU) for South Africa, 2000 – 2020.

Table 2.2: Trends and annual change in emissions (excluding and including FOLU), 2000 – 2020.

	Emissions (excl. FOLU)		Emissions (incl. FOLU)	
	Gg CO_2e	Annual change (%)	Gg CO_2e	Annual change (%)
2000	464 980.2		445 884.9	
2001	469 020.3	0.87	458 927.4	2.93
2002	481 452.8	2.65	473 627.2	3.20
2003	500 838.7	4.03	483 934.5	2.18
2004	515 101.4	2.85	507 629.3	4.90
2005	512 016.4	-0.60	521 916.8	2.81
2006	508 202.2	-0.74	515 672.0	-1.20
2007	535 000.8	5.27	538 597.3	4.45
2008	532397.2	-0.49	546 991.0	1.56
2009	558 546.8	4.91	552 757.5	1.05
2010	526 195.7	-5.79	526 987.2	-4.66
2011	524 061.3	-0.41	517 895.1	-1.73
2012	535 793.2	2.24	529 487.2	2.24
2013	535 144.2	-0.12	519 763.6	-1.84
2014	513 877.2	-3.97	503 710.4	-3.09
2015	515 464.1	0.31	495 969.7	-1.54
2016	512 663.5	-0.54	479 366.4	-3.35
2017	498 349.3	-2.79	479 766.8	0.08
2018	507 047	1.75	490 451.2	2.23
2019	497 653.4	-1.85	475 998.2	-2.95
2020	468 811.7	-5.80	442 125.1	-7.12

2.1.1.2 Net emissions (including FOLU)

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

2000 – 2020

South Africa's GHG emissions (incl. FOLU) were 445 885 Gg CO_2e in 2000 and these decreased by 0.8% by 2020 (Table 2.1). Emissions (incl. FOLU) in 2020 were estimated at 442 125 Gg CO_2e. The emissions incl. FOLU followed a similar trend to the emissions excl. FOLU. Emissions, therefore, increased slowly between 2000 and 2009 after which there was a decline to 2011 with a slight increase in 2012, after which emissions declined to 2020 (Figure 2.1). Between 2000 and 2009 the average annual growth rate was 2.4%, however between 2010 and 2020 there was an average annual decline of 2.0%.

2017 – 2020

Emissions (incl. FOLU) decreased by 7.8% since the last inventory submission, and this was due to a decline in *Energy, IPPU* and *AFOLU* emissions during this time (Table 2.1).

2.1.2 Indicator trends

2.1.2.1 Total emission indicators

South Africa's carbon and energy intensity trends were determined from the GHG emissions, GDP data (Statistics SA, 2018, 2020 & 2022), total primary energy supply data (DMRE Energy balance data) and population data (Statistics SA, 2018).

South Africa's per capita carbon[1] intensity was 10.22 t CO_2e in 2000 and this increased to a maximum of 10.96 t CO_2e in 2009, after which it declined steadily to 7.42 t CO_2e per capita by 2020 (Figure 2.2). The carbon intensity of the economy (i.e. emissions per million Rand of GDP) has declined by 40.1% 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. There was a sharp decline between 2009 and 2010 due to a significant increase in the GDP in 2010, along with a decline in emissions.

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

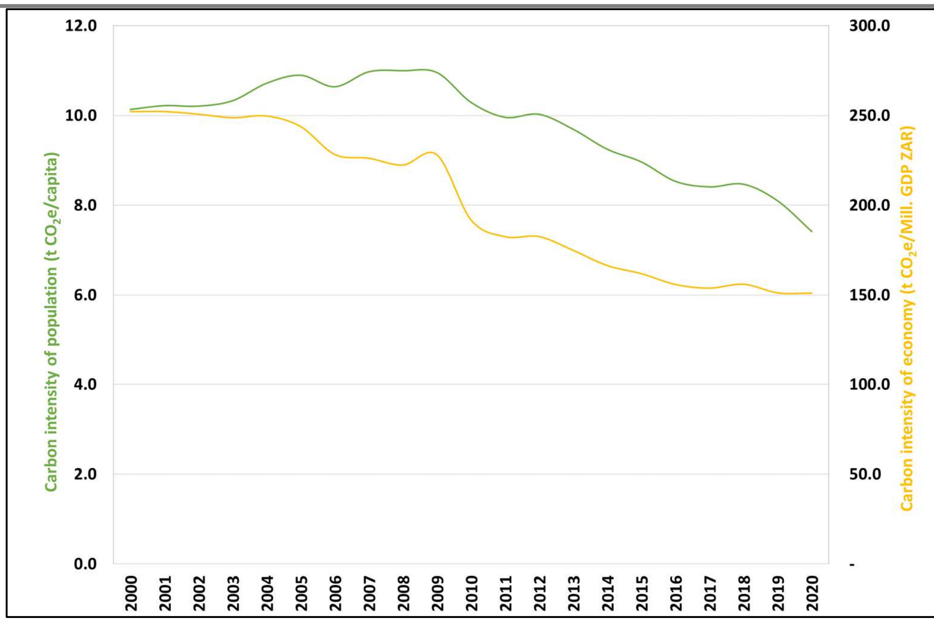


Figure 2.2: Trends in overall carbon intensity of the population and of the economy of South Africa between 2000 and 2020.

2.1.2.2 Energy emission indicators

The energy carbon intensity of the population (i.e. energy sector emissions per capita) increased (8.3%) between 2000 and 2009then showed a decline (30.3%) between 2009 and 2020 (Figure 2.3). Energy emissions per capita accounted for 82.6% of the total emissions (incl. FOLU) per capita in 2000 and this increased to 85.8% by 2020. The energy carbon intensity per capita trend is similar to that of the total carbon intensity of the population. This shows the large contribution to emissions from the energy sector.

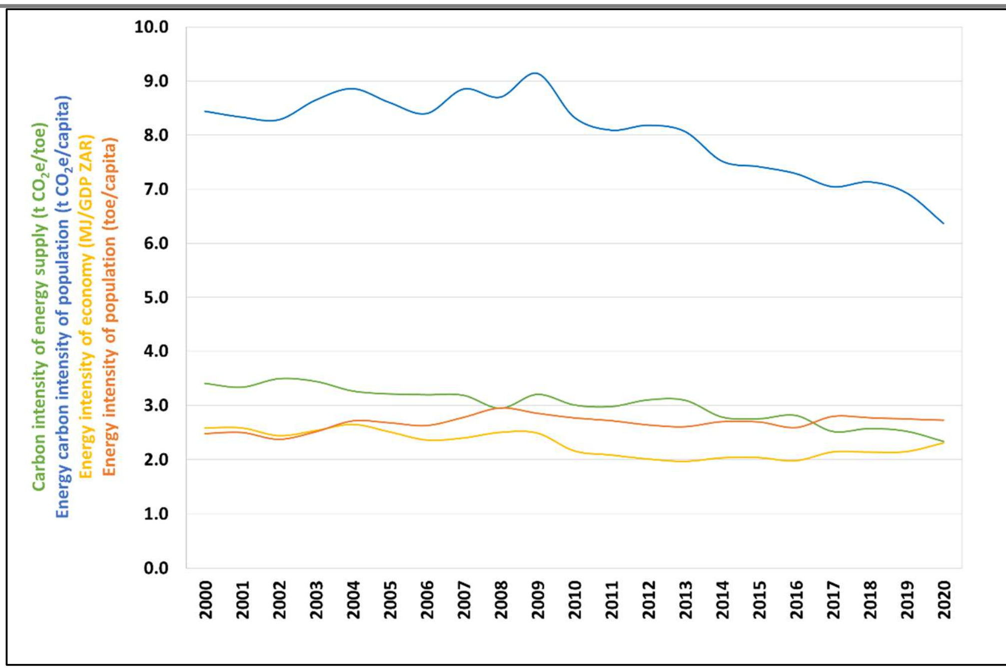


Figure 2.3: Trends in energy intensity indicators for South Africa between 2000 and 2020.

In terms of energy supply the Total Primary Energy Supply (TPES) data 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 2020 and declines by 32.3% over the 20-year period (Figure 2.3). The energy intensity of the population (TPES per person) has increased by 10.1% between 2000 and 2020.

The energy intensity of the economy, which is TPES MJ per unit GDP, has declined between 2000 and 2020 (10.5%). As mentioned above the decline is likely due to the decline in the manufacturing and mining sectors and an increase in GDP in the service sectors in recent years.

2.2 Description and interpretation of emission trends by greenhouse gas

CO_2 gas is the largest contributor to South Africa's emissions (Figure 2.4). This is followed by CH_4 and N_2O.

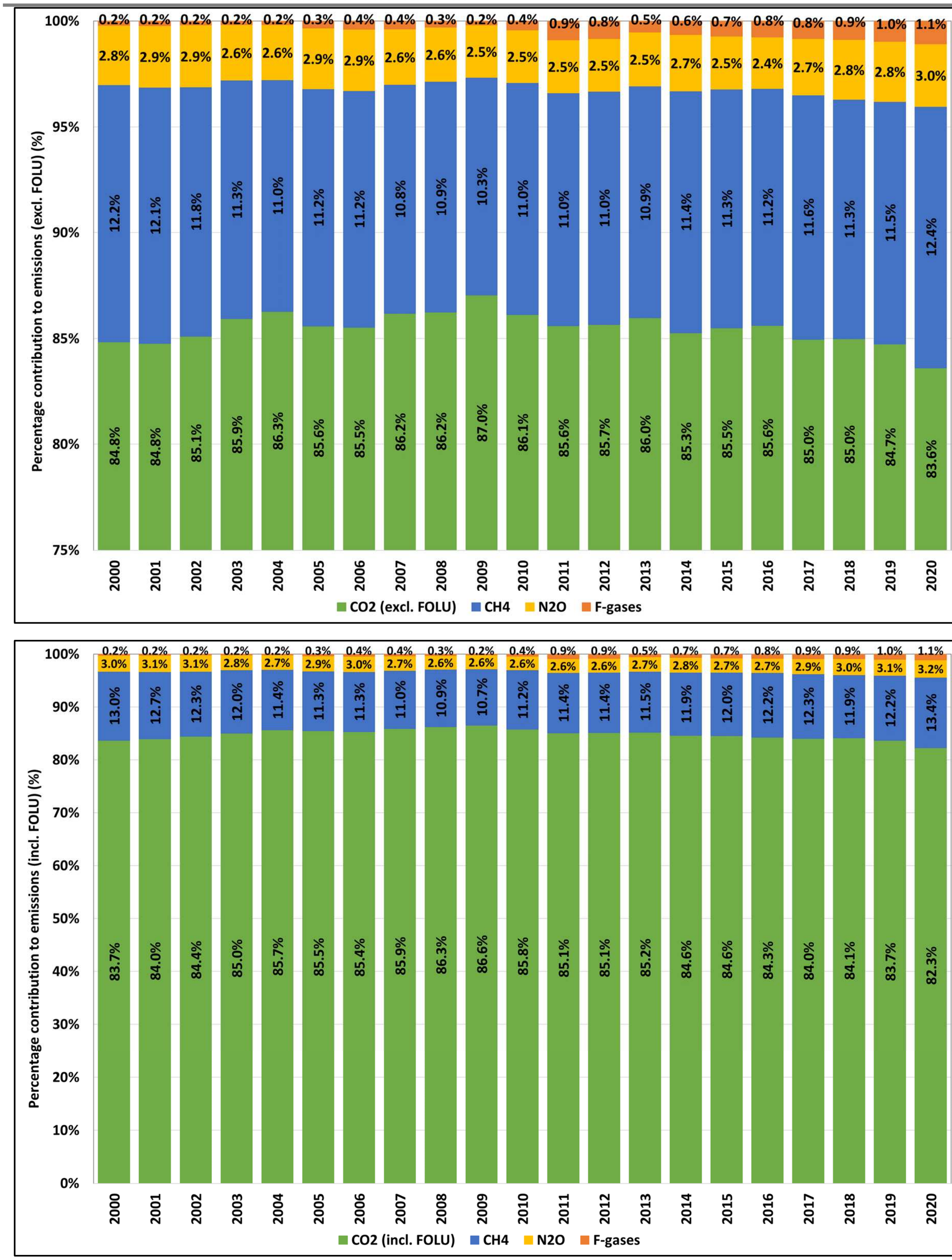


Figure 2.4: Percentage contributions from each of the gases to South Africa's emissions (excl. FOLU (top) and incl. FOLU (bottom)) between 2000 and 2020.

2.2.1 Carbon dioxide (CO_2)

The CO_2 emissions totalled 391 993 Gg CO_2 (excl. FOLU) and 363 677 Gg CO_2 (incl. FOLU) in 2020 (Table 2.3). Figure 2.35 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 80.7% between 2000 and 2020. The categories *1A1 energy industries* (60.1%), and *1A3 Transport* (12.0%) were the major contributors to the CO_2 emissions in 2020. The *IPPU* sector contribution an average of 6.2% between 2000 and 2020, while the AFOLU sector (excl. FOLU) contributed an average of 0.2%.

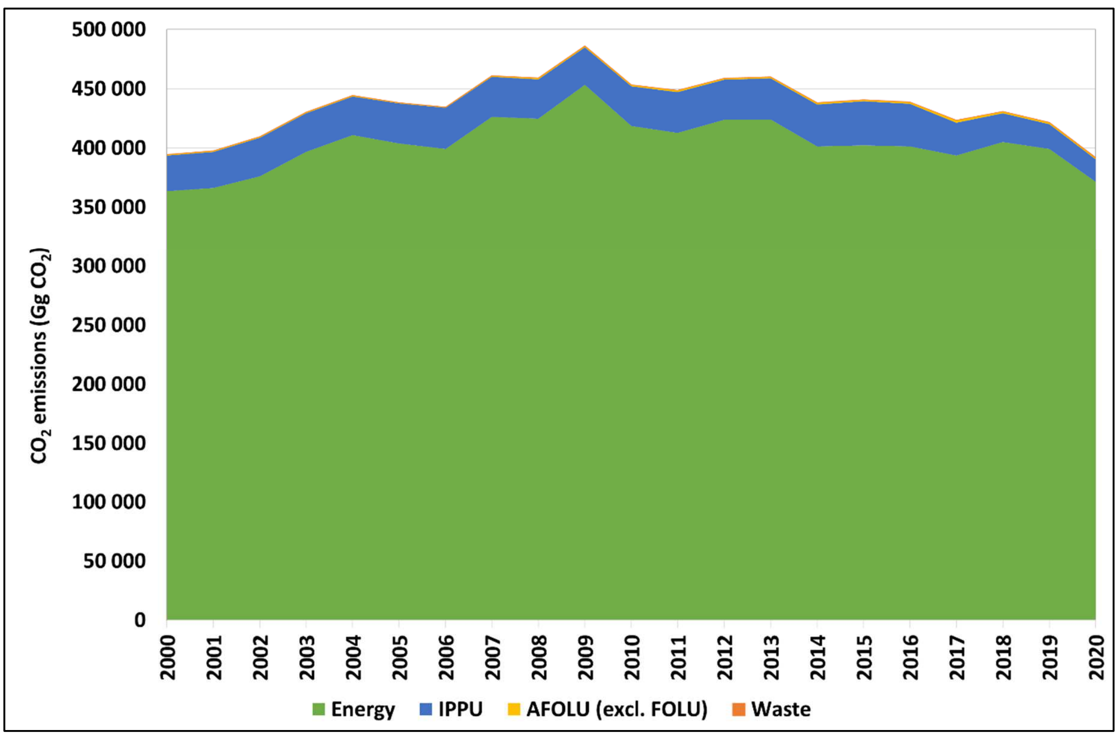


Figure 2.5: Trend and sectoral contribution to CO_2 emissions (excl. FOLU), 2000 – 2020.

Table 2.3: Trend in CO_2, CH_4, N_2O and F-gases between 2000 and 2020.

	Emissions										
	CO_2 (excl. FOLU)	CO_2 (incl. FOLU)	CH_4 (excl. FOLU)		CH_4 (incl. FOLU)		N_2O (excl. FOLU)		N_2O (incl. FOLU)		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	Gg N_2O	Gg CO_2e
2000	394 484.5	373 220.0	56 521.8	2 691.5	58 109.7	2 767.1	12 990.6	41.9	13 572.0	43.8	983.2
2001	397 557.7	385 322.5	56 771.8	2 703.4	58 339.9	2 778.1	13 683.1	44.1	14 257.3	46.0	1 007.7
2002	409 764.8	399 823.8	56 682.7	2 699.2	58 231.1	2 772.9	14 108.2	45.5	14 675.2	47.3	897.1
2003	430 383.6	411 391.1	56 436.2	2 687.4	57 964.8	2 760.2	13 122.7	42.3	13 682.4	44.1	896.2
2004	444 395.1	434 861.7	56 413.2	2 686.3	57 922.0	2 758.2	13 403.6	43.2	13 956.1	45.0	889.4
2005	438 243.9	446 110.1	57 372.6	2 732.0	58 861.6	2 802.9	14 686.6	47.4	15 231.8	49.1	1 713.4
2006	434 664.8	440 127.3	56 824.8	2 705.9	58 294.1	2 775.9	14 731.7	47.5	15 269.7	49.3	1 980.9
2007	461 093.0	462 709.3	57 854.7	2 755.0	59 304.2	2 824.0	14 019.1	45.2	14 549.8	46.9	2 034.1
2008	459 145.4	471 786.0	58 072.4	2 765.4	59 502.1	2 833.4	13 605.8	43.9	14 129.3	45.6	1 573.6
2009	486 203.4	478 488.0	57 463.7	2 736.4	58 873.6	2 803.5	13 779.4	44.4	14 295.7	46.1	1 100.3
2010	453 215.6	452 108.0	57 665.6	2 746.0	59 055.7	2 812.2	13 110.8	42.3	13 619.9	43.9	2 203.7
2011	448 609.4	440 571.0	57 694.1	2 747.3	59 064.5	2 812.6	13 072.5	42.2	13 574.3	43.8	4 685.2
2012	458 967.5	450 816.4	59 016.0	2 810.3	60 366.7	2 874.6	13 302.8	42.9	13 797.4	44.5	4 506.8
2013	460 170.5	442 971.8	58 539.8	2 787.6	59 870.6	2 851.0	13 581.3	43.8	14 068.6	45.4	2 852.5
2014	438 182.7	426 224.6	58 720.4	2 796.2	60 031.5	2 858.6	13 686.1	44.1	14 166.2	45.7	3 288.2
2015	440 708.4	419 450.0	58 181.4	2 770.5	59 472.7	2 832.0	12 871.5	41.5	13 344.4	43.0	3 702.7
2016	438 930.1	403 895.9	57 372.6	2 732.0	58 644.2	2 792.6	12 475.0	40.2	12 940.6	41.7	3 885.7
2017	423 405.8	403 112.7	57 566.1	2 741.2	58 817.9	2 800.9	13 230.0	42.7	13 688.4	44.2	4 148.0
2018	430 948.0	412 669.2	57 334.0	2 730.2	58 566.0	2 788.9	14 309.1	46.2	14 760.2	47.6	4 455.9
2019	421 726.6	398 415.3	57 040.7	2 716.2	58 253.0	2 774.0	14 115.3	45.5	14 559.2	47.0	4 770.8
2020	391 992.6	363 676.9	57 935.0	2 758.8	59 127.5	2 815.6	13 830.5	44.6	14 267.2	46.0	5 053.5

2.2.2 Methane (CH_4)

The sector contributions to the total CH_4 emissions in South Africa are shown in Figure 2.6. National CH_4 emissions (excl. FOLU) increased from 56 522 Gg CO_2e (2 692 Gg CH_4) in 2000 to 57 935 Gg CO_2e (2 759 Gg CH_4) in 2020 (Table 2.3). In the *Land* sector wetlands contributed 1 193 Gg CO_2e (57 Gg CH_4) to the total CH_4, pushing the total CH_4 (incl. FOLU) to 59 128 Gg CO_2e. The *AFOLU livestock* category and *Waste* sectors were the major contributors, providing 48.7% and 37.5%, respectively, to the total CH_4 emissions in 2020.

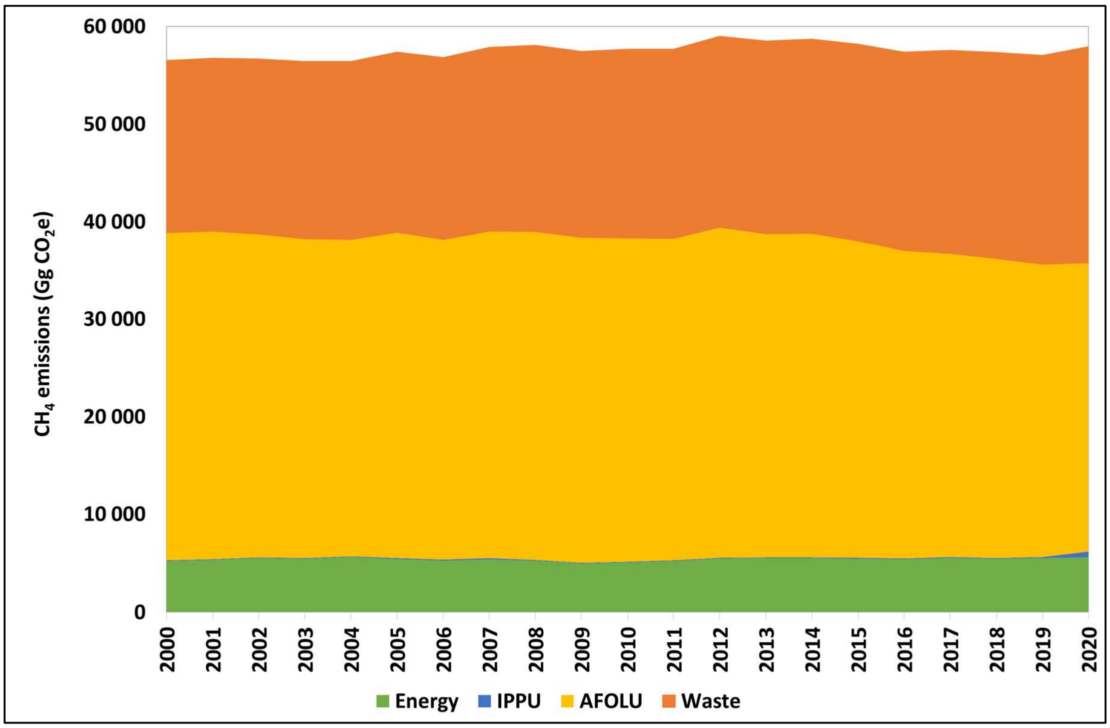
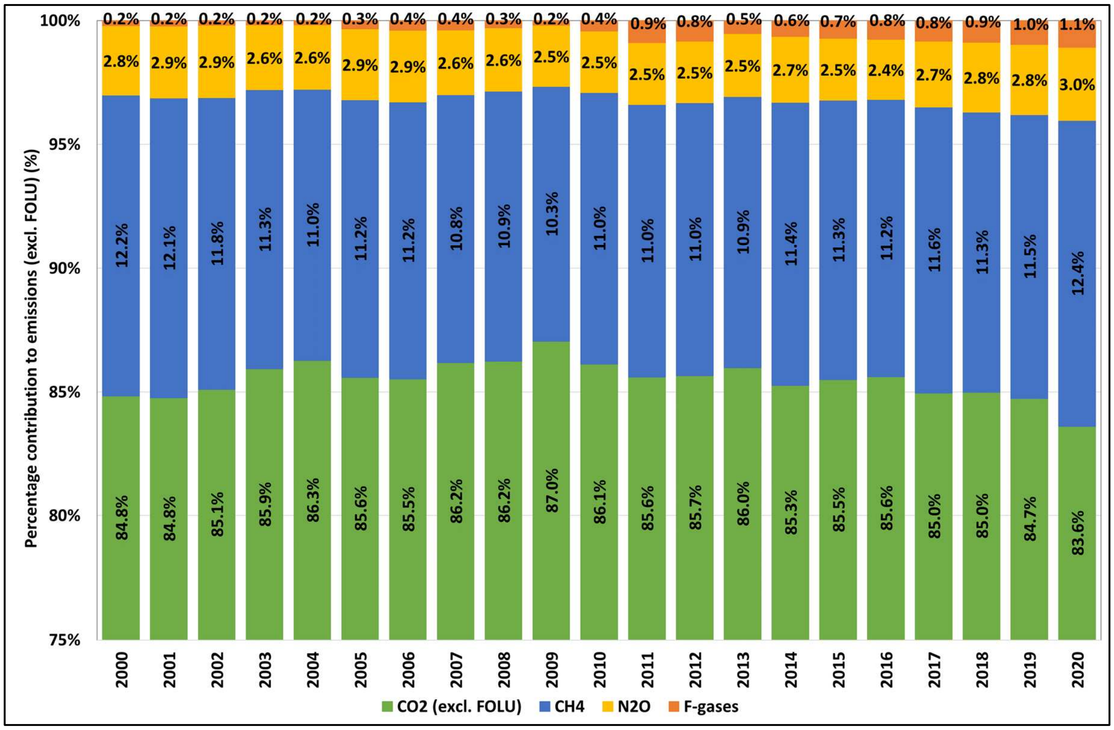


Figure 2.6: Trend and sectoral contribution to the CH_4 emissions (excl. FOLU), 2000 – 2020.

2.2.3 Nitrous oxide (N_2O)

Figure 2.7 shows the contribution from the major sectors to the national N_2O emissions in South Africa. The emissions (excl. FOLU) were 13 831Gg CO_2e (44.6 Gg N_2O) in 2020 and 14 267 Gg CO_2e (46.0 Gg N_2O) including FOLU (Table 2.3). The main contributors are the

AFOLU **(70.9%) and** ***Energy*** **(17.4%) sectors (**



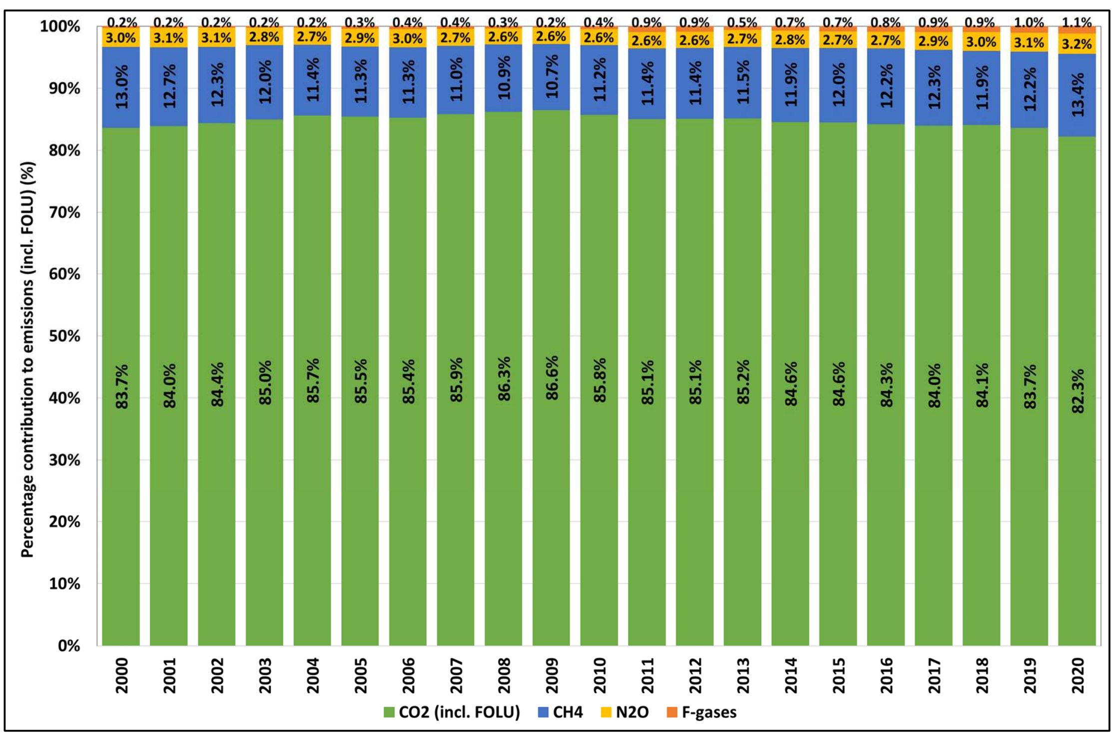


Figure 2.4). The categories 3C *Aggregated and non-CO_2 sources on land* (which includes emissions from managed soils and biomass burning), 3A *Livestock* and 1A *Fuel combustion activities* are the main contributors to N_2O. Livestock manure, urine and dung

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, but then increased again in 2018. The increase between 2018 and 2020 is due to improved data through the GHG Reporting Regulation.

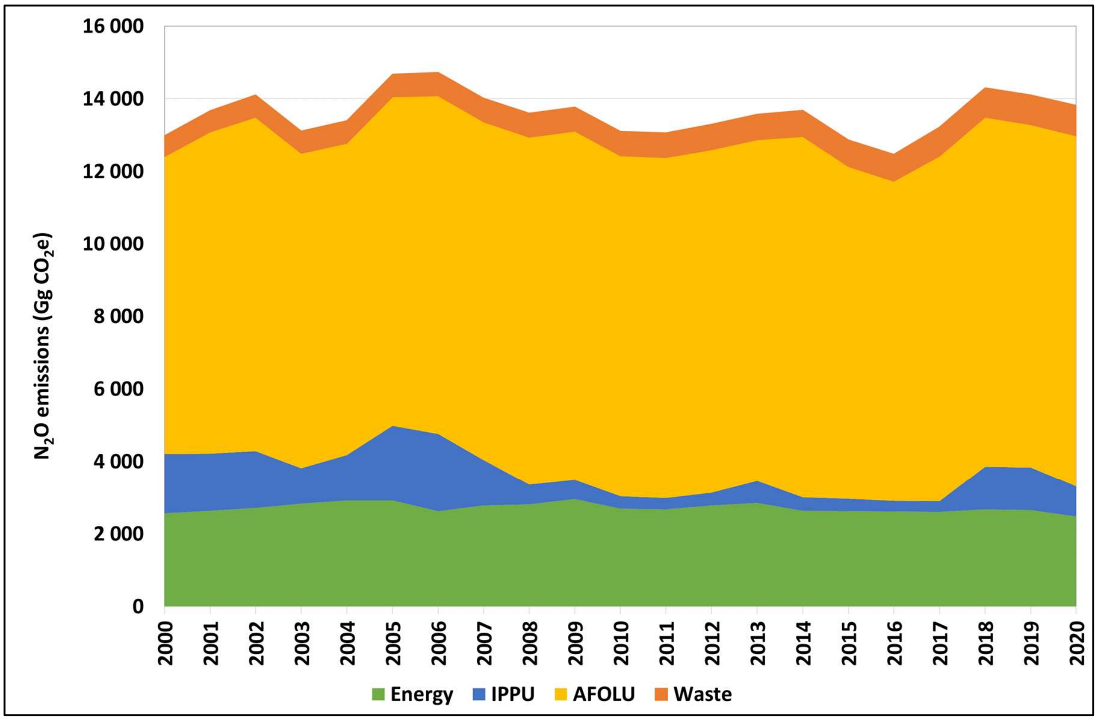


Figure 2.7: Trend and sectoral contribution to N_2O emissions (excl. FOLU) in South Africa, 2000 – 2020.

2.2.4 F gases

Estimates of HFC and PFC emissions were only estimated for the IPPU sector in South Africa. F-gas emission estimates varied annually (Figure 2.8) and contributed 1.1% to overall emissions (excl. FOLU) in 2020. Emissions increase from 2011 due to the addition of HFC emissions from *air conditioning*, *foam blowing agents*, *fire protection* and *aerosols*. There is no data prior to 2005 so this time-series is not consistent. The elevated F-gas emissions are therefore not necessarily due to an increase in emissions but rather due to the incorporation of new categories.

PFC emissions were estimated at 983 Gg CO_2e in 2000. This increased to 1 979 Gg CO_2e in 2012, then declined to 120 Gg CO_2e in 2020. 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. 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 Tetrafluoroethylene (C_2F_4) and Carbon tetrafluoromethane (CF_4). CF_4 emissions contribute the most to the PFC emissions (Table 2.4).

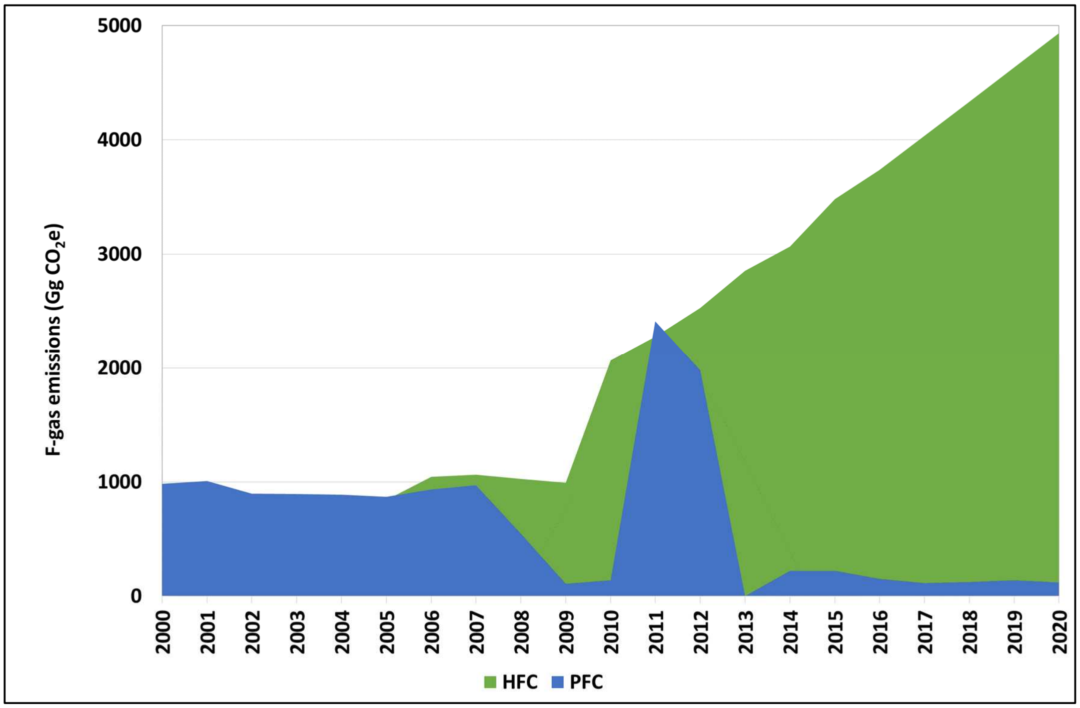


Figure 2.8: Trend in F-gas emissions in South Africa, 2000 – 2020.

HFCs increased from 842 Gg CO_2e in 2005 to 4 933 Gg CO_2e in 2020, and the largest contributor is HFC-134a (Table 2.4).

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

	CF_4	C_2F_6	HFC-23	HFC-32	HFC-125	HFC-134a	HFC-152a	HFC-143a	HFC-227ea	HFC-365mfc
	(Gg)									
SAR GWP	6 500	9200	11 700	650	2 800	1 300	140	3 800	2 900	890
2000	0.133	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2001	0.136	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2002	0.122	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2003	0.122	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2004	0.121	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2005	0.118	0.011	0.001	0.000	0.000	0.643	0.000	0.000	0.000	0.000
2006	0.127	0.012	0.004	0.000	0.039	0.442	0.100	0.079	0.000	0.000
2007	0.132	0.013	0.000	0.000	0.012	0.750	0.000	0.014	0.000	0.000
2008	0.074	0.007	0.002	0.000	0.004	0.696	0.000	0.022	0.000	0.000
2009	0.014	0.002	0.000	0.000	0.001	0.744	0.000	0.006	0.000	0.000
2010	0.018	0.002	0.001	0.000	0.013	1.423	0.000	0.045	0.000	0.000
2011	0.325	0.033	0.000	0.007	0.038	1.465	0.000	0.061	0.008	0.002
2012	0.267	0.027	0.000	0.010	0.050	1.588	0.000	0.076	0.009	0.002
2013	0.000	0.000	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
2018	0.016	0.002	0.001	0.041	0.164	2.276	0.000	0.218	0.019	0.001
2019	0.018	0.002	0.001	0.046	0.183	2.391	0.000	0.241	0.021	0.001
2020	0.016	0.002	0.001	0.051	0.201	2.506	0.000	0.264	0.022	0.001

2.3 Description and interpretation of emission trends by category

Table 2.5 shows the percentage contributed by each sector over the period 2000 - 2020 and Figure 2.9 shows the trend in the contribution from the four sectors to the total GHG emissions (excl. FOLU) in South Africa over the same period.

Table 2.6: Trend in emissions and removals by sector for 2000 to 2020.

	Energy	IPPU	AFOLU (excl. FOLU)	AFOLU (incl. FOLU)	Waste
	Emissions (Gg CO_2e)				
2000	371 344.6	32 955.2	42 439.1	23 343.8	18 241.2
2001	374 140.0	33 220.9	43 315.8	33 223.0	18 343.6
2002	384 308.9	35 204.1	43 373.4	35 547.7	18 566.4
2003	405 170.8	34 506.9	42 357.8	25 453.6	18 803.2
2004	419 521.7	34 617.1	42 103.8	34 631.7	18 858.8
2005	411 995.4	37 825.5	43 109.9	53 010.3	19 085.5
2006	407 032.8	38 900.2	42 973.3	50 443.0	19 295.9
2007	434 434.7	37 239.4	43 824.9	47 421.4	19 501.8
2008	432 848.2	35 441.5	44 365.4	58 959.2	19 742.1
2009	461 135.5	33 612.5	44 066.5	38 277.3	19 732.3
2010	426 504.9	35 928.4	43 755.3	44 546.9	20 007.0
2011	420 764.5	39 510.4	43 672.5	37 506.3	20 113.9
2012	432 091.1	38 654.1	44 741.1	38 435.1	20 306.9
2013	432 562.8	38 213.3	43 876.9	28 496.3	20 491.1
2014	409 532.8	39 097.3	44 587.0	34 420.0	20 660.4
2015	410 240.7	41 402.0	42 925.1	23 430.7	20 896.3
2016	409 456.8	40 120.7	41 962.6	8 665.5	21 123.4
2017	401 901.4	32 261.0	42 488.1	23 905.1	21 699.3
2018	413 151.3	30 104.6	41 802.0	25 206.3	21 989.0
2019	407 382.7	27 040.8	40 930.6	19 275.3	22 299.3
2020	379 505.2	25 486.1	40 774.6	14 088.0	23 045.8

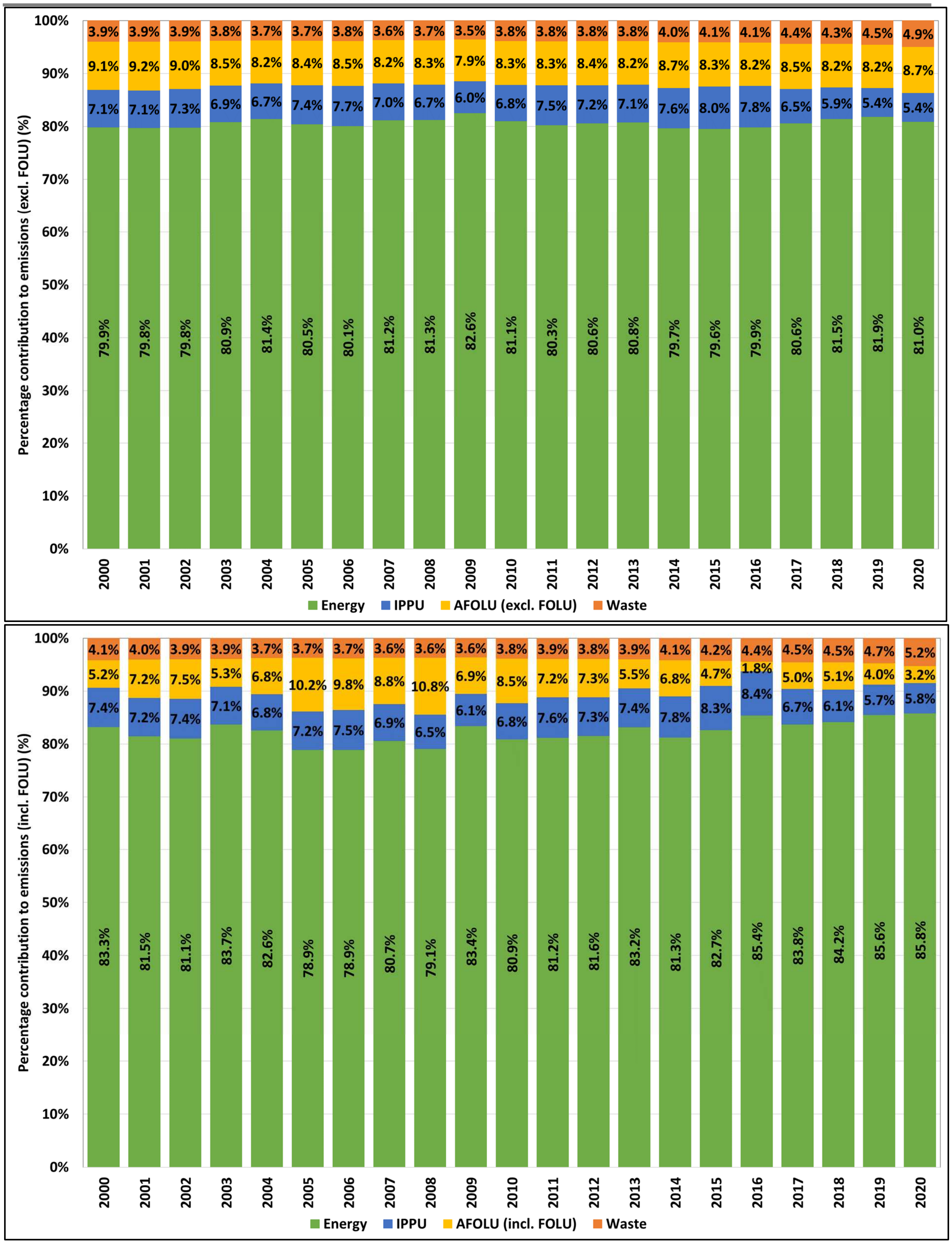


Figure 2.10: Percentage contributions from each of the sectors to South Africa's emissions (excluding (top) and including (bottom) FOLU) between 2000 and 2020.

2.3.1 Energy

The *Energy* sector is the largest contributor to South Africa's emissions (excl. FOLU), contributing 81% in 2020 (Figure 2.11). *Energy* sector emissions increased between 2000 and 2009, then declined to 2014 after which total emissions were stable until 2019 (Table 2.7). Emissions declined by 6.8% between 2019 and 2020. This decline was due to *Commercial/institutional* emissions declining by 19.7%, along with a 13.7% reduction in *Road transport* and a 54.3% reduction in *Civil aviation* emissions. These reductions can be attributed to the reduced travel and trading during the COVID-19 lockdown restrictions.

2.3.2 IPPU

The *IPPU* sector contributed 5.4% to the total GHG emissions (excl. FOLU) in 2020 and this is a decline from 7.1% in 2000 (Figure 2.12). In 2020 the IPPU contribution was 25 486 Gg CO_2e (**Error! Reference source not found.**). IPPU sector emissions increased between 2000 and 2006 by 18.0%, after which they declined by 13.6% to 2009. Emissions increased between 2010 and 2016 due to an increase in production in the *Mineral* and *Metal industries*. There was an increase of 8.9% during this time within the *Mineral industry* and an increase of 2.4% within the *Metal industry*, which led an overall increase of 11.7% for the IPPU sector. Emissions decreased by 19.6% between 2016 and 2017 as demand in the *Chemical* and *Metal industries* dropped.

Emissions within the sector decreased further from 2017 to 2020 by 21.0% due to lower production demands in the *Mineral*, *Chemical* and *Metal* industry. The economy in 2020 was further strained due to the COVID-19 pandemic and stringent lockdown regulations within South Africa. The *Mineral industry* emissions decreased by 23.7% (1 483 Gg CO_2e) since 2017, and the *Metal industry* showed an overall decrease of 40.0% (8 150 Gg CO_2e).

The largest source category is the *Metal industry* category, which contributes 48% to the total IPPU sector emissions. *Iron and steel production* and *ferroalloys production* are the biggest contributors to the *Metal industry* subsector, producing 3 853 Gg CO_2e (31.5%) and 7 069 Gg CO_2e (57.8%) respectively to the total *Metal industry* emissions.

2.3.3 AFOLU

The *AFOLU* sector (excl. FOLU) contributed an average of 8.5% to the total emissions (excl. FOLU) between 2000 and 2020 (Figure 2.13). The contribution has declined by 3.9% since 2000. The main driver of change in the *AFOLU* emissions (excl. FOLU) is the livestock population. Livestock have input into the *Enteric fermentation*, *Manure management,* as well as *Direct and Indirect N_2O emissions from managed soils*. *Enteric* *fermentation* emissions show a declining trend due to a decline in livestock population. Dairy cattle, pigs and poultry are the largest contributors to *Manure management* emissions, and with increasing poultry numbers these emissions increase over the 20-year period.

The *AFOLU* sector produced 40 775 Gg CO_2e (excl. FOLU) in 2020, while the emissions including FOLU were 14 088 Gg CO_2e (Table 2.8). The largest contributor to the sink is the *Forest land*, followed by *Grasslands*, while *Other land* is the main contributor to the source in the Land sector. Emissions from *Forests land* increase between 2003 and 2008 due to a combination of factors. During this time there was an increase in losses due to fire, both in plantations and natural vegetation classes, and an increase in wood harvest. Emissions and removals from *Grasslands* remained fairly constant, with *Grasslands remaining grasslands* and *Other land converted to grasslands* contributing to the sink.

Aggregated and non-CO_2 emissions on land contributed 23.1% to the AFOLU (excl. FOLU) emissions in 2020, and the largest contributor to this category is *Direct N_2O from managed soils* (56.1%). Within the *Direct N_2O from managed soils* category, nitrogen inputs from crop residues contribute 57.5%, followed by 19.0% from inorganic fertilisers and 14.9% from urine and dung deposits.

2.3.4 Waste

The *Waste* sector emissions have increased from 18 241 Gg CO_2e in 2000 to 23 046 Gg CO_2e in 2020 (Table 2.9). The *Waste* sector contribution to overall emissions (excl. FOLU) has slowly increased from 3.9% in 2000 to 4.9% in 2020 (Figure 2.14). Solid waste disposal is the main contributor to this sector and these emissions are driven mainly by population growth.

2.4 Description and interpretation of emission trends for indirect GHG

The trend in emissions of CO, NOx and NMVOCs is shown in Table 2.10 These emissions were estimated for biomass burning only. There is annual variability because the emissions include wildfires as well as controlled fires.

Table 2.11: Trends in indirect GHG emissions between 2000 and 2020.

	NOx	CO	NMVOC
	(Gg)		
2000	59.9	1 313.4	56.8
2001	67.8	1 438.6	68.0
2002	71.4	1 503.3	76.0
2003	54.1	1 203.9	62.4
2004	50.5	1 120.9	53.0
2005	77.4	1 672.6	82.5
2006	75.0	1 592.1	75.5
2007	73.3	1 680.1	84.9
2008	69.0	1 476.7	76.1
2009	65.9	1 409.0	69.3
2010	67.3	1 441.3	68.0
2011	64.3	1 344.8	67.3
2012	58.3	1 246.1	63.6
2013	58.8	1 262.1	61.2
2014	60.5	1 344.0	69.5
2015	43.4	952.1	49.8
2016	24.6	545.0	30.0
2017	47.6	1 062.4	54.4
2018	49.2	1 091.8	58.4
2019	45.4	1 018.5	55.4
2020	48.7	1 093.9	53.4

2.5 References

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Chapter 3: Energy

3.1 Sector overview

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 for a 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% of the GDP.

In 2019, the Department of Mineral Resources and the Department of Energy (DOE) were combined to form the DMRE. The Energy division is responsible for the management, processing, exploration, utilisation, and development of South Africa's energy resources.

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

The primary energy supply in South Africa (Figure 3.1) is dominated by coal (65 %), followed by crude oil (18 %), renewable and waste resources (11 %), gas (3 %) and nuclear (2 %) (DMRE, 2021).

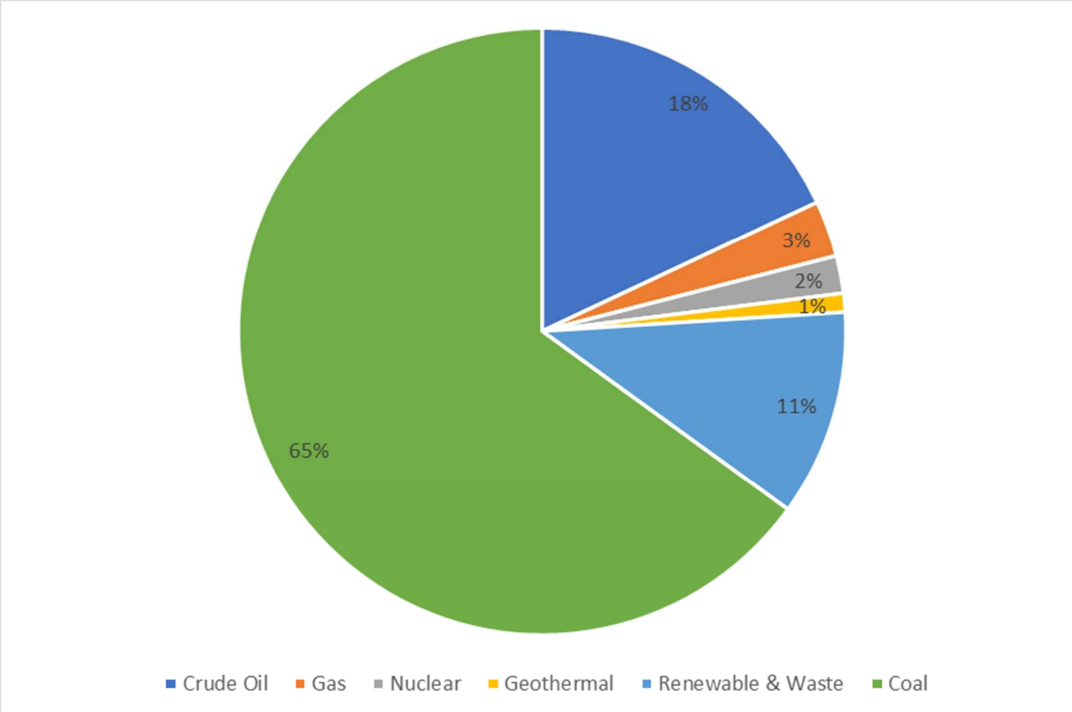

Figure 3.1: Total Primary Energy Supply in South Africa, 2018

In terms of energy demand, South Africa is divided into six sectors: industry, agriculture, commerce, residential, transport and other. At 51%, 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 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).

3.1.1 Shares and trends in emissions

Total emissions from the *Energy* sector for 2020 are estimated to be 379 505 Gg CO_2e (Table 3.1). *Energy industries* were the main contributor, accounting for 62% of emissions from the *Energy* sector. This is followed by *transport* (13%), *manufacturing industries and construction* (9%) and *fugitive emissions* (8%). The other sectors contribute less than 3% to the total emissions while *Non-specific sector* (1A5) accounts for 5% of emissions. This is because of an improved energy balance, which resulted in massive reduction of coal usage in the commercial and residential sectors from 2014. The *residential* and *commercial* sectors are both heavily reliant on electricity for meeting most of the energy needs. A summary table of all emissions from the Energy sector by gas is provided in Appendix C.

Table 3.1: Summary of emissions from the Energy sector in 2020.

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	371 409.3	267.3	5613.4	8	2482.4	379 505.2
1A Fuel combustion activities	345 085.0	23.9	502.5	7.7	2 482.4	348 069.9
1B Fugitive emissions from fuels	26 324.3	243.4	5 110.9			31 435.2
1C Carbon dioxide transport and storage	NE					NE

Between 2000 and 2020, the *energy* sector emissions increased by 2.2% (Table 3.2). This growth in emissions is mainly from the 3.1% increase in *fuel combustion activities*. There was an increase of 7.2% in emissions in *energy industry* emissions, as well as 19.9% increase in transport sector emissions (Table 3.2). On the other hand, *fugitive emissions from fuels* declined by 6.4%, mainly due to the decrease in fugitive emissions from the petroleum sector. 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.

Energy emissions decreased by 6% (22 396 Gg CO_2e) since the previous 2017 submission. The main contributors to decrease were the *energy industries and transport* which decreased by 5.7% (12 679 Gg CO_2e) and 13.9% (5 590 Gg CO_2e) respectively. The *Other sectors* decreased by 60%, and the *Non-specified* sector increased by 1.4%, while the *Fugitive emissions* decreased by 6.4%. The decrease in *Other sectors* is due to the change in allocation of fuel. Most of the coal that could not be accounted for within the residential sector was accounted for within the *Non-Specific sector* (1A5a). In the previous inventory the bulk of the coal that could not be accounted for was put in commercial sector. Therefore, the improvement in this inventory was to change such allocation so that the unexplained spikes in data changes can be absorbed by the None-specific Sector.

Table 3.2: Summary of the change in emissions from the Energy sector between 2000 and 2020.

Greenhouse gas source and sink categories	Emissions ($Gg\ CO_2e$)			Difference ($Gg\ CO_2e$)		Change (%)	
	2000	2017	2020	2000-2020	2017-2020	2000-2020	2017-2020
1. ENERGY	**371345**	**401901**	**379505**	**8161**	**-22396**	**2.2%**	**-5.6%**
1A Fuel combustion activities	**337759**	**370,448.48**	**348,069.95**	**10,311.19**	**-22,378.54**	**3.1%**	**-6.0%**
1A1 Energy industries	*220709*	*249342*	*236662*	*15954*	*-12679*	*7.2%*	*-5.1%*
1A1a Electricity and heat production	*186083*	*216489*	*205621*	*19538*	*-10868*	*10.5%*	*-5.0%*
1A1b Petroleum refining	*4050*	*3333*	*2414*	*-1636*	*-919*	*-40.4%*	*-27.6%*
1A1c Manufacture of solid fuels	*30576*	*29519*	*28627*	*-1949*	*-892*	*-6.4%*	*-3.0%*
1A2 Manufacturing industries and construction	*28928*	*30872*	*33336*	*4408*	*2464*	*15.2%*	*8.0%*
1A3 Transport	*40198*	*53783*	*48193*	*7995*	*-5590*	*19.9%*	*-10.4%*
1A3a Domestic aviation	*2257*	*1527*	*696*	*-1561*	*-832*	*-69.2%*	*-54.4%*
1A3b Road transportation	*37099*	*51407*	*44957*	*7858*	*-6450*	*21.2%*	*-12.5%*
1A3c Railways	*618*	*490*	*554*	*-64*	*63*	*-10.4%*	*12.9%*
1A3d Water-borne navigation (domestic)	*224*	*358*	*1986*	*1762*	*1628*	*786.8%*	*454.1%*
1A3e Other transportation	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*
1A4 Other sectors	*30680*	*14333*	*12399*	*-18282*	*-1934*	*-59.6%*	*-13.5%*
1A4a Commercial/Institutional	*21095*	*4777*	*3758*	*-17337*	*-1019*	*-82.2%*	*-21.3%*
1A4b Residential	*7125*	*3408*	*2715*	*-4410*	*-693*	*-61.9%*	*-20.3%*
1A4c Agriculture/Forestry/Fishing/Fish farms	*2460*	*6148*	*5926*	*3466*	*-222*	*140.9%*	*-3.6%*
1A5 Non-specified	*17243*	*22119*	*17480*	*237*	*-4639*	*1.4%*	*-21.0%*
1B Fugitive emissions from fuels	**33586**	**31453**	**31435**	**-2151**	**-18**	**-6.4%**	**-0.1%**
1B1 Solid fuels	*2,369*	*2,881*	*2,931*	*562*	*50*	*23.7%*	*1.7%*
1B2 Oil and natural gas	*752*	*642*	*642*	*-110*	*-*	*-14.7%*	*0.0%*
1B3 Other emissions from energy production	*28,147*	*25,746*	*25,645*	*-2,502*	*-102*	*-8.9%*	*-0.4%*
1C Carbon dioxide transport and storage	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**

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

Figure 3.2 shows the time-series for the *Energy* sector from 2000 to 2020. Emissions increased until 2009, followed by a decline in emissions in 2009/2010 due to the economic crisis in 2009, when South Africa's economy shrank by 1.4%. The economy rebounded from 2011 albeit at a very slow pace and not to the same growth level it was before the economic crisis. Consequently, the emissions also slightly increased from 2011 and reached a peak in 2013. In 2020, there was a 6.8% decline in emissions (Figure 3.3) which could partly be attributed to the COVID-19 lockdown during this time.

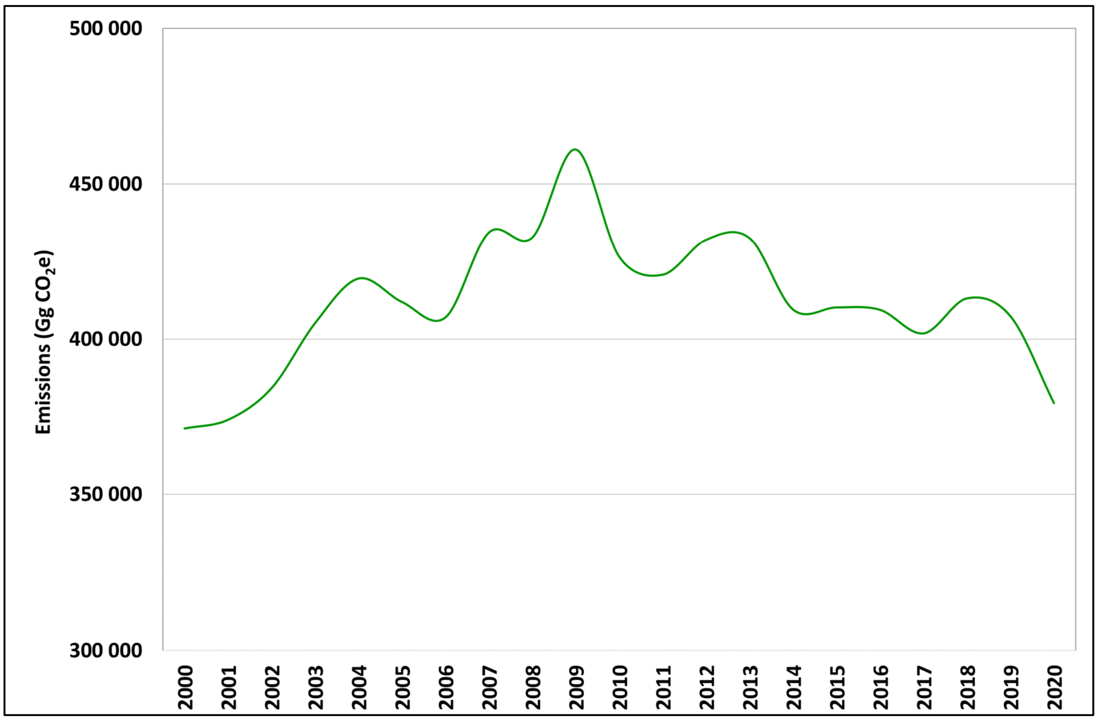

Figure 3.2: Trends in South Africa's energy sector emissions, 2000 – 2020.

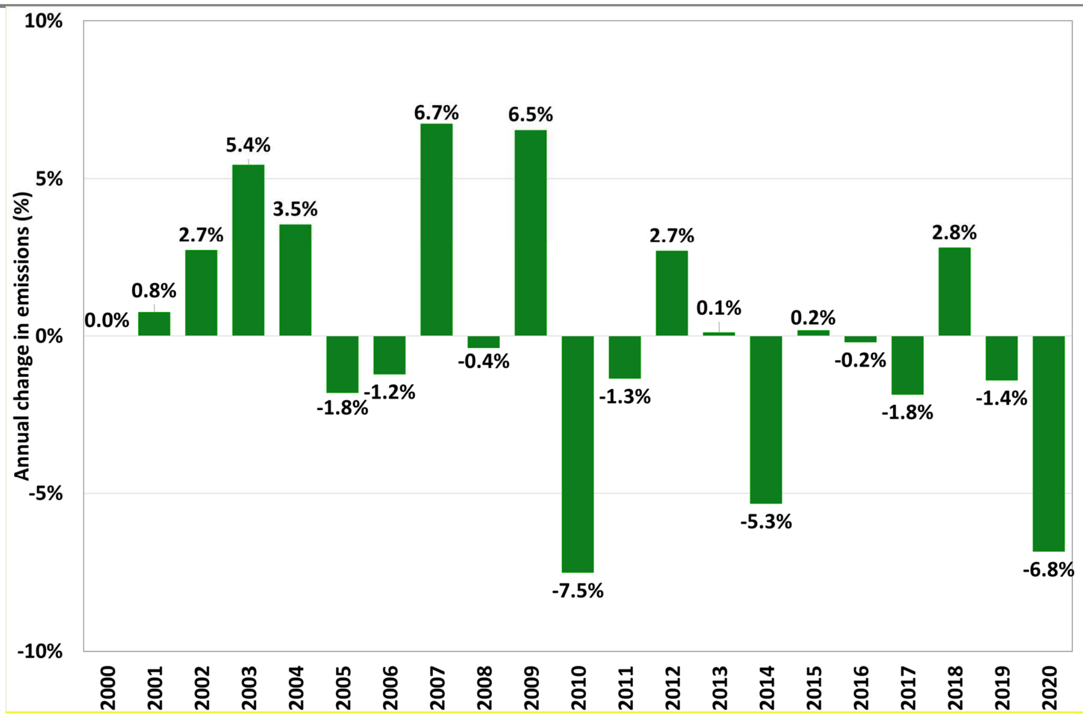

Figure 3.3: Trend in annual change in the total energy emissions in South Africa, 2000 – 2020.

3.1.1.1 Fuel combustion activities

Total estimated emissions from *fuel combustion* were 376 033 Gg CO_2e in 2019, equal to 92.3% of the *energy* sector emissions. In 2020, the emissions were at 348 070 Gg CO_2e. *Energy industries* contributed 68% to the total fuel combustion activity emissions in 2020.

From a series perspective, emissions increased by an average of 0.2% per annum from 2000 to 2020. While the economy was growing, there was a steady increase in emissions until 2008, followed by a decline in emissions due to the global economic crisis of 2008. There is a slight decline from 2014 to 2016 due to a decline in the energy industries emissions (Figure 3.4) as Eskom coal power stations were having lower energy availability factors, low economic growth, and an increasing share of renewables into the electricity grid. There was a slight increase in 2017 and emissions stabilised in 2018 due to very slow economic growth. Details of these declines, as well as further information about methodologies, emission factors, uncertainty, and quality control and assurance are provided in the various sub-category sections below.

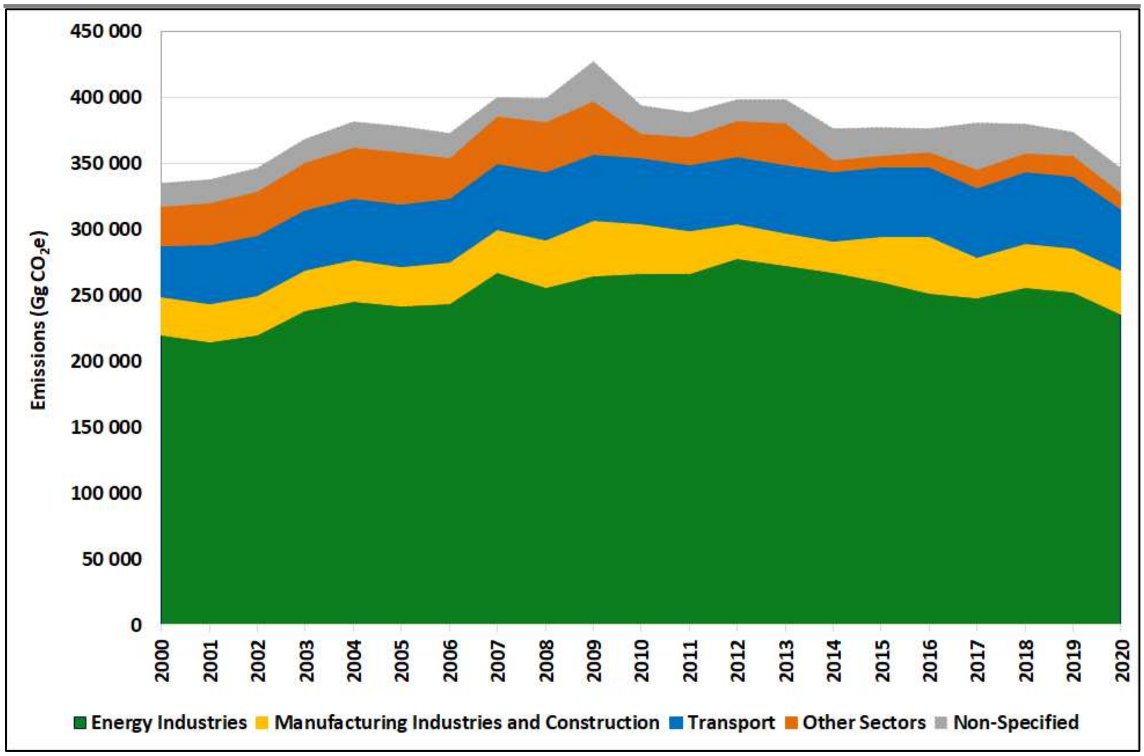

Figure 3.4: Trends and subcategory contributions to fuel combustion activity emissions in South Africa, 2000 – 2020.

Energy industries

The *Energy industries* were estimated to produce 236 662 Gg CO_2e in 2020, which is 68% of the *Fuel combustion activities* emissions and 62.4% of *Energy* sector emissions. From the trend perspective, the emissions are 15 954 Gg CO_2e (7.2%) above the 2000 level and this was due to an increase in the electricity consumption over this period.

Public electricity producer (1.A.1.a)

Emissions from the public electricity producer were 86% 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 3.3). Electricity generation increased by 6.4% over the 2000 - 2020 period, while emissions increased by 16.4%. The consumption of electricity, and the associated emissions, increased between 2000 and 2007 due to robust economic growth. In late 2007 and early 2008 the public electricity producer started to experience difficulties supplying electricity and resorted to shedding customer loads. The load shedding had a negative impact on the key drivers of economic growth. GHG emissions from the public electricity producer decreased by 4.2% as a result of the electricity disruptions. The global economic crisis in late 2008 also affected key drivers of growth such as the manufacturing and mining sectors. The manufacturing sector consumes approximately 45% of South Africa's electricity. Emissions from the public electricity producer increased thereafter to a peak in 2012 (Table 3.3). Since 2013 there has been a 7.9% decline in electricity consumption, leading to 14.8% decline in emissions from the public electricity producer.

Table 3.3: Emission trends for the public electricity producer, 2000 - 2020

	CO_2	CH_4	N_2O	Total
	Gg CO_2	Gg CH_4	Gg N_2O	Gg CO_2e
2000	173 858	1.8	2.7	174 736
2001	175 475	1.8	2.7	176 361
2002	181 307	1.9	2.8	182 222
2003	194 985	2.0	3.0	195 970
2004	204 690	2.1	3.2	205 724
2005	206 209	2.1	3.2	207 250
2006	207 465	2.2	3.2	208 512
2007	228 111	2.4	3.6	229 263
2008	218 543	2.3	3.4	219 645
2009	224 579	2.4	3.5	225 711
2010	231 405	2.4	3.6	232 572
2011	233 189	2.5	3.6	234 364
2012	243 497	2.6	3.8	244 723
2013	237 464	2.6	3.7	238 657
2014	232 115	2.5	3.6	233 280
2015	223 999	2.5	3.4	225 121
2016	217 118	2.3	3.4	218 212
2017	214 668	2.3	3.3	215 750
2018	222 370	2.4	3.5	223 490
2019	217 995	2.4	3.4	219 099
2020	202 376	2.2	3.2	203 421

Despite the economy growing throughout the 2011 – 2019 period, (at an average rate of 1.6% per annum), the emissions decreased between 2013 and 2016. The decline in emissions is attributed to the decline of emissions from coal generated electricity as the energy availability factor for coal power stations decreased between those years as shown in Figure 3.5 (Eskom, 2018). The 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 one of the two coal silos at the Majuba Power station. The station has an installed capacity of 3 600 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 (2010 – 2013), the availability factor was between 77.7% and 85% (Figure 3.5).

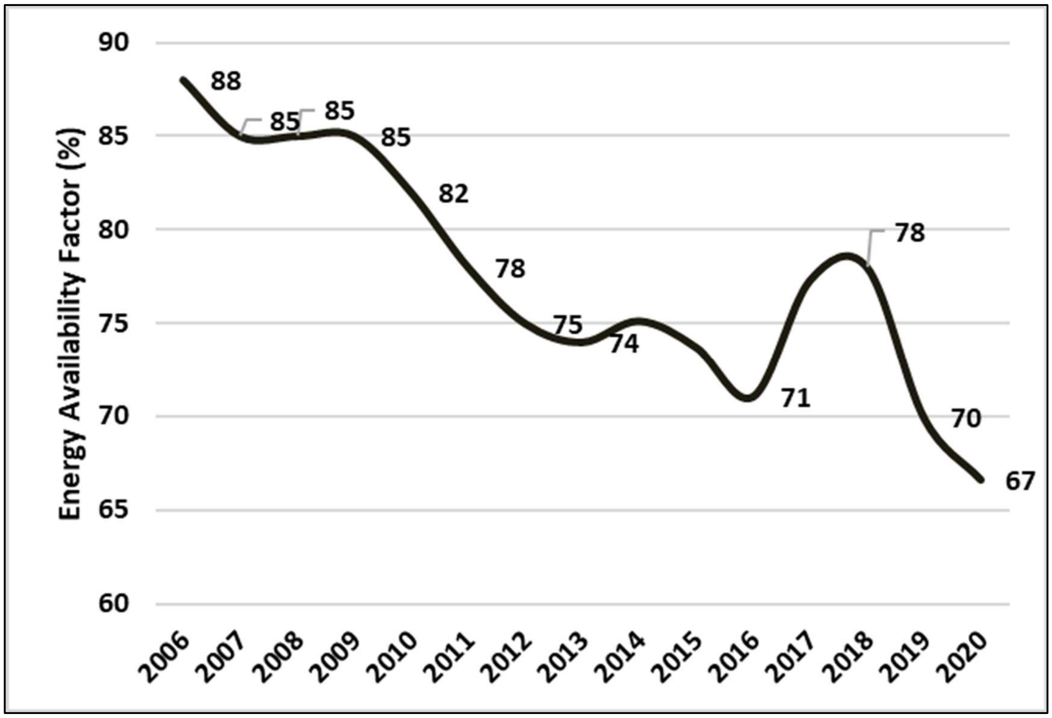

Figure 3.5: Eskom's system energy availability factor (%)

Given that electricity production contributes 53.6% of emissions in the Energy sector, a significant drop in coal use in the power stations results in reduced emissions. At the same time, the penetration of renewable energy resources (wind solar PV and concentrated solar power) within the electric grid (from the REIPPP) have steadily been increasing (Figure 3.6). The installed capacity increased from 457 MW in 2013 to 4 054 MW by the end of 2019 (CSIR, 2021). In 2013, about 0.1 TWh of electricity was produced from renewables and by 2019, 11.5 TWh of electricity was produced from wind, solar PV and Concentrated Solar Power (CSP) resulting in avoided emissions (CSIR, 2019). Using a high-level assumption that electricity from these sources, with a penetration level of 5% replaced coal, 3 945 Gg of CO_2 was avoided resulting in 1.6% emissions reductions.

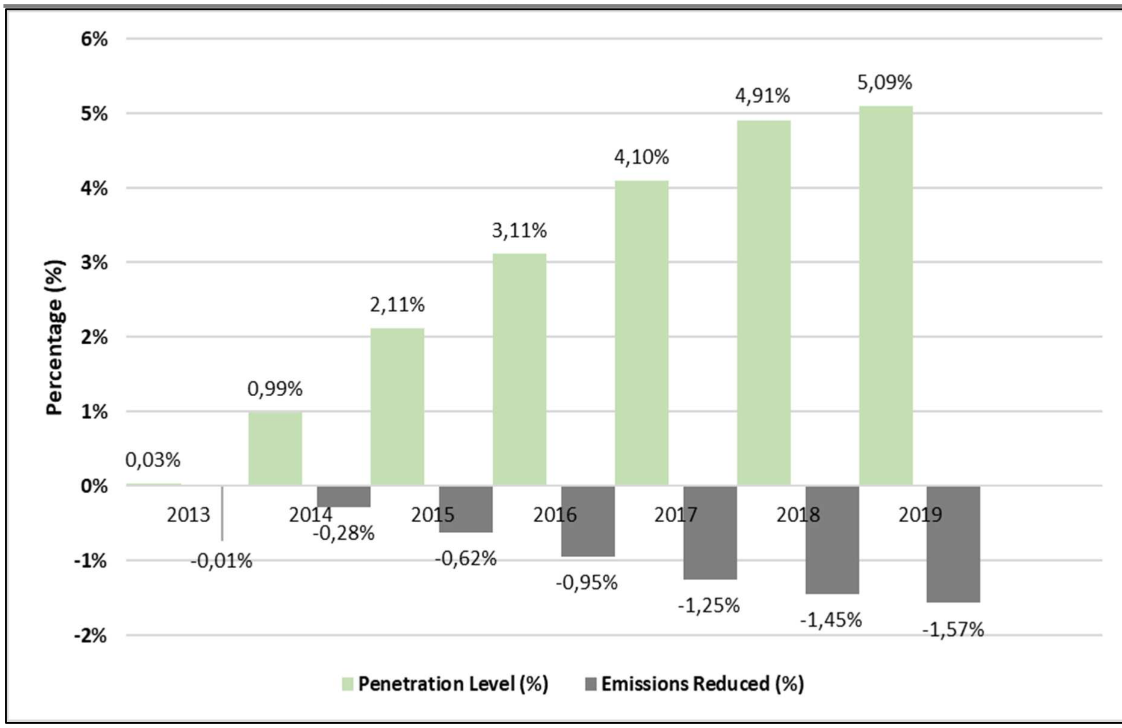

Figure 3.6: Renewable penetration and corresponding emissions reduction.

Auto electricity producers (1.A.1.a)

Total emissions from auto electricity producers in South Africa fluctuated significantly from year to year (Table 3.4). 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 0.9% decline in GHG emissions during 2008. Overall, there has been a declining trend in emissions with a decline of 86.1% (9 146 Gg CO_2e) since 2000, with 81.2% of this occurring since 2010. This was mainly brought about by the decommissioning of some coal power plants within municipalities.

Table 3.4: Trend in emissions from the auto electricity producers, 2000 – 2020.

	CO_2	CH_4	N_2O	Total
	Gg CO_2	Gg CH_4	Gg N_2O	Gg CO_2e
2000	11 291	0,12	0,18	11 347
2001	4 607	0,05	0,07	4 630
2002	4 992	0,05	0,08	5 017

2003	7 982	0,09	0,12	8 022
2004	6 259	0,07	0,10	6 291
2005	2 727	0,03	0,04	2 741
2006	3 856	0,04	0,06	3 875
2007	4 693	0,05	0,07	4 716
2008	3 898	0,04	0,06	3 918
2009	6 653	0,07	0,10	6 687
2010	2 200	0,02	0,03	2 211
2011	892	0,01	0,01	896
2012	1 197	0,01	0,02	1 203
2013	1 189	0,01	0,02	1 195
2014	1 219	0,01	0,02	1 226
2015	5 699	0,01	0,02	5 705
2016	208	0,00	0,00	209
2017	736	0,01	0,01	739
2018	657	0,01	0,01	660
2019	2 088	0,04	0,03	2 098
2020	2 191	0,04	0,03	2 201

Petroleum refining (1.A.1.b)

The total GHG emissions from *petroleum refining* was estimated at 4 050 Gg CO_2e in 2000, decreasing to 2 414 Gg CO_2 e in 2020. In 2000 refinery gas contributed 57.0% to the total GHG emissions in this subcategory and this increased to 72% in 2020. Emissions from residual fuel oil decreased from contributing 17% in 2000 to only 5.3% in 2019. A shift from residual fuel oil to refinery gas in most refineries is the main driver of emissions reduction in this source category.

Manufacture of solid fuels and other energy industries (1.A.1.c)

Emissions from *manufacture of solid fuels and other energy industries* totalled 28 627 Gg CO_2e in 2020, and these emissions have remained fairly stable over the 20-year period since 2000. Emissions in this subsector decreased by 6.4% (1 949 Gg CO_2e) since 2000.

Manufacturing industries and construction

The *manufacturing industries and construction* were estimated to produce 33 336 Gg CO_2e in 2020, which is 8.8% of the *Energy* sector emissions. In the 20-year period, emissions from the sector increased by 4 408 Gg CO_2e (15.2%). The emissions increased at an annual average rate of 0.5%. This sector is growing in a very slow manner due to multitude of economic and structural issues, therefore, emissions are expected to not increase significantly. High share of emissions come from coal usage. Figure 3.7 shows that 64% of emissions within this sector comes from combustion of coal in stationary appliances. The significance of gas works gas has reduced from 14% in 2000 to 3% in 2020. This is due to increased use of natural gas. The country started importing additional gas from Mozambique and as a result natural gas usage increased from 8% in 2000 to 17% in 2020. Overall, gaseous fuels have contributed about 20% of emissions in the sector throughout the entire 20-year period. The share of emissions coming from diesel has increased from 7% to 12% in 2020.

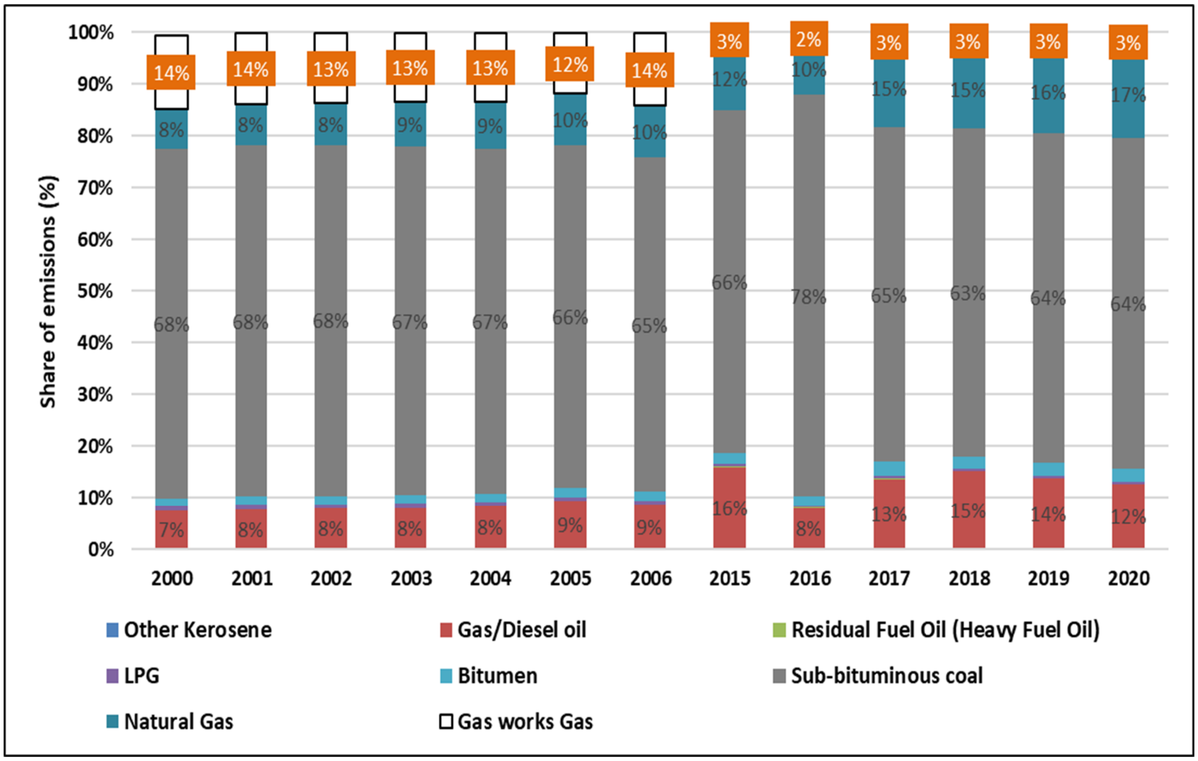

Figure 3.7: Manufacturing Industries & Construction Emissions by fuel source

Transport

Emissions from the *transport* sector have been in upward trend since 2000. In 2020 there is a 13.7% decline from 2019 emissions levels. The reduction is mainly coming from reduction from passenger travel in 2020 that was imposed as people shifted from working at the office to working from home due to the COVID-19 pandemic. In 2000 the transport sector contributed 11 % of the total Energy sector emissions, and in 2020 the transport sector contributed 13 % of the emissions. About 93% of emissions from the transport sector comes from road transport (1A3b). Diesel and Motor Gasoline are the main contributing fuels as shown in Figure 3. 8. Over the 20 years period, the contribution by diesel increased from 32% in 2000 to 51% in 2020 while that of gasoline decreased from 58% in 2000 to 40% in 2020.

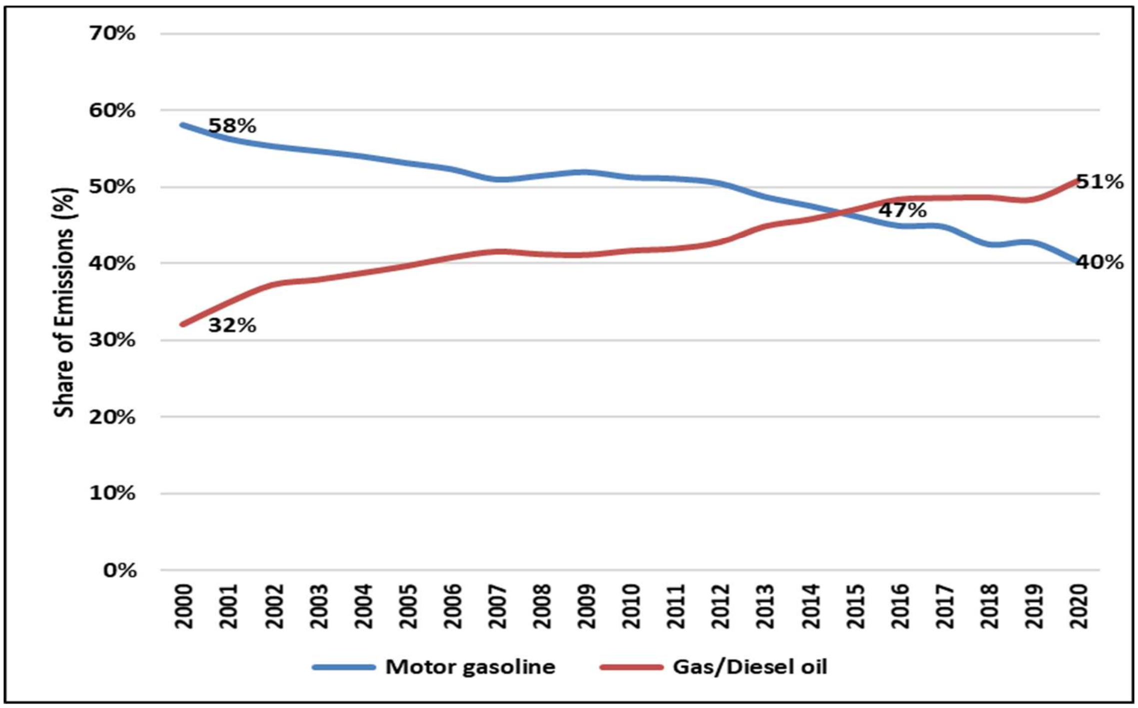

Figure 3. 8: Contribution of diesel and gasoline used in road transport to the total transport emissions

Other sectors

The *other sectors* were estimated to produce 15 446 Gg CO_2e and 12 399 Gg CO_2e in 2019 and 2020 respectively. In 2020, other sectors contributed 3% to the total energy sector emissions. The largest contributor to this category is the agricultural emissions (48%) followed by commercial sector at 30% and residential sector at 22%. In 2020, total *other sector* emissions were 18 282 Gg CO_2e below the 2000 level of 30 680 Gg CO_2e (Table 3.5).

Table 3.5: Trend in emissions from other sectors, 2000 – 2020.

	Commercial/ Institutional	Residential	Agriculture/ Forestry/ Fishing/ Fish farms	Total
	Gg CO_2e			
2000	21 095	7 125	2 460	30 680
2001	20 821	9 263	2 537	32 621
2002	20 639	11 152	2 624	34 416
2003	21 551	12 354	2 742	36 647
2004	23 068	14 044	2 817	39 928
2005	22 357	15 081	2 802	40 239
2006	9 758	17 338	3 518	30 613
2007	11 767	21 226	3 631	36 625
2008	13 046	22 603	3 496	39 145
2009	14 182	23 781	3 526	41 489
2010	5 141	10 063	3 423	18 627
2011	5 855	11 664	3 777	21 296
2012	8 193	16 204	3 486	27 884
2013	9 791	18 449	3 884	32 124
2014	2 646	2 698	3 937	9 281
2015	2 352	2 394	4 010	8 757
2016	3 150	2 798	6 134	12 082
2017	4 777	3 408	6 148	14 333
2018	5 228	2 750	6 292	14 270
2019	6 305	2 700	6 440	15 446
2020	3 758	2 715	5 926	12 399

Non-specified

The *non-specified* subsector was estimated to produce 17 480 Gg CO_2e in 2020, and these were 237 Gg CO_2e up from the 2000 level. The increase was due to more coal being attributed to this sector, as well as having diesel being allocated to this sub-sector as per the Energy Balance allocations.

3.1.1.2 Fugitive emissions from fuels

Total estimated *fugitive emissions* for 2020 were 31 435 Gg CO_2e. Net *solid fuel* emissions contributed 9.3% (2 931 Gg CO_2e) of *fugitive emissions*. *Oil and natural gas* account for 2.0% (642 Gg CO_2e), while *other emissions from energy production* accounted for 88.6%. Overall *fugitive emissions* decreased by 6.4% (2 151 Gg CO_2e) between 2000 and 2020 (Table 3.6). There was a peak of emissions in 2004 (35 387 Gg CO_2e) due to an increase in *other emissions from energy production*, with an 11.2% decrease in 2005. Emissions declined slightly until 2011, after which they increased to 2020.

Table 3.6: Trend in fugitive emissions, 2000 – 2020.

	Solid Fuels	Oil and Natural Gas	Other Emissions from Energy Production	Total
	Gg CO_2e			
2000	2 368.7	752.0	30 465.2	33 585.9
2001	2 428.4	752.9	30 690.9	33 872.2
2002	2 572.2	955.1	30 690.9	34 218.3
2003	2 596.9	1 458.0	29 589.0	33 643.8
2004	2 620.4	1 378.9	31 387.2	35 386.5
2005	2 618.2	1 160.1	27 662.5	31 440.9
2006	2 649.3	1 133.2	27 524.7	31 307.2
2007	2 702.7	1 132.7	27 973.6	31 809.0
2008	2 661.8	1 138.2	26 609.5	30 409.5
2009	2 380.4	1 243.4	26 912.9	30 536.7
2010	2 521.6	964.2	26 704.5	30 190.4
2011	2 650.5	785.8	26 319.8	29 756.1
2012	2 860.0	641.8	27 298.7	30 800.5
2013	2 852.3	641.8	27 705.1	31 199.3
2014	2 889.8	641.8	27 266.8	30 798.4
2015	2 812.8	641.8	26 826.6	30 281.2
2016	2 783.0	641.8	27 032.6	30 457.5
2017	2 880.8	641.8	27 930.4	31 452.9
2018	2 786.0	641.8	27 036.9	30 464.7
2019	2 857.4	641.8	27 850.8	31 350.0
2020	2 930.7	641.8	27 862.7	31 435.2

Solid fuels

The *fugitive emissions from solid fuels* subsector were estimated to produce 2 931 Gg CO_2e in 2020, which is 0.8% of the energy sector emissions. Emissions were 562 Gg CO_2e (23.7%) above the 2000 level. Emissions increased by 6.5% between 2000 and 2010, then there was successive increase between 2011 until 2014. The decline and increase between 2014 and 2020 was minimal to such an extent that the missions stayed constant throughout the years (Table 3.6).

Oil and natural gas

The *fugitive emissions from oil and natural gas* subsector were estimated to produce 642 Gg CO_2e in 2020, 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 3.6). Fugitive emissions between 2013 and 2020 were assumed to be the same as they were in 2012, as there was a lack of updated data.

Other emissions from energy production

Other emissions from energy production were estimated to produce 27 863 Gg CO_2e in 2020, which is 7.3% of the energy sector emissions. Emissions were 2 602 Gg CO_2e (8.5%) below the 2000 level (30 465 Gg CO_2e). Emissions in this subsector decreased by 0.2% (68 Gg CO_2e) since 2017.

3.1.2 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. Table 3.7 provides a summary of the methods and emission factors applied to each energy subsector. The NGERs stipulate that all key emission entities that are compelled to report should use higher tier methodologies. A five-year transition period was however also declared before full implementation, from the 2023 reporting cycle onwards. In the light of this, entities used their own discretion to report using higher tier methodologies, where possible, in the interim.

Table 3.7: 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		NOx	CO	NM VOC	SO_2
		Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor				
1A	**Fuel combustion activities**										
1A1	***Energy industries***										
	a. Main activity electricity and heat production	T1, T2, T3	DF, CS	T1	DF	T1	DF	NE	NE	NE	NE
	b. Petroleum refining	T1	DF	T1	DF	T1	DF	NE	NE	NE	NE
	c. Manufacture of solid fuels and other energy industries	T3	CS	T3	CS	T3	CS	NE	NE	NE	NE
1A2	***Manufacturing industries and construction***	T1, T2	DF, CS	T1	DF	T1	DF	NE	NE	NE	NE
1A3	***Transport***										
	a. Civil aviation	T1	DF	T1	DF	T1	DF	NE	NE	NE	NE
	b. Road transportation	T1	DF	T1	DF	T1	DF	NE	NE	NE	NE
	c. Railways	T1	DF	T1, T2	DF, CS	T1	DF	NE	NE	NE	NE
	d. Water-borne navigation	T1	DF	T1	DF	T1	DF	NE	NE	NE	NE
	e. Other transportation	NA		NA		NA		NA	NA	NA	NA
1A4	***Other sectors***										
	a. Commercial/ Institutional	T1, T2	DF, CS	T1	DF	T1	DF	NE	NE	NE	NE
	b. Residential	T1, T3	DF, CS	T1	DF	T1	DF	NE	NE	NE	NE
	c. Agriculture/ Forestry/ Fishing/ Fish farms	T1, T3	DF, CS	T1	DF	T1	DF	NE	NE	NE	NE
1A5	***Non-specified***										
	a. Stationary	T1, T2	DF, CS	T1	DF	T1	DF	NE	NE	NE	NE
	b. Mobile	IE		IE		IE		NE	NE	NE	NE
1B	**Fugitive emissions from fuels**										
1B1	***Solid fuels***										

GHG Source and sink category		CO_2		CH_4		N_2O		NOx	CO	NM VOC	SO_2
		Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor				
	a. Coal mining and handling	T2	CS	T2	CS	NA		NE	NE	NE	NE
	b. Uncontrolled combustion and burning coal dumps	NE		NE		NA		NE	NE	NE	NE
	c. Solid fuel transformation	IE		IE		NA		NE	NE	NE	NE
1B2	***Oil and natural gas***										
	a. Oil	T3	CS	NE		NA		NE	NE	NE	NE
	b. Natural gas	NE		NE		NE		NE	NE	NE	NE
1B3	***Other emissions from energy production***	T3	CS	T1, T3	DF, CS	NE		NE	NE	NE	NE
1C	**Carbon dioxide transport and storage**										
1C1	***Transport of CO_2***										
	a. Pipelines	NE									
	b. Ships	NE									
	c. Other	NE									
1C2	***Injection and storage***										
	a. Injection	NE									
	b. Storage	NE									
1C3	***Other***	NE		NE		NE		NE	NE	NE	NE

3.1.3 Improvements and recalculations since the 2017 submission

Recalculated emission estimates for the *Energy* sector were between 4.4%-8.5% higher than previous estimates between 2000 and 2009, while in 2014 and 2015 estimates were 1.8% and 0.9% lower than previous estimates for the *Energy* sector (Figure 3.9).

Estimates were 2.2% higher in the current inventory for the year 2017. These recalculations were necessary due to an update of 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 are coal, diesel, natural gas and gas works gas in those sectors. There are three reasons why recalculations had to occur.

1) The energy balance from DMRE has updated fuel allocation in these sectors hence there was a need to recalculate the emissions.
2) The fuel consumption study done by DFFE under the GHG improvement programme was finalised.
3) The DMRE had updated coal statistics in its SAMI report series.

A significant amount of diesel was allocated to 1A5a in the energy balance, which was not there before. 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.

A recent parc model, as part of the Fuel Consumption Study (DEFF, 2020), was completed for the *transport* sector, which provided consumption data based on VKT. In this inventory the petrol, diesel and natural gas consumption data for *Road transport* was updated and this led to a 3.7% increase in the *Road transport* emission estimates between 2017 and 2019. In 2020, the emissions decreased by 13%. It is assumed that most of this reduction occurred due to the restricted travel from *road transport*, especially passenger travel where people converted to working from home. In the *Other emissions from energy production* category, the charcoal consumption data was corrected producing a 1% decline in emission estimates for 2008 to 2012, and a 12% reduction in the 2013 estimates. The new re-allocation of diesel significantly reduced diesel allocation in the manufacturing industries and construction sector.

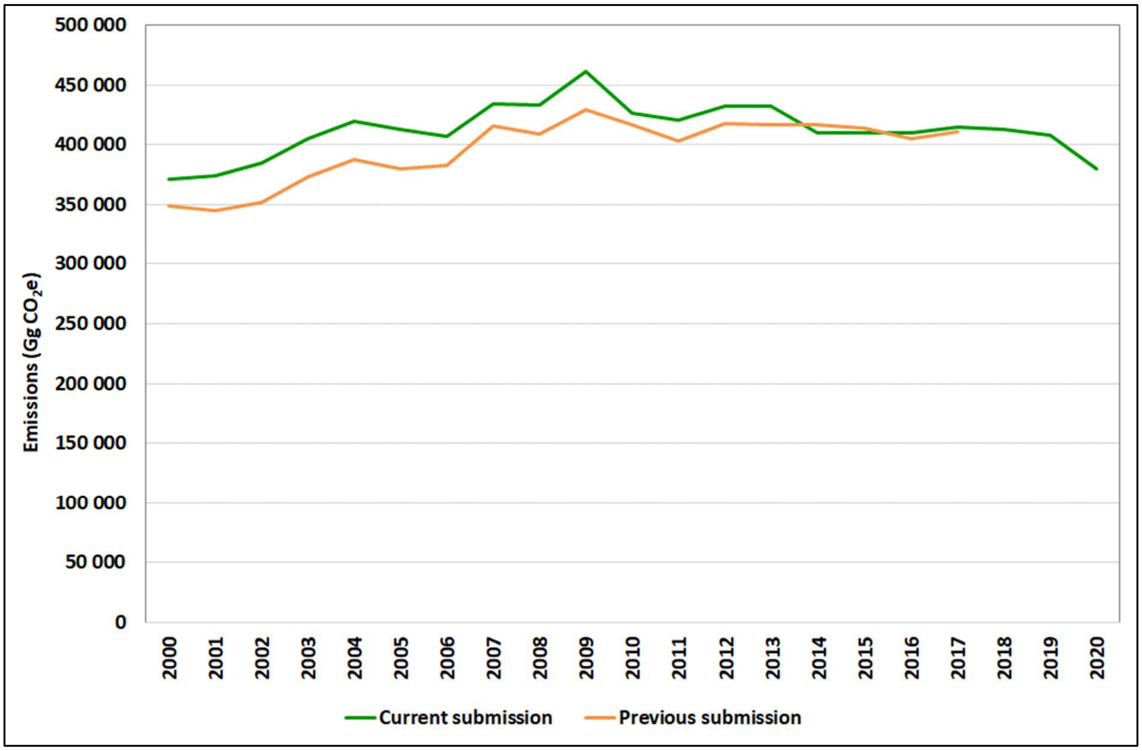

Figure 3.9: Recalculations for the Energy sector between 2000 and 2020.

3.1.4 Key categories in the energy sector

The key categories for the *Energy* sector as determined by the level (L) and trend (T) assessment are shown in Table 3.8.

Table 3.8: Key categories identified in the Energy sector.

IPCC code	IPCC Category	GHG	Criteria
1A1a	Electricity and Heat Production (solid)	CO_2	L, T
1A1a	Electricity and Heat Production (liquid)	CO_2	L, T
1A1b	Petroleum Refining (gas)	CO_2	L, T
1A1c	Manufacture of Solid Fuels and Other Energy Industries (liquid)	CO_2	L, T
1A2	Manufacturing Industries and Construction (solid)	CO_2	L, T
1A2	Manufacturing Industries and Construction (liquid)	CO_2	L, T
1A2	Manufacturing Industries and Construction (gas)	CO_2	L, T
1A3b	Road Transport (liquid)	CO_2	L, T
1A3d	Water-Borne Navigation (liquid)	CO_2	T

1A4a	Commercial/Institutional (solid)	CO_2	T
1A4b	Residential (solid)	CO_2	T
1A4b	Residential (liquid)	CO_2	T
1A4c	Agriculture/Forestry/Fishing/Fish Farms (liquid)	CO_2	L, T
1A5a	Stationary (solid)	CO_2	L, T
1B1a	Coal mining and handling	CH_4	L
1B3	Other Emissions from Energy Production	CO_2	L, T

3.1.5 Planned improvements and recommendations

Improvements planned for the next inventory are:

(i) Two studies, that were conducted to improve the emission factors for fuels used in industry, were completed in 2022. This is to move from Tier 1 to Tier 2 in those applicable industries. The emission factors will be used in the next inventory. These studies are:
   1) Development of CO_2 emission factors for alternative fuels (mainly waste fuels such as tyres) used within the cement production industry.
   2) The second study is planned to look at country specific CO_2 emission factors for gaseous and liquid fuels used in stationary application.

(ii) There is a study that is being conducted to improve the emission factors for solid fuels used in industry. This is to move from Tier 1 to Tier 2 in those applicable industries. The resulting emission factors will be incorporated in future inventories.

(iii) There is currently another study under the GHG improvement programme that is trying to improve the activity data for fuel wood consumption in different sub-sectors.

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

(v) Time-series will be extended back to 1990 over the next few years, but this will likely only be available in the 1st BTR.

3.2 Fuel combustion (1.A)

3.2.1 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

3.2.2 Methodological issues

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:

$$(E)_{ij} = Q_i \times EC_i \times EF_{ij} / 1\,000\,000$$

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 3.10)
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 3.11)
A factor of 1 000 000 (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.

3.2.2.1 Activity data

The required activity data and the main data providers for each subsector are provided in Table 3.9. The net calorific values for converting fuel quantities into energy units for solid, liquid and gaseous fuels are provided in Table 3. 10 and are taken from Technical Guidelines for Monitoring, Reporting and Verification of Greenhouse Gas Emissions by Industry, DEA (2017).

Table 3.9: Data sources for the fuel combustion subcategory.

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

Sub-category	Activity data	Activity data sources
	LPG consumption	Energy balance (DMRE)
	Sub-bituminous coal consumption	Energy balance (DMRE)
	Other fuel consumption	Energy balance (DMRE)
Agriculture/forestry/fishing/fish farms	Other kerosene consumption	Energy balance (DMRE)
	Gas/diesel oil consumption	Energy balance (DMRE)
	Other fuel consumption	Energy balance (DMRE)
Stationary non-specified	Fuel consumption	Energy balance (DMRE)

Table 3. 10: Net calorific values for solid, liquid and gaseous fuels as provided by the South African Petroleum Industry Association.

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

3.2.2.2 Emission factors

Table 3.11 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, 2017).

Table 3.11: Emission factors for stationary combustion (solid, liquid, gaseous and other fuels).

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

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)
	Coke	Coke oven coke and lignite coke	107 000		1		1.5	
	Coke	Gas coke	107 000		1		0.1	
	Coal tar		80 700		1		1.5	
	Derived gases	Gas works gas	44 400		1		0.1	
	Derived gases	Coke oven gas	44 400		1		0.1	
	Derived gases	Blast furnace gas	260 000		1		0.1	
	Derived gases	Oxygen steel furnace gas	182 000		1		0.1	
Gaseous fuels	Natural gas		56 100		1		0.1	
Other fuels								
Other fossil fuels	Municipal wastes (non-biomass fraction)		91 700		30		4	
Other fossil fuels	Industrial wastes		143 000		30		4	
Other fossil fuels	Waste oils		73 300		30		4	
Other fossil fuels	Peat		106 000		1		1.5	
Solid biofuels	Wood/wood waste		112 000		30		4	
Solid biofuels	Sulphite lyes (Black liquor)		95 300		3		2	
Solid biofuels	Other primary solid biomass		100 000		30		4	
Solid biofuels	Charcoal		112 000		30		4	
Liquid biofuels	Biogasoline		70 800		3		0.6	
Liquid biofuels	Biodiesels		70 800		3		0.6	
Liquid biofuels	Other liquid biofuels		79 600		3		0.6	
Gas biomass	Landfill gas		54 600		1		0.1	
Gas biomass	Sludge gas		54 600		1		0.1	
Gas biomass	Other biogas		54 600		1		0.1	

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)
Other non-fossil fuels	**Municipal wastes (biomass fraction)**	100 000		30		4	

3.2.3 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 from combustion of mainly fossil fuels. The Reference Approach was applied on the basis of relatively easily available energy supply statistics. It is good practice to apply both a Sectoral Approach and the Reference Approach to estimate a country's 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 (energy balance data for 2019 to 2020 was not available at the time of publication) and the CO_2 emissions were always higher using the Reference Approach (Figure 3.10). The difference in CO_2 emissions using the reference and sectoral approach was 19 % and 14 % for the years 2017 and 2018, respectively. The largest differences were seen in the solid fuels, where consumption is consistently higher with the Reference Approach (Appendix D). Allocation of solid fuels between energy use, non-energy use as well as use for synthetic fuels production remains one of the key drivers of the differences observed between the two datasets. The opposite is true for liquid fuels, with the Sectoral Approach showing higher values (Appendix D), whereas for gaseous fuels the consumption data is higher with the Reference Approach (Appendix D). 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.
- NCVs used in the Sectoral Approach differ from those used in the Reference Approach. In power generation, NCVs in the sectoral approach vary over the 2000-2016 time series based on the information provided by industry.
- Activity data on liquid fuels in the Sectoral Approach particularly for energy industries is sourced directly from the companies involved and has been reconciled with other publicly available datasets.
- Inconsistencies on the sources of activity data within the time series and in some cases the application of extrapolation.
- The misallocation of the quantities of fuels used for conversion into derived products (other than power or heat) or quantities combusted in the energy sector.
- Simplifications in the Reference Approach. There are small quantities of carbon which should be included in the Reference Approach because their emissions fall under fuel combustion. These quantities have been excluded where the flows are small or not represented by a major statistic available within energy data.

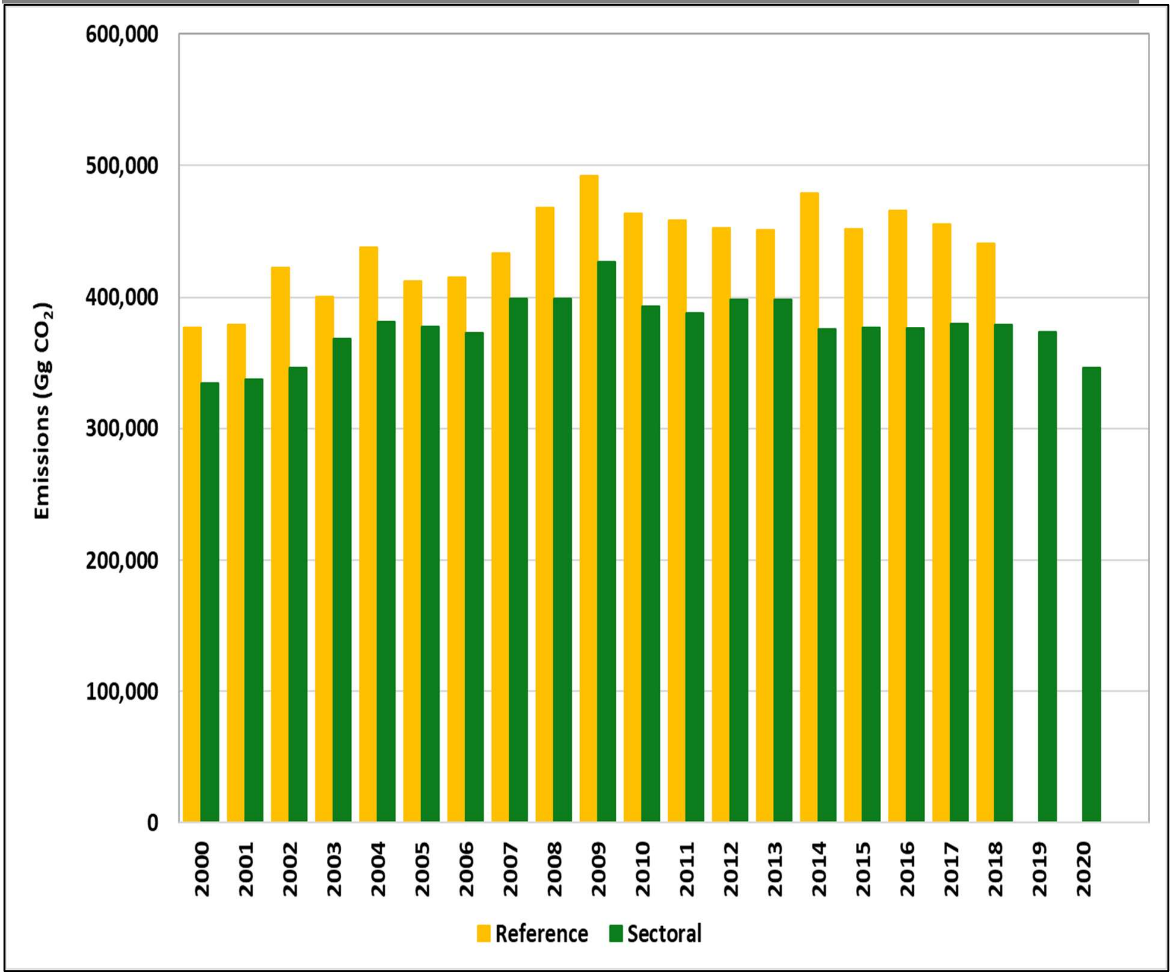

Figure 3.10: Comparisons between the reference and sectoral approach of determining the CO_2 emissions for the energy sector for South Africa.

3.2.4 International bunker fuels

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*.

3.2.5 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.

3.2.6 Energy industries (1.A.1)

3.2.6.1 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 60% of electricity to various sectors, such as the industrial, commercial, agricultural and residential sectors. Forty percent of the electricity distribution is done by the municipalities.

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 224 366 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).

3.2.6.2 Methodological issues

Electricity generation (1.A.1.a)

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.

Petrol refining (1.A.1.b)

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

Manufacture of solid fuels and other energy industries (1.A.1.c)

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

Electricity generation (1.A.1.a)

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 2020. 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 3.12. 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 3.12). The energy consumed to produce electricity dropped by 5.5% between 2019 and 2020.

Table 3.12: Trend in fuel consumption for the various categories in the energy industry sector, 2000 – 2020.

	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

	Public electricity producer	Auto electricity producer	Petroleum refining
	Fuel consumption (TJ)		
2016	2 259 087	2 133	50 731
2017	2 233 426	7 562	50 345
2018	2 314 985	6 750	50 147
2019	2 291 699	17 079	49 952
2020	2 166 339	16 448	37 154

Petroleum refining (1.A.1.b)

Activity data on the fuel consumed by refineries is sourced directly from refineries (Table 3.12). 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. The energy used in refining dropped by 26% between 2019 and 2020.

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 3.11.

3.2.6.3 Uncertainties and time-series consistency

Activity data uncertainty

Regarding 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 3.13).

Emission factor uncertainty

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 factors 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.

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. From 2017 to 2020, the data was in calendar year as per the reporting requirements.

Table 3.13: Uncertainty for South Africa's fuel combustion emission estimates.

Gas	Sectors	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
CH_4	1A1 Energy industries – liquid fuels	5	IPCC 2006	75	IPCC 2006
	1A1 Energy industries – solid 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

3.2.6.4 Category specific QA/QC and verification

Consumption data from refineries was checked against the energy balance data and where there seems to be over-estimation of emissions, the data from refineries was queried and re-submissions were requested.

3.2.6.5 Category specific recalculations

No recalculations are conducted for this category.

3.2.6.6 Category specific planned improvements

Main activity electricity and heat production (1.A.1.a)

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:

- 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.

Petroleum refining (1.A.1.b)

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.

Manufacture of solid fuels and other energy industries (1.A.1.c)

To improve the estimation of GHG emissions from the *manufacture of solid fuels and energy industries*, information from the SAGERS will be used to estimate the emissions from the sector. That would improve the time series and consistency of the data.

3.2.7 Manufacturing industries and construction (1.A.2)

3.2.7.1 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.

3.2.7.2 Methodological issues

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 and Tier 2methodology was applied. The fuel consumption data within the Energy balance by the individual sub-sectors does not have a complete time series, therefore a decision was made to report this sector at an aggregated level, which reduces uncertainty when applying data amputation techniques to fill up the data for missing years.

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, 2019) 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. 10 shows the total fuel consumption in this category for the period 2000 to 2020. NCV's are provided in Table 3. 10.

Table 3.14: Fuel consumption (TJ) in the manufacturing industries and construction category, 2000 – 2020

Year	Other Kerosene	Gas/ Diesel Oil	Residual Fuel Oil	LPG	Bitumen	Sub-Bituminous Coal	Natural Gas	Gas Works	Biomass	Total
	(TJ)									
2000	698	28 234	191	3 870	5 053	202 749	39 532	91 402	98 619	470 347
2001	640	29 499	194	3 814	5 584	204 130	41 241	88 807	96 379	470 288
2002	606	30 955	187	3 719	6 161	210 505	43 048	90 788	94 316	480 286
2003	626	32 915	185	3 566	6 276	217 464	48 749	92 373	92 839	494 994
2004	649	34 769	199	3 367	6 382	217 134	50 361	93 641	91 268	497 770
2005	619	36 784	171	3 133	7 038	205 238	53 166	78 425	89 946	474 520
2006	599	36 015	166	2 869	7 245	210 508	56 038	98 712	87 245	499 398
2007	547	38 199	164	2 640	7 707	221 647	58 908	98 712	84 924	513 449
2008	589	50 628	164	2 431	7 475	236 878	61 778	98 712	82 620	541 276
2009	504	44 769	207	2 257	7 602	341 078	69 749	17 564	80 026	563 757
2010	594	39 725	219	2 253	8 044	294 415	76 984	16 079	74 742	513 056
2011	594	48 835	167	2 339	7 536	233 387	76 576	15 816	72 084	457 335
2012	549	52 164	198	2 378	9 807	171 402	75 755	15 058	73 909	401 220
2013	501	53 346	186	2 455	9 095	152 795	75 443	16 631	76 667	387 120
2014	539	62 475	186	2 540	9 384	134 189	77 164	20 382	74 285	381 144
2015	419	73 652	186	2 623	9 673	236 467	74 589	21 048	70 504	489 162
2016	531	46 981	186	2 705	9 963	352 754	77 476	19 808	70 642	581 045
2017	642	55 637	187	2 785	10 252	206 062	81 675	21 876	77 820	456 936
2018	643	68 247	188	2 735	10 297	223 113	93 423	23 214	76 796	498 656
2019	645	61 689	189	2 685	10 342	221 862	96 747	23 224	75 785	493 168
2020	289	55 865	224	2 426	10 387	220 124	99 832	24 246	74 788	488 182

Emission factors

Emission factors are provided in Table 3.11. A country-specific emission factor 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.

3.2.7.3 Uncertainties and time series consistency

The time-series is consistent, and the uncertainties are provided in Table 3.15.

Table 3.15: Uncertainty for South Africa's Manufacturing industries and construction emission estimates.

Gas	Sectors	Activity data uncertainty		Emission factor uncertainty	
		%	Source	%	Source
CO_2	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
CH_4	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
N_2O	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

Activity data uncertainty

Uncertainty associated with activity data based on less-developed statistical systems was in the range of 10 to 15%. Activity data sourced on fuel consumption was complete and hence there was no need to apply IPCC methodologies for filling data gaps.

Emission factor uncertainty

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.

Time-series consistency

There are no time-series inconsistencies for this category. To ensure time-series consistency in this source category the same emission factors were used for the complete time-series estimates.

3.2.7.4 Category specific QA/QC and verification

The national energy balances and the digest of energy statistics were used to verify fuel consumption data reported in the SAMI report.

3.2.7.5 Category-specific recalculations

No recalculations were performed for this category.

3.2.7.6 Category-specific planned improvements

In future, facility-level data needs to be sourced and country-specific emission factors have to be developed in order to move towards a Tier 2 methodology. The reliance on energy balances and other publications for the compilation of emissions needs to be reduced by sourcing facility-level activity data. The industry reporting required by the new GHG regulation should assist in providing some of this more detailed data. Improved detail would also help to reduce the uncertainty associated with the activity data.

3.2.8 Transport (1.A.3)

3.2.8.1 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 (NO_x, CO, SO_x, NMVOCs, particulates, and trace components). Civil aviation data were sourced from both domestic and international aircrafts, including departures and arrivals. That also included civil commercial use of airplanes, scheduled and charter traffic for passengers and freight, 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 includes 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 period. Data splicing techniques described in the 2006 IPCC Guidelines were used to extrapolate fuel consumption activity data to the period 2013-2017. Previously, emissions related to water-borne navigation as well as international navigation were assumed to be included under the category *other sectors*.

3.2.8.2 Methodological issues

A Tier 1 approach was applied for this subsector.

Activity data

Civil aviation (1.A.3.a)

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 was then used to quantify the actual fuel consumption for both international and domestic aviation.

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 aviation gasoline and jet kerosene.

Road transportation (1.A.3.b)

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

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

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

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

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

Road transport was responsible for the most fuel consumed in the transport sector (93% in 2020). Gas/diesel contributed Motor gas contributed 54% of the *road transport* fuel consumption in 2020, while motor gas contributed 46%. 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 3.11).

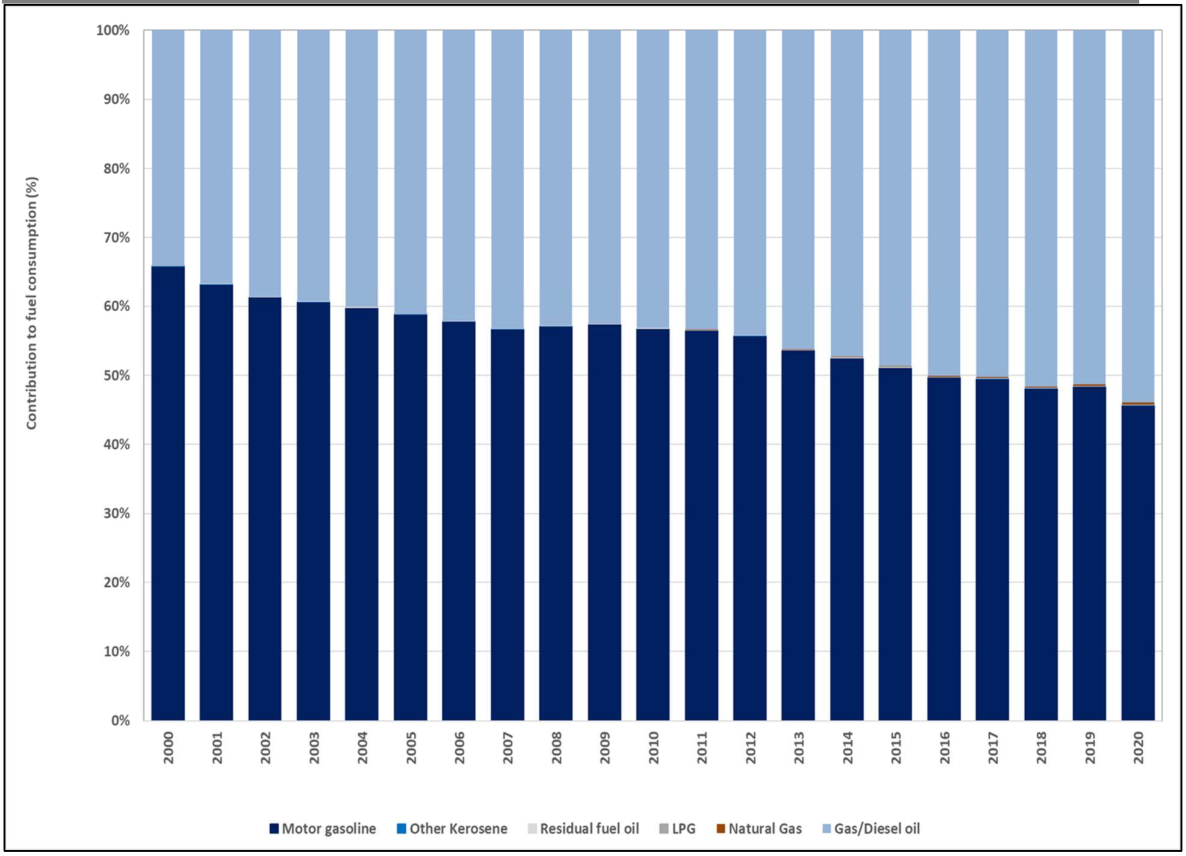

Figure 3.11: Percentage contribution of the various fuel types to fuel consumption in the road transport category (1A3b), 2000 – 2020.

Railways (1.A.3.c)

The national railway operator, Transnet, provided activity data for railways for the period 2000-2020.

Water-borne navigation (1.A.3.d)

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 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).

3.2.8.3 Uncertainties and time series consistency

Civil aviation (1.A.3.a)

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

Road transport (1.A.3.b)

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.

Railways (1.A.3.c)

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.

Water-borne navigation (1.A.3.d)

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 on 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%.

Table 3.16: Uncertainty for South Africa's transport emission estimates.

Gas	Sectors	Activity data uncertainty		Emission factor uncertainty	
		%	Source	%	Source
CO_2	1A3a Civil aviation – liquid fuels	5	IPCC 2006	1.5	IPCC 2006
	1A3b Railways liquid fuels	5	IPCC 2006	5	IPCC 2006
	1A3d Waterborne navigation – liquid fuels	5	IPCC 2006	5	IPCC 2006
CH_4	1A3a Civil aviation – liquid fuels	5	IPCC 2006	50	IPCC 2006
	1A3b Railways – liquid fuels	5	IPCC 2006	9	IPCC 2006
	1A3d Waterborne navigation – liquid fuels	5	IPCC 2006	50	IPCC 2006
N_2O	1A3a Civil aviation – liquid fuels	5	IPCC 2006	50	IPCC 2006
	1A3b Railways - liquid fuels	5	IPCC 2006	72	IPCC 2006
	1A3d Waterborne navigation – liquid fuels	5	IPCC 2006	50	IPCC 2006

Time-series consistency

The time-series is complete for this subsector. All uncertainties are provided in Table 3.16.

3.2.8.4 Category specific QA/QC and verification

All activity data was compared to the energy balance data.

3.2.8.5 Category-specific recalculations

No recalculations were performed for this category.

3.2.8.6 Category-specific planned improvements

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.

Civil aviation (1.A.3.a)

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.

Road transport (1.A.3.b)

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.

Railways (1.A.3.c)

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.

Water-borne navigation (1.A.3.d)

No further improvements are planned for this subcategory.

3.2.9 Other sectors (1.A.4)

3.2.9.1 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, motor gasoline, LPG and natural gas. In the residential sector there is also charcoal and other solid biomass.

3.2.9.2 Methodological issues

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

Activity data

Commercial/Institutional (1.A.4.a)

Data on fuel consumption in the commercial/institutional buildings category was sourced from the DMRE's energy balance reports, the DMRE's SAMI report (solid fuels and natural gas) and SAPIA (liquid fuels) for 2000 to 2018 as well as the Fuel Consumption Study (DFFE, 2019). NCVs are provided in Table 3. 10. Fuels included are residual fuel oil, other kerosene, gas/diesel oil, sub-bituminous coal, LPG and natural gas (Figure 3.12).

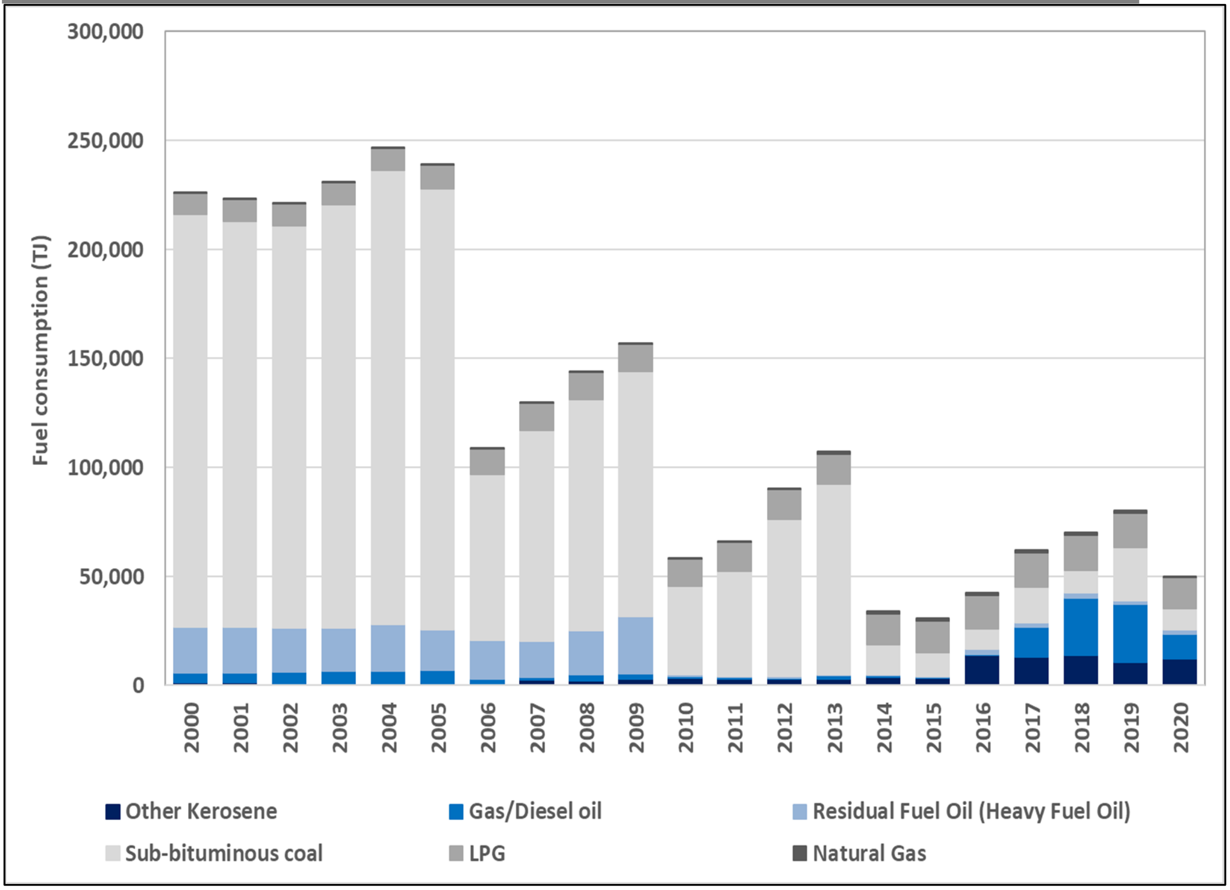

Figure 3.12: Fuel consumption in the commercial/institutional category, 2000 – 2020.

Residential (1.A.4.b)

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 (DEFF, 2020), 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. NCVs are given in Table 3. 10.

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 3.13) therefore the biomass fuel source declined. Domestic coal consumption increases between 2000 and 2009, decreasing in 2010 and increasing again to 2013. After this the coal consumption was minimal.

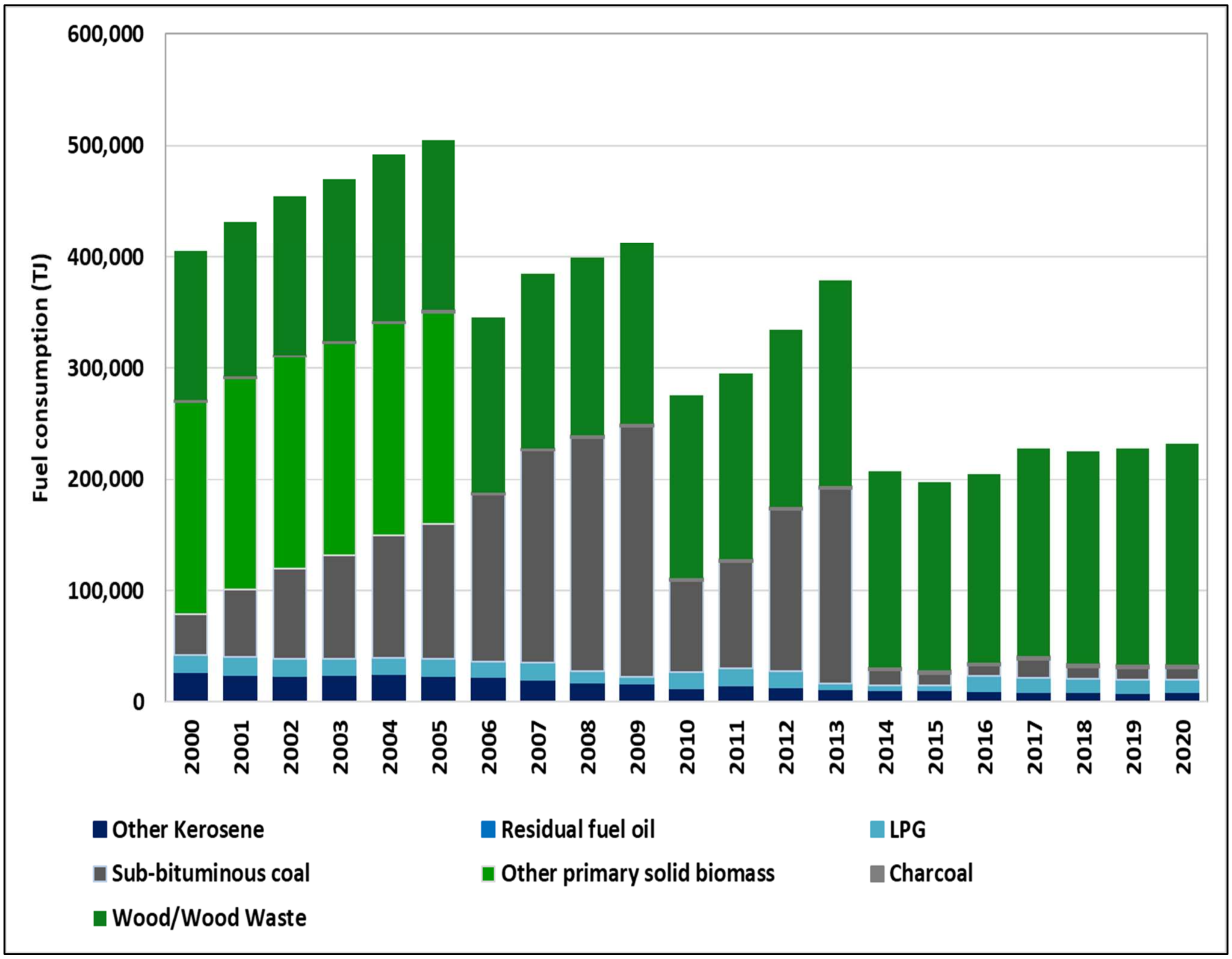

Figure 3.13: Trend in fuel consumption in the residential category, 2000 – 2020.

Agriculture/Forestry/Fishing/Fish farms (1.A.4.c)

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 2020. NCVs are provided in Table 3. 10.

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 3.14).

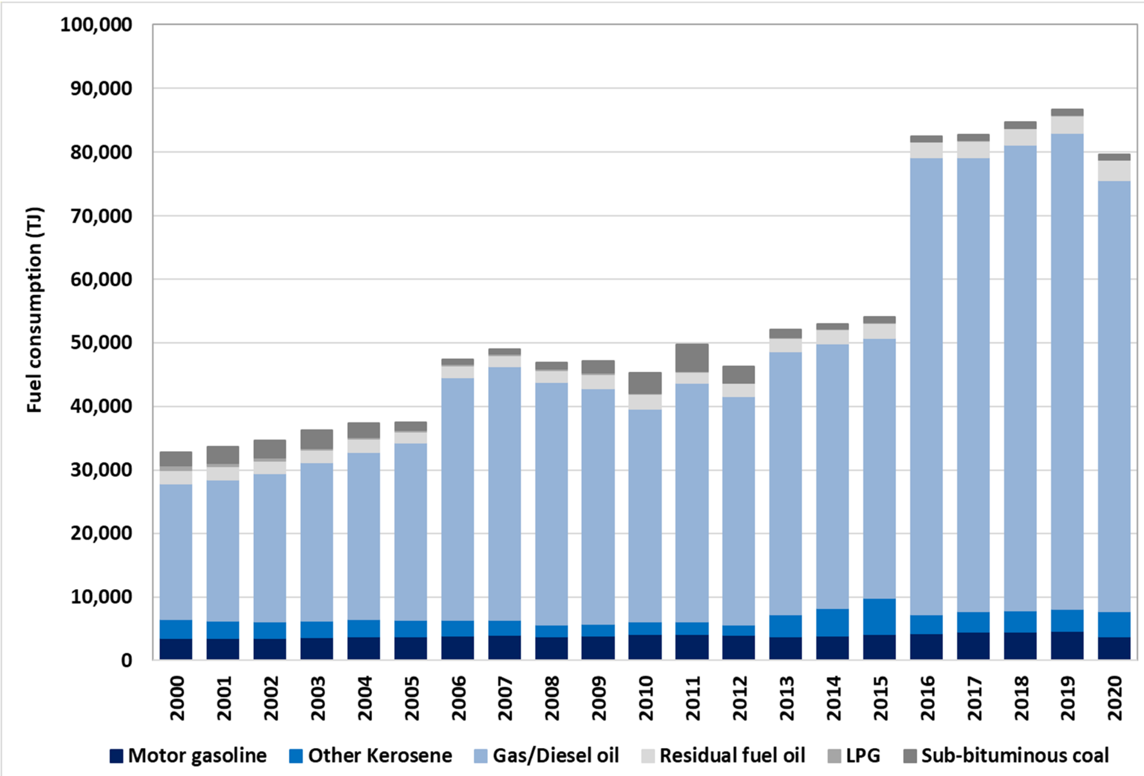

Figure 3.14: Trend in fuel consumption in the agriculture/forestry/fishing category, 2000 – 2020.

Emission factors

A country specific emission factor for CO_2 for sub-bituminous coal was applied (Table 3.11). For all other fuels the IPCC 2006 Guideline default emission factors were used.

3.2.9.3 Uncertainties and time series consistency

Activity data uncertainty

The data for this category for non-gaseous fuels comes from the Energy Balance of the DMRE. For the gaseous fuels the data was sourced from the Fuel Consumption Study (DFFE, 2019). The data is not published with uncertainty information and as a result the default uncertainty from the IPCC 2006 Guidelines were used.

Emission factor uncertainty

The uncertainties in CO_2 emissions are relatively low in fossil fuel combustion. These emission factors are determined by the carbon content of the fuel. Emission factors for CH_4 and more specifically N_2O are highly uncertain. The uncertainty on the CH_4 emission factor is 50 to 150%, while for N_2O it is an order of magnitude higher. This high uncertainty is due to the lack of relevant and accurate measurements and/or insufficient understanding of the emission generating process. The default uncertainty for emission factors from the IPCC 2006 Guidelines were used.

Table 3.17: Uncertainty for South Africa's Other sectors emission estimates.

Gas	Sectors	Activity data uncertainty		Emission factor uncertainty	
		%	Source	%	Source
CO_2	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
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
N_2O	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

Time-series consistency

There is no time-series inconsistency in the data.

3.2.9.4 Category specific QA/QC and verification

Consumption data determined from SAMI and SAPIA reports were compared to the energy balance data. The data from specific industries was perceived to be more accurate than the data from the energy balance.

3.2.9.5 Category-specific recalculations

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

3.2.9.6 Category-specific planned improvements

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.

Commercial/ institutional (1.A.4.a)

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.

Residential (1.A.4.b)

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.

Agriculture/ forestry/ fishing/ fish farms (1.A.4.c)

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.

3.2.10 Non-specified sectors (1.A.5)

3.2.10.1 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. In comparison to previous inventory reports, where most of the coal was allocated in the commercial sector, in this inventory, the coal that is not accounted for in other sectors was allocated here as per the Energy Balance from the DMRE.

3.2.10.2 Methodological issues

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. 10 provides the NCVs. The coal consumption was taken from SAMI Reports (Department of Mineral Resources, 2017) while the diesel consumption was taken from the DMRE’s energy balances.

Emission factors

IPCC 2006 default emission factor are shown in Table 3.11.

3.2.10.3 Uncertainties and time series consistency

Activity data uncertainty

The data for 1A5 comes solely from the Energy Balance of the DMRE. The data is not published with uncertainty information and as a result the default uncertainty from the IPCC 2006 Guidelines were used.

Emission factor uncertainty

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.

Time-series consistency

There is limited time-series uncertainty as data was sourced from 1 source.

3.2.10.4 Category specific QA/QC and verification

Data from SAPIA was compared to the energy balance data. In cases where the energy balance differed with the industry specific data (SAPIA), SAPIA data was used over the data reported in the energy balance.

3.2.10.5 Category-specific recalculations

Due to new allocation of coal use from *Commercial* to *Non-specified* category, a recalculation occurred for this category. Emission estimates are on average 350% (or 14 365 Gg CO_2e) higher than estimated in the previous inventory.

3.2.10.6 Category-specific planned improvements

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 Fugitive emissions from fuels (1.B)

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 released 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).

3.3.1 Solid fuels (1.B.1)

3.3.1.1 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 the coal breakage stage.
- *Low-temperature oxidation:* Emissions are released when coal is exposed to oxygen in air; the coal oxidizes to slowly produce CO_2.
- *Uncontrolled combustion:* Uncontrolled combustion occurs when heat produced by low-temperature oxidation is trapped. This type of combustion is characterized by rapid reactions, sometimes visible flames, and rapid CO_2 formation. It may be anthropogenic or occur naturally.

3.3.1.2 Methodological issues

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.

Activity data

Data on coal production was obtained from the South Africa's Mineral Industry (SAMI), a report compiled by the DMRE (DMR, 2017) and Coaltech (Table 3.18).

Table 3.18: Amount of coal produced from opencast and underground mining, 2000 – 2020.

	Opencast	Underground
	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
2018	125 037 631	205 735 169
2019	124 172 907	211 010 145
2020	123 314 162	216 420 371

Emission factors

Country specific emission factors were sourced from the study undertaken by the local coal research institute (DME, 2002) (South African Institute of Mining and Metallurgy Journal 105(8) August 2005:483-490 Methane release from South African coal mines.). This study showed that emission factors for the South African coal mining industry are significantly lower than the IPCC default emission factors (Table 3. 19).

The 2006 IPCC Guidelines do not provide CO_2 emission factors related to the low-temperature oxidation of coal; however, South Africa has developed country-specific CO_2 emission factors for this and, therefore, has estimated emissions related to this activity.

Table 3. 19: Emission factors for coal mining and handling.

Mining method	Activity	GHG	Emission factor (m^3/tonne)	
			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

3.3.1.3 Uncertainties and time series consistency

Activity data uncertainty

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 3.20.

Emission factor uncertainty

The default IPCC uncertainty for coal mining is used and the values are presented in Table 3.20.

Table 3.20: Uncertainty for South Africa's fugitive emissions estimates.

Gas	Mining Method	Sub-category	Activity data uncertainty		Emission factor uncertainty	
			%	Source	%	Source
CO_2	Underground mining	1B1ai1 Mining	10	IPCC 2006	63	IPCC 2006
		1B1ai2 Post-mining seam gas emissions	10	IPCC 2006	50	IPCC 2006
	Surface mining	1B1ai1 Mining	10	IPCC 2006	200	IPCC 2006
		1B1ai2 Post-mining seam gas emissions	10	IPCC 2006	50	IPCC 2006
CH_4	Underground mining	1B1ai1 Mining	10	IPCC 2006	63	IPCC 2006
		1B1ai2 Post-mining seam gas emissions	10	IPCC 2006	50	IPCC 2006
	Surface mining	1B1ai1 Mining	10	IPCC 2006	200	IPCC 2006
		1B1ai2 Post-mining seam gas emissions	10	IPCC 2006	50	IPCC 2006

Time-series consistency

The data comes from South African Mineral's Industry reports and since it is from 1 source, the data has time series consistency.

3.3.1.4 Category specific QA/QC and verification

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

3.3.1.5 Category-specific recalculations

No recalculations have been undertaken for this category.

3.3.1.6 Category-specific planned improvements

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

3.3.2 Oil and natural gas (1.B.2)

3.3.2.1 Category description

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

3.3.2.2 Methodological issues

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

Activity data

Emissions data is supplied by refineries only, and not the activity data. Data on oil and natural gas emissions for 2000 to 2012 were obtained directly from refineries and, to a lesser extent, from the energy digest reports (DoE, 2009a). Data was not available for the years 2013 to 2017 therefore the 2012 estimates were carried through to 2017. This data will be updated in the next submission using SAGERS data from 2019 onwards.

Emission factors

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

3.3.2.3 Uncertainties 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 3.20. The default IPCC uncertainty ranges are used for this category.

Time-series consistency

The data has time-series consistency.

3.3.2.4 Category specific QA/QC and verification

No category specific checks were undertaken.

3.3.2.5 Category-specific recalculations

No recalculations were conducted for this category.

3.3.2.6 Category-specific planned improvements

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

3.3.3 Other emissions from energy production (1.B.3)

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

3.3.3.2 Methodological issues

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

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.

3.3.3.3 Uncertainties and time series consistency

Activity data

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.

Emission factors

Tier 3 emissions estimates are used in this category as the data solely comes from the SAGERS reporting programme.

Time-series consistency

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. The data is internally consistent because for the entire time series (2000 – 2020), the same data source is used specifically for all sectors that are not reporting to the SAGERS data collection system.

3.3.3.4 Category specific QA/QC and verification

The department reviews the material balance and measurement data supplied by facilities.

3.3.3.5 Category-specific recalculations

No recalculations were done for this sub-sector.

3.3.3.6 Category-specific planned improvements

No improvements are planned for this section.

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Chapter 4: Industrial Processes and Product Use (IPPU)

The IPPU sector includes non-energy related emissions from industrial processing plants. The main emission sources are released from industrial processes that chemically or physically transform raw materials and thereby release GHGs, (e.g., ammonia products manufactured from fossil fuels), GHG emissions released during these processes are CO_2, CH_4, N_2O, HFCs and PFCs. Emissions from the following industrial processes are included in South Africa's IPPU sector:

- Cement Production
- Lime Production
- Glass Production
- Other Product Uses of Carbonates
- Ammonia Production
- Nitric Acid Production
- Carbide Production
- Titanium Dioxide Production
- Soda Ash Production
- Petrochemical and carbon black production
- Hydrogen Production
- Other Chemicals
- Production of steel from iron and scrap steel
- Ferroalloys Production
- Aluminium Production
- Lead Production
- Zinc Production
- Lubricant Use
- Paraffin Wax Use
- Product Uses as Substitutes for Ozone Depleting Substances

HFCs and PFCs are used in many products and in refrigeration and air conditioning equipment. PFCs are also emitted because 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 ferroalloys.

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. The Covid 19 pandemic caused economic growth to decline during 2020, especially during the second half of the year when lockdown measures where stricter.

4.1.1 Shares and trends in emissions

The *IPPU* sector produces CO_2 emissions (74.6%), fluorinated gases (19.4%) and smaller amounts of CH_4 (2.3%) and N_2O (3.3%) (Table 4.1). Carbon dioxide and any other emissions from combustion of fuels in these industries are reported under the *energy* sector.

In 2020 the IPPU sector produced 25 486 Gg CO_2e which is 5.4% of South Africa's emission (excl. FOLU). The largest source category is the *metal industry* category. which contributes 48% 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 3 853 Gg CO_2 (31.5%) and 7 069 Gg CO_2 (57.8%) respectively to the total metal industry CO_2 emissions.

The *mineral industry* and the *Product used as substitutes for ozone depleting substances* subsectors contribute 18.7% and 19.4%, respectively, to the IPPU sector emissions (Table 4. 1).

Carbide production, carbon black production, iron and steel production, ferroalloy production and *ammonia production* produce 576 Gg CO_2e of CH_4, while *chemical industries* are estimated to produce 836 Gg CO_2e of N_2O.

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

Table 4. 1: Summary of the estimated emissions from the IPPU sector in 2020 for South Africa.

GHG source categories	CO_2	CH_4	N_2O	HFCs	PFCs	Total
	Gg CO_2e					
2.IPPU	**19 021**	**576**	**836**	**4 933**	**120**	**25 486**
2.A Mineral industry	4 774	NA	NA	NA	NA	4 774
2.B Chemical industry	1 348	80	836	NA	NA	2 264
2.C Metal industry	11 604	496	NA	NA	120	12 220
2.D Non-energy products from fuels and solvents	1 295	NA	NA	NA	NA	1 295
2.E Electronic industry	NE	NE	NE	NE	NE	NE
2.F Product uses as substitute ODS	NA	NA	NA	4 933	NE	4 933
2.H Other	NE	NE	NE	NE	NE	NE

Numbers may not sum exactly due to rounding off.

Estimated emissions from the *IPPU* sector are 7 469 Gg CO_2e (22.7%) lower than the emissions in 2000 (Table 4. 2). There was a decline in *cement production*, *iron and steel production* and *paraffin wax usage* in 2020 compared to 2019. An increase in production was observed in *ferroalloy production* since 2019. There was an overall decrease in IPPU emissions in 2020 due to a decrease in the *mineral industry* of 18.4% since 2019. Emissions also decreased by 1.9% in the *metal industry* and 34.3% in subsector *non-energy products from fuels and solvent use*.

Figure 4. 1 shows that IPPU emissions increased by 18.0% between 2000 and 2006, after which there was a 13.6% decline to 2009. This decrease was mainly due to the global economic recession and the electricity crisis that occurred in South Africa during this period. In 2010 emissions increased by 6.9% due to an increase in the *metal industry* and *products used as substitutes for ozone depleting substances* subsectors. The economy was beginning to recover from the global recession. Another reason for the increase in GHG emissions in 2010 was that South Africa hosted the 2010 FIFA World Cup and as a result an increase in demand for commodities was experienced.

Emission increased between 2010 and 2016 due to an increase in production in the *mineral* and *metal industries*. There was an increase of 8.9% during this time within the *mineral industry* and an increase of 2.5% within the *metal industry*. The overall increase between 2010 and 2016 was 11.7%. Emissions decreased by 19.6% between 2016 and 2017 as demand in the *chemical* and *metal industries* dropped.

Emissions within the sector decreased further from 2017 to 2020 by 21.0% due to lower production demands in the *mineral*, *chemical* and *metal industries*. The economy in 2020 was further strained due to the COVID-19 pandemic and stringent lockdown regulations within South Africa. The *mineral industry* emissions decreased by 23.7% (1 483 Gg CO_2e) since 2017, and the *metal industry* showed an overall decrease of 40.0% (8 150 Gg CO_2e).

Table 4. 2: Summary of the change in emissions from the IPPU sector between 2000 and 2020.

GHG source categories	Emissions ($Gg CO_2e$)			Difference ($Gg CO_2e$)		Change (%)	
	2000	2017	2020	2000-2020	2017-2020	2000-2020	2017-2020
2.IPPU	**32 955**	**32 261**	**25 486**	**7 469**	**6 775**	**-22.7**	**-21.0**
2.A Mineral industry	**4 371**	**6 257**	**4 774**	**-403**	**1 483**	**9.2**	**-23.7**
2A1 Cement Production	3 870.6	5 246.4	3 795.7	74.9	1 450.7	-1.9	-27.7
2A2 Lime Production	426.1	890.0	714.9	-288.8	175.2	67.8	-19.7
2A3 Glass Production	74.4	120.9	154.5	-80.1	-33.6	107.8	27.8
2A4 Other Process Uses of Carbonates	*NE*	*NE*	109.3	-109.3	-109.3	-	-
2.B Chemical industry	**2 774**	**1 068**	**2 264**	**510**	**-1 196**	**-18.4**	**112.0**
2B1 Ammonia Production	C	C	C	C	C	C	C
2B2 Nitric Acid Production	C	C	C	C	C	C	C
2B5 Carbide Production	C	C	C	C	C	C	C
2B6 Titanium Production	C	C	C	C	C	C	C
2B7 Soda Ash Production	NE	NE	C	C	C	-	-
2B8f Petrochemical and Black Carbon Production	C	C	C	C	C	C	C
2B8g Hydrogen Production	NE	NE	C	C	C	-	-
2B10 Other	NE	NE	C	C	C	-	-
2.C Metal industry	**25 615**	**20 370**	**12 220**	**13 394**	**8 150**	**-52.3**	**-40.0**
2C1 Iron and Steel Production	15 334.4	7 722.2	3 853.0	11 481.2	3 869.1	-74.9	-50.1
2C2 Ferroalloy Production	8 082.4	11 329.5	6 977.6	1 103.5	4 260.5	-12.5	-37.6
2C3 Aluminium Production	2 074.4	1 256.2	1 255.2	819.3	1.0	-39.5	-0.1
2C5 Lead Production	15.1	9.6	6.6	8.5	3.1	-56.4	-31.8
2C6 Zinc Production	108.4	52.9	36.6	71.8	16.4	-66.2	-30.9
2.D Non-energy products from fuels and solvents	**196**	**531**	**1 295**	**-1 098.9**	**-764**	**560.9**	**144.0**
2D1 Lubricant Use	188.5	424.5	667.3	-478.9	-242.9	254.1	57.2
2D2 Paraffin Wax Use	7.4	106.2	627.4	-620.0	-521.2	8 337.8	490.9
2.E Electronic industry	*NE*	*NE*	*NE*	*NE*	*NE*	-	-
2.F Product uses as substitute ODS	*NE*	**4 035**	**4 933**	**-4 933**	**-898**	-	22.3
2F1 Refrigeration and Air Conditioning	*NE*	3 963.5	4 846.9	-4 846.9	-883.4	-	22.3
2F2 Foam Blowing Agents	*NE*	2.1	2.1	-2.1	0.0	-	0.0
2F3 Fire Protection	*NE*	51.1	65.9	-65.9	-14.8	-	29.0
2F4 Aerosols	*NE*	18.2	18.2	-18.2	0.0	-	0.0
2.G Other product manufacture and use	*NE*	*NE*	*NE*	*NE*	*NE*	-	-
2.H Other	*NE*	*NE*	*NE*	*NE*	*NE*	-	-

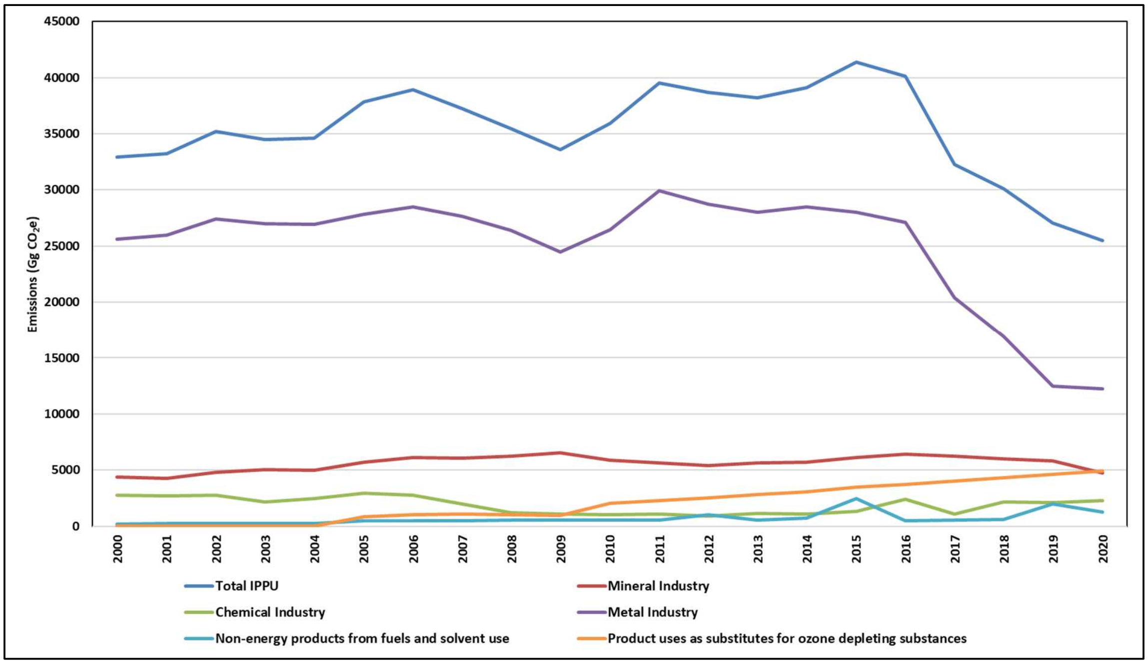

Figure 4. 1: Trend in South Africa's IPPU sector emissions, 2000 – 2020.

4.1.1.1 Mineral industry

In 2020 the *mineral industries* produced 4 774 Gg CO_2, which is 18.7% of the IPPU sector emissions. *Cement production* accounted for 79.5% of emissions from the *mineral industry*. All the emissions in this category were CO_2 emissions.

The emissions were 9.2% (403 Gg CO_2) higher than the 4 371 Gg CO_2 in 2000. There was a 49.9% increase in the *mineral industry* emissions between 2000 and 2009, after which emissions declined by 17.3% in 2012 (Figure 4. 2). The increase between 2000 and 2009 was due to increased emissions from *cement* and *lime production* as a result of economic growth during this period. In 2009 the South African economy went into recession and the GDP decreased by 1.8% in that year.

Cement demand in the residential market and construction industry in 2009/2010 decreased due to higher interest rates, increased inflation, and the introduction of the National Credit Act (DMR, 2010). Between 2012 and 2018 emissions increased again by 611.7 Gg CO_2 (11.3%) due to the increase in *cement production* and the inclusion of the *other process uses of carbonates* category in the 2018 inventory. Emissions declined between 2019 and 2020 due to a decrease in the *cement*, *lime,* and *glass production* categories. This also could be attributed to the COVID-19 pandemic and the stringent lockdown regulations within South Africa during 2020.

Cement production is the largest contributor to the emissions from this category (Figure 4. 2).

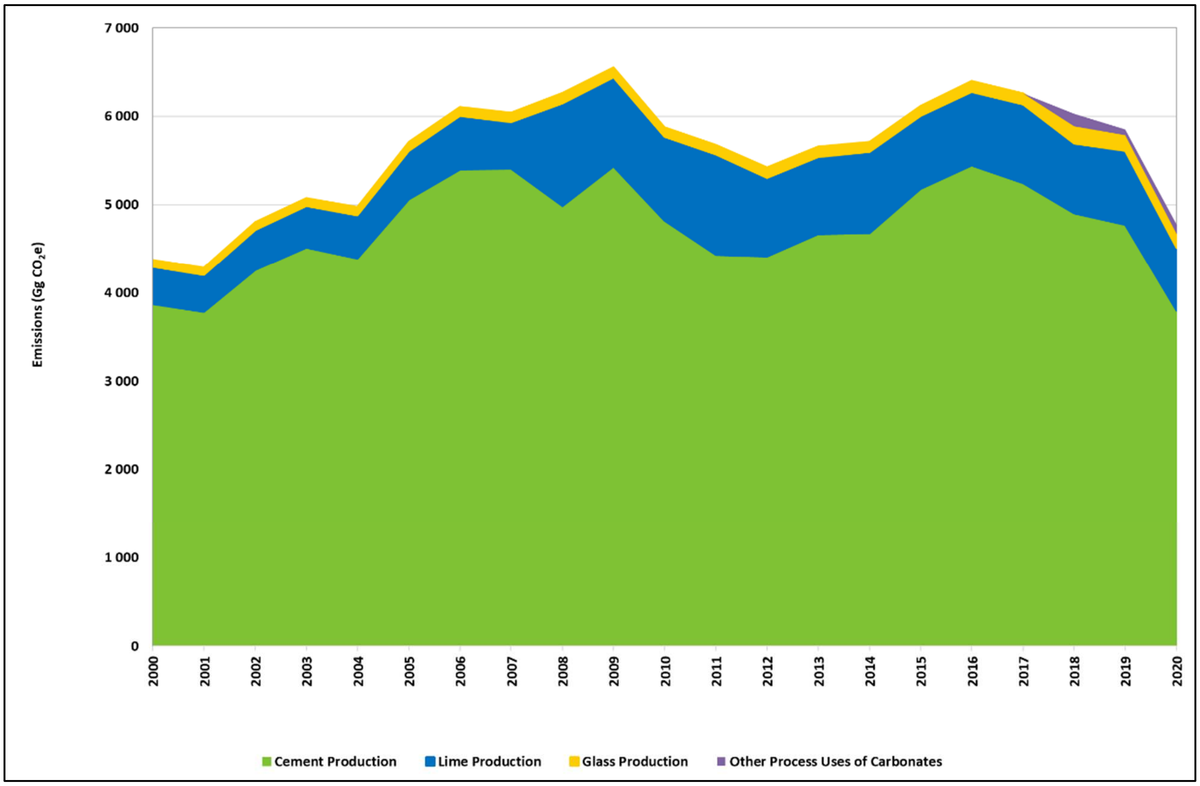

Figure 4. 2: Category contribution and trend for the mineral subsector, 2000 – 2020.

Cement production

Cement production was estimated to produce 3 796 Gg CO_2e in 2020, which is 14.9% of the *IPPU* sector emissions. Emissions were 74.9 Gg CO_2e (-1.9%) below the 2000 level (3 871 Gg CO_2e). Emissions in this subsector showed a 27.7% decrease (1 451 Gg CO_2e) since 2017.

Lime production

Lime production was estimated to produce 715 Gg CO_2 in 2020. which is 2.8% of the *IPPU* sector emissions. Emissions were 289 Gg CO_2 (67.8%) above the 2000 level (426 Gg CO_2). The fluctuations in *lime production* were directly linked to developments and investments in the steel and metallurgical industries. It should however be noted that there is an inconsistency in the time series with the data prior to 2008. Only pyrometallurgical quicklime and hydrated lime (only included lime for water purification) were included.

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 2020 is not only an increase due to emissions but also due to a change in the activity data. Furthermore, lime production reported for the 2018 inventory did not segregate quicklime from hydrated lime. Emissions for 2018 and 2019 were extrapolated for quicklime due to a lack of activity data received. The 2019 inventory also included the addition of dolomitic lime to the calculation, as previously this type of lime was not reported. Emissions in this subsector decreased by 19.7% (175 Gg CO_2e) since 2017.

Glass production

Glass production was estimated to produce 155 Gg CO_2 in 2020. which is 0.6% of the IPPU sector emissions. Emissions were 80.1 Gg CO_2e (107.8%) above the 2000 level (74 Gg CO_2). Emissions increased by 33.6 Gg CO_2e (27.8%) since 2017.

Other Process Uses of Carbonates (OPUC)

Emissions from the Other Process Uses of Carbonates (*OPUC)* were not reported in previous inventories due to a lack in activity data and emissions. *OPUC* emissions were estimated to produce 109 Gg CO_2 in 2020, which is 0.4% of the IPPU sector emissions. Emissions were estimated from 2018 for this category.

4.1.1.2 Chemical industry

The *chemical industries* were estimated to produce 2 263 Gg CO_2e in 2020, which is 8.9% of the IPPU sector emissions. The largest contributions are from *titanium dioxide production* and *nitric acid production*.

Emissions from the *chemical industries* decreased by 510 Gg CO_2e (18.4%) since 2000 (2 774 Gg CO_2e). Emissions from this subsector fluctuated considerably over the 20-year period (Figure 4. 1). Between 2000 and 2006 emissions fluctuated between 2 169 Gg CO_2e and 2 974 Gg CO_2e (Figure 4. 1) 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. *Hydrogen production* was included since 2018, while *silicon carbide* and *soda ash production* since 2019 and *other chemicals* since 2020.

4.1.1.3 Metal industry

The *metal industry* was estimated to produce 12 220 Gg CO_2e in 2020, which is 48% of the IPPU sector emissions. The largest contribution comes from *ferroalloy production* (7 069 Gg CO_2e or 57.8%), followed by *iron and steel production* (3 853 Gg CO_2e or 31.5%).

Emissions from the *metal industry* decreased by 13 394 Gg CO_2e (52.3%) below the 2000 emissions of 25 615 Gg CO_2e. Figure 4. 3 shows that emissions from the *metal industries* increased slowly (11.2%) between 2000 and 2006, after which there was a 14.1% decline to 24 471 Gg CO_2e in 2009. This decrease was evident in the *iron and steel production* emissions (26.1%) *aluminium production* emissions (40.7%) and *zinc production* emissions (17.6%).

Aluminium production emissions more than doubled between 2010 and 2011 due to increased PFC emissions (Figure 4. 3). In 2000 almost half (47.4%) of the *aluminium production* emissions were PFC emissions. This rose to 65.0% in 2011 and 2012 due to the closure of the Soderberg and Side-Worked Pre-Bake processes in 2009. The aluminium plants released large amounts of C_2F_4 and CF_4 during 2011 and 2012 due to inefficient operations (switching on and off at short notice) as they were used to control the electricity grid. In 2017 the contribution from PFCs to emissions from aluminium production emissions was 9.0%. In 2020 PFCs contribution rose to 9.6%.

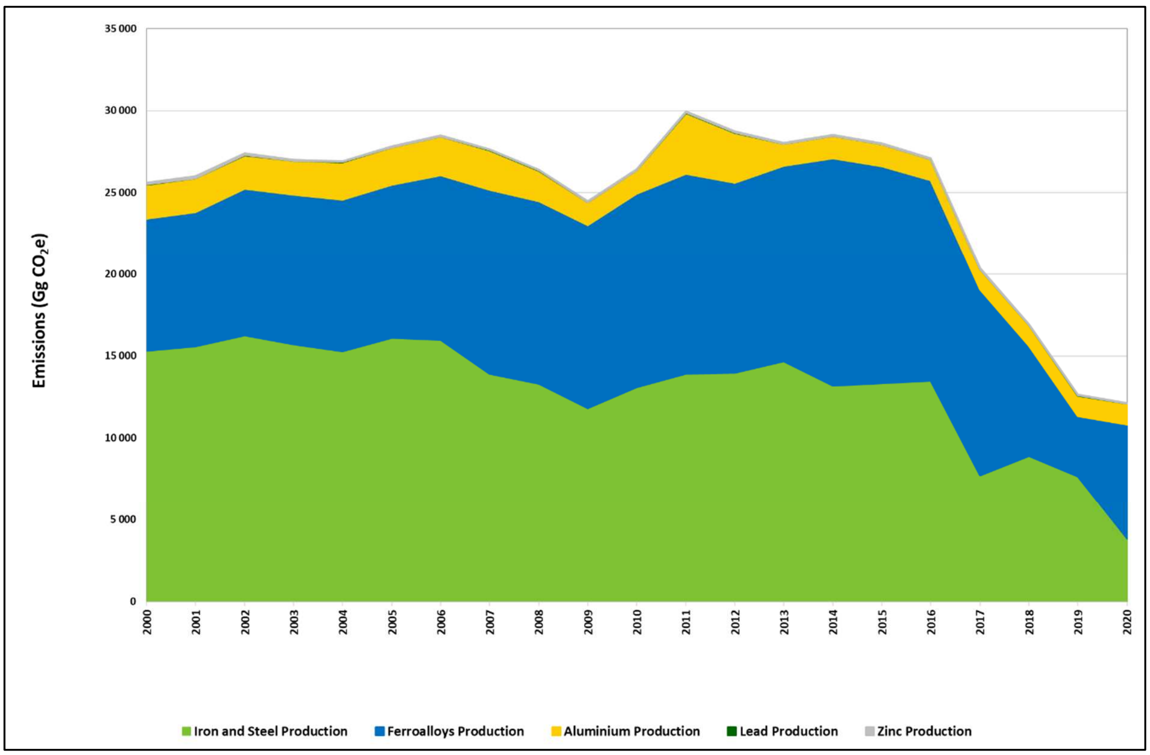

Figure 4. 3: Trend and category contribution to emissions from the metal industries, 2000 – 2020.

Iron and steel production

Iron and steel production was estimated to produce 3 853 Gg CO_2e in 2020, which is 15.1% of the IPPU sector emissions. Emissions were 11 481 Gg CO_2e (74.9%) below the 2000 level (15 334 Gg CO_2e). Emissions in this subsector decreased by 50.1% (3 869 Gg CO_2e) since 2017.

Ferroalloy production

Ferroalloys production was estimated to produce 7 069 Gg CO_2e in 2020, which is 27.7% of the IPPU sector emissions. Emissions were 1 013 Gg CO_2e (12.5%) below the 2000 level (8 082 Gg CO_2e). Emissions in this subcategory declined by 37.6% (4 261 Gg CO_2e) since 2017.

Aluminium production

Aluminium production was estimated to produce 1 255 Gg CO_2e in 2020, which is 4.9% of the IPPU sector emissions. Emissions were 819 Gg CO_2e (39.5%) below the 2000 level (2 074 Gg CO_2e). In 2020 CO_2 emissions accounted for 90.4% of the total aluminium production emissions, with the rest being PFCs (CF_4 and C_2F_6). Emissions in this subsector decreased by 0.08% (1.0 Gg CO_2e) since 2017.

Lead production

Lead production was estimated to produce 6.6 Gg CO_2e in 2020. which is 0.03% of the IPPU sector emissions. Emissions were 8.5 Gg CO_2e (56.4%) below the 2000 level (15.1 Gg CO_2e). During 2003/04 South Africa's lead mine production declined by 6.2%, as did the emissions, due mainly to the depletion of a part of the Broken Hill ore body at Black Mountain mine, which contained a higher-grade ore (DMR, 2005). Emissions from *lead production* decreased by 3.1 Gg CO_2e (31.8%) since 2017.

Zinc production

Zinc production was estimated to produce 36.6 Gg CO_2e in 2020. which is 0.1% of the IPPU sector emissions. Emissions were 71.8 Gg CO_2e (66.2%) below the 2000 level (108 Gg CO_2e).

In 2009/2010, emissions from zinc production increased by 28.6%, 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. *Zinc production* emissions decreased by 16.4 Gg CO_2e (30.1%) since 2017.

4.1.1.4 Non-energy products from fuels and solvents

The *non-energy products from fuels and solvent use* were estimated to produce 1 295 Gg CO_2e in 2020, which is 5.1% of the IPPU sector emissions.

Emissions from the *non-energy products from fuels and solvent use* category were 1 099 Gg CO_2e (561%) higher than the 2000 level of 196 Gg CO_2e. Emissions increased steadily from 2000 to 2015 to 2 495 Gg CO_2e as usage of lubricant wax increased. A sharp increase in paraffin wax usage was seen in 2015 which contributed largely to the steep increase in emissions (Figure 4. 4). Emissions dropped from 2015 to 2018 to 639 Gg CO_2e as consumption of both lubricants and paraffin wax decreased. Between 2018 and 2020 consumption of lubricants has remained steady as consumption of paraffin wax has increased which has seen an increase in emissions from 639 Gg CO_2e to 1 295 Gg CO_2e. Emissions increased by 764 Gg CO_2e (144%) since 2017.

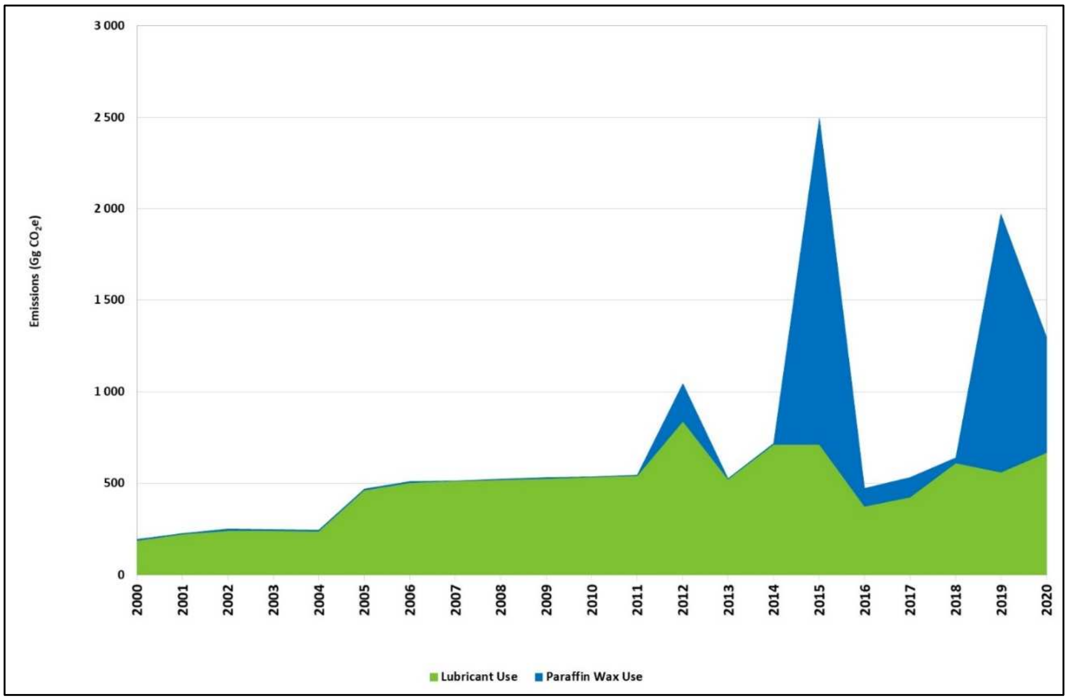

Figure 4. 4: Trend and category contribution in the emissions from non-energy products from fuels and solvents. 2000 – 2020.

Lubricant use

Lubricant use was estimated to produce 667 Gg CO_2e in 2020, which is 2.6% of the IPPU sector emissions. Emissions increased since 2000, with an increase of 479 Gg CO_2e

(254%) above the 2000 level (189 Gg CO_2e). Emissions in this subsector increased by 57% (243 Gg CO_2e) since 2017.

Paraffin wax use

Paraffin wax use was estimated to produce 627 Gg CO_2e in 2020. Emissions were 620 Gg CO_2e (8 338%) above the 2000 level (7.4 Gg CO_2e). Emissions in this subsector increased by 491% (521 Gg CO_2e) since 2017.

4.1.1.5 Products used as substitutes ODS

The *products used as substitutes for ODSs* category was estimated to produce 4 933 Gg CO_2e in 2020. which is 19.4% of the IPPU sector emissions. The largest contribution comes from *refrigeration and air conditioning* (4 847 Gg CO_2e or 98.3%).

Emissions were only estimated from 2005 when emissions were estimated at 842 Gg CO_2e in 2005. In 2010 emissions more than doubled (Figure 4. 5) due to an increase in the *refrigeration and stationary air conditioning* emissions. In 2011 emissions from *mobile air conditioning*, *foam blowing agents*, *fire protection* and *aerosols* were added, therefore the emissions for this subcategory increased to 2 853 Gg CO_2e in 2013. There was then a 73% increase in emissions between 2013 and 2020. The increase was seen through all the subcategories.

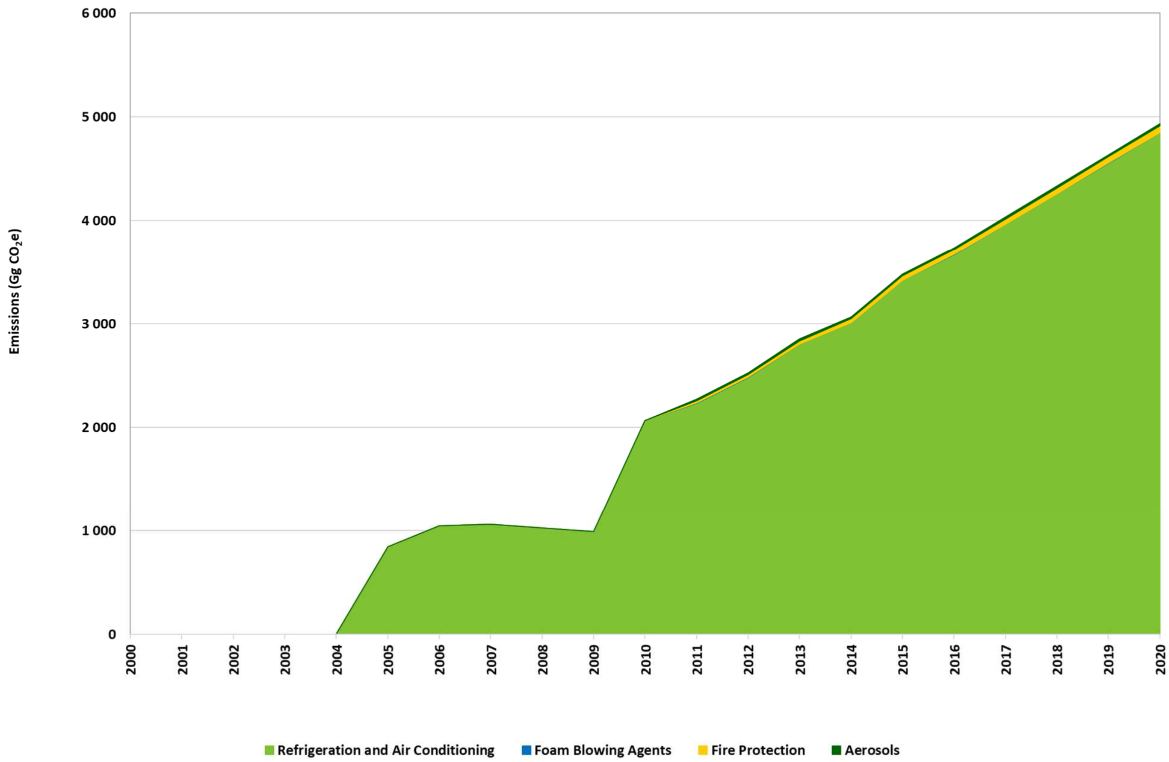

Figure 4. 5: Trend and category contribution to the product uses as substitutes for ODS emissions, 2000 – 2020.

Refrigeration and air conditioning

Refrigeration and air conditioning was estimated to produce 4 847 Gg CO_2e of HFCs in 2020, which is 98.3% of the *products used as substitutes ODS* emissions.

Since the addition of the *mobile air conditioning* estimates in 2010 the emissions for this subcategory have more than doubled (Figure 4. 5). Emissions from *refrigeration and air conditioning* have increased by 883Gg CO_2e (22.3%) since 2017.

Foam blowing agents

Emissions from *foam blowing agents* was estimated to produce 2.1 Gg CO_2e in 2020. Emissions in this subcategory were added since the 2011 inventory, but recalculations were not done for the years prior to 2011 due to a lack of data. Emissions in this subcategory have not changed since 2015.

Fire protection

Emissions from *fire protection* were estimated to be 65.9 Gg CO_2e in 2020. Emissions in this subcategory were added since the 2011 inventory, but recalculations were not done for the years prior to 2011 due to a lack of data. Emissions in this subcategory increased by 14.8 Gg CO_2e (29%) since 2017.

Aerosols

Emissions from *aerosols* was estimated to produce 18.2 Gg CO_2e in 2020. Emissions in this subcategory were added since the 2011 inventory, but recalculations were not done for years prior to 2011 due to a lack of data. Emissions in this subcategory have not changed since 2015.

4.1.2 Overview of methodology and completeness

Table 4. 3 provides a summary of the methods and emission factors applied to each subsector of IPPU.

Table 4. 3: Summary of methods and emission factors 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		SF6		NOx	CO	NMVOC	SO_2
		Method applied	Emission factor	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	NE										NE	NE	NE	NE
2	*Lime production*	T1, T2	DF	NE										NE	NE	NE	NE
3	*Glass production*	T3	CS	NE										NE	NE	NE	NE
4	*Other process uses of carbonates*	T1, T3	DF, CS	NE										NE	NE	NE	NE
B	**Chemical industry**																
1	*Ammonia production*	T3	CS	T3	CS	NE								NE	NE	NE	NE
2	*Nitric acid production*	NE		NE		T3	CS							NE	NE	NE	NE
3	*Adipic acid production*	NO		NO		NO								NO	NO	NO	NO
4	*Caprolactam, glyoxal and glyoxylic acid production*	NO		NO		NO								NO	NO	NO	NO
5	*Carbide production*	T1	DF	T1	DF	NE								NE	NE	NE	NE
6	*Titanium dioxide production*	T3	CS	NE		NE								NE	NE	NE	NE
7	*Soda Ash production*	T3	CS	NE		NE								NE	NE	NE	NE
8a	*Methanol*	NO		NO		NO								NO	NO	NO	NO
8b	*Ethylene*	NO		NO		NO								NO	NO	NO	NO
8c	*Ethylene Dichloride and Vinyl Chloride Monomer*	NO		NO		NO								NO	NO	NO	NO

8d	*Ethylene Oxide*	NO		NO		NO								NO	NO	NO	NO
8e	*Acrylontrile*	NO		NO		NO								NO	NO	NO	NO
8f	*Petrochemical and carbon black production*	T1	DF	T1	DF	NE								NE	NE	NE	NE
8g	*Hydrogen Production*	T3	CS	NE		NE								NE	NE	NE	NE
9	*Fluorochemical production*							NO		NO		NO		NO	NO	NO	NO
11	*Other*	T2	CS	T2	CS	NE		NE		NE		NE		NE	NE	NE	NE
C	**Metal industry**																
1	*Iron and steel production*	T1, T3	DF, CS	T1	DF	NE								NE	NE	NE	NE
2	*Ferroalloy production*	T1, T3	DF, CS	T1, T3	DF, CS	NE								NE	NE	NE	NE
3	*Aluminium production*	T3	CS	NE						T3	CS			NE	NE	NE	NE
4	*Magnesium production*	NO						NO		NO		NO		NO	NO	NO	NO
5	*Lead production*	T1	DF											NE	NE	NE	NE
6	*Zinc production*	T1	DF											NE	NE	NE	NE
D	**Non-energy products from fuels and solvents**																
1	*Lubricant use*	T1	DF											NE	NE	NE	NE
2	*Paraffin wax use*	T1	DF	NE		NE								NE	NE	NE	NE
3	*Solvent use*													NE	NE	NE	NE
E	**Electronics industry**																
1	*Integrated circuit or semiconductor*	NE				NE		NE		NE		NE		NE	NE	NE	NE
2	*TFT flat panel display*							NE		NE		NE		NE	NE	NE	NE
3	*Photovoltaics*							NE		NE		NE		NE	NE	NE	NE
4	*Heat transfer fluid*													NE	NE	NE	NE
F	**Product uses as substitute ODS**																

1	*Refrigeration and air conditioning*	NE						T2a, T2b	DF	NE				NE	NE	NE	NE
2	*Foam blowing agents*	NE						T1	DF	NE				NE	NE	NE	NE
3	*Fire protection*	NE						T1	DF	NE				NE	NE	NE	NE
4	*Aerosols*							T1a, T2a	DF	NE				NE	NE	NE	NE
5	*Solvents*							NE		NE				NE	NE	NE	NE
G	**Other product manufacture and use**																
1	*Electrical equipment*									NE		NE		NE	NE	NE	NE
2	*SF6 and PFCs from other product uses*									NE		NE		NE	NE	NE	NE
3	*N_2O from product uses*					NE								NE	NE	NE	NE
H	**Other**																
1	*Pulp and paper industry*	NE		NE										NE	NE	NE	NE
2	*Food and beverage industry*	NE		NE										NE	NE	NE	NE

4.1.3 Improvements and recalculations since 2017 submission

Through the introduction of the National Greenhouse Gas Emissions Reporting Regulations in 2017 (DEA. 2016), amendments to these regulation in 2020 (DEFF, 2020) as well as the introduction of the SAGERS, the GHG reporting tool, there have been various additions to the inventory as well as recalculations. The following are improvements and recalculations made to the inventory since 2017:

- *Mineral Industry:*
  - The addition of the OPUC(2A4) category from 2018.
  - Activity data for 2018 and 2019 were extrapolated for quicklime due to lack of activity data.
  - The addition of dolomitic lime from 2019.
- *Chemical Industry:*
  - Addition of silicon carbide production in 2019.
  - Titanium dioxide production saw an error in activity data corrected from 2014 onwards resulting in higher but accurate emissions
  - Addition of Soda ash production (2B7) category from 2019.
  - Addition of hydrogen production (2B8g) from 2018.
  - Addition of the Other (2B10) from 2020
- *Metal Industry:*
  - The addition of treatment of secondary raw material under *Lead production*, which has led to a change throughout the time series where the emission factor was changed from 0.52 to 0.2 from 2000 – 2020.

4.1.4 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. 4.

Table 4. 4: Key categories identified in the IPPU sector.

IPCC Code	Category	GHG	Criteria
2A1	Cement Production	CO_2	L
2B	Chemical industry	C	L, T
2C1	Iron and Steel Production	CO_2	L, T
2C2	Ferroalloys Production	CO_2	L, T
2C2	Ferroalloys Production	CH_4	T
2C3	Aluminium Production	CO_2	L

2D1	Lubricant Use	CO_2	T
2D2	Paraffin Wax Use	CO_2	T
2F1	Refrigeration and Air Conditioning	HFCs	L, T

4.1.5 Planned improvements and recommendations

There following are planned improvements and recommendations for the IPPU Sector going forward (Table 4.5): Planned improvements and recommendations

Table 4. 5: Planned improvements and recommendations

IPCC Code	Improvement/Recommendation
General	• Have sector specific engagements discussing the expectations regarding moving to the higher Tier methods. • Address time series consistency issues as data becomes available for specific categories that have been newly included in the inventory.
2A1	• Investigate historical data for the imports and exports of clinker
2A2	• Undertake a completeness assessment to determine if non-marketed lime is reported
2A3	• Disaggregate the cullet ratio by facility.
2B6	• Investigate the availability of the historical data.
2C5	• Investigate the air quality database for those data providers that trigger reporting under Lead Battery processing
2C6	• Investigate if secondary zinc production occurs in South Africa • Investigate the air quality database regarding pyrometallurgical process involving the use of an imperial smelting furnace is used for combined zinc and lead production.
2D1	• South Africa to undertake a desktop study regarding two-stroke engines and the use of blended lubricant.

4.2 Mineral industry (2.A)

Mineral production emissions are 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 four subcategories: *cement production (2A1), lime production (2A2). glass production (2A3) and other process uses of carbonates (2A4)*.

4.2.1 Cement production (2.A.1)

4.2.1.1 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 pozzolanic components such as blast-furnace slag, micro silica, fly ash and ground limestone. CEM III cements have a lower clinker content and are also split into subgroups: A (35 – 64% clinker) and B (20 – 34% clinker). South Africa's cement production plants produce Portland cement and blended cement products, such as CEM I, and more recently CEM II and CEM III. Cement produced in South Africa is sold locally and to other countries in the Southern Africa region, such as Namibia, Botswana, Lesotho, and Swaziland.

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

4.2.1.2 Methodological issues

A Tier 1 approach was used to determine emissions from clinker produced in the *cement production* category as per the 2006 IPCC Guidelines. From 2008 to 2015 imports of clinker were included in the calculations as the information was available for these years.

Activity data

Data on cement production in South Africa was obtained from the SAMI Annual Reports produced by the DMRE for 2000 to 2017 (Table 4.6). Clinker production for the years 2018 and 2019 were provided by the cement industries (Table 4.6) via the GHG Reporting Programme. Clinker fraction for the years 2000 to 2012 were obtained from cement industries but was not available for the period between 2013 and 2017, therefore it was assumed to remain unchanged between 2012 and 2017. This will be updated once new data becomes available. The clinker fraction for the years 2018 and 2019 were not provided by all cement industries, however the clinker produced was provided (Table 4. 6). The clinker fraction was available for the 2020 reporting period through the GHG reporting programme.

Table 4. 7: Production data for the mineral industries, 2000 – 2020.

	Cement production	Clinker production	Quick lime production	Hydrated lime production	Dolomitic lime production	Glass production	Ceramics	Other uses of soda ash	Other
	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			
2018		9 429 754	1 055 730				689 841.2	12 135	278 551
2019		9 174 824	1055315		61 810		752 256.2		115 048
2020		7 299 346	818211	146 158	24 729	1 418 5061	146 936	58 757	114 871

Emission factors

For the calculation of GHG emissions in *cement production*. CO_2 emission factors were sourced from the 2006 IPCC Guidelines. It was assumed that the Calcium Oxide (CaO) composition (one tonne of clinker) contains 0.65 tonnes of CaO from Calcium Carbonate ($CaCO_3$). 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 country-specific clinker fraction for the period 2000 to 2020 ranged between 69% - 76%.

4.2.1.3 Uncertainties and time-series consistency

Activity data uncertainty

The largest uncertainty in this sub-category is the 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 Cement Kiln Dust (CKD) correction factor default assumption; and 10% on the trade data.

Emission factor uncertainty

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% in terms of estimation of % of calcination of CKD (IPCC, 2006, Table 2.3).

Time-series consistency

A Tier 1 method has been used from 2000 to 2020 to estimate emissions from this category. Import data was available and used for estimations from 2008 to 2015. Emissions were estimated throughout the time-series by using clinker production, which was calculated by multiplying cement production, obtained from the SAMI Report, by clinker fraction from 2000 to 2017. Company specific clinker production was provided from 2018 onwards.

4.2.1.4 Category specific QA/QC and verification

No category specific QC checks were completed for this sub-category.

For verification of cement production data, the facility-level clinker production submitted by cement industries via the SAGERS for the inventory was compared with estimated clinker production from previous inventories. The clinker production however for 2020 showed a decrease compared to previous years. This decrease could be due to the COVID-19 pandemic which saw stringent lockdown measures being implemented in South Africa during 2020.

In previous years (2000 -2017) comparisons against the SAMI reports produced by DMR was also conducted although the information with the report is not clinker production but rather the total amount of lime and dolomite sold to the cement industry however using a clinker fraction of 69% - 76% indicates that clinker production follows the same trend as that from the facility level data from cement industries. It is important to note that the numbers in the SAMI Report 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 DMR data do not include clinker exports due to a lack of data. It is not clear if the industry level clinker data within the report takes imports and exports into account. These differences lead to increased uncertainty and the reasons for the discrepancies need to be further investigated.

4.2.1.5 Category specific recalculations

Recalculations were not performed for this category.

4.2.1.6 Category specific planned improvements

There is a planned improvement for this subcategory which includes investigating historical import and export data for clinker.

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 (2000 – 2017), however further data collected by SAGERS could assist in reducing this uncertainty and aid in more consistent reporting in future.

4.2.2 Lime production (2.A.2)

4.2.2.1 Category description

Lime is the most widely used chemical alkali in the world. Calcium oxide (CaO or quicklime or slaked lime) is sourced from $CaCO_3$. 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. Page 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. Quicklime sales for both pyrometallurgical 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 period (DMR, 2019).

4.2.2.2 Methodological issues

A Tier 1 and Tier 2 approach was used to estimate emissions from this category as per the 2006 IPCC Guidelines. 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, hydrated lime and dolomitic lime produced.

Activity data

The DMRE publishes data on lime products that is divided into quicklime which includes pyrometallurgical and chemical components; and hydrated lime that includes water purification, chemical and other uses (DMR, 2019). In the previous submissions only pyrometallurgical quicklime and water purification hydrated lime was incorporated from the SAMI Reports (DMR, 2019) were used (Table 4.6). It was assumed that all quicklime is high calcium lime. The 2020 inventory included activity data provided by the lime industries reported via the South African GHG Reporting Programme. The types of lime reported were quicklime, hydrated lime and dolomitic lime. Quicklime activity data for 2018 and 2019 were extrapolated due to lack of data received for these years. Activity data for hydrated lime during 2018 and 2019 was not provided by industry through the Reporting Programme and the updated SAMI report was not available for use.

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. The 2006 IPCC default emission factor of 0.77 tonnes CO_2 per tonne lime was applied to dolomitic lime. The 2006 IPCC default emission factor of 0.59 tonnes CO_2 per tonne lime was applied to hydrated lime.

4.2.2.3 Uncertainties and time-series consistency

Activity data uncertainty

According to the 2006 IPCC Guidelines, uncertainty of the Lime Kiln Dust (LKD) correction factor for hydrated lime adds to the uncertainty of the activity data due to not knowing the amount of LKD produced and what percentage is calcined, as with the CKD correction factor used for estimating emissions from cement production. Therefore, it can be assumed that the uncertainty for LKD is equal to the uncertainty of CKD which is 30%.

Emission factor uncertainty

According to the IPCC 2006 Guidelines, the uncertainty on *lime production* emissions is: 6% for assuming an average CaO in lime; 2% for high-calcium EF; 5% for correction for hydrated lime.

Time-series consistency

A Tier 1 and Tier 2 method was used to estimate emissions from 2000 to 2020. The time series was updated to include the 2006 IPCC default emission factor of 0.59 for hydrated lime in 2017. Dolomitic lime was added to the time series in 2019.

4.2.2.4 Category specific QA/QC and verification

No category specific QC checks were completed for this sub-category.

The only available data for *lime production* was sourced from the SAMI report for the 2000 to 2017 inventories, however, for the 2020 inventory, data was sourced from the lime production industry: therefore, there was no comparison of data across different plants previously. The numbers in the DMR report are 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. Reporting is currently not consistent between plants, and verification will be undertaken as consistency is achieved in the future. The SAGERS which became active in 2020, will allow for consistency to be achieve going forward.

4.2.2.5 Category specific recalculations

Recalculations were not undertaken for this category.

4.2.2.6 Category specific planned improvements

There is an improvement project planned to investigate the inclusion of non-marketed lime within the inventory in the future.

4.2.3 Glass production (2.A.3)

4.2.3.1 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).

4.2.3.2 Methodological issues

A Tier 3 approach was used to determine estimates of the GHG emissions from glass production by the glass production industries for the 2020 inventory. Data Providers used a mass balance approach to estimate emissions providing inputs and outputs of their process and carbon content factors specific to their materials.

Activity data

Production data was provided by the glass production industries (PG Group, Consol Glass and Isanti Glass), via the SAGERS.

Emission factors

All glass production industries determined their own emissions using a Tier 3 approach and provided these emission estimates to DFFE. In most cases the activity data and emission factors used are not supplied due to confidentiality issues.

4.2.3.3 Uncertainties and time-series consistency

Activity data uncertainty

As per the 2006 IPCC Guidelines. uncertainty related to activity data using a Tier 3 approach is between 1 – 3% (IPCC, 2006, Chapter 2.4.2.2). Carbonates lost as dust is negligible under the Tier 3 method.

Emission factor uncertainty

As per the 2006 IPCC Guidelines, uncertainty related to emission factors developed using a Tier 3 approach is between 1 – 3% (IPCC, 2006, p. 2.31). There is some uncertainty when assuming that all carbonates are calcined, but this is minimal.

Time-series consistency

A Tier 1 method was used to estimate emissions from 2000 to 2017, using the cullet ratio and the default emission factor of 0.2. From 2018 onwards after the promulgation of the NGERS, glass production industries began using the Tier 2 and Tier 3 methods to estimate emissions, using a mass balance approach.

4.2.3.4 Category specific QA/QC and verification

No category specific QC checks were completed for this sub-category.

4.2.3.5 Category specific recalculations

No recalculations were performed for this category.

4.2.3.6 Category specific planned improvements

There is an improvement project planned to investigate the inclusion separation of cullet ratio reported per facility.

4.2.4 Other process uses of carbonates (2.A.4)

4.2.4.1 Category description

Limestone ($CaCO_3$), dolomite ($CaMg (CO_3)_2$) and other carbonates (e.g., $MgCO_3$ and $FeCO_3$) are basic raw materials having commercial applications in a number of industries. The calcination of carbonates at high temperatures yields CO_2. In addition to those industries already discussed individually above, carbonates also are consumed in metallurgy, agriculture, construction and environmental pollution control (IPCC, 2006). The use of lime in the following specific source categories are reported within the mineral category, such as ceramics, other soda ash usage and non-metallurgical magnesia production.

Ceramics include the production of bricks and roof tiles, vitrified clay pipes, refractory products, expanded clay products, wall and floor tiles, table and ornamental ware (household ceramics), sanitary ware, technical ceramics, and inorganic bonded abrasives. Emissions from the ceramic production industry are process related and are emitted when calcination of clay occurs and when additives are added to the process (IPCC, 2006).

Soda ash is used in a variety of applications, including, glass production, soaps and detergents, flue gas desulphurisation, chemicals, pulp and paper and other common consumer products. Soda ash production and consumption results in the release of CO_2 emissions (IPCC, 2006)

Magnesite ($MgCO_3$) is one of the key inputs into the production of magnesia, and ultimately fused magnesia. There are three major categories of magnesia products: calcined magnesia, dead burned magnesia (periclase) and fused magnesia. Magnesia is produced by calcining $MgCO_3$ which results in the release of CO_2 (IPCC, 2006). Emissions may result from several other source categories that are not included above.

4.2.4.2 Methodological issues

A Tier 1 and 3 approach was adopted to estimate emissions from the *ceramics* and *soda ash usage* subcategories. The Tier 3 approach included data providers undertaking analysis of their raw materials used within the process to determine the carbon content and then applying this value to their production data. A Tier 1 approach was used to estimate emissions from other uses of carbonates. *Other uses of carbonates* included the use of dolomite and calcite within separate processes.

Activity data

Activity data for 2020 were obtained from industries operating under the relevant sector. Activity data was reported via the GHG Reporting Programme. This is a new category added to the inventory from 2018 and all activity data has been reported via the SAGERS.

Emission factors

The 2006 IPCC default emission factors for calcite (0.43971 tonnes CO_2 per tonne carbonate), magnesite (0.52197 tonnes CO_2 per tonne carbonate) and for soda ash usage (0.41492 tonnes CO_2 per tonne carbonate) was applied where a Tier 1 approach was used. The 2006 IPCC default emission factor for other usage of carbonates (0.47732 tonnes CO_2 per tonne lime) was applied to dolomite usage.

4.2.4.3 Uncertainties and time-series consistency

Activity data uncertainty

According to the 2006 IPCC Guidelines. uncertainty arising from a Tier 3 approach is between 1-3%, and where a Tier 1 approach has been used uncertainty rises to between 15-85%. As both approaches were used to estimate emissions in 2020 activity data for subcategories *Ceramics and Soda Ash Usage* uncertainty will fall between the range of 1 - 85%.

Emission factor uncertainty

As per the 2006 IPCC Guidelines, emission factors used correctly to activity data that has been collected correctly uncertainty is negligible. However, should there be an error in the assumption of carbonates an uncertainty of between 1-5% should apply.

Time-series consistency

The *Other Process Uses of Carbonates* is a new category introduced to the inventory in 2018. This has result in an inconsistent time series as historical data is unavailable currently. The time series consistency will be updated as industry continues to report in future via the SAGERS Portal.

4.2.4.4 Category specific QA/QC and verification

No category specific QC checks were completed for this sub-category.

4.2.4.5 Category specific recalculations

Recalculations were not undertaken for this category.

4.2.4.6 Category specific planned improvements

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

4.2.5 Other mineral products processes

No activities were included under this sub-category.

4.3 Chemical industry (2.B)

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*, *soda ash production*, *titanium dioxide production*, *carbon black*, *hydrogen production* and *other chemical processes*. 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.

4.3.1 Ammonia production (2.B.1)

4.3.1.1 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.

4.3.1.2 Methodological issues

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 is not provided within this report due to confidentiality.

Emission factors

The emission factors are not provided within this report due to confidentiality reasons.

4.3.1.3 Uncertainties and time-series consistency

Activity data uncertainty

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*. Uncertainty of ±2% was applied to activity data as advised in the 2006 IPCC Guidelines (p.3.17) should activity data be obtained from producers. The uncertainty was assumed to be the same for both CO_2 and CH_4 emission estimates as guidance was not provided per GHG.

Emission factor uncertainty

The 2006 IPCC Guidelines default uncertainty for Tier 1 is 6% (IPCC, 2006, Table 3.1) therefore it is expected that for a Tier 3 approach the uncertainty would be less, therefore an assumption of ±2% is made as per information provided in the 2006 IPCC Guidelines (p. 3.17) for activity data obtained from plants. The uncertainty was assumed to be the same for both CO_2 and CH_4 emission estimates as guidance was not provided per GHG.

Time-series consistency

A Tier 3 method was used throughout the time-series, with emission data being provided by industry.

4.3.1.4 Category specific QA/QC and verification

No category specific QC checks were completed for this sub-category.

4.3.1.5 Category specific recalculations

No recalculations were performed for this category.

4.3.1.6 Category specific planned improvements

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

4.3.2 Nitric acid production (2.B.2)

4.3.2.1 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.

4.3.2.2 Methodological issues

The emissions from *nitric acid production* were calculated based on continuous monitoring (Tier 3 approach) and approved country specific emission factors.

Activity data

Consumption data is not provided within this report due to confidentiality.

Emission factors

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

4.3.2.3 Uncertainties and time-series consistency

Activity data uncertainty

According to the 2006 IPCC Guidelines (p. 3.24) the plant-level activity data required for the Tier 3 approach includes production data disaggregated by technology and abatement system type. 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, p.3.25).

Emission factor uncertainty

According the 2006 IPCC Guidelines (p. 3.24), default emission factors have very high uncertainties for two reasons: a) N_2O may be generated in the gauze reactor section of nitric acid production as an unintended reaction by-product; and b) the exhaust gas may or may not be treated for NO_x control and the NO_x abatement system may or may not reduce the N_2O concentration of the treated gas. Since a Tier 3 approach was applied in this inventory it was assumed that the uncertainty value was ±2 as per Tier 3 approach (IPCC, 2006, p.3.24).

Time-series consistency

A Tier 3 method was used throughout the time-series, with emission data being provided by industry.

4.3.2.4 Category specific QA/QC and verification

No category specific QC checks were completed for this sub-category.

4.3.2.5 Category specific recalculations

No recalculations were performed on this category.

4.3.2.6 Category specific planned improvements

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

4.3.3 Adipic acid production (2.B.3)

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

4.3.4 Caprolactuam. glyoxal and glyoxylic acid production (2.B.4)

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

4.3.5 Carbide production (2.B.5)

4.3.5.1 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) while silicon carbide is produced from silica sand or quartz and petroleum coke.

4.3.5.2 Methodological issues

Emissions from *carbide production* were calculated based on a Tier 1 approach as per the 2006 IPCC Guidelines.

Activity data

Calcium carbide and silicon carbide consumption values were sourced from the carbide production plants but are not shown due to confidentiality issues. Calcium carbide is not estimated for 2019 and the production plant is no longer operational. Silicon carbide emission estimates have been included since 2019 through the GHG Reporting Programme.

Emission factors

An IPCC 2006 default emission factor was applied and is shown in Table 4.7.

Table 4. 8: Emission factors applied for carbide production emission estimates.

Sub-category	CO_2 EF (tonnes CO_2/tonne product)	CH_4 EF (kg CH_4/tonne product)	Source
Calcium Carbide production	1.09		IPCC 2006
Silicon Carbide Production	2.62	11.6	IPCC 2006

4.3.5.3 Uncertainties and time-series consistency

Activity data uncertainty

According to the IPCC 2006 Guidelines (p. 3.45), the uncertainty of the activity data that accompanies the method used here is approximately ±5%. The uncertainty was assumed to be the same for both CO_2 and CH_4 emission estimates as guidance was not provided per GHG.

Emission factor uncertainty

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). Emission factor uncertainty for Tier 1 is ±10%. The uncertainty was assumed to be the same for both CO_2 and CH_4 emission estimates as guidance was not provided per GHG.

Time-series uncertainty

The emissions from *carbide production* were sourced from the specific carbide production plants therefore there was no comparison of data across different plants. A Tier 1 method was used across the time series, with the addition of silicon carbide in 2019.

4.3.5.4 Category specific QA/QC and verification

No category specific QC checks were carried out.

4.3.5.5 Category specific recalculations

No recalculations were performed on this category.

4.3.5.6 Category specific planned improvements

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

4.3.6 Titanium dioxide production (2.B.6)

4.3.6.1 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 TiO_2 production that result in GHG emissions, namely, a) titanium slag production in electric furnaces; b) synthetic rutile production using the Becher Process and c) rutile TiO_2 production through the chloride route.

4.3.6.2 Methodological issues

A Tier 3 approach was used for calculating GHG emissions from titanium dioxide production. Data providers used a mass balance approach to estimate emissions.

Activity data

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

Emission factors

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

4.3.6.3 Uncertainties and time-series consistency

Activity data uncertainty

According to the IPCC 2006 Guidelines (p. 3.50), the uncertainty of the activity data when using a Tier 2 approach is ±2% for activity data collected at plant level. It is therefore assumed that the uncertainty is ±2 as data was provided at a plant level.

Emission factor uncertainty

The 2006 IPCC Guidelines state that uncertainty for titanium slag is unavailable due to confidentiality and lack of production plants. However, an assumption of ±2 was made as per the uncertainty of the activity data (IPCC, 2006, p.3.50)

Time-series consistency

The total GHG emissions were sourced from the specific titanium dioxide production plants therefore, no comparison of data across different plants was made. A Tier 3 approach was used across the time series.

4.3.6.4 Category specific QA/QC and verification

No category specific QC checks were completed for this sub-category.

4.3.6.5 Category specific recalculations

No recalculations were performed on this category.

4.3.6.6 Category specific planned improvements

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

4.3.7 Soda ash production (2.B.7)

4.3.7.1 Category description

Soda ash (sodium carbonate, Na_2CO_3) is a white crystalline solid that is used as a raw material in many industries including glass manufacture, soap and detergents, pulp and paper production and water treatment. CO_2 is emitted during production with the quantity emitted dependent on the industrial process used to manufacture soda ash (IPCC, 2006).

Emissions of CO_2 from the production of soda ash vary substantially with the manufacturing process. Four different processes may be used commercially to produce soda ash. Three of these processes, monohydrate, sodium sesquicarbonate (trona) and direct carbonation, are referred to as natural processes. The fourth, the Solvay process, is classified as a synthetic process. Calcium carbonate (limestone) is used as a source of CO_2 in the Solvay process.

4.3.7.2 Methodological issues

A Tier 3 approach was used for calculating GHG emissions from *soda production*. Data providers used a mass balance approach to estimate emissions for 2020.

Activity data

The *soda ash production* emissions data were sourced from the production plants and activity data was not supplied in this report due to confidentiality issues.

Emission factors

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

4.3.7.3 Uncertainties and time-series consistency

Activity data uncertainty

According to the IPCC 2006 Guidelines (p. 3.54), the uncertainty of the activity data when uncertainty is unavailable is ±5% for activity data collected at plant level.

Emission factor uncertainty

The 2006 IPCC Guidelines state that the uncertainty of the default emission factor is negligible as an assumption of 100% purity of input and output materials is made (IPCC, 2006, p.3.54).

Time-series consistency

The time series is not consistent as soda ash production is a new category added in 2019. Historical data is not available. The time series will be built on in future as more data becomes available.

4.3.7.4 Category specific QA/QC and verification

No category specific QC checks were completed for this sub-category.

4.3.7.5 Category specific recalculations

No recalculations were performed on this category.

4.3.7.6 Category specific planned improvements

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

4.3.8 Carbon black production (2.B.8.f)

4.3.8.1 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.

4.3.8.2 Methodological issues

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

Activity data

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

Emission factors

For the calculation of emissions from *carbon black production*, the IPCC 2006 default CO_2 and CH_4 emission factors were applied (Table 4.8). Carbon black is mainly produced through the furnace black process; however, a small portion of carbon black production is known to be produced through the acetylene black process.

Table 4. 9: Emission factors applied for carbon black production emission estimates.

Sub-category	CO_2 EF (tonnes CO_2/tonne product)	CH_4 EF (kg CH_4/tonne product)	Source
Carbon black production (Furnace Black Process)	2.62	0.06	IPCC 2006
Carbon black production (Acetylene Black Process)	0.12		IPCC 2006

4.3.8.3 Uncertainties and time-series consistency

Activity data uncertainty

According to the IPCC 2006 Guidelines, the uncertainty of the activity data that accompanies the method used here is in the range of ±15% for CO_2 and ±85% for CH_4 as per the 2006 IPCC Guidelines (Table 3.27).

Emission factor uncertainty

According to the IPCC 2006 Guidelines, the uncertainty of the emission factors that accompanies the method used here is in the range of ±15% for CO_2 and ±85% for CH_4 as per the 2006 IPCC Guidelines (Table 3.27).

Time-series consistency

A Tier 1 approach was used throughout the time series with activity data being collected from industry. Carbon black produced via the acetylene black process was reported for the years 2016 to 2018 when the company shut down.

4.3.8.4 Category specific QA/QC and verification

No category specific QC checks were completed for this sub-category.

4.3.8.5 Category specific recalculations

No recalculations were performed on this category.

4.3.8.6 Category specific planned improvements

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

4.3.9 Hydrogen Production (2.B.8.g)

4.3.9.1 Category description

Hydrogen (H_2) is a gas with flammable properties like natural gas and gasoline. Currently hydrogen is used as raw material in refineries and in the production of ammonia, methanol and various chemicals (IPCC, 2019). Hydrogen can also be used as an energy carrier in the transport sector, as energy storage and buffer systems in renewable electricity production, as a main constituent in coal gas used for heating and cooking, as well as in semiconductor industry processing and welding (IPCC, 2019). Hydrogen can be produced through various processes, the most common being steam reforming (95%), which uses fossil fuels or renewable fuels as a feedstock. The use of fossil fuels results in GHGs being emitted (Zohuri, 2018).

4.3.9.2 Methodological issues

A Tier 3 approach was used for calculating GHG emissions from *hydrogen production*. Data Providers used a mass balance approach to estimate emissions for 2020.

Activity data

The *hydrogen production* emissions data were sourced from the production plants and activity data was not supplied in this report due to confidentiality issues.

Emission factors

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

4.3.9.3 Uncertainties and time-series consistency

Activity data uncertainty

According to the IPCC 2019 Refinements (p. 3.50), the uncertainty of the activity data when plant level data is available is ±2%.

Emission factor uncertainty

Uncertainty is not provided in the IPCC 2019 Refinements for emission factors; therefore, it was assumed to be the same as with activity data, ±2%.

Time-series consistency

The time series is not consistent as hydrogen production is a new category added in 2018. Historical data is not available. The time series will be built on in future as more data becomes available.

4.3.9.4 Category specific QA/QC and verification

No category specific QC checks were completed for this sub-category.

4.3.9.5 Category specific recalculations

No recalculations were performed on this category.

4.3.9.6 Category specific planned improvements

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

4.3.10 Other Chemical Processes (2.B.10)

4.3.10.1 Category description

This category includes emissions from chemicals manufacturing industries that are not covered elsewhere in the 2006 IPCC Guidelines. Emissions of CO_2 and CH_4 are reported within this category. Process emission from the Phthalic Anhydride process and partial oxidation of Butane and Ortho-Xylene are included in this category.

4.3.10.2 Methodological issues

A Tier 3 approach was used for calculating GHG emissions from *this subcategory*. Data Providers used stack monitoring reports to estimate emissions for 2020.

Activity data

The emissions data were sourced from the production plants and activity data was not supplied in this report due to confidentiality issues.

Emission factors

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

4.3.10.3 Uncertainties and time-series consistency

Activity data uncertainty

The 2006 IPCC Guidelines have not provided guidance on the uncertainty from activity data therefore an assumption of ±5% was made based on the default uncertainty from *Carbide Production* for both CO_2 and CH_4.

Emission factor uncertainty

The 2006 IPCC Guidelines have not provided guidance on the uncertainty from emission factors therefore an assumption of ±5% was made based on the default uncertainty from *Carbide Production* for both CO_2 and CH_4.

Time-series consistency

The time series is not consistent as this is a new category added in 2020. Historical data is not available. The time series will be built on in future as more data becomes available.

4.3.10.4 Category specific QA/QC and verification

No category specific QC checks were completed for this sub-category.

4.3.10.5 Category specific recalculations

No recalculations were performed on this category.

4.3.10.6 Category specific planned improvements

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

4.4 Metal industry (2.C)

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 and emissions of CH_4 were estimated from *iron and steel production* and *ferroalloy production*, and perfluorocarbons (CF_4 and C_2F_6) from *aluminium production*.

4.4.1 Iron and steel production (2.C.1)

4.4.1.1 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.

4.4.1.2 Methodological issues

A Tier 1 and 3 approach was applied to calculate the emissions from *iron and steel production* for the different process types in 2020. Default IPCC emission factors were used for the calculation of GHG emissions from basic oxygen furnace, electric arc furnace, pig iron production, direct reduced iron production and sinter production. Industry also used a Tier 3 approach to estimate emissions from electric arc furnaces using raw material input and output.

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 under the Energy Sector.

Activity data

Activity data was provided by the *iron and steel production* plants (Table 4.9) via the SAGERS Portal, through the GHG Reporting Programme.

Table 4. 10: Production data for the iron and steel industry, 2000 – 2020.

	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	4 242 430.8	1 153 047	101 115	660 605.4	3 631 445.2	107 153
2018	4 967 074	1 443 030		837 515	4 060 025	107 153
2019	4 242 431	1 555 741	10 115	684 134	3 631 445	
2020	2 085 522	1 785 642	48 670	236 497	2 173 112	

Emission factors

IPCC default emission factors were applied for the calculation of emissions from *iron and steel production* (Table 4.10). 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.

Table 4. 11: Emission factors applied in the iron and steel industry emission estimates.

Sub-category	CO_2 EF (tonnes CO_2/tonne product)	CH_4 EF (kg CH_4/tonne product)	Source
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	0.07	IPCC 2006
Other*	1.06		IPCC 2006

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

4.4.1.3 Uncertainties and time-series consistency

Activity data uncertainty

As both a Tier 1 and Tier 3 approach was used to estimate emissions from this category it was assumed that the uncertainty ranged from ±5% to ±10% as per the 2006 IPCC Guidelines (Table 4.4)

Emission factor uncertainty

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, Table 4.4). As both a Tier 1 and Tier 3 approach was used to estimate emissions an uncertainty range of ±5% and ±25% was used for the EF.

Time-series consistency

Data was not consistent throughout the time series as the data was provided by different sources for the 2019 inventory. The 2020 inventory included activity data directly from industry via the SAGERS through the GHG Reporting Programme. Prior to 2017 sinter production was not reported, however, since the promulgation of the GHG Reporting Regulations there has been disaggregation between direct reduced iron and sinter processes.

4.4.1.4 Category specific QA/QC and verification

No specific QC checks were completed for this sub-category.

4.4.1.5 Category specific recalculations

No recalculations were performed on the emissions from this subcategory.

4.4.1.6 Category specific planned improvements

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

4.4.2 Ferroalloys production (2.C.2)

4.4.2.1 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).

4.4.2.2 Methodological issues

A Tier 1 and 3 approach was applied across the different ferroalloy production plants for different types of ferroalloys.

Activity data

Ferroalloy production data for 2000 to 2012 were obtained from ferroalloy production plants. Activity data from 2013 to 2017 were obtained from the SAMI Annual Reports (DMR. 2019), however, for 2018 to 2020 activity data was again supplied by the ferroalloy production plants due to the implementation of the GHG Reporting Regulations. Activity data is provided in Table 4.11. 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. 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).

Most plants provided a split between ferromanganese 1% and 7%, however, where the split was not made, the split from 2013 was applied. The inconsistency will be overcome in future inventories as the SAGERS requires the split to be made.

Table 4. 12: Production data for the ferroalloy industry, 2000 – 2020.

	Ferro-chromium	Ferro-manganese (7% C)	Ferro-manganese (1% C)	Ferro-silicon (65% Si)	Ferro-silicon (75% Si)	Silicon metal	Ferro-vanadium	Silico-manganese	Other
	Production (tonne)								
2000	2 574 000	596 873	310 400	108 500		40 600			
2001	2 141 000	523 844	259 176	107 600		39 400			

2002	2 351 000	618 954	315 802	141 700		42 500			
2003	2 813 000	607 362	313 152	135 300		48 500			
2004	3 032 000	611 914	373 928	140 600		50 500			
2005	2 802 000	570 574	275 324	127 000		53 500			
2006	3 030 000	656 235	277 703	148 900		53 300			
2007	3 561 000	698 654	327 794	139 600		50 300			
2008	3 269 000	502 631	259 014	134 500		51 800			
2009	2 346 000	274 923	117 683	110 400		38 600			
2010	3 607 000	473 000	317 000	127 700		46 400			
2011	3 422 000	714 000	350 000	126 200		58 800			
2012	3 063 000	706 000	177 000	83 100		53 000			
2013	3 219 000	681 000	163 000	78 400		34 000			
2014	3 719 000	814 263	194 737	87 700		47 200			
2015	3 685 000	492 000	123 000	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			
2018	3 578 355	144 436	36 109	101 815		46 062	3 049		
2019	1 854 178			96 614		31 285			38 627
2020	2 971 325				47 925		5 414	108 060	66 370

Emission factors

The emission factors used where a Tier 1 approach was used is provided below in Table 4.12.

Table 4. 13: Emission factors applied in the ferroalloy industry emission estimates.

Sub-category	CO_2 EF (tonnes CO_2/tonne product)	CH_4 EF (kg CH_4/tonne product)	Source
Ferromanganese (7% C)	1.3		IPCC 2006
Ferromanganese (1% C)	1.5		IPCC 2006
Ferrosilicon 65% Si	3.6	1.0	IPCC 2006
Ferrosilicon 75% Si	4.0	1.0	IPCC 2006
Silicon metal	5.0	1.2	IPCC 2006
Silicomanganese	1.4		IPCC 2006

4.4.2.3 Uncertainties and time-series consistency

Activity data uncertainty

An uncertainty of ±5% on activity data was assumed as per the 2006 IPCC Guidelines (Table 4.9). The uncertainty was assumed to be the same for both CO_2 and CH_4.

Emission factor uncertainty

IPCC 2006 Guidelines indicates that for Tier 1, the default emission factors may have an uncertainty of ± 25% (IPCC, 2006, Table 4.9). For this inventory, as both a Tier 1 and Tier 3 approach was used the uncertainty range was assumed to be between ±5% and ±25% for both CO_2 and CH_4.

Time-series consistency

The time series is not consistent due to a change in data sources in 2018 and 2019. During 2020 industry reported via the SAGERS through the GHG Reporting Programme.

4.4.2.4 Category specific QA/QC and verification

No specific QC checks were completed for this sub-category.

4.4.2.5 Category specific recalculations

No recalculations were performed for the category.

4.4.2.6 Category specific planned improvements

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

4.4.3 Aluminium production (2.C.3)

4.4.3.1 Category description

According to the 2006 IPCC Guidelines, aluminium production is takes place 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):

- CO_2 emissions from the consumption of carbon anodes in the reaction to convert aluminium oxide to aluminium metal;

- PFC emissions of CF_4 and C_2F_6 during anode effects. Also emitted are smaller amounts of process emissions, CO, Sulphur dioxide (SO_2), and NMVOCs. Sulphur hexafluoride (SF_6) is not emitted during the electrolytic process and is only rarely used in the aluminium manufacturing process. where small quantities are emitted when fluxing specialized high-magnesium aluminium alloys.

4.4.3.2 Methodological issues

A Tier 1 approach was used for CO_2 emission estimation, while a Tier 3 methodology was applied to the PFCs between 2000 and 2012. In the Tier 3 approach the amount of CF_4 and C_2F_6 produced were tracked and used to determine emissions in this category. The Tier 3 method was then extrapolated for the 2013-15 period (using activity data and an implied emission factor). It is considered that the extrapolation of a Tier 3 method might overestimate or underestimate the emissions. Therefore, in the 2000-2017 inventory. this was corrected so that actual plant-performance data is used to quantify emissions for the 2013-2017 period. A Tier 3 method was used to estimate emissions for both CO_2 and PFCs in the 2018-2020 period.

Activity data

The source of activity data for *aluminium production* were the aluminium production plants. Data is not shown in this report due to confidentiality.

Emission factors

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

4.4.3.3 Uncertainties and time-series consistency

Activity data uncertainty

As per the 2006 IPCC Guidelines, uncertainty is minimal regarding aluminium production data. A default uncertainty of ±1% is used (IPCC, 2006, Page 4.57).

Emission factor uncertainty

The uncertainty on the Tier 3 CO_2 emission factors for aluminium production is ±5% (IPCC, 2006, Page 4.56) for estimating CO_2 emissions. Even though a Tier 3 approach was used for *aluminium production* PFC emissions, 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, page 4.56).

Time-series uncertainty

Emissions were estimated using a Tier 1 approach for Prebake and Soderberg processes from 2000 to 2013 and 2000 to 2008, respectively. A Tier 3 approach was used to estimate emissions from Cantre-Worked Prebake (CWPB), Side Worked Prebake (SWPB), Vertical Stud Søderberg (VSS) and Horizontal Stud Søderberg (HSS) processes from 2000 to 2008.

The Soderberg, SWPB, VSS and HSS processes were stopped in 2008. A Tier 3 approach was used to estimate emissions for CWPB from 2012 onwards and Prebake from 2014 onwards.

4.4.3.4 Category specific QA/QC and verification

No specific QC checks were completed for this sub-category.

4.4.3.5 Category specific recalculations

No recalculations were performed for this category.

4.4.3.6 Category specific planned improvements

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

4.4.4 Magnesium production (2.C.4)

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

4.4.5 Lead production (2.C.5)

4.4.5.1 Category description

According to the 2006 IPCC Guidelines, there are two primary processes to produce 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.

Secondary lead processing, according to the 2006 IPCC Guidelines, involves the recycling of lead acid batteries. Recycling occurs through the following processes:

- crushed using a hammer mill and entered the smelting process with or without desulphurization; or
- smelted whole

4.4.5.2 Methodological issues

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

Activity data

Lead production data for 2000 to 2017 were obtained from the SAMI Annual Reports (DMR, 2019) and are provided in Table 4. 13, however for 2018 to 2020 activity data was supplied by the lead production plants through the GHG Reporting Programme, via the SAGERS.

Table 4. 14: Production data for the lead and zinc industries, 2000 – 2020.

	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
2018	32 383	21 090
2019	37 519	20 918
2020	32 860	21 268

Emission factors

IPCC 2006 default emission factor of 0.2 t CO_2 per tonne of lead produced was applied (IPCC, 2006, Table 4.21).

4.4.5.3 Uncertainties and time-series consistency

Activity data uncertainty

For *lead production* emissions using the Tier 1 method there is a ±10% uncertainty on the activity data (IPCC, 2006, Table 4.23).

Emission factor uncertainty

Uncertainty for default lead production emission factors has an uncertainty of ±50% (IPCC, 2006, Table 4.23).

Time-series consistency

The time series is not consistent as the source of activity data changed in 2018 from the SAMI Report (DMR, 2019) to industry reporting via the SAGERS Portal.

4.4.5.4 Category specific QA/QC and verification

No specific QC checks were completed for this sub-category.

4.4.5.5 Category specific recalculations

A recalculation was undertaken for the 2000 – 2019 where initially emissions were estimated using the emissions factor 0.52 tonnes CO_2/tonne product. In 2020 we were made aware that the production was not primary but secondary and the emission factor was adjusted to 0.2 tonnes CO_2/tonne product.

4.4.5.6 Category specific planned improvements

There is a planned improvement project to investigate outstanding data providers who trigger the regulations and should be reporting under secondary production of lead. It is also planned to investigate the use of imperial smelting furnaces (pyrometallurgical) in the country used to produce both lead and zinc production.

4.4.6 Zinc production (2.C.6)

4.4.6.1 Category description

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

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

4.4.6.2 Methodological issues

Emissions from *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 by applying an extrapolation from 2018.

Emission factors

The IPCC, 2006 default emission factor of 1.72 t CO_2 per tonne zinc produced was applied. It was assumed that for *zinc production* it was 60% imperial smelting and 40% Waelz Kiln (IPCC, 2006).

4.4.6.3 Uncertainties and time-series consistency

Activity data uncertainty

For *zinc production* emissions there is a ±10% uncertainty on the activity data (IPCC, 2006, Table 4.25).

Emission factor uncertainty

Uncertainty for default zinc production emission factors has an uncertainty of ±50% (IPCC, 2006, Page 4.25).

Time-series consistency

The time series is inconsistent as activity data has not been available since 2017 and an extrapolation was undertaken to obtain data values.

4.4.6.4 Category specific QA/QC and verification

No specific QC checks were completed for this sub-category.

4.4.6.5 Category specific recalculations

No recalculations were performed for this category.

4.4.6.6 Category specific planned improvements

There is a planned improvement project to investigate outstanding data providers who trigger the regulations and should be reporting under secondary production of zinc. It is also planned to investigate the use of imperial smelting furnaces (pyrometallurgical) in the country used to produce both lead and zinc production.

4.4.7 Other (2.C.7)

No activities were included under this sub-category.

4.5 Non-Energy Products from Fuels and Solvent Use (2.D)

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.

4.5.1 Lubricant use (2.D.1)

4.5.1.1 Category description

According to the 2006 IPCC Guidelines. lubricants are produced either at refineries through separation from crude oil or at petrochemical facilities.

Methodological issues

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 4.14). Activity data was interpolated for 2007 to 2010 using 2006 and 2011 data as the data was unreliable for this period. An extrapolation was applied to the 2020 activity data, as the updated energy balance tables are currently unavailable.

Table 4. 15: Lubricant and paraffin wax consumption, 2000 – 2020.

	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	34 913	141
2008	35 435	182
2009	35 957	231
2010	36 478	27.9
2011	37 000	52.6
2012	57 160	13 939
2013	35 574	207.2
2014	48 652	366.2
2015	48 531	121 608
2016	25 490	6 756
2017	28 940	7 240
2018	41 671	1 872
2019	38 180	96 263
2020	45 500	42 780

Emission factors

The IPCC, 2006 default carbon content (20 tC/TJ) and oxidised fraction factor (0.2) applied to this subsector.

4.5.1.2 Uncertainties and time-series consistency

Activity data uncertainty

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 (IPCC, 2006, Page 5.10). Therefore, an uncertainty range of ±10% to ±20% was used.

Emission factor uncertainty

The default oxidised during use (ODU) factors available in the IPCC guidelines are uncertain, as they are based on limited knowledge of typical lubricant oxidation rates. Expert judgment suggests using a default uncertainty of 50% (IPCC, 2006, Page 5.10).

Time-series consistency

The time series is inconsistent as activity data has not been available for 2020 and an extrapolation was undertaken to obtain data values.

4.5.1.3 Category specific QA/QC and verification

No specific QC checks were completed for this sub-category.

4.5.1.4 Category specific recalculations

No recalculations were performed for this category.

4.5.1.5 Category specific planned improvements

The is a planned improvement project to determine the use of blended lubricant in two-stroke engines.

4.5.2 Paraffin wax use (2.D.2)

4.5.2.1 Category description

According to the 2006 IPCC Guidelines this category includes petroleum jelly, paraffin waxes and other waxes, including ozokerite (mixtures of saturated hydrocarbons, solid at ambient temperature). Paraffin waxes are separated from crude oil during the production of light lubricating oils.

4.5.2.2 Methodological issues

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 4.14). An extrapolation was applied to the 2020 activity data, as the updated energy balance tables are currently unavailable.

Emission factors

The IPCC, 2006 default carbon content (20 tC/TJ) and oxidised fraction factor (0.2) applied to this subsector.

4.5.2.3 Uncertainties and time-series consistency

Activity data uncertainty

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 (IPCC, 2006, Page 5.13).

Emission factor uncertainty

The default 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, Page 5.13).

Time-series consistency

The time series is inconsistent as activity data has not been available for 2020 and an extrapolation was undertaken to obtain data values.

4.5.2.4 Category specific QA/QC and verification

No specific QC checks were completed for this sub-category.

4.5.2.5 Category specific recalculations

No recalculations were performed for this category.

4.5.2.6 Category specific planned improvements

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

4.5.3 Solvent use (2.D.3)

No activities were included under this sub-category.

4.6 Electronics industry (2.E)

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.

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

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. HFCs and, to a limited extent, PFCs are 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.

4.7.1 Refrigeration and air conditioning (2.F.1)

4.7.1.1 Category description

According to the 2006 IPCC Guidelines, refrigeration, and air-conditioning (RAC) systems may be classified in up to six sub-application categories:

- Domestic refrigeration.
- Commercial refrigeration including different types of equipment, from vending machines to centralised refrigeration systems in supermarkets.
- Industrial processes including chillers, cold storage, and industrial heat pumps used in the food, petrochemical and other industries.
- Transport refrigeration including equipment and systems used in refrigerated trucks, containers, reefers, and wagons.
- Stationary air conditioning including air-to-air systems, heat pumps, and chillers for building and residential applications.
- Mobile air-conditioning systems used in passenger cars, truck cabins, buses, and trains.

4.7.1.2 Methodological issues

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 4.15 summarises the approach used for each sub-application in the RAC sector:

Table 4. 16: Methodology and data sources used for each RAC sub-application.

Sub-application	Method	Motivation

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

Activity data

Stakeholders in the refrigeration and air conditioning sector in South Africa were identified by means of desktop research and the membership lists of the various industry associates in the refrigeration and air conditioning sector, such as the South African Institute of Refrigeration and Air Conditioning (SAIRAC), the South African Refrigeration & Air Conditioning Contractors' Association (SARACCA) and the South African Refrigeration Distribution Association (SARDA).

Other sources included the members of the DFFE's Chemical Management Hydrochlorofluorocarbons (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% (IPCC, 2006). The percentage of HFC destroyed at the end-of-life was assumed to be 25% (IPCC, 2006).

4.7.1.3 Uncertainties and time-series consistency

Activity data uncertainty

An uncertainty of ±25% was assumed for activity data (IPCC, 2006).

Emission factor uncertainty

An uncertainty of ±25% was assumed for emission factors (IPCC, 2006).

Time-series consistency

Time series is not consistent over the full 20-year 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.

4.7.1.4 Category specific QA/QC and verification

No specific QC checks were completed for this sub-category.

4.7.1.5 Category specific recalculations

No recalculations were performed for this category.

4.7.1.6 Category specific 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.

4.7.2 Foam blowing agents (2.F.2)

4.7.2.1 Category description

HFCs are being used as replacements for Chlorofluorocarbons (CFCs) and HCFCs in foams and particularly in insulation applications according to the 2006 IPCC Guidelines. Compounds that are being used include HFC-245fa, HFC-365mfc, HFC-227ea, HFC-134a, and HFC-152a. The division of foams into open-cell or closed-cell relates to the way in which blowing agent is lost from the products.

For open-cell foam. emissions of HFCs used as blowing agents are likely to occur during the manufacturing process and shortly thereafter. In closed-cell foam, only a minority of emissions occur during the manufacturing phase. Emissions therefore extend into the in-use phase, with often the majority of emissions not occurring until end-of-life (de-commissioning losses).

4.7.2.2 Methodological issues

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). 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 United Nations Environmental Programme (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 2010-2020 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% (IPCC, 2006). The percentage of HFC destroyed at the end-of-life was assumed to be 25% (IPCC, 2006). Other factors applied are shown in Table 4.16.

Table 4. 17: Emission factors and defaults applied in the foam blowing agents emission estimates.

Sub-category	Value	Units	Source
Product life	34	Years	(UNEP, 2005; IPCC. 2006)
First year loss	14	%	
Annual loss	0.66	%	
Landfilling loss	16	%	
Landfill annual loss	0.75	%	

4.7.2.3 Uncertainties and time-series consistency

Activity data uncertainty

An uncertainty of ±25% was assumed for activity data (IPCC, 2006).

Emission factor uncertainty

An uncertainty of ±25% was assumed for emission factors (IPCC, 2006).

Time-series consistency

Time series is not consistent over the full 20-year 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.

4.7.2.4 Category specific QA/QC and verification

No specific QC checks were completed for this sub-category.

4.7.2.5 Category specific recalculations

No recalculations were performed for this category.

4.7.2.6 Category specific planned improvements

Extrapolation of HFCs across the full time-series will be considered in the next inventory. The equation was pulled through correctly from 2016 on the calculation sheet as a zero-emission value was appearing before.

4.7.3 Fire protection (2.F.3)

4.7.3.1 Category description

According to the 2006 IPCC Guidelines there are two general types of fire protection (fire suppression) equipment that use HFCs and/or PFCs as partial replacements for halons: portable (streaming) equipment, and fixed (flooding) equipment. While actual emissions from the fire protection sub-sector are expected to be quite small, the use is normally non-emissive in provision of stand-by fire protection and is growing.

4.7.3.2 Methodological issues

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).

4.7.3.3 Uncertainties and time-series consistency

Activity data uncertainty

An uncertainty of ±25% was assumed for activity data (IPCC, 2006).

Emission factor uncertainty

An uncertainty of ±25% was assumed for emission factors (IPCC, 2006).

Time-series consistency

Time series is not consistent over the full 20-year 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.

4.7.3.4 Category specific QA/QC and verification

No specific QC checks were completed for this sub-category.

4.7.3.5 Category specific recalculations

No recalculations were undertaken for this category as they were not previously estimated.

4.7.3.6 Category specific planned improvements

No further improvements are planned for this sub-category.

4.7.4 Aerosols (2.F.4)

4.7.4.1 Category description

Most aerosol packages contain hydrocarbon (HC) as propellants but. in a small fraction of the total. HFCs and PFCs may be used as propellants or solvents. Emissions from aerosols usually occur shortly after production. on average six months after sale. During the use of aerosols, 100 percent of the chemical is emitted. The 5 main sub-applications are as follows:

- Metered Dose Inhalers (MDIs).
- Personal Care Products (e.g., hair care. deodorant. shaving cream).
- Household Products (e.g., air-fresheners. oven and fabric cleaners).
- Industrial Products (e.g., special cleaning sprays such as those for operating electrical contact. lubricants. pipe-freezers).
- Other General Products (e.g., silly string. tyre inflators. klaxons).

4.7.4.2 Methodological issues

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 EF of 50% of the initial charge per year (IPCC, 2006).

4.7.4.3 Uncertainties and time-series consistency

Activity data uncertainty

An uncertainty of ±25% was assumed for activity data (IPCC, 2006).

Emission factor uncertainty

An uncertainty of ±25% was assumed for emission factors (IPCC, 2006).

Time-series consistency

Time series is not consistent over the full 20-year 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.

4.7.4.4 Category specific QA/QC and verification

No specific QC checks were completed for this sub-category.

4.7.4.5 Category specific recalculations

No recalculations were performed for this category as they were not previously estimated.

4.7.4.6 Category specific planned improvements

Extrapolation of HFCs across the full time-series will be considered in the next inventory. The equation was pulled through correctly from 2016 on the calculation sheet as a zero-emission value was appearing before.

4.8 Other product manufacture and use (2.G)

Emissions from this category were not estimated for South Africa due to a lack of data.

4.9 Other (2.H)

Emissions from this category were not estimated for South Africa due to a lack of data from the Pulp and Paper Industry and the Food and Beverages Industry.

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Chapter 5: Agriculture, Forestry and Other Land Use (AFOLU)

5.1 Sector overview

This chapter includes GHG emissions and removals from agriculture as well as land, forestry, and other land use. Based on the IPCC 2006 Guidelines, the main categories included in the emission estimates for the AFOLU sector are shown in Table 5. 1.

Table 5. 1: Main IPCC categories included in the AFOLU sector emission estimates.

IPCC Category	Category name	Included
3A1	Enteric fermentation	√
3A2	Manure management	√
3B1	Forest lands	√
3B2	Croplands	√
3B3	Grasslands	√
3B4	Wetlands	√
3B5	Settlements	√
3B6	Other lands	√
3C1	Biomass burning	√
3C2	Liming	√
3C3	Urea application	√
3C4	Direct N_2O emissions from managed soils	√
3C5	Indirect N_2O from managed soils	√
3C6	Indirect N_2O from manure management	√
3C7	Rice cultivation	NO
3C8	Other	NO
3D1	Harvested wood products	√
3D2	Other	NO

Livestock included are dairy cattle, other cattle, sheep, goats, horses, mules and asses, swine and poultry. Emissions from ruminants in privately owned game parks were excluded due to comments made during the UNFCCC review. The land use component includes Forest lands, Croplands, Grasslands, Wetlands, Settlements and Other lands. In addition, for each of these classes both land remaining in the same land use as well as land converted to another land use are considered. The land component includes biomass, DOM and SOC. A Tier 1 (Formulation B) approach to the mineral soil carbon pool. Organic carbon is considered insignificant in this inventory (discussed further in section 5.4.1).

Rice cultivation is not included. Food and Agriculture Organization (FAO) statistics indicate that there is a small area of rice cultivation in South Africa and therefore in the UNFCCC review it was indicated that this should be investigated and included if necessary. Discussions with various experts at the ARC suggests that there have been some small experimental plots for rice cultivation, but the precise area was not known but it is thought to be less than 50 ha. For this reason, rice cultivation is considered insignificant.

Emissions from fuel combustion in this sector are not included here as these falls under the *agriculture/forestry/fisheries* subsector (see Section 3.2.9) in the energy sector.

5.1.1 Shares and trends in emissions

5.1.1.1 Overall AFOLU

The overall AFOLU emissions totalled 14 088 Gg CO_2e (incl. FOLU) in 2020, and 40 775 Gg CO_2e excluding FOLU (Figure 5.1). There was a 4% decline in emissions (excl. FOLU) and 40% decline in emissions including FOLU between 2000 and 2020. The various trends and drivers are discussed in the sections below.

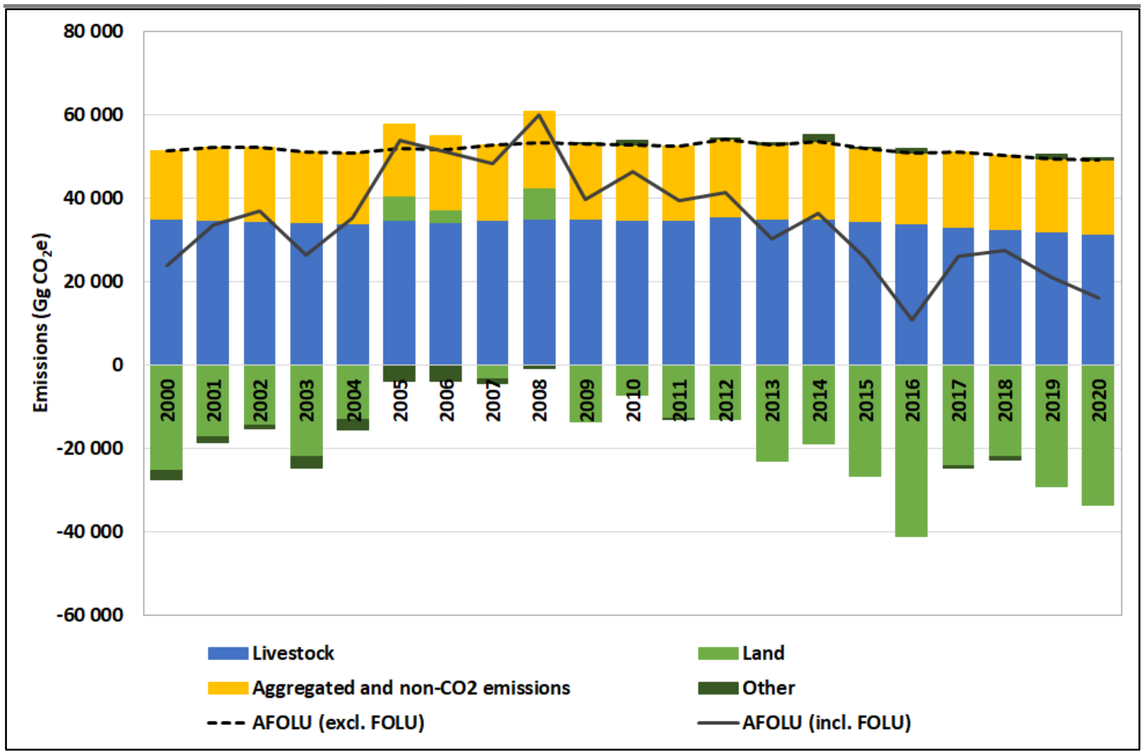

Figure 5.1: The overall AFOLU emissions for South Africa between 2000 – 2020.

5.1.1.2 Agriculture

Livestock (3A)

Enteric fermentation (3A1)

Enteric fermentation emissions have been fairly constant between 2000 and 2015, with a slight decline in 2006 and a slight increase in 2012. After 2015 emissions declined to 2020 (Figure 5.2;Table 5. 2). This trend follows the same pattern as cattle population, the largest contributors to emissions from the livestock population data (Figure 5.3). The main reasons for the declining livestock numbers in recent years are the consecutive droughts that occurred in 2015 and 2016 (BFAP, 2018) and livestock owners struggling to rebuild their herds to pre-2014 levels.

The other cattle[2] population has declined by 12.5% since 2014, leading to a decline in other cattle emissions. In comparison to other cattle, the total number of dairy cattle[3] (less than 10% of the cattle population) declined slightly between 2000 and 2007 but returned to similar levels by 2017. There was a slight drop in 2019, with numbers recovering in 2020 and this is reflected in the enteric fermentation emissions. 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 2020 the *Enteric fermentation* category contributed 27 589 Gg CO_2e (Table 5. 3). Other cattle and sheep were the largest contributors to the *Enteric fermentation* category (Table 5. 3). Emissions from horses showed a slight increase between 2000 and 2020, while emissions from all other livestock declined during this time.

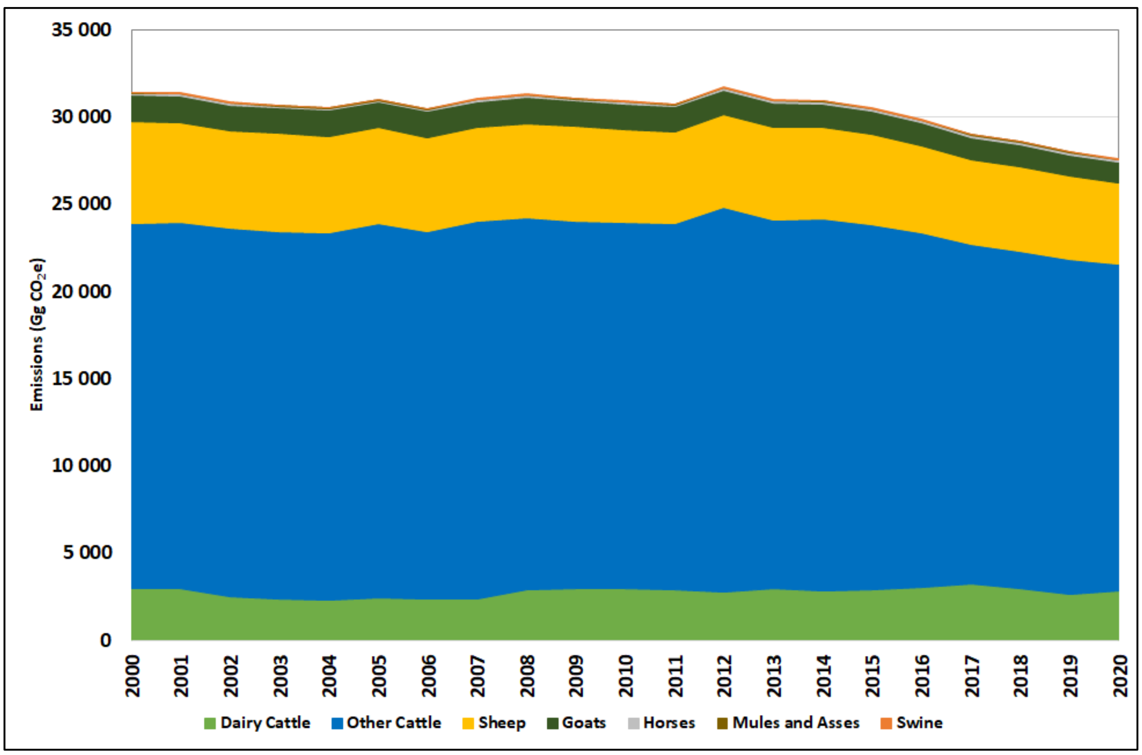

Figure 5.2: *Enteric fermentation* emission trends, 2000 – 2020.

[2] All cattle except dairy cows and lactating heifers.
[3] Only dairy cows and lactating heifers.

Table 5. 2: Enteric fermentation emission trends between 2000 and 2020.

	2000	2005	2010	2015	2016	2017	2018	2019	2020
	Gg CO_2e								
Dairy cattle	2 933	2 429	2 962	2 874	2 992	3 199	2 933	2 607	2 814
Other cattle	20 968	21 438	21 013	20 952	20 354	19 469	19 361	19 212	18 740
Buffalo	NO	NO	NO	NO	NO	NO	NO	NO	NO
Sheep	5 837	5 505	5 292	5 151	5 015	4 893	4 871	4 798	4 653
Goats	1 493	1 463	1 441	1 351	1 299	1 260	1 244	1 209	1 190
Camels	NO	NO	NO	NO	NO	NO	NO	NO	NO
Horses	102	102	113.4	119	121	122	124	125	125
Mules & asses	34	34	35	35	34	34	34	34	34
Swine	40	40	38	37	36	36	35	34	33
Other	NO	NO	NO	NO	NO	NO	NO	NO	NO
Total	31 408	31 011	30 895	30 519	29 851	29 014	28 601	28 019	27 589

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

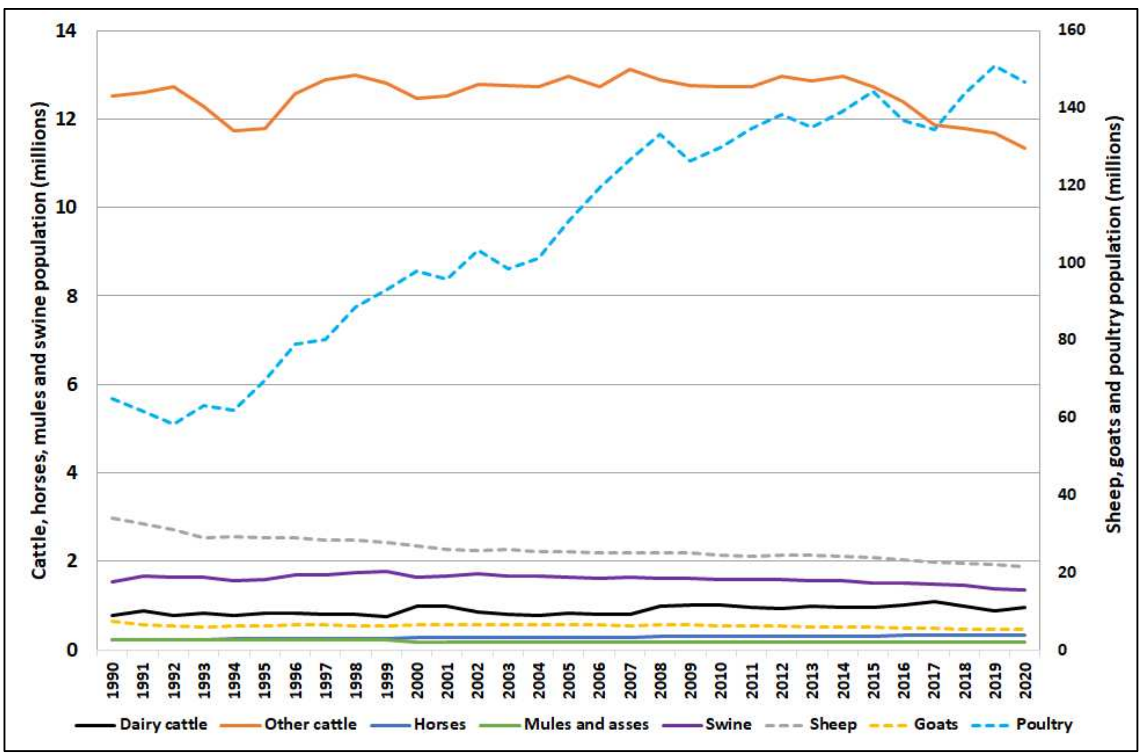

Figure 5.3: Livestock population trends, 2000 – 2020 (Data source: DALRRD, 2020).

Table 5. 3: Change in Enteric fermentation emissions (2000 – 2020) and relative contribution of the various livestock categories to the total emissions.

	Emissions (Gg CO_2e)		Change (2000-2020)		Share of enteric fermentation (%)	
	2000	2020	Diff	%	2000	2020
Dairy cattle	2 933	2 814	-118.5	-4.0	9.3	10.2
Other cattle	20 968	18 740	-2 227.9	-10.6	66.8	67.9
Buffalo	NO	NO	NO	NO	NO	NO
Sheep	5 837	4 653	-1 183.8	-20.3	18.6	16.9
Goats	1 493	1 190	-303.1	-20.3	4.8	4.3
Camels	NO	NO	NO	NO	NO	NO
Horses	102	125	22.7	22.2	0.3	0.5
Mules & asses	34	34	-0.5	-1.5	0.1	0.1
Swine	40	33	-7.0	-17.6	0.1	0.1
Other	NO	NO	NO	NO	NO	NO
Total	31 408	27 589	-3 818.2	-12.2	**100**	**100**

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

Manure management (3A2)

Emissions from manure management increased by 11.8% between 2000 and 2020 (Table 5. 4). CH_4 emissions declined, while N_2O emissions increased.

Table 5. 4: Trends and changes in manure management emissions (2000 to 2020).

	Emissions (Gg CO_2e)		Change (2000 – 2020)		Share of manure management	
	2000	2020	Diff	%	2000 %	2020 %
Methane	1 191.2	1 175.9	-15.3	-1.3	35.2	31.1
Nitrous oxide	2 190.5	2 606.3	415.8	19.0	64.8	68.9
Total manure management	**3 381.7**	**3 782.2**	400.5	11.8	100	100

Most of South Africa's livestock (cattle, sheep, goats, horses, mules and asses) are kept on pasture, range and paddock (Table 5. 5), therefore the *Manure management* category emissions were relatively small in 2020. Methane from *Manure management* declined in 2019 and started to increase again in 2020 (Figure 5.4), while the N_2O emissions have been increasing from 2000 to 2015, after which the emissions started to level off. The

N_2O emissions have remained constant since the last inventory in 2017. This is because, even though, poultry numbers are increasing, the decline in cattle numbers has been counteracting this increase (Figure 5.5). Managed manure from non-dairy and dairy cattle contributed the most to the CH_4 emissions (37.9% and 35.1% respectively); while the largest contributors to the N_2O emissions were non-dairy cattle (41.5%) and poultry (37.5%).

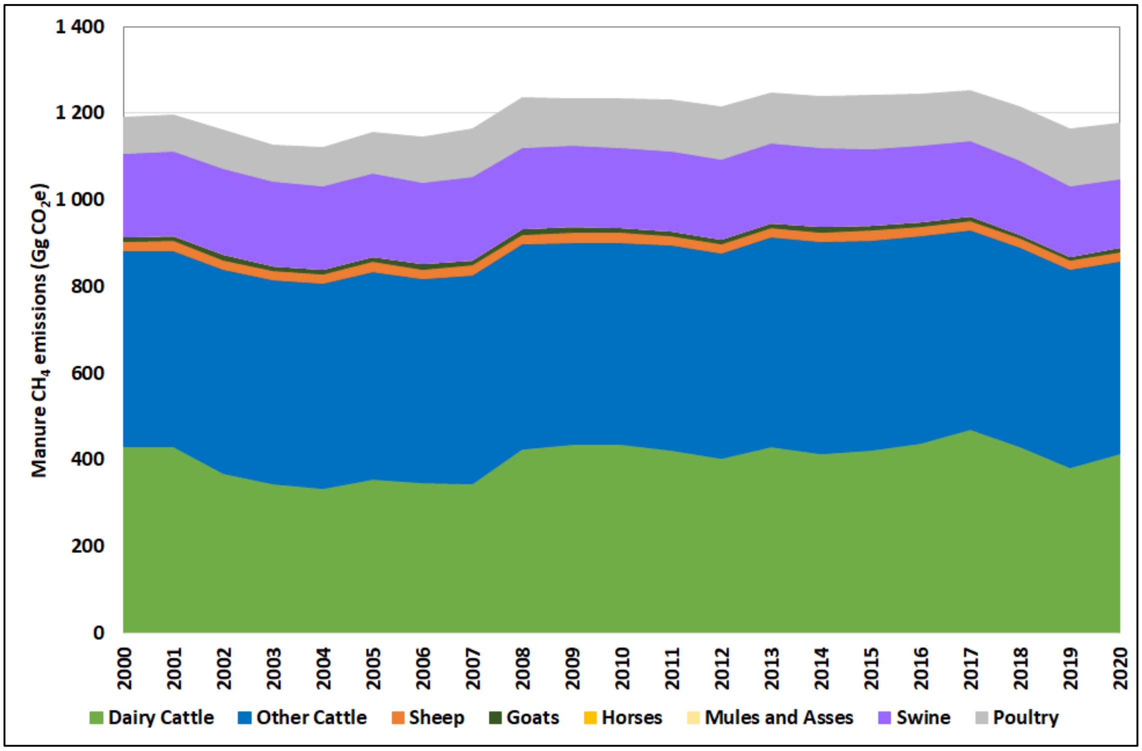

Figure 5.4: Trend in manure management CH_4 emissions from livestock, 2000 – 2020.

Table 5. 6: Manure management CH_4 emission trends between 2000 and 2020.

	2000	2005	2010	2015	2016	2017	2018	2019	2020
	Gg CO_2e								
Dairy cattle	430.0	356.1	434.3	421.3	438.7	469.1	430.0	382.2	412.6
Other cattle	451.6	478.8	466.8	485.1	477.8	461.9	460.3	458.3	446.4
Buffalo	NO	NO	NO	NO	NO	NO	NO	NO	NO
Sheep	22.1	22.4	23.2	23.6	22.8	21.9	20.8	19.5	21.1
Goats	11.3	11.6	11.6	10.7	10.3	10.0	9.8	9.5	9.4
Camels	NO	NO	NO	NO	NO	NO	NO	NO	NO
Horses	NO	NO	NO	NO	NO	NO	NO	NO	NO

	2000	2005	2010	2015	2016	2017	2018	2019	2020
	Gg CO_2e								
Mules & asses	NO	NO	NO	NO	NO	NO	NO	NO	NO
Swine	192.0	192.5	185.8	177.6	176.3	172.7	169.5	162.0	158.2
Poultry	84.2	94.5	112.0	123.5	118.3	115.1	123.8	131.6	128.2
Other	NO	NO	NO	NO	NO	NO	NO	NO	NO
Total	1 191.2	1 155.8	1 233.8	1 241.8	1 244.1	1 250.6	1 214.2	1 163.3	1 175.9

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

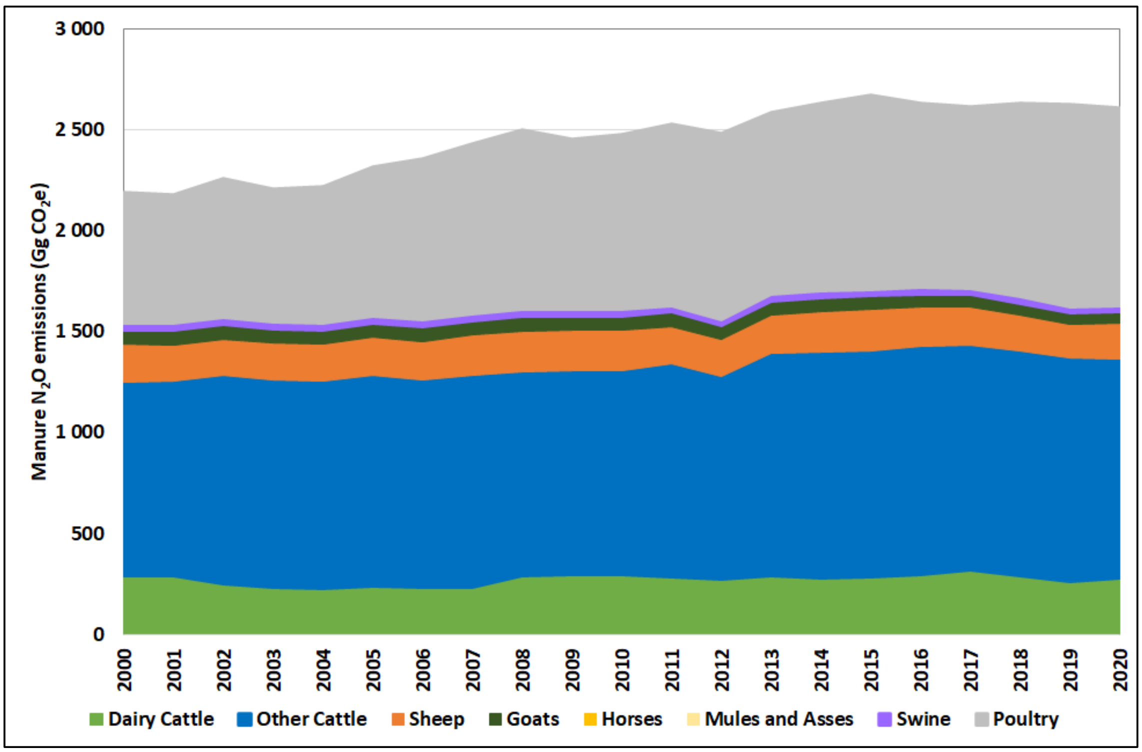

Figure 5.5: Trend in manure management N_2O emissions from livestock, 2000 – 2020.

Table 5. 7: Manure management N_2O emission trends between 2000 and 2020.

	2000	2005	2010	2015	2016	2017	2018	2019	2020
	Gg CO_2e								
Dairy cattle	291.2	241.2	294.2	285.3	297.1	317.7	291.2	258.9	279.4
Other cattle	958.2	1 038.9	1 010.0	1 120.3	1 127.2	1 114.9	1 111.0	1 108.2	1 080.8
Buffalo	NO	NO	NO	NO	NO	NO	NO	NO	NO
Sheep	185.3	189.6	199.9	205.5	197.8	189.4	178.0	165.7	182.5
Goats	69.2	71.2	71.1	65.9	63.1	61.2	60.5	58.5	57.9
Camels	NO	NO	NO	NO	NO	NO	NO	NO	NO
Horses	NO	NO	NO	NO	NO	NO	NO	NO	NO
Mules & asses	NO	NO	NO	NO	NO	NO	NO	NO	NO
Swine	34.7	34.8	33.6	32.1	31.8	31.2	30.6	29.3	28.6
Poultry	651.9	740.4	866.9	962.3	910.9	897.8	958.3	1 004.1	977.1
Other	NO	NO	NO	NO	NO	NO	NO	NO	NO
Total	2 190.5	2 316.0	2 475.6	2 671.4	2 628.0	2 612.2	2 629.7	2 624.6	2 606.3

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

Aggregated and non-CO_2 emissions on land (3C)

Emissions from *Aggregated and non-CO_2 emissions on land* are summarised in Table 5. 8. *Direct N_2O from managed soils* contribute the most toward this category, while *Biomass burning* is the second largest contributor. The contribution from biomass burning and indirect N_2O from managed soils has declined since 2000, while all others increased. Emissions in this category have remained constant over the period of 2000 to 2020, except for a decline in 2003-2004 and 2015-2016 (Figure 5.6). Reduced emissions due to biomass burning appears to be the main contributor to these dips.

Table 5. 8: Changes in aggregated and non-CO_2 emission sources on land between 2000 and 2020.

Category	Emissions (Gg CO_2e)		Change (2000 – 2020)	
	2000	2020	Diff	%
Biomass burning	1 936.6	1 649.2	-287.3	-14.8
Liming	384.1	942.3	558.2	145.3
Urea application	297.3	584.7	287.3	96.6

Direct N_2O from managed soils	4 093.0	5 276.0	1 183.0	28.9
Indirect N_2O from managed soils	737.5	723.3	-14.2	-1.9
Indirect N_2O from manure management	201.4	227.5	26.1	13.0
Total	**7 649.7**	**9 402.9**	**1 753.2**	**22.9**

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

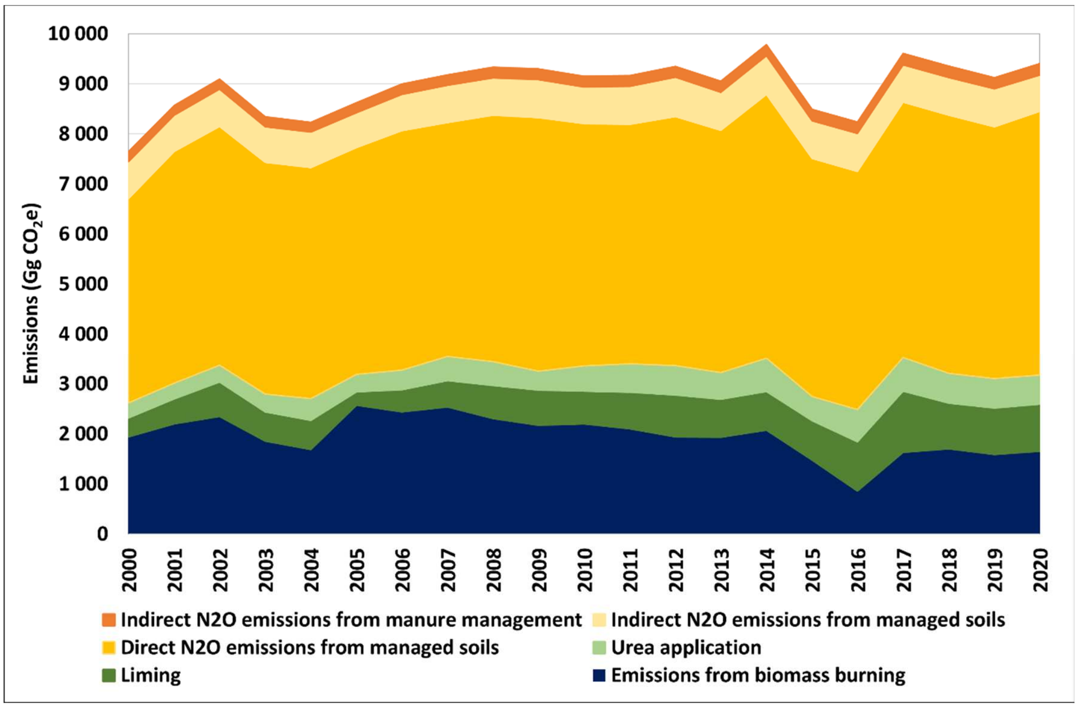

Figure 5.6: Trends in aggregated and non-CO_2 emissions on land, 2000 – 2020.

5.1.1.3 FOLU

Forest land (3B1)

Forest land was a sink between 2000 and 2004 after which it became a source. In 2011 Forest land became a sink again and this sink increased to 2020 (Figure 5.7). In 2020 the sink was estimated at 24 575 Gg CO_2. *Forest land remaining forest land* was the main contributor to the source between 2005 and 2008 due to increased biomass losses due to fires. Fuelwood removals[4] decline over the time-series, due to increased electrification and reduced demand, but start to stabilise after 2017 (Figure 5.8) as the number of households using wood does not change significantly over this period. This initial decline contributes 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.

Another driver is loss due to biomass burning. The burnt area declined between 2009 and 2016 (contributing to the increasing sink during this time) and then increased again in 2017 between 2019. There are also emissions due to conversion between the various forest types and a conversion from indigenous forest to woodland, for example, leading to a loss of carbon. The last contributing factor to the increasing sink is the increasing Forest land area. Indigenous forest and woodland area increased, while thicket area decreased. The total forest land area increased from 20 363 984 ha to 21 037 901 ha between 1990 and 2020. Increasing area means an increase in the gains and this is enhanced by reduced losses.

Plantations are shown to be a slight source of emissions; however, this varies from year to year depending on the amount of wood removals and so in some years it is a sink, but numbers vary around zero.

Grasslands converted to forest lands are the largest sink component in the converted lands category, and to a lesser extent *Croplands converted to Forest lands*. Biomass is the dominant pool contributing to change in the Forest land (Table 5. 9).

[4] Note that this is only fuelwood collected from live biomass, and thus excludes that collected as deadwood (see section 5.4.6 for more details).

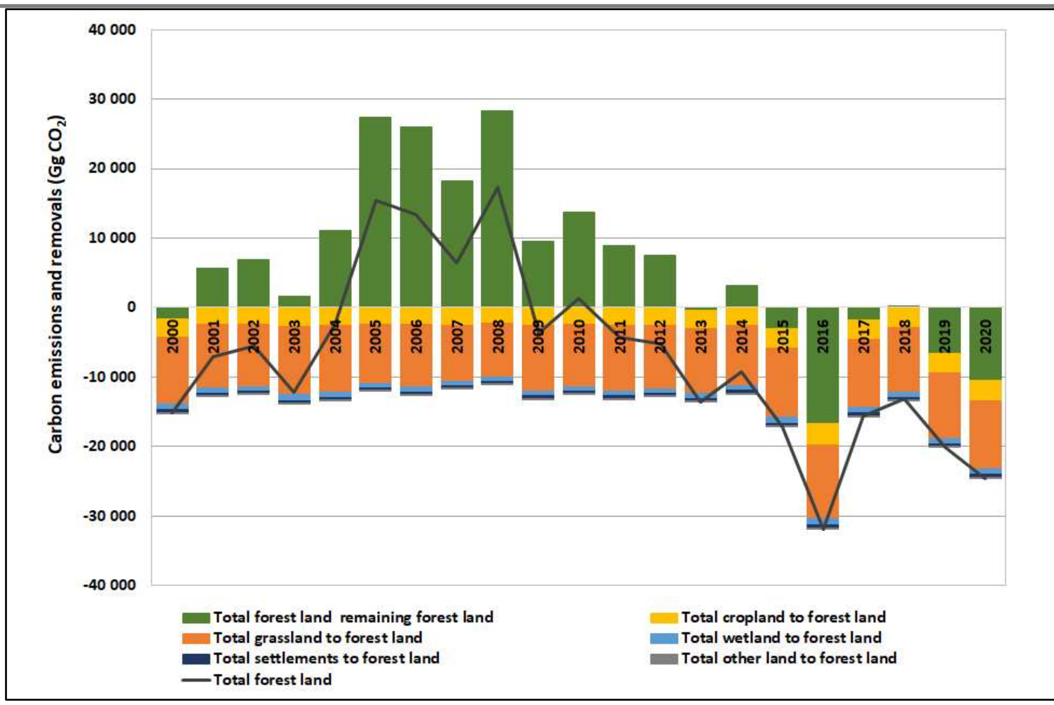

Figure 5.7: South Africa's carbon stock change (Gg CO_2) for Forest land, 2000 – 2020.

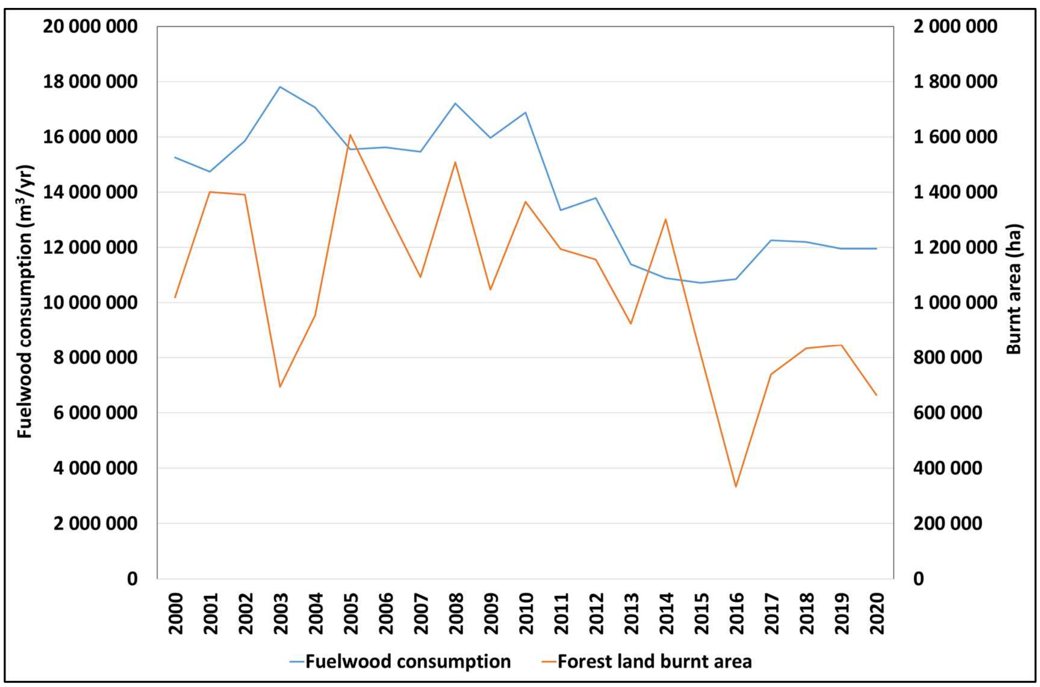

Figure 5.8: Estimated fuelwood consumption (blue) and forest burnt area (orange) between 2000 and 2020.

Table 5. 9: South Africa's net carbon stock change (Gg CO_2) by carbon pool for the Forest land, 2000 – 2020.

	Forest land remaining forest land			Land converted to forest land		
	Biomass	DOM	Mineral soil	Biomass	DOM	Mineral soil
2000	-1 757.5	52.6	0.0	-12 079.5	-579.3	-812.6
2001	5 624.1	52.6	0.0	-11 329.0	-579.3	-822.6
2002	6 865.5	52.6	0.0	-11 054.4	-579.3	-823.8
2003	1 594.5	52.6	0.0	-12 493.0	-579.3	-819.3
2004	10 971.6	52.6	0.0	-12 034.0	-579.3	-822.9
2005	27 316.8	52.6	0.0	-10 537.6	-579.3	-823.6
2006	25 916.0	52.6	0.0	-11 117.5	-579.3	-846.5
2007	18 109.0	52.6	0.0	-10 287.7	-579.3	-827.6
2008	28 217.2	52.6	0.0	-9 571.7	-579.3	-827.2
2009	9 484.7	52.6	0.0	-11 767.1	-579.3	-843.4
2010	13 657.9	52.6	0.0	-11 012.8	-579.3	-845.9
2011	8 834.7	52.6	0.0	-11 683.8	-579.3	-869.9
2012	7 505.1	52.6	0.0	-11 344.2	-579.3	-872.7
2013	-415.7	52.6	0.0	-11 774.1	-579.3	-877.5
2014	3 058.9	52.6	0.0	-10 889.5	-579.3	-879.1
2015	-3 125.7	52.6	0.0	-12 573.8	-579.3	-902.5
2016	-16 755.1	52.6	0.0	-13 627.1	-579.3	-898.0
2017	-1 868.1	52.6	0.0	-12 355.7	-579.3	-893.2
2018	244.0	52.6	0.0	-11 872.0	-579.3	-928.2
2019	-6 668.7	52.6	0.0	-11 942.0	-579.3	-917.5
2020	-10 595.4	52.6	0.0	-12 543.5	-579.3	-909.5

Cropland (3B2)

Croplands are estimated to be an overall source of CO_2. *Cropland remaining cropland* is a sink (1 391 Gg CO_2 in 2020) and this is mainly due to biomass in orchards and vineyards and mineral SOC. *Land converted to croplands* emitted 3 559 Gg CO_2 in 2020 (Figure 5.9) and this is because all land types, except for *Settlements* and *Other lands*, converted to croplands results in an emission of CO_2. The dominant contributor to the emissions is the conversion of *Grassland* to *Croplands*. There is some annual variation in the emissions and these are due to losses due to fire and changes in management practices or areas of the various crop types. For *Croplands remaining croplands* the sink is declining very slightly between 2000 and 2020 and this is because only the growth in orchards and vineyards is considered and these show a slight decline in area. In *Land converted to croplands* there is little annual variation as there are not large changes in crop areas and management. The SOC pool is the dominant carbon pool followed by biomass (Table 5. 10).

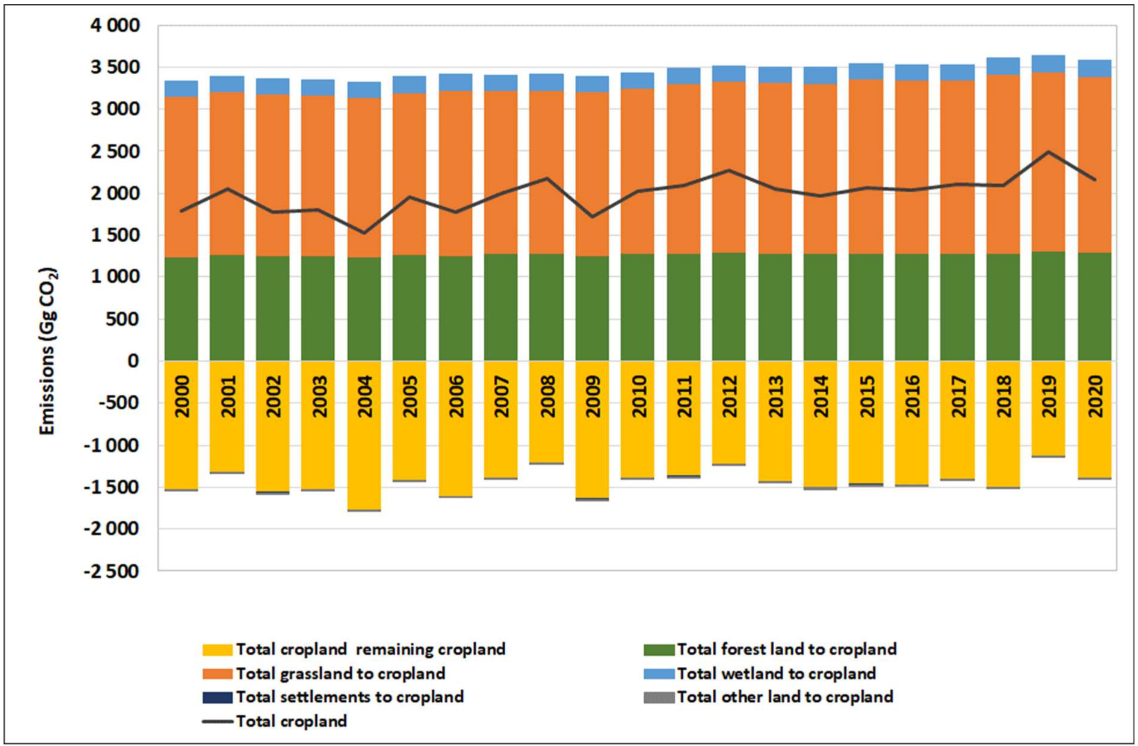

Figure 5.9: CO_2 emissions and removals (Gg CO_2) due to changes in carbon stocks between 2000 and 2020 for South Africa's Cropland.

Table 5. 10: South Africa's net carbon stock change (Gg CO_2) by carbon pool for Croplands, 2000 – 2020.

	Cropland remaining cropland			Land converted to cropland		
	Biomass	DOM	Mineral soil	Biomass	DOM	Mineral soil
2000	-1 548.4	29.1	-7.8	726.8	8.6	2 607.9
2001	-1 342.0	29.1	-8.1	756.2	8.6	2 632.9
2002	-1 582.9	29.1	-8.1	726.6	8.6	2 635.9
2003	-1 550.2	29.1	-8.0	725.6	8.6	2 624.6
2004	-1 798.4	29.1	-8.1	690.4	8.6	2 633.6
2005	-1 434.6	29.1	-8.1	749.6	8.6	2 635.3
2006	-1 635.1	29.1	-8.9	718.9	8.6	2 692.5
2007	-1 406.2	29.1	-8.3	755.3	8.6	2 645.4

2008	-1 236.9	29.1	-8.2	769.6	8.6	2 644.2
2009	-1 664.8	29.1	-8.8	708.1	8.6	2 684.7
2010	-1 407.9	29.1	-8.8	743.6	8.6	2 691.1
2011	-1 388.6	29.1	-9.6	737.3	8.6	2 751.1
2012	-1 246.2	29.1	-9.7	759.2	8.6	2 758.0
2013	-1 447.0	29.1	-9.8	731.7	8.6	2 769.9
2014	-1 523.5	29.1	-9.9	720.7	8.6	2 774.1
2015	-1 483.6	29.1	-10.6	715.6	8.6	2 832.5
2016	-1 492.4	29.1	-10.5	706.8	8.6	2 821.1
2017	-1 426.9	29.1	-10.3	724.0	8.6	2 809.1
2018	-1 514.8	29.1	-11.4	709.4	8.6	2 896.6
2019	-1 144.2	29.1	-11.1	764.0	8.6	2 870.0
2020	-1 409.6	29.1	-10.9	729.1	8.6	2 850.0

Grassland (3B3)

Grasslands remaining grasslands are a sink of CO_2 (Figure 5.10) due mainly to the SOC pool, but also because of the conversions of low shrubland and degraded land (which are also included under *Grasslands*) to grasslands. The sink amounted to 1 057 Gg CO_2 in 2020. *Land converted to grassland* is a sink of 10 027 Gg CO_2 in 2020. There is annual variation, and the driver of the annual variation is burnt area which varies across the time-series. The dominant contributor to the land conversion sink is the conversion of *Other land* to *Grassland* (8 901 Gg CO_2) as this represents both a gain in biomass and soil carbon. This is followed by *Cropland to Grassland* (3 232 Gg CO_2). Soil carbon contributed 77% to the *Grassland* sink (Table 5. 11).

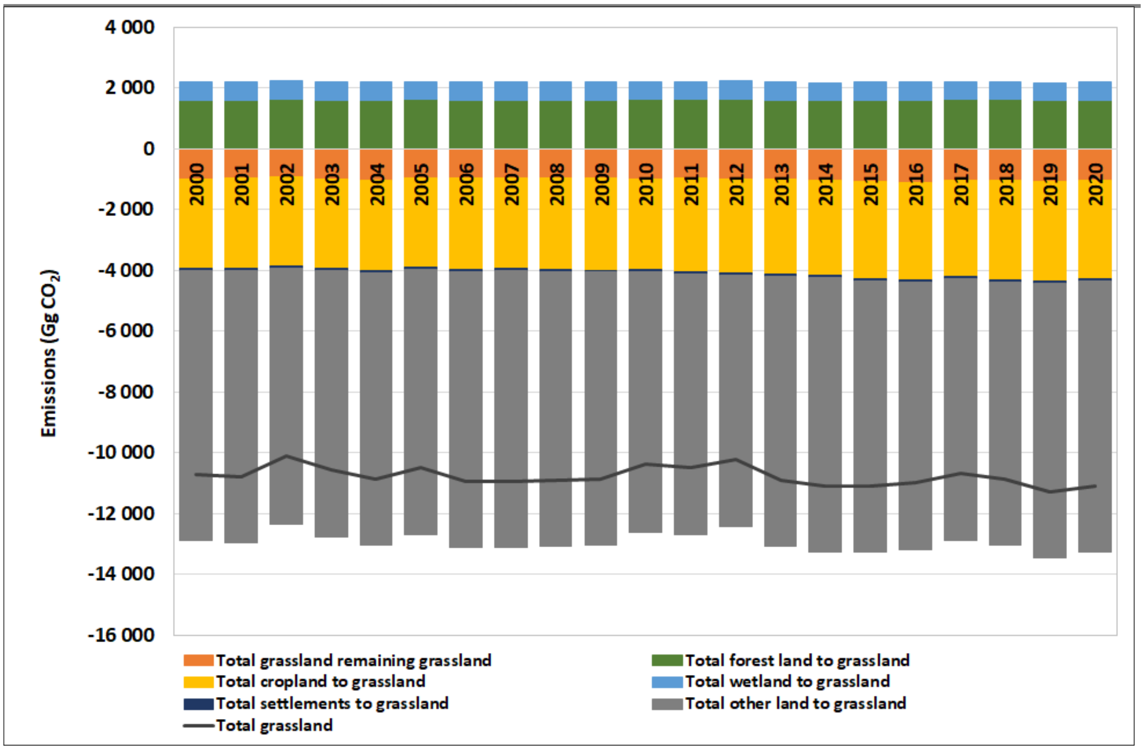

Figure 5.10: CO_2 emissions and removals (Gg CO_2) due to changes in carbon stocks between 2000 and 2020 for South Africa's Grassland.

Table 5. 11: South Africa's net carbon stock change (Gg CO_2) by carbon pool for Grasslands, 2000 – 2020.

	Grassland remaining grassland			Land converted to grassland		
	Biomass	DOM	Mineral soil	Biomass	DOM	Mineral soil
2000	-1 526.4	582.3	-56.9	-1 051.6	-446.6	-8 198.9
2001	-1 503.4	582.3	-56.9	-1 122.6	-446.6	-8 230.0
2002	-1 471.1	582.3	-56.9	-498.9	-446.6	-8 233.7
2003	-1 536.8	582.3	-56.9	-892.6	-446.6	-8 219.6
2004	-1 574.0	582.3	-56.9	-1 148.0	-446.6	-8 230.9
2005	-1 478.4	582.3	-56.9	-864.1	-446.6	-8 232.9
2006	-1 472.2	582.3	-56.9	-1 243.8	-446.6	-8 303.9
2007	-1 494.6	582.3	-56.9	-1 281.0	-446.6	-8 245.4
2008	-1 508.9	582.3	-56.9	-1 239.9	-446.6	-8 244.0
2009	-1 500.3	582.3	-56.9	-1 146.3	-446.6	-8 294.2
2010	-1 511.8	582.3	-56.9	-656.0	-446.6	-8 302.2
2011	-1 508.8	582.3	-56.9	-674.1	-446.6	-8 376.5

2012	-1 532.7	582.3	-56.9	-362.8	-446.6	-8 385.2
2013	-1 529.0	582.3	-56.9	-1 037.9	-446.6	-8 399.9
2014	-1 559.2	582.3	-56.9	-1 199.4	-446.6	-8 405.1
2015	-1 605.8	582.3	-56.9	-1 099.3	-446.6	-8 477.6
2016	-1 655.0	582.3	-56.9	-960.9	-446.6	-8 463.4
2017	-1 581.8	582.3	-56.9	-733.0	-446.6	-8 448.5
2018	-1 577.0	582.3	-56.9	-805.1	-446.6	-8 557.0
2019	-1 603.2	582.3	-56.9	-1 233.9	-446.6	-8 524.0
2020	-1 582.5	582.3	-56.9	-1 081.4	-446.6	-8 499.3

Wetlands (3B4)

Wetlands, assumed to be wetlands on mineral soils, are an overall sink for CO_2 over the period 2000 to 2020 (Figure 5.11) with a sink of 437 Gg CO_2 in 2020. If the CH_4 and N_2O emissions are included, then Wetlands become a source (1 193 Gg CO_2e in 2020). *Wetlands remaining wetlands* are a very small source of CO_2, and this is due to conversions between wetlands and waterbodies. A conversion of a wetland to a waterbody results in a loss of carbon. They do, however, lead to an emission of CH_4 and N_2O. Land conversions to wetlands led to a sink of 476 Gg CO_2 in 2020 with the main contributor being the conversion of grasslands to wetlands. *Land converted to wetlands* produced 536 Gg CO_2e in CH_4 and N_2O.

Non-CO_2 emissions declined from 2 169 Gg CO_2e in 2000 to 1 629 Gg CO_2e in 2020. The decline in non-CO_2 emissions is as a result of the decline in the wetland area during this time.

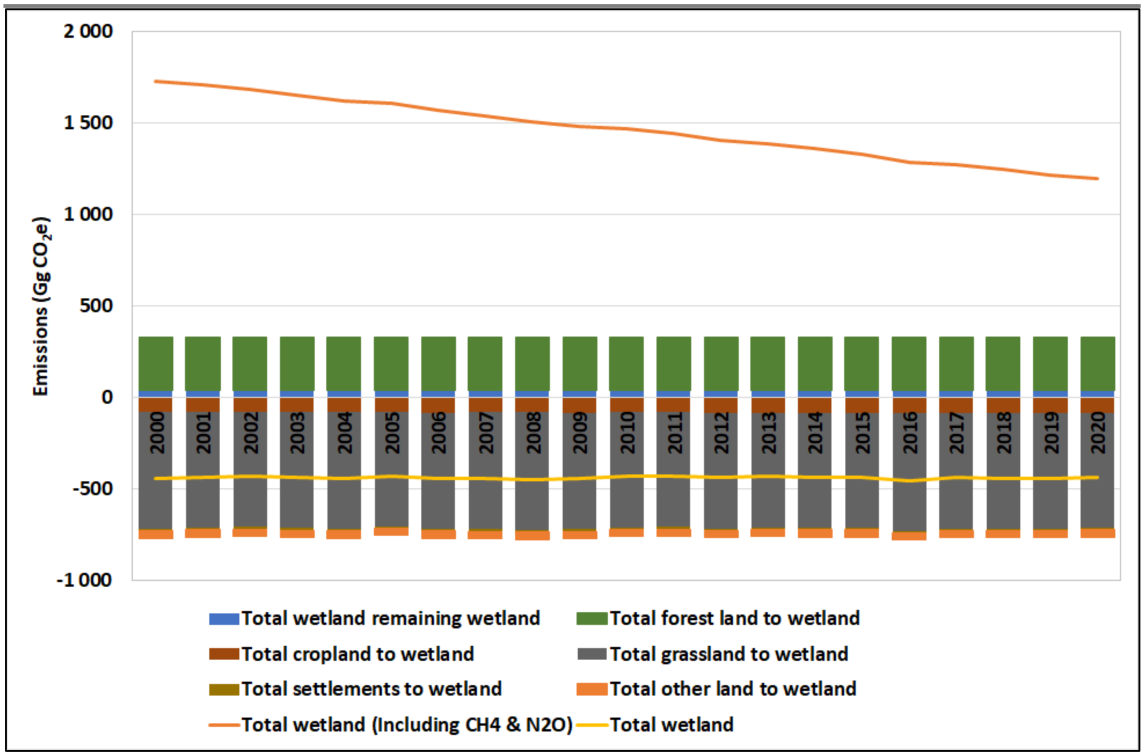

Figure 5.11: CO_2 emissions and removals (Gg CO_2) due to changes in carbon stocks between 2000 and 2020 for South Africa's Wetlands.

Settlements (3B5)

Settlements were estimated to be a sink of CO_2 (Figure 5.12) and this is due to the presence of biomass in settlement areas. Generally, the conversion of land to settlements results in an emission of CO_2, except when *Other land* is converted to settlements. *Forest land* converted to *Settlements* is the main contributor to the land conversion emissions. The emission is due to the loss of biomass and a reduction in SOC. The biomass pool is dominant in the *Settlements* category (Table 5. 12).

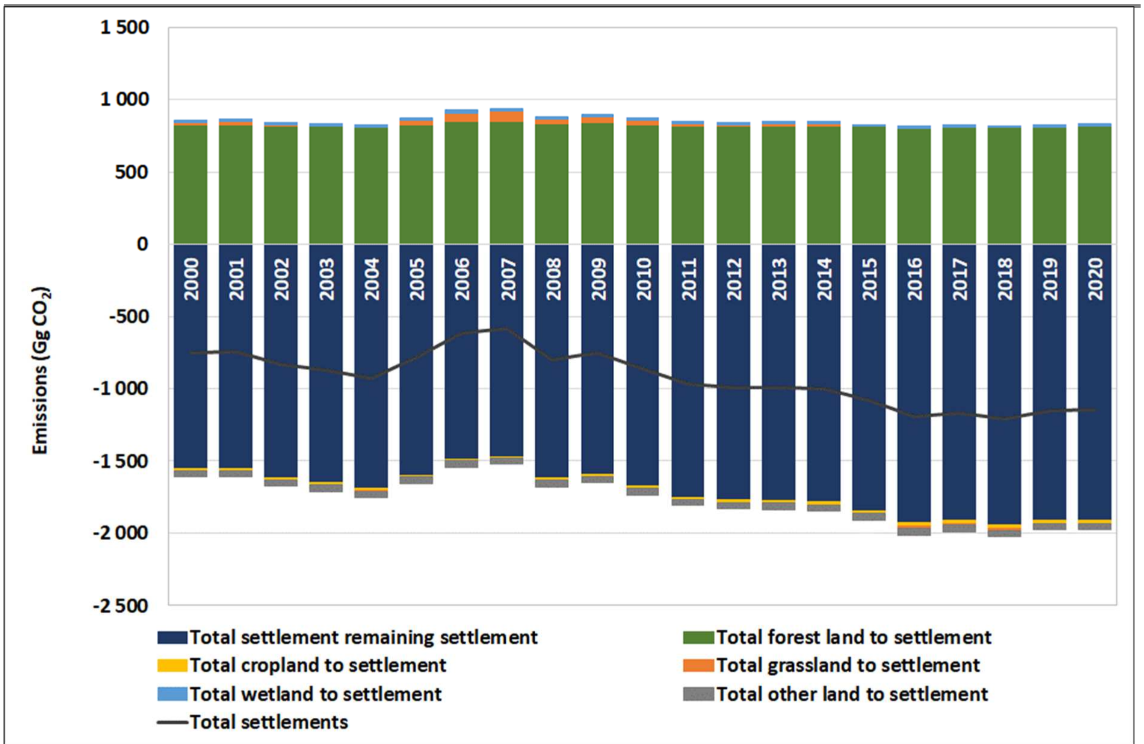

Figure 5.12: CO_2 emissions and removals (Gg CO_2) due to changes in carbon stocks between 2000 and 2020 for South Africa's Settlements.

Table 5. 12: South Africa's net carbon stock change (Gg CO_2) by carbon pool for Settlements, 2000 – 2020.

	Settlements remaining settlements			Land converted to settlements		
	Biomass	DOM	Mineral soil	Biomass	DOM	Mineral soil
2000	-1 558.7	4.7	0.0	865.3	20.2	-87.4
2001	-1 558.1	4.7	0.0	873.1	20.2	-87.9
2002	-1 619.8	4.7	0.0	849.9	20.2	-87.9
2003	-1 652.9	4.7	0.0	840.9	20.2	-87.7
2004	-1 692.7	4.7	0.0	828.8	20.2	-87.9
2005	-1 602.1	4.7	0.0	880.7	20.2	-87.9
2006	-1 493.0	4.7	0.0	941.0	20.2	-88.9
2007	-1 475.1	4.7	0.0	956.2	20.2	-88.1
2008	-1 625.0	4.7	0.0	890.8	20.2	-88.1
2009	-1 596.8	4.7	0.0	911.0	20.2	-88.8
2010	-1 678.5	4.7	0.0	879.1	20.2	-88.9
2011	-1 754.3	4.7	0.0	851.8	20.2	-90.0
2012	-1 773.8	4.7	0.0	849.7	20.2	-90.1

2013	-1 779.8	4.7	0.0	853.9	20.2	-90.3
2014	-1 789.3	4.7	0.0	856.5	20.2	-90.4
2015	-1 849.7	4.7	0.0	834.4	20.2	-91.4
2016	-1 932.9	4.7	0.0	804.4	20.2	-91.2
2017	-1 917.6	4.7	0.0	817.7	20.2	-91.0
2018	-1 950.6	4.7	0.0	811.0	20.2	-92.5
2019	-1 914.9	4.7	0.0	833.1	20.2	-92.1
2020	-1 918.9	4.7	0.0	838.4	20.2	-91.7

Other lands (3B6)

Other lands are estimated to be a source of CO_2 due to the loss of carbon in the and the *land converted to Other lands* (Figure 5.13) categories. Both biomass and soil carbon is lost when vegetated lands are converted to non-vegetated lands. *Grasslands* converted to *Other lands* is the dominant contributor to the emissions. The biomass carbon pool is the most dominant in this category, however the DOM and the SOC pools are also significant contributors (Table 5. 13).

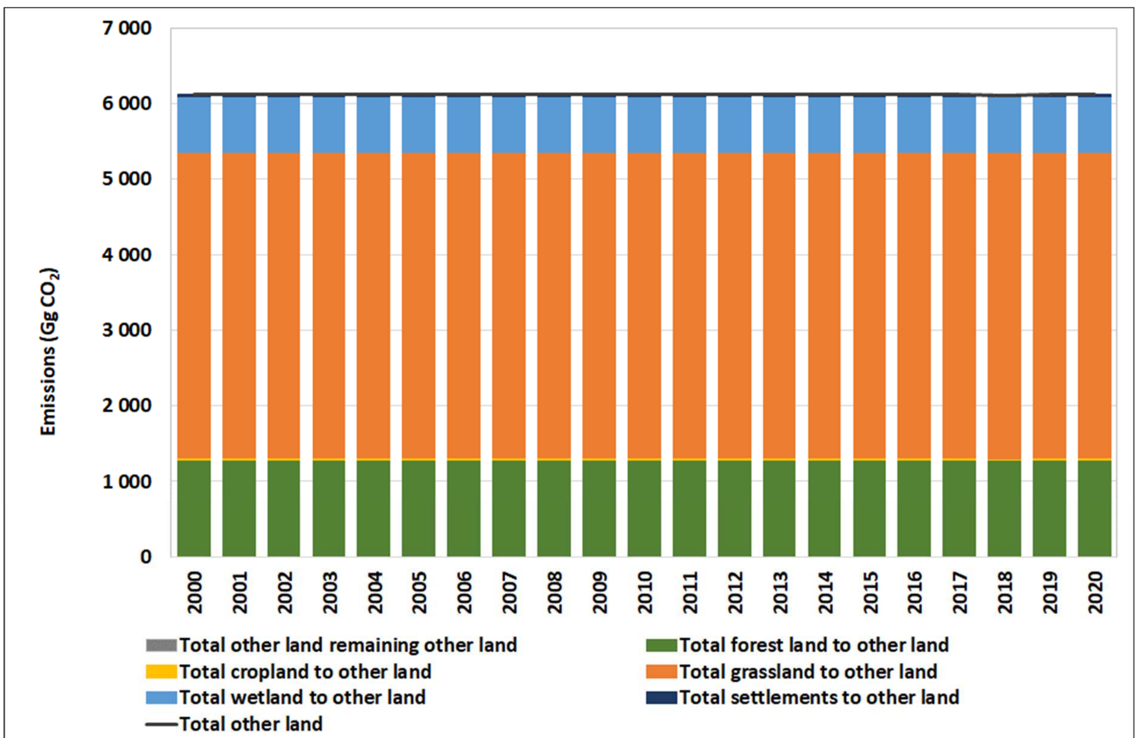

Figure 5.13: CO_2 emissions and removals (Gg CO_2) due to changes in carbon stocks between 2000 and 2020 for South Africa's Other lands.

Table 5. 13: South Africa's net carbon stock change (Gg CO_2) by carbon pool for Other lands, 2000 – 2020.

	Other land remaining other land			Land converted to other land		
	Biomass	DOM	Mineral soil	Biomass	DOM	Mineral soil
2000	0.0	0.0	0.0	3 201.6	1 188.1	1 737.2
2001	0.0	0.0	0.0	3 201.6	1 188.1	1 737.1
2002	0.0	0.0	0.0	3 201.6	1 188.1	1 737.1
2003	0.0	0.0	0.0	3 201.6	1 188.1	1 737.1
2004	0.0	0.0	0.0	3 201.6	1 188.1	1 737.1
2005	0.0	0.0	0.0	3 201.6	1 188.1	1 737.1
2006	0.0	0.0	0.0	3 201.6	1 188.1	1 736.7
2007	0.0	0.0	0.0	3 201.6	1 188.1	1 737.0
2008	0.0	0.0	0.0	3 201.6	1 188.1	1 737.0
2009	0.0	0.0	0.0	3 201.6	1 188.1	1 736.7
2010	0.0	0.0	0.0	3 201.6	1 188.1	1 736.7
2011	0.0	0.0	0.0	3 201.6	1 188.1	1 736.3
2012	0.0	0.0	0.0	3 201.6	1 188.1	1 736.2
2013	0.0	0.0	0.0	3 201.6	1 188.1	1 736.1
2014	0.0	0.0	0.0	3 201.6	1 188.1	1 736.1
2015	0.0	0.0	0.0	3 201.6	1 188.1	1 735.7
2016	0.0	0.0	0.0	3 201.6	1 188.1	1 735.8
2017	0.0	0.0	0.0	3 201.6	1 188.1	1 735.9
2018	0.0	0.0	0.0	3 201.6	1 188.1	1 735.3
2019	0.0	0.0	0.0	3 201.6	1 188.1	1 735.4
2020	0.0	0.0	0.0	3 201.6	1 188.1	1 735.6

Harvested wood products (3D1)

In 2020 harvested wood products were a source of 635 Gg CO_2 (Table 5. 14). Most years prior to 2009 showed a sink, while most years thereafter are a source of CO_2. There is annual variability which is related to production and the exports.

Table 5. 14: Trends in HWP net emissions and removals between 2000 and 2020.

	HWP
	Gg CO_2e
2000	-2 106.2
2001	-1 394.3
2002	-919.1
2003	-2 792.4
2004	-2 531.0
2005	-3 931.0
2006	-3 865.1
2007	-1 002.1
2008	-796.0
2009	139.4
2010	1 155.8
2011	-138.2
2012	322.3
2013	529.0
2014	1 700.6
2015	303.7
2016	1 262.5
2017	-588.8
2018	-900.7
2019	1 003.6
2020	635.2

Note: Negative values are a sink, while positive values show emissions.

5.1.2 Overview of methodology and completeness

The IPCC 2006 methodology is applied in this sector, with a few updated methodologies being taken from the IPCC 2019 Refinement and the 2013 Wetlands Supplement. Default constants and emission factors are also sourced from these two guideline documents, with details being provided in the methodology sections within each category section. Table 5. 15shows the methods and types of EF used in the AFOLU inventory.

Table 5. 15: 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		NO_x	CO	NMVOC	SO_2
		Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor				
3A LIVESTOCK	***1 Enteric fermentation***										
	a.i. Dairy cattle			T2	CS			NA	NA	NA	NA
	a.ii. Other cattle			T2	CS			NA	NA	NA	NA
	b. Buffalo			NO	NO			NA	NA	NA	NA
	c. Sheep			T2	CS			NA	NA	NA	NA
	d. Goats			T2	CS			NA	NA	NA	NA
	e. Camels			NO	NO			NA	NA	NA	NA
	f. Horses			T1	DF			NA	NA	NA	NA
	g. Mules and asses			T1	DF			NA	NA	NA	NA
	h. Swine			T2	CS			NA	NA	NA	NA
	j. Other			NO	NO			NA	NA	NA	NA
	2 Manure management										
	a.i. Dairy cattle			T2	CS	T2	DF	NE	NA	NA	NE
	a.ii. Other cattle			T2	CS	T2	DF	NE	NA	NA	NE
	b. Buffalo			NO	NO	NO	NO	NE	NA	NA	NE
	c. Sheep			T2	CS	NO	NO	NE	NA	NA	NE
	d. Goats			T2	CS	NO	NO	NE	NA	NA	NE
	e. Camels			NO	NO	NO	NO	NE	NA	NA	NE
	f. Horses			T2	CS	NO	NO	NE	NA	NA	NE
	g. Mules and asses			T2	CS	NO	NO	NE	NA	NA	NE
	h. Swine			T2	CS	T2	DF	NE	NA	NA	NE
	i. Poultry			T2	CS	T2	DF	NE	NA	NA	NE
	j. Other			NO	NO	NO	NO	NE	NA	NA	NE

	GHG Source and sink category	CO_2		CH_4		N_2O		NO_x	CO	NMVOC	SO_2
		Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor				
3B LAND	***1 Forest land***										
	a. Forest land remaining forest land	Biomass: T2	Biomass: CS	NE		NE		NA	NA	NA	NA
		Litter: T1	Litter: CS					NA	NA	NA	NA
		Soil: T2	Soil: CS					NA	NA	NA	NA
	b. Land converted to forest land	Biomass: T2	Biomass: CS	NE		NE		NA	NA	NA	NA
		Litter: T1	Litter: CS					NA	NA	NA	NA
		Soil: TE	Soil: T2					NA	NA	NA	NA
	2 Cropland										
	a. Cropland remaining cropland	Biomass: T1	Biomass: CS	NE		NE		NA	NA	NA	NA
		Litter: T1	Litter: CS					NA	NA	NA	NA
		Soil: T2	Soil: CS					NA	NA	NA	NA
	b. Land converted to cropland	Biomass: T2	Biomass: CS	NE		NE		NA	NA	NA	NA
		Litter: T1	Litter: CS					NA	NA	NA	NA
		Soil: T2	Soil: T2					NA	NA	NA	NA
	3 Grassland										
	a. Grassland remaining grassland	Biomass: T1	Biomass: DF	NE		NE		NA	NA	NA	NA
		Litter: T1	Litter: CS					NA	NA	NA	NA
		Soil: T2	Soil: CS					NA	NA	NA	NA
	b. Land converted to grassland	Biomass: T2	Biomass: CS	NE		NE		NA	NA	NA	NA
		Litter: T1	Litter: CS					NA	NA	NA	NA
		Soil: T2	Soil: T2					NA	NA	NA	NA
	4 Wetland										
	a. Wetland remaining wetland	Biomass: T1 Litter: T1 Soils: T2	Biomass: CS Litter: CS Soil: CS	T1	CS	T1	CS	NA	NA	NA	NA

GHG Source and sink category	CO_2		CH_4		N_2O		NO_x	CO	NMVOC	SO_2
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor				
b. Land converted to wetland	Biomass: T2 Litter: T1 Soil: T2	Biomass: CS Litter: CS Soil: T2	NE		NE		NA	NA	NA	NA
5 Settlements										
a. Settlements remaining settlements	Biomass: T1	Biomass: CS	NE		NE		NA	NA	NA	NA
	Litter: T1	Litter: CS					NA	NA	NA	NA
	Soil: T2	Soil: CS					NA	NA	NA	NA
b. Land converted to settlements	Biomass: T2	Biomass: CS	NE		NE		NA	NA	NA	NA
	DOM: T2	Litter: CS					NA	NA	NA	NA
	Soil: T2	Soil: T2					NA	NA	NA	NA
6 Other land										
a. Other land remaining other land	Biomass: T1	Biomass: CS	NE		NE		NA	NA	NA	NA
	Soil: T2	Soil: CS					NA	NA	NA	NO
b. Land converted to other land	Biomass: T2	Biomass: CS	NE		NE		NA	NA	NA	NO
	Soil: T2	Soil: T2					NA	NA	NA	NO
3C AGGREGATED SOURCES AND										
1 Biomass burning										
Biomass burning in all lands	T2	DF, CS	T2	DF, CS	T2	DF, CS	T2	T2	T2	T2
2 Liming										
Liming	T1	DF					NA	NA	NA	NA
3 Urea application										
Urea application	T1	DF					NA	NA	NA	NA
4 Direct emissions from managed soils										
Synthetic fertilizers					T1	DF	NA	NA	NA	NA
Animal waste added to soils					T1	DF	NA	NA	NA	NA
Other organic fertilizers					T1	DF	NA	NA	NA	NA
Urine and dung deposited by grazing livestock					T1	DF	NA	NA	NA	NA

	GHG Source and sink category	CO_2		CH_4		N_2O		NO_x	CO	NMVOC	SO_2
		Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor				
	Crop residues					T1	DF	NA	NA	NA	NA
	5 Indirect emissions from managed soils										
	Atmospheric deposition					T1	DF	NA	NA	NA	NA
	Nitrogen leaching and runoff					T1	DF	NA	NA	NA	NA
	6 Indirect emissions from manure management										
	Volatilization					T1	DF	NA	NA	NA	NA
	Nitrogen leaching and runoff					T1	DF	NA	NA	NA	NA
	7 Rice cultivation										
	Rice cultivation	NO		NO		NO		NO	NO	NO	NO
3D OTHER	***1 Harvested wood products***										
	Harvested wood products	T2	DF					NA	NA	NA	NA
	2 Other										
	Other	NO		NO		NO		NO	NO	NO	NO

NA = Not applicable; NO = Not occurring; NE = Not estimated; IE = Included elsewhere; T1 = Tier 1; T2 = Tier 2; DF = IPCC default factor; CS = Country specific factor.

5.1.3 Improvements and recalculations since the 2017 submission

The AFOLU sector is under continual improvement which leads to recalculations. The recalculations for the AFOLU sector led to an average 15.7 % decrease in the estimates excluding FOLU and an average 7.5% decrease (although this varied annually) in emissions including FOLU over the times series (Figure 5.14).

The recalculations led to a 25.1% increase in the 2017 estimates for *Livestock* with the main improvements being:

a) Incorporation of Tier 2 data for enteric fermentation and manure management emission factor calculations for cattle, goats, and sheep.
b) Changes in livestock categorisation (Disaggregated categories were changed in this inventory to match the ARC report data); and
c) Updated manure management data.

These updates also had an impact on the *Aggregated and non-CO_2 emissions on land* which showed a 57% decrease in the 2017 emission estimates. Other updates in this category include:

a) Updated MODIS collection 6 burnt area data.

The *Land* category showed a 39.8% decline in the 2017 sink estimate which was high compared to the other years. This was because there was a correction in the burnt area data for 2017. Between 2011 and 2016 the recalculated emission values were, on average, 22.8% higher than was estimated in the previous inventory. These changes are due to:

a) Incorporation of 1990-2018 CALC land change data.
b) Updated land change assumptions for natural land classes based on the land change assessment report (DEFF, 2020).
c) Inclusion of carbon stock changes for mineral wetlands.
d) Incorporation of updated biomass and litter data.
e) Updated biomass accumulation rates.
f) Division of forests into primary and secondary forest to include different growth rates.
g) Inclusion of mortality in forest land and harvest losses in croplands.
h) Incorporation of country specific SOC reference data and stock change data.
i) Inclusion of CO_2, CH_4 and N_2O emissions from wetlands in mineral soils; and
j) Updated plantation BCEF factors.

Recalculations for *HWP* due to the inclusion of country specific data produced a 24.2% decline in the 2017 estimates, but this varied annually (showing both increases and decreases) over the full time series.

Specific details of the improvements and their impacts are provided in the relevant category sections below.

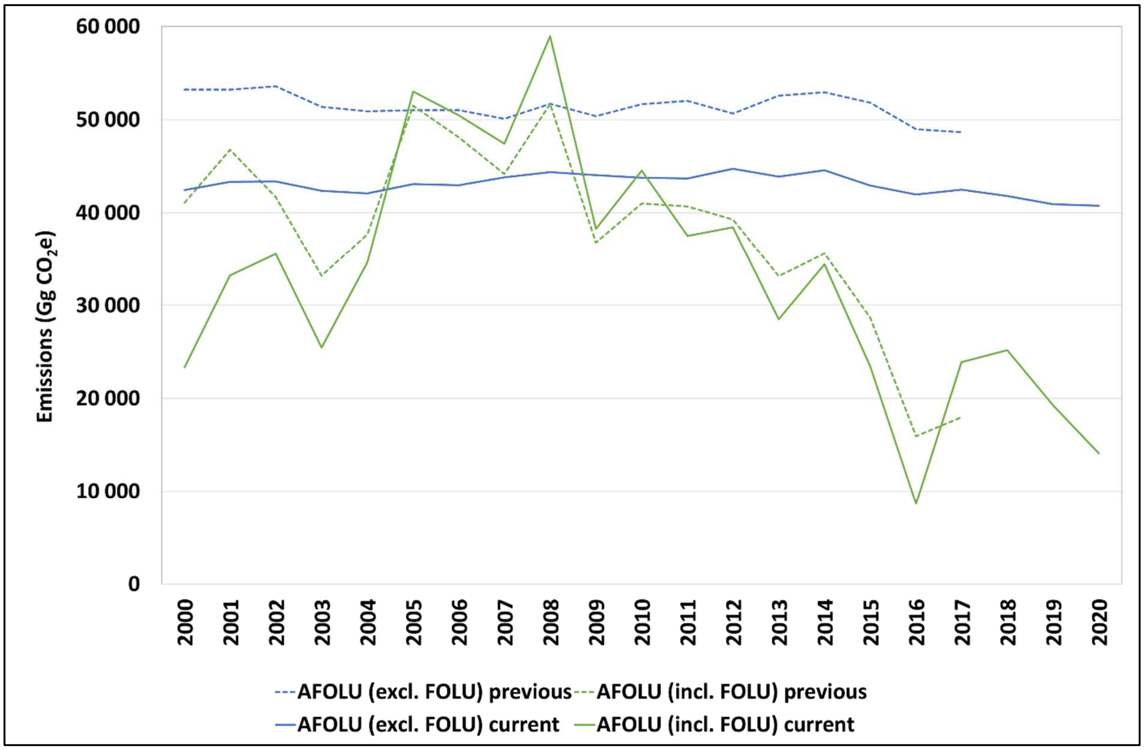

Figure 5.14: Change in AFOLU emission estimates due to recalculations since 2017 submission.

In addition to the actual estimates, time was spent on improving the calculation files to improve their transparency. A lot of detail and verification was incorporated into the agriculture calculation file along with data sources. It was noted in the previous inventory review that the Land sector excel file was very large and complex making it difficult to complete error and logic checking. Therefore, an attempt was made to improve the transparency of the file and to include all calculations and equations so data could be followed through. In addition, factors were named in the equations and details of the equations included. In future, however, it would be useful to move towards a more dynamic model that can use spatial data and incorporate models as well. In a previous inventory an attempt was made to use the ALU software (https://www.nrel.colostate.edu/projects/alusoftware/download-software.php) as it can take spatial data as an input, however the numbers of categories in South Africa's land cover maps (72 classes), together with 6 soil types and the various biomes created a huge number of data points and so the software was running at its limit. Also, data needed to be entered for all data points and so time was a limitation.

5.1.4 Key categories in the AFOLU sector

The key categories for the AFOLU sector are shown in Table 5. 16 with the detailed key category results presented in Appendix B.

Table 5. 16: Key categories in the AFOLU sector in 2020.

IPCC Code	Category	GHG	Identification#
3A1a	Enteric fermentation - cattle	CH_4	L, T
3A1c	Enteric fermentation - sheep	CH_4	L, T
3A1d	Enteric fermentation - goats	CH_4	T
3A2a	Manure management - cattle	N_2O	L
3A2i	Manure management - poultry	N_2O	L
3B1a	Forest land remaining forest land	CO_2	L, T
3B1b	Land converted to forest land	CO_2	L, T
3B2b	Land converted to cropland	CO_2	L, T
3B3b	Land converted to grassland	CO_2	L
3B5a	Settlements remaining settlements	CO_2	L
3B6b	Land converted to other lands	CO_2	L
3C2	Liming	CO_2	L, T
3C3	Urea application	CO_2	T
3C4	Direct N_2O emissions from managed soils	N_2O	L, T

#L = Level Assessment; T = Trend Assessment

5.1.5 Planned improvements and recommendations

In terms of livestock there are six recommendations for improving estimates in the future:

a) Improve livestock population data: There have been several studies on the emission factors and now the population data is the most uncertain component.

Setting up a Livestock Estimates Committee could assist with this, although this has been mentioned before and not much progress has been made in terms of the committee. Further engagement is required between DFFE and the Department of Agriculture. It could also be an activity to discuss with the Agricultural Research Council which has a livestock division.

b) National data set on manure management systems: This data seems to be highly variable depending on where the information comes from. In addition, data on the amount of manure being diverted to biogas needs to be included as this is a mitigation option and has been highlighted in previous inventory reviews. It is recommended to find a mechanism to track manure management practices or systems used in South Africa, as this could allow for incorporation of dynamics driven by changes in management regimes, and thus improve the accuracy of manure related emissions.
c) A detailed study on the herd composition of the various livestock and the number of days each livestock sub-category is alive in a year would contribute to a reduction in uncertainty.
d) Collect and include in NIR background information of the livestock population original data sources (surveys, questionnaires etc.)
e) Use appropriate MCFs depending on the average temperature for each year of the time series. Stratify the estimates depending on the average temperature in different regions in South Africa.
f) Investigate if there are studies available about the burning of manure in South Africa.

In terms of the Land Use, Land-Use Change and Forestry (LULUCF) sector there are three very critical issues (a – c) and three important issues (d – g which need attention, and which are a much higher priority than the agriculture improvement requirements, and these are:

a) Obtain the 8-class annual land cover maps and use them to determine how much variability is likely due to natural seasonal changes. This can then be utilised to identify the actual areas of change more accurately.
b) Conduct further assessments of the land cover classifications and the impact of the Landsat versus the Sentinel data on the area changes to improve assumptions and incorporate the various land cover maps (2014, 2018, 2020).
c) Explore the QGIS Plugin which was developed as part of the NTCSA to determine what the data requirements are and the feasibility of updating the carbon density maps on a more frequent basis. If the carbon density maps can be updated more regularly then the possibility of moving to the stock-difference method can be explored.

d) Investigate the overlap between burnt area data and land use change data to determine if there are areas that are just burnt as opposed to being an actual land cover change (i.e., to ensure no double counting of losses).
e) Further investigate the soils maps and incorporate organic soils.
f) Explore a more dynamic model, to aid in producing the LULUCF inventory; and
g) Conduct a detailed uncertainty analysis on all LULUCF data, particularly the spatial data. This was due to happen in this inventory but there was insufficient capacity and data to complete the uncertainty analysis.

5.2 Livestock (3.A)

5.2.1 Livestock population and characterisation

5.2.1.1 Population data sources and estimations

The data sources for the livestock population estimates are shown in Table 5. 17. The main data source is the Abstracts of Agricultural Statistics (DALRRD, 2021a) which is a sustainable data source released every year. The livestock population data is collected 4 times in a year (every 3 months). For example, the 2020 data was initially collected in February, the second datasets were collected in May, the 3rd in August and the 4th in November. In addition, the total livestock numbers for cattle, sheep, goats and pigs is obtained from data provided by the DALRRD (2021b). The same data for number of animals of the various animal groups is used in all the different calculations of emissions.

Table 5. 17: Livestock population data sources.

Livestock category		Data source
Cattle	Total cattle	DALRRD (2021b)
	Commercial dairy cows (>2yrs)	DALRRD (2021a)
	Commercial dairy heifers (1-2 yrs)	DALRRD (2021a)
	Feedlot cattle	Feedlot SA (2021)
	Commercial other cattle total	DALRRD (2021a)
	Subsistence cattle	Calculated (see text)
Sheep	Total sheep	DALRRD (2021b)
	Commercial sheep total	DALRRD (2021a)
	Feedlot sheep	Calculated from DALRRD (2021a) slaughter data (see text)
	Subsistence sheep	Calculated (see text)
Goats	Total goats	DALRRD (2021b)

	Commercial goats total	DALRRD (2021a)
	Subsistence goats	Calculated (see text)
Horses, mules & asses		FAOSTAT (2021)
Swine	Total swine	DALRRD (2021b)
	Commercial swine	Calculated (see text)
	Subsistence swine	Calculated (see text)
Poultry	Commercial broilers	Leadingedge Poultry Software CC (2021)
	Commercial broiler parents	Leadingedge Poultry Software CC (2021)
	Commercial layers	Leadingedge Poultry Software CC (2021)
	Commercial pullets	Leadingedge Poultry Software CC (2021)
	Subsistence broilers	Calculated (see text)
	Subsistence layers	Calculated (see text)

Other cattle calves and subsistence cattle

The total number of calves is obtained from the Abstracts of Agricultural Statistics (DALRRD, 2021a), but the feedlot cattle are all assumed to be calves, so these are subtracted from the total calves to obtain the estimate of commercial calves in the other cattle category.

The total number of cattle is provided by DALRRD (2021b). The number of dairy heifers and cows is subtracted from the total number of cattle to obtain the total number of other cattle. The Abstracts of Agricultural Statistics (2021a) provides the total commercial other cattle; therefore, this is subtracted from the total other cattle to obtain an estimate of the subsistence cattle population.

Subsistence and feedlot sheep

There is limited data on feedlot sheep, so several assumptions were applied. The number of sheep slaughtered is obtained from the Abstracts of Agricultural Statistics (DALRRD, 2021a). It was assumed that 70% of the slaughtered animals come from feedlots. Feedlot sheep are estimated to be in the feedlots on average for 35 days (pers. comm. Mokhele Moeletsi, 2021) and are weaned or sold at about 120 days which means the feedlot sheep are alive for 155 days. This data was applied to equation 10.1 of the IPCC 2006 Guidelines to determine the annual average population. The feedlot total is assumed to be included in the total commercial sheep numbers provided by Abstracts of Agricultural Statistics (DALRRD, 2021a).

The subsistence sheep population is estimated by subtracting the total commercial sheep (DALLRD, 2021a) from the total sheep (DALRRD, 2021b).

Subsistence goats

The subsistence goat population is estimated by subtracting the total commercial goats (DALLRD, 2021a) from the total goats (DALRRD, 2021b).

Commercial and subsistence swine

The total swine population provided by DALRRD (2021b) is almost the same as that provided in the Abstracts of Agricultural Statistics (DALRRD, 2021a), suggesting that there are no subsistence swine. Du Toit et al (2013c) noted that there was a large discrepancy between DALRRD (2021a) data and data from industry with industry suggesting a much lower population. Du Toit et al. (2013c) indicated that 26% of the population was subsistence, so based on this it is assumed that the total swine population is as given in the DALRRD (2021b) data, but that this data is split into commercial and subsistence using the 0.26 ratio provided by Du Toit et al. (2013c).

Poultry

The number of broilers and layers is obtained from Leadingedge Poultry Software CC (2021), who provides data to the South African Poultry Association (SAPA). The data is modelled data. In this inventory the total broiler parents and pullets are also included. These numbers are small and were not in the previous inventory. Data for parents and pullets are only available for 2018 onwards for these categories. A ratio between the parents and the broilers, as well as the pullets and the layers, is determined and this ratio is extrapolated (linear) backwards to 1990 to complete the time-series for the parent population.

Leadingedge Poultry Software CC (2021) indicated that in 2015 the subsistence population was 4-5% of the commercial poultry population. The percentage (4%) is assumed constant between 2000 and 20015. In 2020 the number provided for subsistence poultry is 4-5% of commercial poultry, therefore 5% was applied in 2020 and a linear extrapolation is used to estimate the percentage of subsistence poultry in the other years.

5.2.1.2 Population characterisation and herd composition

In the previous inventory there was a more detailed livestock characterisation. This was based on a study in 2010 (Du Toit et al., 2013a, b, c) which provided country-specific emission factors for all livestock categories. The population data for the detailed livestock characterisation in the previous inventory utilised the same national data as provided in this inventory but applied the population and herd composition data provided in Du Toit et al. (2013a, b, c) to split the population into the more detailed categories. Subsequent to this there have been further studies on livestock emissions which made use of fewer herd composition categories but added more detailed breed classes. To accommodate new data and improve consistency, the list of categories has been revised (Table 5. 18) and some of the herd classes were aggregated. In addition, instead of incorporating the detailed category information into the population break down, the detail is incorporated into the emission factors. Thus, the national statistics population data categories are kept, and the detailed breed and herd composition data is used to calculate a weighted average emission factor (based on the composition and assumptions provided in Table 5. 18) for each class. This way the national population data categories can be kept constant for reporting purposes, and any detailed data gathered in the future can be incorporated into the emission factors.

Table 5. 18: Livestock characterization and herd composition data sources and assumptions.

Main category	Production category	Subcategory	Herd composition data and assumptions
Dairy cattle	• High production (Holstein) • Medium production (Jersey)	• Mature female cows • Heifers (12-18 months) • Heifers (6-12 months) • Heifers (3-6 months)	Herd composition based on DALRRD (2021a) data; 57% Holstein and 43% Jersey; even distribution of heifer categories
Other cattle	Commercial (Afrikaner; Angus; Beefmaster; Bonsmara; Boran; Brahams; Brangus; Braunvich; Charolais; Drakensburger; Hereford; Hugenoot; Limousin; Bradford; Santa Gertrudis; Simbra; Simmentaler; Susses; Wagyu; Tuli)	• Mature cows • Bulls • Young bulls • Heifers (12-18 months) • Heifers (6-12 months) • Heifers (3-6 months) • Ox • Young ox • Calves	Commercial herd composition based on ARC Report (2021) data; even distribution of heifer categories; herd composition assumed to be the same for all breeds; even distribution of breeds
	• Subsistence	• Mature cows • Bulls • Heifers (12-18 months) • Heifers (6-12 months) • Heifers (3-6 months) • Ox • Young ox • Calves	Subsistence herd composition based on ARC Report (2021) data; even distribution of heifer categories
	• Feedlot		All calves

Sheep	• Commercial wool (Merino) • Commercial meat (Dorper) • Commercial dual-purpose (Mutton Merino, Dohne merino)	• Mature ewe • Replacement ewe • Mature ram • Young ram • Female lamb • Male lamb	Commercial sheep herd composition based on ARC Report (2021) data; even distribution of mature and replacement ewes; even distribution of mature and young rams; even distribution of male and female lambs; species distribution taken from ARC Report (2021a)
	• Subsistence	• Mature ewe • Replacement ewe • Mature ram • Young ram • Female lamb • Male lamb	Subsistence sheep herd composition based on ARC Report (2021) data; even distribution of mature and replacement ewes; even distribution of mature and young rams; even distribution of male and female lambs; all species assumed to be dual purpose
	• Feedlot		All weaned sheep
Goats	• Commercial (Angora; Boer) • Commercial dairy goat (Saanen; Toggenburg; British Alpine)	• Mature doe • Replacement doe • Mature buck • Young buck • Female kid • Male kid	Commercial goat herd composition based on ARC Report (2021) data; even distribution of mature and replacement does; even distribution of mature and replacement buck; even distribution of male and female kids; distribution of commercial and dairy goats taken from ARC Report (2021a); even distribution of dairy goats and also commercial goats
	• Subsistence	• Mature doe • Replacement doe • Mature buck • Young buck • Female kid • Male kid	Subsistence goat herd composition based on ARC Report (2021) data; even distribution of mature and replacement does; even distribution of mature and replacement buck; even distribution of male and female kids)

Horses, mules, asses	• All breeds		
Swine	• Commercial	• Boars • Cull boars • Replacement boars • Cull sows • Replacement sows • Dry gestating sows • Lactating sows • Pre-wean-piglets	Commercial swine herd composition based on Du Toit et al. (2013c) data
	• Subsistence	• Boars • Cull boars • Replacement boars • Cull sows • Replacement sows • Dry gestating sows • Lactating sows • Pre-wean-piglets	Commercial swine herd composition based on Du Toit et al. (2013c) data
Poultry	• Commercial • Subsistence	• Broilers • Broiler parents • Layers • Pullets	Composition determined from population data

5.2.1.3 Population data verification

The livestock population data is compared to FAO data and other studies. For all livestock except poultry, the national statistics data (DALRRD, 2021a) utilised in this inventory match those from the FAO database. There are small discrepancies in the earlier years (1990 – 2002) but thereafter the data is aligned. In terms of poultry data, the data applied in this inventory is on average 33% lower than the FAO data. It is noted though that much of the FAO poultry data is estimated and does not come from official data sources. In 2005 and 2006 official data is indicated to be reported and, in these years, the current data is 9% and 5% lower, respectively. Official data is also indicated to be used between 2013 and 2015, and in these years the data is 12% to 19% lower than the reported data in the FAO database.

In another study by Moeletsi and Tongwane (2015) the same national statistics data was applied for all livestock except poultry. Moeletsi and Tongwane (2015) reported broiler data that is 4% higher and layer data that is 24% lower for the year 2004.

A study by Du Toit et al. (2013a, b, c) made use of population data from the livestock industry associations for the year 2010. This study provides a total dairy population that is 7% higher than the DALRRD (2021a) data. The commercial and subsistence other cattle numbers provided by Du Toit et al. (2013a) are 22% and 4% higher than the DALRRD (2021a) data, respectively.

For sheep Du Toit et al. (2013b) utilized national statistics from Statistics SA and these numbers are within 0.5% of the data from DALRRD (2021a). Goat population data from Du Toit et al. (2013b) were obtained from the industry associations and are 34% higher for commercial goats, while subsistence numbers are only 1% higher.

Swine population data from industry (Du Toit et al., 2013c) are 60% lower than that provided in DALRRD (2021a). Broiler and layer commercial population data is 19% and 15% lower than the Du Toit et al. (2013c) data for 2010.

All of this data suggests that there is still a discrepancy between the national statistics and data from livestock associations. As has been mentioned in previous inventories, it would be beneficial to set up a Livestock Estimates Committee which brings together government and livestock association representatives on an annual basis to discuss livestock population data to obtain consensus. The committee could also be used for discussions on ways to improve livestock population estimates and the reporting thereof.

5.2.1.4 Population data uncertainty

Uncertainty data is provided in Moeletsi et al. (2015a), although it is not clear how the uncertainty was derived. In this report dairy population data is indicated to have an uncertainty of ±10%. Considering the comparisons above this uncertainty value appears reasonable. A ±10% uncertainty is also assigned to commercial beef cattle categories, except calves which has an uncertainty of ±5%. The comparisons with Du Toit et al. (2013a) suggest that the uncertainty could be around ±20%. The comparison is only for one year, therefore an uncertainty of ±20% is applied to all commercial beef cattle categories except calves (which remains at ±5%). Moeletsi et al. (2015a) indicate a ±10% uncertainty on commercial sheep and goat population data. The comparisons with Du Toit et al. (2013b) suggest that this uncertainty is reasonable for sheep but may be too low for goats. The goat uncertainty is therefore increased to ±20%. The ±10-20% uncertainty provided in Moeletsi et al. (2015a) for swine appears to be low with Du Toit et al. (2013c) reporting values 60% lower. The uncertainty for swine population is therefore increased to ±50%. Moeletsi et al. (2015a) does not provide uncertainty data for poultry but considering the comparisons with FAO and Du Toit et al. (2013c) an uncertainty of ±20% is assigned to poultry population data.

5.2.2 Manure management

5.2.2.1 Data sources

The manure management data for cattle, sheep and goats was sourced from the recent ARC Report (2021) and there were various sources for this data as indicated in Table 5. 19. Data for horses, swine and poultry is sourced from Moeletsi and Tongwane (2015) and Du Toit et al. (2013c).

5.2.2.2 Data verification

Manure management data is compared to data from various studies and Table 5. 20 shows that there is high variation in the results for cattle and poultry. The data variability is much less for sheep, goats, horses, mules/asses and swine. The percentage allocation differs significantly from the IPCC 2019 Refinement Sub-Saharan Africa (SSA) default value, but this is not unexpected as the default is for the whole SSA region while the numbers from the other studies are more specific to SA which has some high productivity systems. There is some agreement on the types of manure management systems utilised, except that SA does not mention pit storage systems. In addition, no manure is allocated to burning or digesters which is something to investigate further in the future. There are some cattle feedlots and piggeries which make use of digesters, but the data is limited, and it is thought to be minimal. This should, however, be monitored in future, particularly because of the energy production benefits of the digesters.

5.2.2.3 Manure management data uncertainty

Moeletsi et al. (2015) reported a ±20% uncertainty on mixed diet dairy cattle manure management, and a ±25% and ±10% uncertainty on pasture and Total Mixed Ratio (TMR) manure management systems, respectively. Considering the variation in the reported data (Table 5. 19) the uncertainty seems to be much higher, therefore an uncertainty of ±50% is assigned to dairy cattle manure management. For non-dairy cattle an uncertainty of ±15% is provided, and considering the variation shown in this is not unreasonable, although it might be slightly on the low side. The uncertainty is therefore adjusted to ±20%. The ±5% uncertainty assigned by Moeletsi et al. (2015) to goats and horses, and the ±2% assigned to horses, mules/asses and sheep appears to be reasonable, but it is unclear why the uncertainty for sheep is lower than goats when the manure management data is the same in all studies for these two livestock categories. Based on this, and the data in Table 5. 20, the uncertainty for goats is adjusted to ±2%. Poultry and swine manure management data has an uncertainty of ±15% (Moeletsi et al., 2015). The variation in the data reported in Table 5. 20 is low for swine but is high for poultry, therefore the uncertainty is adjusted to ±10% and ±25% for swine and poultry, respectively.

Table 5. 19: Manure management systems for the various livestock types and their data sources.

Livestock	Lagoon	Liquid/ slurry	Dry lot/ Kraals	Solid storage	Daily spread	Compost	Manure with litter	Manure without litter	Pasture, range, paddock (PRP)
Dairy cattle									
Mature female cows	5[1]	5[1]	20[1]	5	5				60[3]
Heifers (6 - 24 months)			2						98[4]
Other cattle									
Commercial			3						97[4]
Subsistence			35						65[4]
Feedlot	5		85[2]	10					
Sheep									
Commercial[4]			2						98
Subsistence			35[6]						65[4]
Feedlot[6]	2		98						
Goats									
Commercial			2[2]						98[4]
Subsistence[4]			35						65
Dairy goats[4]			10						90
Horses, mules, asses[2]									100
Swine									
Commercial[2,5]	71	11	13		3	2			
Subsistence[5]	25	10	35						30
Poultry									
Commercial[2]			80			5	15		
Subsistence[2]		5	70		5	10		10	

[1] DEA (2014); [2] Moeletsi and Tongwane (2015); [3]Malaka (2017) ; [4]Expert opinion, [5]Du Toit et al. (2013c);

Table 5. 20: Verification of livestock manure management systems.

Livestock	DAFF (2010)	Du Toit et al. (2013a, b, c)	Moeletsi et al. (2015)	Moeletsi and Tongwane (2015)	ARC Report (2021)	IPCC 2019 Refinement (SSA default)
Dairy cattle	Cows and heifers: 45% lagoon, 10% liquid slurry, 15% dry lot, 10% compost, 20% PRP	TMR: 10% lagoon, 0.5% liquid slurry, 1% daily spread, 88.5% PRP; Pasture: 3% lagoon, 7% daily spread, 90% PRP	TMR: 95% lagoon, 5% manure with bedding; Pasture: 11% lagoon, 8% dry lot, 10% solid storage, 3% daily spread, 60% PRP	Cows: 20% lagoon, 5% liquid slurry, 25% dry lot, 45% PRP, 5% manure with bedding; Heifers: 5% dry lot, 2% compost, 93% PRP	Cows: 5% lagoon, 5% liquid slurry, 20% dry lot, 5% solid storage, 5% daily spread, 60% PRP; Heifers: 2% dry lot, 98% PRP	20% solid storage, 29% dry lot, 45% PRP, 6% burned for fuel
Other cattle	Commercial: 25% dry lot, 5% compost, 70% PRP; Feedlot: 1.5% lagoon, 1.5% liquid slurry, 20% dry lot, 2% daily spread, 10% compost, 65% PRP Subsistence: 10% dry lot, 90% PRP	Commercial: 100% PRP; Feedlot: 80% dry lot, 20% solid storage; Subsistence: 100% PRP	Commercial: 2% solid storage, 1% daily spread, 95% PRP, 2% manure with bedding; Feedlot: 20% solid storage, 80% manure with bedding; Subsistence: 10% dry lot, 30% PRP, 60% manure with bedding	Commercial: 5% dry lot, 5% compost, 90% PRP Feedlot: 5% lagoon, 5% liquid slurry, 75% dry lot, 5% daily spread, 10% compost; Subsistence: 10% dry lot, 80% PRP, 10% manure with bedding	Commercial: 3% dry lot, 97% PRP; Feedlot: 5% lagoon, 85% dry lot, 10% solid storage; Subsistence: 35% dry lot, 65% PRP	15% solid storage, 30% dry lot, 50% PRP, 5% burned for fuel
Sheep	Commercial: 2% dry lot, 98% PRP; Subsistence: 5% dry lot, 95% PRP	Commercial and subsistence: 100% PRP	Commercial and subsistence: 100% PRP	Commercial: 2% dry lot, 98% PRP; Subsistence: 5% dry lot, 95% PRP	Commercial: 2% dry lot, 98% PRP; Subsistence: 35% dry lot, 65% PRP; Feedlot: 2% lagoon, 98% dry lot	17% solid storage, 3% dry lot, 80% PRP

Livestock	DAFF (2010)	Du Toit et al. (2013a, b, c)	Moeletsi et al. (2015)	Moeletsi and Tongwane (2015)	ARC Report (2021)	IPCC 2019 Refinement (SSA default)
Goats	Commercial: 2% dry lot, 98% PRP; Subsistence: 5% dry lot, 95% PRP	Commercial and subsistence: 100% PRP	Commercial and subsistence: 100% PRP	Commercial: 2% dry lot, 98% PRP; Subsistence: 5% dry lot, 95%PRP	Commercial: 2% dry lot, 98% PRP; Subsistence: 35% dry lot, 65% PRP	17% solid storage, 3% dry lot, 80% PRP
Horses	100% PRP	40% dry lot, 60% PRP	100% PRP	100% PRP		
Mules/asses	100% PRP	100% PRP	100% PRP	100% PRP		
Swine	Commercial: 50% lagoon, 20% liquid slurry, 20% dry lot, 5% daily spread, 5% compost	Commercial: 92% lagoon, 1.5% liquid slurry, 5% dry lot, 1.5% daily spread; Subsistence: 50% dry lot, 50% daily spread	Commercial: 50% lagoon, 20% liquid slurry, 20% dry lot, 10% solid storage	Commercial: 50% lagoon, 20% liquid slurry, 20% dry lot, 5% daily spread, 5% compost		High productivity: 7% liquid slurry, 6% solid storage, 86% dry lot, 1% pit<1; Low productivity: 5% lagoon, 30% liquid slurry, 15% solid storage, 15% dry lot, 15% pit<1, 5% pit>1, 5% daily spread, 5% digester, 5% PRP
Poultry	Layers and broilers: 80% dry lot, 20% compost	Layers: 100% poultry manure without litter; Broilers: 100% poultry manure with litter	Layers and broilers: 10% dry lot, 5% daily spread, 2% compost, 5% poultry manure without litter, 78% poultry manure with litter	Layers: 5% liquid slurry, 70% dry lot, 5% daily spread, 10% compost, 10% poultry manure without litter; Broilers: 80% dry lot, 5% compost, 15% poultry manure with litter		Layers: 90% pit>1 month, 10% poultry manure with litter; Broilers: 100% poultry manure with litter

5.2.3 Enteric Fermentation (3.A.1)

5.2.3.1 Category description

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.

According to IPCC the method for estimating CH_4 emissions from enteric fermentation requires three basic steps:

a) Divide livestock population into animal subgroups based on sex, age, and production level.
b) Estimate the emission factors for each subgroup in terms of kilograms of CH_4 per animal per year.
c) Multiply the subgroup emission factors by the subgroup populations to estimate subgroup emissions and sum across the subgroups to estimate total emission.

Enteric fermentation contributed 27 589 Gg CO_2e in 2020, which is 67.7% of the AFOLU (excl. FOLU) sector emissions. Emissions decreased by 20.7% in the period 2000-2020 and decreased by 4.6% between 2017-2020.

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.

5.2.3.2 Methodological issues

A Tier 1 methodology is used to calculate CH_4 emissions from enteric fermentation in horses, mules and asses by multiplying the population data by IPCC default emissions factors (IPCC Equation 10.19, IPCC 2019 Refinement).

For all other livestock a Tier 2 methodology was applied by following the basic IPCC equations:

$$CH_4 \text{ emissions} = EF * \text{Population}$$

and

$$EF = (GE * (Ym/100) * 365\ days)/\ 55.65\ MJ\ (kg\ CH_4)^{-1}$$

Where:

EF = emission factor (kg CH_4 head^{-1} yr^{-1})

GE = gross energy intake (MJ head^{-1} day^{-1})

Ym = methane conversion factor (percentage gross energy in feed converted to methane) (Table 5. 21)

These equations assume that the emission factors are for an entire year. Since the population data is census data it is assumed that the population data is representative of a typical population on any one day of the year.

Table 5. 21: Methane conversion factors and their sources.

Livestock category	Sub-category	Breed	Methane conversion factor (Ym)
Dairy cattle	Mature female cows	Holstein	6[1]
		Jersey	6.3[1]
	Heifers (6 - 24 months)		7[1]
Other cattle	Commercial	All breeds	7[1]
	Subsistence		6.5[2]
	Feedlot		3[1]
Sheep	Commercial	All breeds	6.7[1]
	Subsistence		6.7[1]
	Feedlot		6.7[1]
Goats	Commercial	All breeds	5.5[1]
	Subsistence		5.5[1]
Swine	Commercial		0.7[3]
	Subsistence		0.7[3]

[1]IPCC 2019 Refinement, [2]IPCC 2006 Guidelines, [3]Du Toit et al. (2013c).

Activity data

The activity data for enteric fermentation is livestock population and this is described in detail in section 5.2.1.

Emission factors

Tier 1 IPCC default emission factors of 18 kg CH_4 head^{-1} yr^{-1} and 10 kg CH_4 head^{-1} yr^{-1} are applied to horses, and mules/asses, respectively (IPCC Table 10.10, IPCC 2019 Refinement). Emission factors for all other livestock are determined using the IPCC Tier

2 methodology. The emission factors for the detailed livestock categories are used to determine weighted averages (Table 5. 22) for the livestock categories with population data. The weighting is based on the herd and breed composition assumptions provided in Table 5. 18.

Table 5. 22: Enteric fermentation emission factors (kg CH_4 head-1 yr-1) and their sources per livestock category.

Livestock category	Sub-category	Enteric EF (kg CH_4 head^{-1} yr^{-1})	Reference
Dairy cattle	Mature cows	141.07	Calculated (see text)
	Heifers	70.91	Calculated (see text)
Other cattle	Commercial bulls	113.00	Du Toit et al. (2013a)
	Commercial young bulls	51.6	Assumed the same as young ox
	Commercial cows	118.41	Calculated (see text)
	Commercial heifers	65.23	Calculated (see text)
	Commercial ox	89.40	Du Toit et al. (2013a)
	Commercial young ox	51.60	Du Toit et al. (2013a)
	Commercial calves	51.60	Du Toit et al. (2013a)
	Feedlot	41.61	Calculated (see text)
	Subsistence cattle	61.47	Calculated (see text)
Sheep	Commercial wool	9.95	Calculated (see text)
	Commercial dual-purpose	10.89	Calculated (see text)
	Commercial meat	13.80	Calculated (see text)
	Feedlot	7.22	Calculated (see text)
	Subsistence sheep	5.61	Calculated (see text)
Goats	Commercial mohair	6.64	Calculated (see text)
	Commercial meat	14.38	Calculated (see text)
	Commercial dairy	19.99	Calculated (see text)
	Subsistence goats	9.33	Calculated (see text)
Swine	Commercial swine	1.09	Calculated (see text)
	Subsistence swine	1.33	Calculated (see text)
Horses		18	IPCC 2019 Refinement, Table 10.10
Mules/asses		10	IPCC 2019 Refinement, Table 10.10

Cattle

Emission factors for commercial and subsistence bulls, young bulls, ox, young ox and calves are taken directly from Du Toit et al. (2013a) where the methods are described in detail. For the other, more dominant livestock categories, all the background data is included in the calculation files to enable the direct calculation of the emission factors using the IPCC Tier 2 equations (Table 5. 23).

Sheep and goats

Emission factors for sheep and goats are calculated using a Tier 2 methodology (Table 5. 24). The net energy for growth and lactation for goats is determined in the same way as for sheep as the IPCC 2019 Refinement indicates that this is the updated approach for goats.

Table 5. 23: Equations for the calculation of emissions factors for cattle using the Tier 2 approach.

IPCC Equation	IPCC 2006 equations	Variables/constants/assumptions
10.3	$\mathrm{NE_m} = \mathrm{Cf}_i \times (weight)^{0.75}$	NE_m = net energy for maintenance (MJ day^{-1}) Cf_i = maintenance coefficient (MJ day^{-1} kg^{-1}) [IPCC 2019 Refinement, Table 10.4: Lactating dairy cows = 0.386, Non-lactating cattle = 0.322, Bulls = 0.37] *Weight* = live weight of animal (kg)
10.4	$\mathrm{NE_a} = \mathrm{C}_a \times \mathrm{NEm}$	NE_a = net energy for activity (MJ day^{-1}) C_a = coefficient corresponding to animal's feeding situation [Dairy cattle assumed to feed in pastures[1], other cattle assume to graze on large grazing areas[1]; IPCC 2019 Refinement, Table 10.5: Dairy cattle = 0.17, Other cattle = 0.36]
10.6	$\mathrm{NE_g} = 22.02 \times (\frac{BW}{C \times MW})^{0.75} \times (WG)^{1.097}$	NE_g = net energy for growth (MJ day^{-1}) BW = average live body weight of animals in the population (kg) C = growth coefficient [IPCC 2019 Refinement, Equation 10.6: Females = 0.8, Castrates = 1.0, Bulls = 1.2] MW = mature live body weight of an adult animal in moderate condition (kg) WG = average daily weight gain of animals in the population (kg day^{-1})
10.8	$\mathrm{NE_l} = Milk \times (1.47 + 0.40 \times Fat)$	NE_l = net energy for lactation (MJ day^{-1}) *Milk* = amount of milk produced (kg milk day^{-1}) *Fat* = milk fat content (% by weight)
10.11	$\mathrm{NE_{work}} = 0.10 \times \mathrm{NE_m} \times Hours$	NE_{work} = net energy for work (MJ day^{-1}) *Hours* = number of hours of work daily

10.13	$NE_p = C_{preg} \times NE_m$	NE_m = net energy for pregnancy (MJ day^{-1}) C_{preg} = pregnancy coefficient [IPCC 2019 Refinement, Table 10.7: Cattle = 0.1]
10.14	$REM = \left[1.123 - (4.092 \times 10^{-3} \times DE\%) + [1.126 \times 10^{-5} \times (DE\%)^2] - \left(\frac{25.4}{DE\%}\right)\right]$	REM = ratio of net energy available in a diet for maintenance to digestible energy consumed DE% = digestible energy as a percentage of gross energy [ARC (2021): Mature dairy cows = 70%, Dairy heifers = 60%, Other commercial cattle in grazing land = 60%, Cattle feedlot = 75%, Other subsistence cattle in grazing land = 50%]
10.15	$REG = \left[1.164 - (5.160 \times 10^{-3} \times DE\%) + [1.308 \times 10^{-5} \times (DE\%)^2] - \left(\frac{37.4}{DE\%}\right)\right]$	REG = ratio of net energy available for growth in a diet to digestible energy consumed DE% = digestible energy as a percentage of gross energy [see above]
10.16	$GE = \left[\frac{\left(\frac{NE_m + NE_a + NE_l + NE_{work} + NE_p}{REM}\right) + \left(\frac{NE_g}{REG}\right)}{\frac{DE\%}{100}}\right]$	GE = gross energy intake (MJ head^{-1} day^{-1}) DE% = digestible energy as a percentage of gross energy [see above]
10.21	$EF = \left[\frac{GE \times \left(\frac{Y_m}{100}\right) \times 365}{55.65}\right]$	EF = emissions factor (kg CH_4 head^{-1} yr^{-1}) Y_m = methane conversion factor (percent of gross energy in feed converted to methane) [IPCC 2019 Refinement, Table 10.12: Holstein high milk producing dairy cows = 6%, Jersey medium milk producing dairy cows = 6.3%, Dairy heifers = 7%, Non-dairy commercial cattle = 7%, Non-dairy subsistence cattle = 6.5, Feedlot cattle = 3%] 55.65 (MJ kg^{-1} CH_4) is the energy content of CH_4 constant

[1]**ARC (2021)**

Table 5. 24: Equations for the calculation of emissions factors for sheep and goats using the Tier 2 approach.

IPCC Equation	IPCC 2006 equation	Variables/constants/assumptions
10.3	$NE_m = Cf_i \times (weight)^{0.75}$	NE_m = net energy for maintenance (MJ day^{-1}) Cf_i = maintenance coefficient (MJ day^{-1} kg^{-1}) [IPCC 2019 Refinement, Table 10.4: Mature and replacement ewes = 0.217, Mature ram = 0.250, Young ram and male lamb = 0.271, Female lamb = 0.236] Weight = live weight of animal (kg)
10.5	$NE_a = C_a \times (weight)$	NE_a = net energy for activity (MJ day^{-1}) C_a = coefficient corresponding to animal's feeding situation (MJ day^{-1}) [Sheep grazing assumed to occur on flat pastures[1]; IPCC 2019 Refinement, Table 10.5: all sheep = 0.0107] *Weight* = live weight of animal (kg)
10.7	$NE_g = \frac{WG_{lamb/kid} \times (a + 0.5b(BW_i + BW_f))}{365}$	NE_g = net energy for growth (MJ day^{-1}) $WG_{lamb/kid}$ = weight gain (BW_f – BW_i) (kg yr^{-1}) BW_i = the live bodyweight at weaning (kg) BW_f = the live bodyweight at 1-year old or at slaughter (kg) a = constant (MJ kg^{-1}) [IPCC 2019 Refinement, Table 10.6: Female sheep = 2..1; Male sheep = 2.5 as it is assumed all male sheep are intact[1]] b = constant (MJ kg^{-1}) [IPCC 2019 Refinement, Table 10.6: Female sheep = 0.45; Male sheep = 0.35 as it is assumed all male sheep are intact[1]]
10.10	$NE_l = \left[\frac{5 \times WG_{wean}}{365}\right] \times EV_{milk}$	NE_l = net energy for lactation (MJ day^{-1}) WG_{wean} = the weight gain of the lamb/kid between birth and weaning (kg)

		EVmilk = the energy required to produce 1 kg of milk (MJ kg^{-1}) [IPCC 2019 Refinement, Equation 10.10: sheep = 4.6, goats = 3]
10.12	$\mathrm{NE_{wool}} = \frac{EV_{wool} \times Production_{wool}}{365}$	NEwool = net energy required to produce wool (MJ day^{-1}) EV_{wool} = the energy value of each kg of wool produced (weighed after drying but before scouring) (MJ kg^{-1}) [IPCC 2019 Refinement, Equation 10.12: sheep = 24, for goats this energy value is not considered] $Production_{wool}$ = annual wool production per sheep (kg yr^{-1})
10.13	$\mathrm{NE_p} = C_{preg} \times \mathrm{NE_m}$	NE_m = net energy for pregnancy (MJ day^{-1}) C_{preg} = pregnancy coefficient [The number of lambs/kids born in a year divided by the number of ewes that are pregnant in a year yields a value less than 1[1], therefore single birth coefficient is applied[2]; IPCC 2019 Refinement, Table 10.7: single births for sheep and goats = 0.077]
10.14	$REM = \left[1.123 - (4.092 \times 10^{-3} \times DE\%) + [1.126 \times 10^{-5} \times (DE\%)^2] - \left(\frac{25.4}{DE\%}\right)\right]$	REM = ratio of net energy available in a diet for maintenance to digestible energy consumed DE% = digestible energy as a percentage of gross energy [ARC (2021): Sheep in grazing land = 60%, Sheep in feedlots = 75%, Subsistence sheep = 50%, Goats in grazing land = 60%, Dairy goats = 70%, Subsistence goats = 50%]
10.15	$REG = \left[1.164 - (5.160 \times 10^{-3} \times DE\%) + [1.308 \times 10^{-5} \times (DE\%)^2] - \left(\frac{37.4}{DE\%}\right)\right]$	REG = ratio of net energy available for growth in a diet to digestible energy consumed DE% = digestible energy as a percentage of gross energy [see above]
10.16	$GE = \left[\frac{\left(\frac{\mathrm{NE_m} + \mathrm{NE_a} + \mathrm{NE_l} + \mathrm{NE_{work}} + \mathrm{NE_p}}{REM}\right) + \left(\frac{\mathrm{NE_g}}{REG}\right)}{\frac{DE\%}{100}}\right]$	GE = gross energy intake (MJ $head^{-1}$ day^{-1}) DE% = digestible energy as a percentage of gross energy [see above]
10.21	$EF = \left[\frac{GE \times \left(\frac{Y_m}{100}\right) \times 365}{55.65}\right]$	EF = emissions factor (kg CH_4 $head^{-1}$ yr^{-1})

		Y_m = methane conversion factor (percent of gross energy in feed converted to methane) [IPCC 2019 Refinement, Table 10.13: Sheep = 6.7%, Goats = 5.5%] 55.65 (MJ kg^{-1} CH_4) is the energy content of CH_4 constant

[1]ARC (2021); [2]IPCC 2019 Refinement

Swine

Gross energy intake data for swine is taken from Du Toit et al. (2013c) and applied in the IPCC Equation 10.21 to determine the emission factors.

5.2.3.3 Uncertainties and time series consistency

Activity data uncertainty

Activity data time-series is complete from 1990 to 2020, however only data from 2000 is presented due to incomplete time-series in other sectors. Activity data uncertainty is discussed in section 5.2.1.4.

Emission factor uncertainty

The uncertainties on the emission factors are provided by ARC (2021) for mature cows, heifers, feedlot cattle, all sheep and all goat sub-categories (Table 5. 25). No uncertainty data is provided by Du Toit et al. (2013c) for bulls, oxen, young oxen, calves, or swine emission factors. For the bulls, young bulls, oxen, young oxen, and calf sub-categories the uncertainty was assumed to be an average of those for mature cows and heifers in each sub-category. For swine IPCC 2006 indicates that a Tier 2 approach is likely to have an uncertainty of around ± 20%. Tier 1 default factors for horses, and mules/asses have an uncertainty of between ± 30% - 50%, hence an average of ± 40% is applied.

Table 5. 25: Enteric fermentation emission factor uncertainties.

Animal categories	Animal subcategories	Emission Factor uncertainty	Reference
Dairy cattle	Mature cows	± 23	ARC (2021)
	Heifer (12 – 18 months)	± 21	ARC (2021)
	Heifer (6 – 12 months)	± 17	ARC (2021)
	Heifer (3 – 6 months)	± 13	ARC (2021)
Commercial beef cattle	Bulls	± 10	Average of uncertainty estimates for cows and heifers
	Young bulls	± 10	
	Mature cows	± 7	ARC (2021)
	Heifer (12 – 18 months)	± 9	ARC (2021)
	Heifer (6 – 12 months)	± 9	ARC (2021)
	Heifer (3 – 6 months)	± 13	ARC (2021)
	Oxen	± 10	Average of uncertainty estimates for cows and heifers
	Young oxen	± 10	
	Calves	± 10	

	Feedlot cattle	± 15	ARC (2021)
Subsistence cattle	Bulls	± 26	Average of uncertainty estimates for cows and heifers
	Young bulls	± 26	
	Mature cows	± 24	ARC (2021)
	Heifer (12 – 18 months)	± 28	ARC (2021)
	Heifer (6 – 12 months)	± 27	ARC (2021)
	Heifer (3 – 6 months)	± 27	ARC (2021)
	Oxen	± 26	Average of uncertainty estimates for cows and heifers
	Young oxen	± 26	
	Calves	± 26	
Sheep	Mature ewes	± 30	ARC (2021)
	Replacement ewes	± 22	ARC (2021)
	Female lambs	± 36	ARC (2021)
	Male lambs	± 27	ARC (2021)
	Young rams	± 33	ARC (2021)
	Rams	± 24	ARC (2021)
	Feedlot sheep	± 29	ARC (2021)
Goats	Mature does	± 35	ARC (2021)
	Replacement does	± 31	ARC (2021)
	Female kids	± 34	ARC (2021)
	Male kids	± 34	ARC (2021)
	Young buck	± 39	ARC (2021)
	Buck	± 40	ARC (2021)
Horses		± 40	IPCC 2006
Mules & asses		± 40	IPCC 2006
Swine		± 20	IPCC 2006

Time-series consistency

The time-series for enteric fermentation is consistent.

5.2.3.4 Category specific QA/QC and verification

Activity data verification is provided in section 5.2.1.3. For the emission factor data, a literature search was conducted, and the results are shown in the calculation files.

Data was also compared to the IPCC default data. The dairy cattle Implied emission Factor (IEF) is higher than the 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. This is the same for non-dairy cattle. The sheep, goat and swine IEFs are generally consistent with the IPCC defaults.

5.2.3.5 Category-specific recalculations

This inventory incorporates new data for the calculation of the Tier 2 emission factors and includes changes and updates to the herd composition and characterisation. In addition, the weighting is applied to the emission factors and not to the population data as was done in the previous inventory. Emissions were therefore recalculated for the entire time series and led to a 16% increase in emissions compared to the previous inventory.

5.2.3.6 Category-specific planned improvements

In this inventory all the background activity data to complete the Tier 2 calculations has been included, however average activity data (i.e., livestock weights, milk production, fat content) are applied in many cases. No specific improvements plans are in place; however, it is recommended that in future inventories annual activity data be collected and incorporated. This means that the emission factor will vary annually and may better reflect any emission changes due to implemented changes (or mitigation actions) in livestock population management, feeding situations and pasture management. South Africa would then be able to track the impacts of possible mitigation actions through the inventory.

5.2.4 Manure Management (3.A.2)

5.2.4.1 Category description

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. This category therefore includes emissions of both CH_4 and N_2O.

Ammonia (NH_3) and NO_x volatilise from manure storage; however, these emissions are not estimated due to a lack of data.

According to IPCC the method for estimating CH_4 and direct N_2O emissions from manure management requires the following steps:

a) Divide livestock population into animal subgroups based on sex, age, and production level.
b) For CH_4 emissions:

i. Estimate the emission factors for each subgroup in terms of kilograms of CH_4 per animal per year.
ii. Multiply the subgroup emission factors by the subgroup populations to estimate subgroup emissions and sum across the subgroups to estimate total emission.

c) For N_2O emissions:
   i. Determine average annual nitrogen excretion rate per head for each livestock subcategory.
   ii. Determine the fraction of total annual nitrogen excretion for each livestock category that is managed in each manure management system.
   iii. Determine N_2O emission factors for each manure management system.
   iv. Multiply the emission factor by the total nitrogen managed in the system and sum over all manure management systems.

Manure management contributes 3 782 CO_2e in 2020, which is 9.3% of the AFOLU (excl. FOLU) sector emissions. Methane emissions contribute 31.1% to these emissions and the rest is N_2O. Emissions increased by 11.8% in the period 2000-2020 and decreased by 2.1% between 2017-2020.

5.2.4.2 Methodological issues

CH_4

Manure CH_4 emissions are calculated with a Tier 2 IPCC methodology for all livestock categories using the following equation:

$$CH_{4\,manure} = EF * Population$$

and:

$$EF_{(T)} = (VS_T \cdot 365) \cdot \left[B_{o(T)} \cdot 0.67\, kg\, m^{-3} \cdot \sum_{S,k} \frac{MCF_{S,k}}{100} \cdot MS_{(T,S,k)} \right]$$

Where:

$EF_{(T)}$ = annual emission factor for defined livestock population T (kg)

$VS_{(T)}$ = daily Volatile solids (VS) excreted for an animal within defined population T (kg)

$B_{o(T)}$ = maximum CH_4 producing capacity for manure produced by an animal within defined population T (m^3 kg of VS^{-1})

$MCF_{S,k}$ = CH_4 conversion factors for each manure management system j by climate region k

$MS_{(T,S,k)}$ = percentage of animal species/category T's manure handled using manure system S in climate region k (%)

N_2O

Direct manure N_2O emissions are calculated following the IPCC equation 10.25 (IPCC, 2006, volume 4, chapter 10).

Activity data

CH_4

Activity for manure CH_4 emissions is livestock population data which is described in section 5.2.1.

N_2O

Direct N_2O emissions require information on livestock population (section 5.2.1), manure management (section 5.2.2) and annual average nitrogen (N) excretion per head of livestock ($N_{ex(T)}$).

Annual N excretion for horses and mules/asses is calculated with a Tier 1 methodology, based on the IPCC default N excretion rate of 0.46 kg N (1000 kg animal mass)$^{-1}$ day^{-1}, and typical animal mass. ARC (2021) provides a typical animal mass of 595 kg for horses and 250 kg for mules and asses.

A Tier 2 methodology (following IPCC 2006 Equation 10.31 and 10.32) is utilised to calculate annual N excretion rates for cattle, sheep, and goats (Table 5. 26). The updated IPCC 2019 Refinement Tier 2 methodology (Equation 10.32A) is applied to swine and poultry to determine N intake rates. The dry matter intake (DMI) data for swine and poultry is taken from Du Toit et al. (2013c). In all cases the N retention values are sourced from IPCC 2006 Table 10.2.

Table 5. 26: Nitrogen excretion rate (kg N/animal/year) for different livestock categories

Livestock category	Subcategories	Nitrogen excretion rate (kg N/animal/year)
Dairy cattle	Mature female cows	113.71
	Heifer 12 - 18 months	27.06
	Heifer 6 - 12 months	21.87
	Calves 0 - 6 months	12.09
Commercial beef cattle	Mature female cows	44.60
	Heifers 12 - 18 months	25.74
	Heifers 6 - 12 months	19.86
	Calves 3 - 6 months	13.34
	Feedlot cattle	59.00
Subsistence cattle	Mature female cows	46.05
	Heifers 12 - 18 months	26.09
	Heifers 6 - 12 months	24.00
	Calves 0 - 6 months	16.46
Commercial sheep	Mature ewes	4.00
	Replacement ewes	2.93
	Female lambs	3.28
	Male lambs	4.06
	Replacement rams	3.82
	Mature rams	5.11
	Feedlot sheep	4.33
Subsistence sheep	Mature ewes	4.47
	Replacement ewes	3.27
	Female lambs	2.42
	Male lambs	2.63
	Replacement rams	2.84
	Mature rams	5.77
Goats	Mature does	6.33
	Replacement does	2.99
	Female kids	2.51
	Male kids	3.31
	Replacement bucks	3.51
	Bucks	5.59
	Dairy goats	-

Emission factors

CH_4

Annual volatile solid (VS) excretion from horses and mules/asses is determined with a Tier 1 methodology (IPCC 2006, Equation 10.22) by using a default VS excretion rate of 7.2 kg VS (1000 kg animal mass)$^{-1}$ day^{-1} (IPCC 2019 Refinement, Table 10.13A).

The annual VS excretion for all other livestock is determined with the IPCC 2006 Equation 10.24. IPCC 2006 suggests a value of 0.04 for the fraction of urinary energy (UE) for all livestock except swine where a value of 0.02 is applied (IPCC 2006, Equation 10.24). The fraction of ash content of feed (ASH) is set at 0.08 for all livestock (IPCC 2006, Equation 10.24), except for swine where a value of 0.17 is applied (Du Toit et al., 2013c).

N_2O

Emission factors for all livestock are obtained from IPCC 2019 Refinement (Table 10.21).

5.2.4.3 Uncertainties and time series consistency

Activity data uncertainty

The population data uncertainties are discussed in section 5.2.1.4. Uncertainty on manure management systems is provided in section 5.2.2.3. The IPCC 2006 default uncertainty for N excretion is ± 50%, but this is for a Tier 1 method. It is therefore assumed that the Tier 2 method reduces uncertainty to ± 30%.

Emission factor uncertainty

Uncertainty on the CH_4 manure emission factors is provided by ARC (2021) for mature cows, heifers, feedlot cattle, all sheep and all goat sub-categories (Table 5. 27). No uncertainty data is provided by Du Toit et al. (2013c) for bulls, oxen, young oxen, calves, or swine emission factors. For the bulls, young bulls, oxen, young oxen, and calf sub-categories the uncertainty was assumed to be an average of those for mature cows and heifers in each sub-category. For swine IPCC 2006 indicates that a Tier 2 approach is likely to have an uncertainty of around ± 20%. The same applies to poultry. Tier 1 default factors for horses, and mules/asses have an uncertainty of between ± 30% - 50%, that an average of ± 40% is applied.

Uncertainty on the IPCC default N_2O manure emission factors is -50% to +100%.

Table 5. 27: Uncertainty data for livestock manure CH_4 emission factors.

Animal categories	Animal subcategories	Emission Factor uncertainty	Reference
Dairy cattle	Mature female	±24	ARC (2021)
	Heifer (12 – 18 months)	±21	ARC (2021)
	Heifer (6 – 12 months)	±18	ARC (2021)
	Heifer (3 – 6 months)	±13	ARC (2021)
Commercial beef cattle	Bulls	± 10	Average of uncertainty estimates for cows and heifers
	Young bulls	± 10	
	Mature female	±7	ARC (2021)
	Heifer (12 – 18 months)	±11	ARC (2021)
	Heifer (6 – 12 months)	±9	ARC (2021)
	Heifer (3 – 6 months)	±9	ARC (2021)
	Oxen	± 10	Average of uncertainty estimates for cows and heifers
	Young oxen	± 10	
	Calves	± 9	
	Feedlot cattle	± 6	ARC (2021)
Subsistence cattle	Bulls	± 17	Average of uncertainty estimates for cows and heifers
	Young bulls	± 17	
	Mature female	±16	ARC (2021)
	Heifer (12 – 18 months)	±19	ARC (2021)
	Heifer (6 – 12 months)	±18	ARC (2021)
	Heifer (3 – 6 months)	±19	ARC (2021)
	Oxen	± 17	Average of uncertainty estimates for cows and heifers
	Young oxen	± 17	
	Calves	± 17	
Sheep	Mature ewes	±15	ARC (2021)
	Replacement ewes	±8	ARC (2021)
	Female lambs	±15	ARC (2021)
	Male lambs	±16	ARC (2021)
	Young rams	±11	ARC (2021)
	Rams	±9	ARC (2021)
	Feedlot sheep	±15	ARC (2021)
Goats	Mature does	±46	ARC (2021)
	Replacement does	±42	ARC (2021)
	Female kids	±46	ARC (2021)
	Male kids	±46	ARC (2021)
	Young buck	±50	ARC (2021)
	Buck	±50	ARC (2021)
Horses		± 30	IPCC 2006
Mules & asses		± 30	IPCC 2006
Swine		± 20	IPCC 2006
Poultry		± 20	IPCC 2006

Time-series consistency

The time-series is consistent throughout the period 2000 – 2020.

5.2.4.4 Category specific QA/QC and verification

Activity data verification is provided in section 5.2.1.3. For the emission factor data, a literature search was conducted, and the results are shown in the calculation files.

Data was also compared to the IPCC default data. The dairy cattle emission factor is higher than the default for Africa. The differences are due to the different manure management systems in these regions which impacts the MCF. The situation is similar for the emission factor for swine. The Other cattle emission factor is much lower than that in other countries and is even lower than the default value for Africa. Sheep and goat emission factors are lower than IPCC default values.

5.2.4.5 Category-specific recalculations

This inventory incorporates new data for the calculation of the Tier 2 emission factors and includes changes and updates to the herd composition and characterisation. In addition, the weighting is applied to the emission factors and not to the population data as was done in the previous inventory. Emissions were therefore recalculated for the entire time series and led to a 59.1% increase (79.8% for manure CH_4 emissions and 49.7% for manure N_2O emissions) in emissions compared to the previous inventory.

5.2.4.6 Category-specific planned improvements

There are no planned improvements for this category in the next year.

5.3 Aggregated and non-CO_2 emissions on land (3.C)

5.3.1 Category description

The aggregated and non-CO_2 emissions on land category is composed of the following sub-categories:

- Biomass burning (3C1)
- Liming (3C2)
- Urea application (3C3)
- Direct N_2O from managed soils (3C4)
- Indirect N_2O from managed soils (3C5)
- Indirect N_2O from manure management (3C6)

Details for calculating emissions for each of these sub-categories is detailed in the sections below.

5.3.2 Emissions from biomass burning (3.C.1)

5.3.2.1 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). 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).

South Africa reports emissions of non-CO_2 gases (CH_4, CO, N_2O and NO_x) from all land categories. There is insufficient data to separate controlled fires from wildfires, so all emissions are for total fires. 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 emissions from burning are not included in this category as they are accounted under the disturbance losses in the Land (3B) category. IPCC indicates that net CO_2 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. All non-CO_2 emissions, on the other hand, are included in this category.

5.3.2.2 Methodological issues

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

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

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

Activity data

Burnt area data

The MODIS Collection 6 Burnt Area data was utilised in this inventory, which is an upgrade from the Collection 5 used in the last inventory. Annual burnt-area maps were produced from the MODIS monthly burnt-area product for the years 2001, 2005, 2010, and 2014-2018. Data was incomplete for 2000 so this data set was excluded, and there was insufficient time to process all the years in between. An IPCC splicing technique using the previous inventory data as proxy data was applied to update the data for the years in between. All years can be updated in the next inventory.

The MODIS Collection 6 Burned Area Product Geotiff version (http://modis-fire.umd.edu/pages/BurnedArea.php?target=GeoTIFF) is 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). Data processing involved the following steps:

a) Burnt area:
   i) Each year's dataset contained 12 files (1 per month). Each month was reclassed to remove NoData (classes -2, -1, and 0) and each day value was changed to 1 to obtain total area burnt per month.
   ii) Every month of data was reprojected into the UTM 35S projection to remain consistent with the 2014 and 2018 land-cover dataset project.

iii) Each month's dataset was clipped (extract by mask) to the South African boundary (South African Boundary shapefile (2018) obtained from the Municipal Demarcation Board (https://dataportal-mdb-sa.opendata.arcgis.com/search?tags=2018) with a 1km buffer. This allowed for improved data retention.

iv) Each month's dataset was combined using the "mosaic to new raster" to create a dataset per year.

v) Each year's dataset was resampled to change the cell size to the same as the land cover dataset:

- For all years the 2014 land cover dataset was used with a cell size of 30 x 30m.

vi) Each year's dataset was clipped (extract by mask) to the actual South African boundary.

b) Land cover/land use:

i) The 2014 (GTI, 2015) and 2018 land cover datasets (GTI, 2019a) (72 and 73 classes, respectively) were reclassed into 20 categories (see section 5.4.2 for more details). The 20 categories are the same as the latest land change categories for 1990-2018 and 2014-2018 using the same process as conducted by the land change study (GTI, 2019a; GTI, 2019b).

c) Combining burnt area and land cover datasets:

i) The land cover type where each year's burnt area was associated with was conducted using the raster calculator feature. This was done for each year.

The output dataset for each year was collated in Microsoft Excel and the total area burnt was calculated in hectares. Due to time limitations not all the post years could be reanalysed using the Collection 6 data. The years 2001, 2005, 2010 and 2014 onwards were analysed and for the in between years the previous Collection 5 data was used as a proxy and the IPCC splicing technique was applied to adjust the years in between. There was not much difference in the two data sets, however, it would be ideal to maintain consistency throughout the time-series.

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

The values for fuel density were sourced from various sources (Table 5. 28). A weighted average for fuel density and the combustion factor (C_f) was determined for low shrublands. According to the 2013/2014 land cover map report (GTI, 2015) low shrublands are mainly karoo type vegetation. Also included in this category is a portion of fynbos (13% according to the 2013/2014 land cover map). The karoo vegetation classes have similar fuel densities and C_f values, but these are very different for fynbos (Table 5. 28). A weighted average fuel density and C_f value was calculated from these numbers for the low shrubland category in this inventory. Wetlands were assumed to have the same values as grasslands as done in the previous inventory (DFFE, 2021).

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. 28: Fuel density and combustion fractions for the various vegetation classes.

Vegetation class	Fuel density (t/ha)			Combustion factor			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				
Natural woodlands	4.4	Van Leeuwen et al. (2014)		0.8	Van Leeuwen et al. (2014)				2.5 – 26.7
Croplands	7	DAFF (2010)		1	DAFF (2010)				4 – 10
Grasslands							4.1	IPCC (2006)	2.1 – 10
Low shrublands	2.42[c]	Weighted average	5.7 – 26.7	0.91[c]	Weighted average	0.61 – 0.95			
Fynbos	*12.9*	*IPCC (2006)*		*1*	*IPCC (2006)*				
Nama karoo	*1*	*1994 NIR*		*0.95*	*1994 NIR*				
Succulent karoo	*0.6*	*1994 NIR*		*0.95*	*1994 NIR*				
Wetlands[d]							4.1	IPCC (2006)	

[a] Fuel consumption is a product of fuel density and the combustion factor.
[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) are applied.

5.3.2.3 Uncertainties and time series consistency

Activity data uncertainty

Boschetti et al. (2019) indicates that MODIS collection 6 burnt area products have an uncertainty of less than 6%. The 2013/14 land cover map showed an average user and producer accuracy of 83.74% and 88.34% respectively. Based on the accuracy assessment in the 2014 SANLC report the following uncertainties were assigned to the various land cover categories:

a) Forest land: ± 45%
b) Cropland: ± 8%
c) Grassland: ± 15%
d) Wetland: ± 12%
e) Settlements: ± 8%
f) Other land: ± 22%

Uncertainty is higher for land use change areas, so these were assumed to have a 5% higher uncertainty. 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%. Based on uncertainties in IPCC (IPCC, 2006; Table 2.4) and van Leeuwen et al. (2014) fuel consumption uncertainty was determined to be 40%, 20%, 75%, 75%, 40% and 10% for forest lands, croplands, grasslands, wetlands, settlements, and other lands respectively.

Emission factor uncertainty

IPCC default uncertainties for emission factors are provided in the guidelines (IPCC, 2006; Table 2.5).

Time-series consistency

Time series is consistent as same data sources are used throughout.

5.3.2.4 Category specific QA/QC and verification

Burnt area data was compared to those from the Meraka Institute (Meraka Institute, 2019) who are also using the MODIS collection 6 data. The datasets compare very well (within 10% of each other) and show the same annual trend.

5.3.2.5 Category-specific recalculations

Recalculations are completed for the entire time series due to the changes in the land cover classes and the updated burnt area maps, particularly for the years 2000 – 2009 as the MODIS collection 6 data replaced the collection 5 data. The updates led to a 6.8% to 16.8% decline in emissions between 2000 and 2005, after which the annual variation is between a 5% decline to a 3.5% increase in emissions, except for 2017 where emissions almost doubled (96%). There appeared to be an error in the previous 2017 data, and this has been corrected.

5.3.2.6 Category-specific planned improvements

There are no specific planned improvements for this category.

5.3.3 Liming (3.C.2)

5.3.3.1 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.

Liming produced 942 Gg CO_2 in 2020 which is 10% of the *Aggregated and non-CO_2 emissions on land* and 2.3% of the AFOLU (excl. FOLU) emissions. These emissions have more than doubled since 2000, however, there was a 23% reduction in emissions since 2017.

5.3.3.2 Methodological issues

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 between 1990 and 2008 are obtained from the Fertilizer Association of South Africa (FertSA) (http://www.fssa.org.za/Statistics.html). This data stops in 2008, and so for later years the amount of agricultural lime sold was obtained from the SAMI report (DMR, 2018). FertSA data was considered more accurate in terms of the amount being applied to soils and it reports the consumption for both dolomite and limestone. These two data sets are therefore spliced together using the IPCC surrogate data technique. The trend in the SAMI consumption data is similar to the limestone consumption data from FertSA, therefore the SAMI data is used as surrogate data to determine the limestone application. The relationship between limestone and dolomite is plotted and a linear extrapolation of the relationship is utilised to calculate the dolomite consumption for 2008-2020. There have not been any updated SAMI Reports and so the data for 2018 to 2020 were extrapolated.

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*.

5.3.3.3 Uncertainties and time series consistency

Activity data uncertainty

Uncertainty is determined from the difference between the SAMI (DMR, 2018) report data and the Fertilizer Association data. For limestone it is -90% to 25% and for dolomite it was determined to be -75% to 15%.

Emission factor uncertainty

The dolomite and limestone default emission factors have an uncertainty of -50% (IPCC 2006 Guidelines, p. 11.27).

Time-series consistency

A splicing technique was used to combine data sets to ensure a consistent time-series.

5.3.3.4 Category specific QA/QC and verification

Past inventory reviews have mentioned upgrading this information and investigating the alternate method of calculating potential lime use. This was done by using the crop area estimates combined with application rates from Tongwane et al. (2016) but this yielded a value of over 3 million tons of lime in 2008 compared to the 1.5 million tons provided by the Fertiliser Association of SA. This data was therefore not incorporated and rather an alternate data source should be sought in future. It may be possible to obtain future data from the SAGERS system.

5.3.3.5 Category-specific recalculations

There have been no recalculations performed for this source category this year.

5.3.3.6 Category-specific planned improvements

No improvements are planned for this category.

5.3.4 Urea application (3.C.3)

5.3.4.1 Category description

Adding urea to soils during fertilization leads to a loss of CO_2 that was fixed in the industrial production process.

Urea application is estimated to produce 585 Gg CO_2 in 2020 (1.4% of the AFOLU (excl. FOLU) emissions) and this is almost double what was emitted in 2000. Emissions declined by 14.0% since 2017.

5.3.4.2 Methodological issues

A Tier 1 approach of the IPCC 2006 Guidelines is used to calculate 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 20/06/2021).

Emission factors

The IPCC default emission factor of 0.2 t C (t urea)$^{-1}$ is applied in the equation to calculate the CO_2 emissions.

5.3.4.3 Uncertainties and time series consistency

Activity data uncertainty

In terms of urea application, it is assumed that all urea imported is applied to agricultural soils and this approach may lead to an over- or under-estimate if the total imported urea is not applied in that particular year. However, over the long-term this bias should be negligible (IPCC, 2006). 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.

Emission factor uncertainty

As for the liming emission factors, the urea emission factor also has an uncertainty of -50% (IPCC 2006 Guidelines, p. 11.32).

Time-series consistency

The time-series is consistent.

5.3.4.4 Category specific QA/QC and verification

Urea data is checked against the FAOStat dataset and found to be very similar.

5.3.4.5 Category-specific recalculations

No recalculations are performed for this category.

5.3.4.6 Category-specific planned improvements

No improvements are planned for this category in the next year.

5.3.5 Direct nitrous oxide emissions from managed soils (3.C.4)

5.3.5.1 Category description

Agricultural soils contribute to GHGs in three ways:

- 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.
- Organic soil that is drained or managed for agricultural purposes; and
- Animal manure deposited on pastures, rangelands, and paddocks.

In this inventory emissions from sewage sludge are included under waste (IE) and organic soils are not included (NE) due to their insignificance.

Direct N_2O emissions from managed soils amounted to 5 276 Gg CO_2e in 2020, which is 12.9% of the AFOLU (excl. FOLU) emissions. The emission contribution of the various types of N inputs is shown in Table 5. 29. The total Direct N_2O emissions increased by 28.9% between 2000 and 2020, showing a 3.3% increase since 2017.

Direct N_2O emissions from managed soils is a key category based on the level and trend assessments.

Table 5. 29: Emission trends for the various sub-categories of direct N_2O emissions from managed soils.

		Inorganic N fertilisers	Organic N fertilisers	Urine and dung from grazing animals	Crop residues
2000	Emissions (Gg CO_2e)	1 013,09	382,20	893,36	1 803,88
	% AFOLU (excl. FOLU)	2,39	0,90	2,11	4,25
2017	Emissions (Gg CO_2e)	1 078,78	457,57	814,47	2 754,06
	% AFOLU (excl. FOLU)	2,54	1,08	1,92	6,48
2020	Emissions (Gg CO_2e)	1 002,29	455,62	783,71	3 033,89
	% AFOLU (excl. FOLU)	2,46	1,12	1,92	7,44
Change	2000 – 2020 (%)	-1,07	19,21	-12,27	68,19
	2017 – 2020 (%)	-7,09	-0,43	-3,78	10,16

5.3.5.2 Methodological issues

A Tier 1 approach is used to calculate Direct N_2O emission from managed soils following the IPCC 2006 Equation 11.1 (IPCC, 2006, Volume 4, Chapter 11).

Inorganic fertiliser N inputs

IPCC Tier 1 methodologies and default emission factors (IPCC 2006) are used for estimating direct N_2O emissions from managed soils. The amount of inorganic N applied to soils is multiplied with the IPCC default emission factor (IPCC 2006).

Organic fertiliser N inputs

The amount of N (kg N yr^{-1}) from organic N additions applied to soil is calculated using IPCC 2006 Equation 11.3 (IPCC, 2006; Volume 4, chapter 11).

Animal manure applied to soils

A Tier 1 approach was used to calculate N from animal manure applied to soils (IPCC 2006, Equation 11.4, vol 4, chapt 11). 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 (IPCC, 2006, volume 4, chapter 10).

Sewage sludge applied to soils

N_2O emissions from sludge are included in the *Waste* sector and are therefore excluded here to avoid double counting.

Compost applied to soils

The amount of compost N applied on managed soils each year is 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 20-year period. It is 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 is considered when estimating N inputs from compost (details provided in DAFF (2010) and Otter (2011)).

Urine and dung N deposited by grazing animals

Manure N 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 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 by grazing animals (F_{PRP}; kg N yr^{-1}) is calculated using Equation 11.5 in the IPCC 2006 Guidelines (Chapter 11, Volume 4).

Crop residues N inputs

The amount of N in crop residues is estimated using the updated IPCC Tier 1 approach for the IPCC 2019 Refinement (Equation 11.6) but with some national factors. Some country specific factors are given for fraction of dry matter, fraction of residue burnt, fraction of residue removed, and ratio of above-ground and below ground residues to harvested yield (Tongwane et al., 2016). IPCC default factors are applied for combustion factors. IPCC default values for N content of above-ground residue, N content of below ground residue, and ratio of below-ground biomass to above-ground biomass (IPCC 2019 Refinement, Table 11.1A) are applied.

Mineralised N due to land use change

The mineralised N resulting from loss of soil organic carbon stocks in mineral soils through land-use change (F_{SOM}) was estimated following the equation 11.8 from the IPCC 2006 guidelines. IPCC recommended defaults for C:N ratio (IPCC 2006, Equation 11.8) are used in the calculation.

Activity data

Inorganic fertiliser N inputs

For nitrogen emissions the Fertilizer Association of SA reports total N consumption (http://www.fertasa.co.za/fertilizer-information/historic-sales-data/ and http://www.fertasa.co.za/wp-content/uploads/2021/03/Fertilizer-Usage-2020-and-2021-RSA.pdf). 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.

Organic fertiliser N inputs

Animal manure inputs

IPCC 2006 Equation 10.34 (IPCC, 2006; volume 4, chapter 10) requires the following data:

a) Livestock population data (section 5.2.1).
b) N excretion data (section 5.2.4.2).
c) Manure management system usage data (Table 5. 30).
d) Amount of managed manure nitrogen that is lost in each manure management system ($Frac_{LossMS}$). IPCC 2006 default values were used here (Table 10.23, Chapter 10, Volume 4, IPCC 2006).
e) Amount of nitrogen from bedding. There were no data available for this, so the values provided by IPCC (IPCC, 2006; pg. 10.66) are utilized; and
f) The fraction of managed manure used for feed, fuel, or construction. Again, there were insufficient data and thus F_{AM} was not adjusted for these fractions (IPCC 2006 Guidelines, p. 11.13).

Compost inputs

The activity data to calculate compost is inorganic N fertiliser data which is described above.

Urine and dung deposited by grazing animals

Activity data for this sub-category are livestock population (section 5.2.1) and manure management (section 5.2.4) data.

Crop residue N inputs

Planted area and production data is obtained from Abstracts of Agricultural Statistics (DALRRD, 2021) and FAO (FAOStat). Production data is used to calculate yield and this is usually dry mass (as indicated in FAOSTAT) so these values are not multiplied by the dry matter content to get dry yield.

Mineralised N due to land use change

The average annual loss of soil carbon from the various land types is the activity data for this subcategory and this data comes from the land conversions data discussed in the Land sector (section 5.4).

Emission factors

Inorganic and organic N fertiliser, crop residues and F_{SOM}

The IPCC default emission factor of 0.005 kg N_2O-N/kg N applied (IPCC 2019 Refinement, Table 11.1, dry climate).

Urine and dung deposited by grazing animals

The IPCC default emission factor of 0.002 kg N_2O-N (kg N)$^{-1}$ for cattle, poultry and pigs and 0.003 kg N_2O-N (kg N)$^{-1}$ for sheep and other animals is applied (IPCC 2019 Refinement, Table 11.1, dry climate).

5.3.5.3 Uncertainties and time series consistency

Activity data uncertainty

Inorganic N fertiliser

Expert opinion (Corne Louw, corne@grainsa.co.za) suggests that the N consumption would likely be within 15% of the number.

Organic N fertiliser

For animal manure inputs the uncertainty is estimated at ±41% based on the uncertainty on livestock population, manure management and N excretion data. No uncertainty data was provided for compost, so a ±25% uncertainty is assumed. This is based on the 15% uncertainty on N consumption, with additional uncertainty on the percentage nitrogen, percentage of compost in total fertiliser application and amount of animal manure in compost.

Urine and dung deposited by grazing animals

The uncertainty estimate for this activity data is 53.6% based on the uncertainty on livestock population data, manure management data and the 50% uncertainty on the FracLossMS factor (IPCC 2006, Table 10.23).

Crop residues

The uncertainty on crop residue input data is high (average of 91.2%) which is estimated from a ±10% uncertainty on crop production data, a ±75% uncertainty on N content, a ±50 uncertainty on above and below ground ratios (IPCC 2019 Refinement, Table 11.1A) and a ±10% uncertainty on residue management data.

FSOM

Uncertainty is estimated at ±33% due to a ±13% uncertainty on land area data, ±30% uncertainty on SOC data and ±5% uncertainty on the C:N ratio.

Emission factor uncertainty

Inorganic and organic N fertiliser, crop residues and F_{SOM}

Uncertainty on the default emission factor applied to these sub-categories is -100% and +200% (IPCC 2019 Refinement, Table 11.1).

Urine and dung deposited by grazing animals

Uncertainty on the default emission factor for cattle, poultry and pigs is -100% to +200% and for the sheep and other animals it is -100% to +230% (IPCC 2019 Refinement, Table 11.1).

Time-series consistency

The time-series for direct N_2O emissions is complete and consistent.

5.3.5.4 Category specific QA/QC and verification

Synthetic N fertiliser consumption data was compared to the FAO data (FAOSTAT) and there was no difference in the data between 2000 and 2014, but after that data varied by up to 23%. It was noted in the FAO data that the last few years were indicated to be unofficial data so this could account for the discrepancy.

5.3.5.5 Category-specific recalculations

Recalculations were performed for the entire time-series and the updated data is on average 71.8% lower than provided in the previous inventory. The difference seen is because of changes in both the activity (livestock herd composition and manure management) and emission factor data. Much of the decline in emissions is due to the updated emission factors in this category. The emission factors provided in the IPCC 2019 Refinement are half of what was used in the previous inventory. This is because the 2019 Refinement disaggregates the data into wet and dry climates and the dry climate data, (which is applied in this inventory) are much lower.

5.3.5.6 Category-specific planned improvements

There are no category specific improvements planned.

5.3.6 Indirect nitrous oxide emissions from managed soils (3.C.5)

5.3.6.1 Category description

Indirect emissions of N_2O-N from managed soils 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).

Indirect N_2O from managed soils contributed 723 Gg CO_2e to the total emissions in 2020.

5.3.6.2 Methodological issues

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

The annual amount of N_2O-N produced from atmospheric deposition of N volatilized from managed soils ($N_2O_{(ATD)}$-N) was calculated with IPCC 2006 Equation 11.9.

Indirect N_2O from leaching/runoff

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. IPCC 2019 Refinement (Chapter 11, Vol. 4, Table 11.3) indicates that the term $Frac_{LEACH-(H)}$ only applies to wet climates, while for dry climates $Frac_{LEACH-(H)}$ is taken as zero. South Africa has a dry climate, therefore zero was applied to urine and dung deposits. 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 as leaching was assumed to occur on irrigated lands. WRI (2018) indicated that 10% of cultivated land is irrigated, therefore a $Frac_{LEACH-(H)}$ value of 0.02 kg N (kg N additions)$^{-1}$ was applied to cultivated lands.

Activity data

The calculation of F_{SN}, F_{ON}, and F_{PRP} are described above.

Emission factors

Indirect N_2O from atmospheric deposition of volatilized N

The emission factor (EF_4), and the volatilization fractions ($Frac_{GASF}$ and $Frac_{GASM}$) were all taken from the IPCC 2019 Refinement default table (Table 11.3, Chapter 11, Volume 4).

Indirect N_2O from leaching/runoff

The emission factor (EF_5) was taken from the IPCC 2019 Refinement (Table 11.3, Chapter 11, Volume 4).

5.3.6.3 Uncertainties and time series consistency

Activity data uncertainty

Uncertainty on activity data for F_{SN}, F_{ON}, and F_{PRP} are provided in section 5.3.5.3. $Frac_{GASF}$ has an uncertainty of -82% and +200%, while $Frac_{GASM}$ has an uncertainty of -100% + 48% (IPCC 2019 Refinement, Table 11.3).

Emission factor uncertainty

The uncertainty on EF_4 is -100% and +120%, and for EF_5 it is -100% and +82% (IPCC 2019 Refinement, Table 11.3).

Time-series consistency

The time-series is consistent throughout the inventory time period.

5.3.6.4 Category specific QA/QC and verification

No were no category specific quality control checks.

5.3.6.5 Category-specific recalculations

Recalculations across the entire time-series produced lower emissions, with an average reduction of 68% for volatilisation and 15% for leaching losses. The reduction in emissions is due mostly to the updated emission factors from the IPCC 2019 Refinement, but also due to changes in livestock herd composition and manure management.

5.3.6.6 Category-specific planned improvements

There are no planned improvements for this category.

5.3.7 Indirect nitrous oxide emissions from manure management (3.C.6)

5.3.7.1 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).

5.3.7.2 Methodological issues

A Tier 1 method is used to determine N_2O emissions from deposition of volatilized N. Indirect N_2O losses due to volatilization are calculated using the Tier 1 method as described by equation 10.26 in the IPCC 2019 Refinement. This is followed by equation 10.28. Data on biogas plants and co-digestion is limited, therefore this term was excluded from the calculation and can be updated in future when more data becomes available.

Indirect N_2O losses due to leaching and runoff are calculated using the Tier 1 method as described by equation 10.27 in the IPCC 2019 Refinement, which is followed by equation 10.29. As with the emissions due to volatilisation the amount of N from co-digestates added to biogas plants was excluded from the calculation and can be updated in future when more data becomes available.

Activity data

Both of the indirect N_2O emission equations require data on livestock population, N excretion, and manure management which are described in section 5.2.1.1, section 5.3.5.2 and section 5.2.2, respectively. The fraction of managed manure that volatilises and that is leached are taken from the IPCC 2019 Refinement (volume 4, chapter 11, Table 10.22).

Emission factors

IPCC default emission factors for N_2O from atmospheric deposition of N on soils and water surfaces, and from leaching and runoff are taken from the IPCC 2019 Refinement (volume 4, chapter 11, Table 11.3). The dry climate factors are applied.

5.3.7.3 Uncertainties and time series consistency

Activity data uncertainty

Uncertainty on activity data for livestock population and N excretion are discussed in sections 5.2.4.3. $Frac_{GASMS}$ and $Frac_{LeachMS}$ uncertainties are provided in IPCC 2019 Refinement (volume 4, chapter 10, Table 10.22).

Emission factor uncertainty

The uncertainty on EF_4 is -100% and +120%, and for EF_5 it is -100% and +82% (IPCC 2019 Refinement, Table 11.3).

Time-series consistency

The time-series for this category is consistent.

5.3.7.4 Category specific QA/QC and verification

No specific quality control checks or verification procedures were undertaken for this category.

5.3.7.5 Category-specific recalculations

Recalculations across the entire time-series produced lower emissions, with an average reduction of 48% for volatilisation and 49% for leaching and runoff. The reduction in emissions is due mostly to the updated emission factors from the IPCC 2019 Refinement, but also due to changes in livestock herd composition and manure management.

5.3.7.6 Category-specific planned improvements

No category specific improvements are planned; however, it is recommended that data be collected on manure inputs to biogas plants so the data can be incorporated into the equation in future.

5.4 Land (3.B)

5.4.1 Category description

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 and N_2O emissions from wetlands were included here.

Organic soils were assumed to be negligible (Moeletsi et al., 2015). A more recent study by Schulze and Schutte (2018) was conducted to identify organic soils and it indicated that high-C soils are very small in area and only 885 out of 27 491 terrain units contain either humic or organic soils in terms of the binomial classification system. In addition, a blue carbon study (Raw et al., 2021) indicates that wetlands cover approximately 19 000ha of which most are assumed to contain high organic soils. It is therefore acknowledged that there is a small percentage of area under organic soils. Initially the incorporation of these soils was considered but due to differences in data between the International Soil Reference and Information Centre (ISRIC) soils data (https://www.isric.org/explore/isric-soil-data-hub) utilised in this inventory and difficulties in integrating the various maps the inclusion of organic soils will be deferred to the next inventory due to its priority.

5.4.1.1 National circumstances

South Africa has an area of 123 562 851 ha and has a warm, temperate, and dry climate. Grasslands dominate the land covering approximately 30 % of the land area, followed by low shrublands which cover around 26% (Table 5. 31). Indigenous forests and plantations cover around 2% of the area, while woodlands are 13% of the area. Thickets have declined from around 5% in 1990 to 1.5% in 2018. The largest change between 1990 and 2018 is seen in the cultivated area, with a 256% increase in the irrigated annual crop area. Grasslands show an increase in area (Table 5. 31). Indigenous forests, thickets and low shrublands have decreased in area, while woodlands have increased over the 28-year period.

Table 5. 31: Land cover change between 1990 and 2081 (Source: GTI, 2015; DFFE, 2021).

Land class	1990		2018		% change
	1000 ha	% of total area	1000 ha	% of total area	
Indigenous Forest	465	0.38	434	0.35	-6.62
Thicket / Dense Bush	6 487	5.25	1 822	1.47	-71.91
Natural woodland	10 950	8.86	16 680	13.50	52.33
Planted Forest	1 915	1.55	2 057	1.66	7.39
Shrubland	41 220	33.36	32 246	26.10	-21.77
Grassland	27 678	22.40	36 817	29.80	33.02
Waterbodies	2 196	1.78	2 153	1.74	-2.00
Wetlands	1 521	1.23	1 049	0.85	-31.00
Barren Land	13 510	10.93	12 695	10.27	-6.03
Eroded Land	446	0.36	438	0.35	-1.81
Cultivated Commercial Permanent Orchards	312	0.25	289	0.23	-7.29
Cultivated Commercial Permanent Vines	161	0.13	140	0.11	-12.50
Commercial Annuals Pivot Irrigated	241	0.20	858	0.69	255.69
Commercial Annuals Non-Pivot	11 464	9.28	10 250	8.30	-10.59
Cultivated Subsistence	1 982	1.60	1 969	1.59	-0.68
Built-Up Residential All	2 391	1.94	2 940	2.38	22.93
Built-Up Smallholdings	246	0.20	244	0.20	-0.79
Built-Up Commercial	45	0.04	84	0.07	88.70

Built-Up Industrial	58	0.05	98	0.08	68.55
Mines	277	0.22	300	0.24	8.10
Total	**123 563**		**123 563**		

5.4.1.2 Emissions and removals

The *Land* sector was estimated to be a source of CO_2 between 2005 and 2008, but a sink in all other years (Figure 5.15). In 2020 *Forest land* was the main contributor to the sink, followed by *Grasslands* and *Settlements*. *Croplands, Wetlands* and *Other lands* were sources (Table 5. 32). The main drivers of change are fires and fuelwood removals.

A detailed summary table of emissions and removals for the *Land* sector in 2020 are provided in Appendix C.

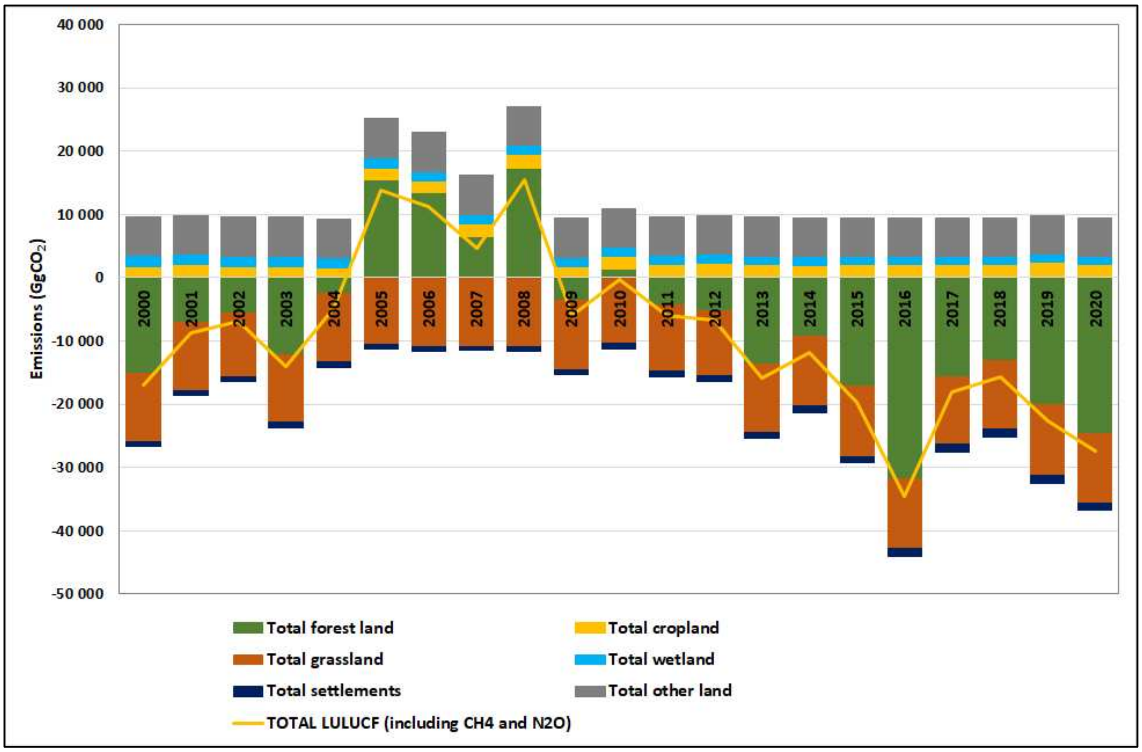

Figure 5.15: Time series for GHG emissions and removals (Gg CO_2) in the Land sector in South Africa, 2000 - 2020.

Table 5. 32: Trends in emissions and removals between 2000 and 2020 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	-15 176.3	1 787.2	-10 698.2	1 727.3	-755.9	6 126.9
2001	-7 054.2	2 047.7	-10 777.2	1 706.4	-748.0	6 126.7
2002	-5 539.4	1 780.1	-10 124.9	1 683.8	-832.9	6 126.7
2003	-12 244.4	1 800.6	-10 570.2	1 650.3	-874.9	6 126.8
2004	-2 412.0	1 526.2	-10 874.2	1 619.0	-926.9	6 126.7
2005	15 429.0	1 950.8	-10 496.7	1 606.1	-784.4	6 126.7
2006	13 425.3	1 776.2	-10 941.2	1 564.2	-616.0	6 126.3
2007	6 467.0	1 994.8	-10 942.3	1 534.6	-582.1	6 126.6
2008	17 291.6	2 177.3	-10 914.1	1 505.8	-797.4	6 126.6
2009	-3 652.5	1 727.9	-10 862.2	1 481.4	-749.7	6 126.3
2010	1 272.4	2 026.6	-10 391.3	1 465.1	-863.4	6 126.3
2011	-4 245.7	2 098.8	-10 480.7	1 441.2	-967.5	6 125.9
2012	-5 238.4	2 270.0	-10 201.9	1 405.6	-989.3	6 125.8
2013	-13 593.9	2 053.5	-10 888.0	1 384.4	-991.3	6 125.8
2014	-9 236.4	1 970.1	-11 085.0	1 356.3	-998.2	6 125.7
2015	-17 128.7	2 062.5	-11 103.9	1 328.5	-1 081.8	6 125.3
2016	-31 806.8	2 033.6	-11 000.5	1 283.6	-1 194.8	6 125.4
2017	-15 643.7	2 104.6	-10 684.6	1 269.9	-1 165.9	6 125.5
2018	-13 082.9	2 088.4	-10 860.5	1 242.2	-1 207.2	6 124.9
2019	-20 054.8	2 487.3	-11 282.4	1 215.1	-1 148.9	6 125.1
2020	-24 575.2	2 167.3	-11 084.5	1 192.6	-1 147.3	6 125.2

5.4.2 Land representation

The land cover maps for South Africa cover the national territory; however, it does not include overseas territories at this point. South Africa possesses two subantarctic islands, namely Marion Island (46° 54′ S, 37° 45′ E; 29 300 ha) and Prince Edward Island (46° 38′ S, 37° 57′ E; 4 500 ha) and together they are known as The Prince Edward Islands (Nel et al., 2001; Smith and Mucina, 2006). These overseas territories are not included in the inventory currently due to their small size and difficulties with accessibility. Marion Island has been occupied permanently by South African research and logistic personnel since February 1948, while there is no occupation of Prince Edward Island. The vegetation on these islands is indicated to be subantarctic tundra, polar desert, and marine microalga vegetation (Smith and Mucina, 2006). With the cold climate it is not expected that these islands will produce any significant emissions relative to the rest of South Africa.

5.4.2.1 Land cover datasets and methodology

South Africa developed land-cover[5] datasets (for 1990 (GTI, 2015), 2013-14 (GTI, 2014), 2018 (DEA, 2019a) and more recently, 2020. The details of the processing and development of each of the maps is provided in the relevant reports (GTI, 2014; 2015; DEA, 2019a; DEA, 2019b) and are summarised here. The original 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. On the other hand, the 2018 dataset was derived from Sentinel 2 data which has a higher spatial resolution compared to Landsat. This has led to improved reclassification of some of the land classes which meant that the land areas for some of the land categories were very different in the 2014 and 2018 datasets. To make the 2018 map more comparable with the 1990 and 2014 map the 2018 map was degraded. This degrading process allows comparisons between the recent maps and older 1990 maps, however this process is hampering better resolution for the future. Ways to overcome this may need to be considered in the future.

The key data processing steps used to generate the 1990/2018 SANLC change assessment outcomes (DEA, 2019b) are:

- Convert all geographic coordinate format SANLC datasets to the new, simplified land-cover change legend format and content.
- Re-project the legend modified geographic coordinate 1990and 2018 SANLC datasets to Albers Equal Area map projection, including a single-step spatial resampling for the SANLC 2018 dataset (using nearest-neighbour class code allocation) to a 30 x 30m cell resolution output.
- Ensure pixel-to-pixel registration between all 30m resolution Albers Equal Area map projection outcomes, using the 2018 SANLC as the reference dataset against which the 1990 datasets are registered. This approach has been taken as the ortho-precision of the source Sentinel 2 imagery from which the SANLC 2018 has been generated and is considered superior to the Landsat imagery used in the compilation of the 1990 datasets.

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

- Ensure pixel-level equivalent extent of land-cover geographic coverage between all SANLC datasets, so that the change assessment results do not include a null class in the year-on-year assessments due to differences in mapped land-cover extents resulting from buffer zone mapping; and
- Generate a national 30m resolution, land-cover class-pair based change-reporting matrix for both 1990 vs 2018 change comparisons.

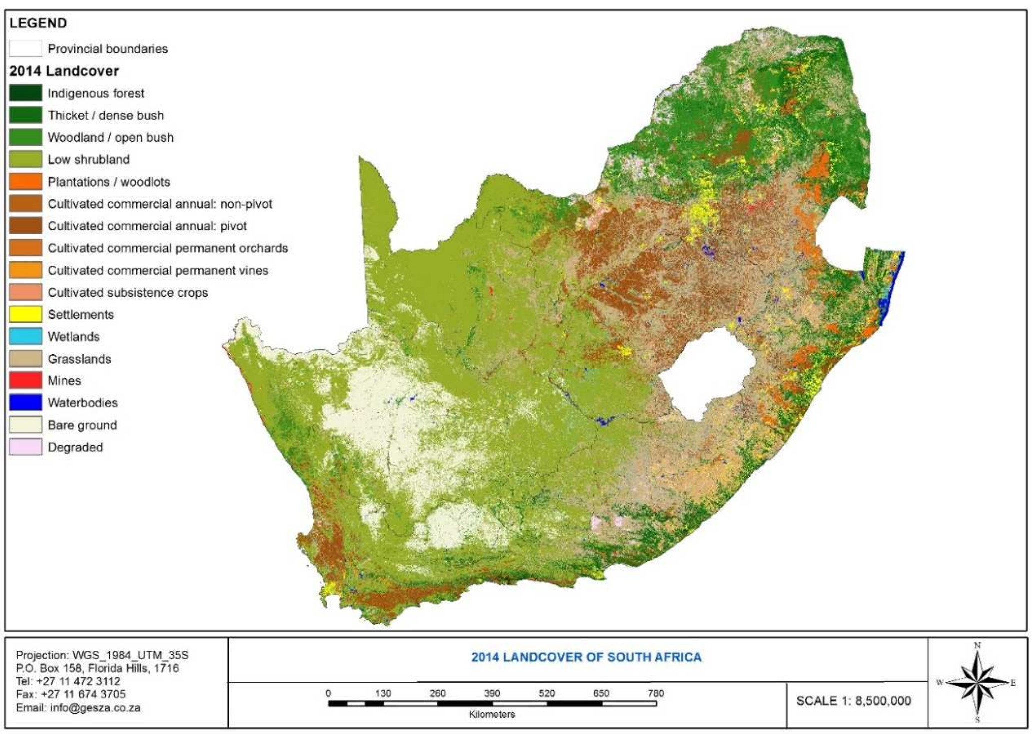

Figure 5.16: Land cover maps for South Africa for 2014 (Source: GTI, 2015).

5.4.2.2 Land category definitions

The 1990-2018 National Land Cover Datasets had 73 land classes (Table 5. 33). For the purpose of this 2020 inventory these were aggregated into 20 classes and the 20 class maps were used to produce the land change matrix. The reason for this is to reduce analysis time as the more categories that are included the more complex and time consuming the land change mapping and calculations become. The processing needs to be completed within the timeframes of the inventory cycle. It is, however, recommended that in future an attempt is made to incorporate the more detailed land use classes, particularly in the forest land category, as this would improve the accuracy of the land data. Information from the detailed classes for settlements and croplands were utilized in the calculations and the methodology is described in further detail in the relevant category methodology sections.

Table 5. 33: Basic definition of classes used in the 2018 SANLC map with further detail provided in DEA (2019a)

Class number	Class name	Class definition
1	Contiguous Forest (*combined* very high, high, medium)	Natural tall woody vegetation communities, with 75% or more canopy cover, and canopy heights exceeding 6 metres. Typically representative of tall, indigenous forests.
2	Contiguous Low Forest & Thicket	Natural tall woody vegetation communities, with 75% or more canopy cover, and canopy heights ranging between 2.5 - 6 metres. Typically representative of low, indigenous forests and dense thicket communities.
3	Dense Forest & Woodland	Natural tall woody vegetation communities, with canopy cover ranging between 35 - 75%, and canopy heights exceeding 2.5 metres. Typically represented by dense bush, dense woodland and thicket communities.
4	Open Woodland	Natural tall woody vegetation communities, with canopy cover ranging between 10 - 35%, and canopy heights exceeding 2.5 metres. Typically represented by open bush and woodland communities.
5	Contiguous & Dense Planted Forest	Dense to contiguous cover, planted tree forests, consisting primarily of exotic timber species, with canopy cover exceeding 35%, and canopy heights exceeding 2.5 metres. Typically represented by mature commercial plantation tree stands. This class also includes smaller woodlots and windbreaks
6	Open & Sparse Planted Forest	Open to sparse cover, planted tree forests, consisting primarily of exotic timber species, with canopy cover ranging between 5 - 35%, and canopy heights exceeding 2.5 metres. Typically represented by young or recently planted commercial plantation tree stands. This class also include smaller woodlots and windbreaks
7	Temporary Unplanted Forest	Temporarily unplanted stands within commercial forest plantations that have recently been harvested, and/or re-planted but the tree saplings are undetectable on the imagery.
8	Low Shrubland (other regions)	Natural, low woody shrubland communities, where the total plant canopy cover is typically both dominant over any adjacent bare ground exposure, and the canopy height ranges between 0.2 – 2 metres. Typically representative of low, indigenous karoo-type vegetation communities, which have been identified using image-based spectral models, but which fall spatially *outside* the SANBI defined boundaries for Fynbos, Succulent and Nama-Karoo vegetation communities.
9	Low Shrubland (Fynbos)	This is the same as class 8, Low Shrubland, but now represents low, indigenous karoo-type vegetation communities, which have been identified using image-based spectral models, but which fall spatially *inside* the SANBI defined boundaries for Fynbos vegetation communities.
10	Low Shrubland (Succulent Karoo)	This is the same as class 8, Low Shrubland, but now represents low, indigenous karoo-type vegetation communities, which have been identified using image-based spectral models, but which fall spatially *inside* the SANBI defined boundaries for Succulent Karoo vegetation communities.
11	Low Shrubland (Nama Karoo)	This is the same as class 8, Low Shrubland, but now represents low, indigenous karoo-type vegetation communities, which have been identified using image-based spectral models, but which fall spatially *inside* the SANBI defined boundaries for Nama Karoo vegetation communities.
12	Sparsely Wooded Grassland	Natural woody vegetation, with a woody canopy cover ranging between only 5 - 10%, and canopy heights exceeding 2.5 metres, in a grass-dominated environment. Typically represented by very sparse woodland or lightly wooded grassland communities.

13	Natural Grassland	Natural and/or semi-natural indigenous grasslands, typically devoid of any significant tree or bush cover, and where the grassland component is typically dominant over any adjacent bare ground exposure.
14	Natural Rivers	Naturally occurring waterbodies associated with perennial and non-perennial rivers and associated tributaries.
15	Natural Estuaries & Lagoons	Naturally occurring coastal region water bodies that are located at river mouths or are replenished by coastal tidal flows.
16	Natural Ocean	Naturally occurring saltwater coastal and ocean waterbodies.
17	Natural Lakes	Naturally occurring, large inland waterbodies containing freshwater.
18	Natural Pans (flooded)	Naturally occurring inland waterbodies within pans, where the water extent is both spatially and temporally sufficient to be image-detectable.
19	Artificial Dams	Man-constructed artificial inland waterbodies, ranging from small farm dams to large reservoirs, and if image-detectable, large irrigation canals.
20	Artificial Sewage Ponds	Man-constructed artificial inland waterbodies, specifically associated with water and effluent treatment activities.
21	Artificial Flooded Mine Pits	Man-generated artificial inland waterbodies, specifically associated with flooded mine pits, tailings ponds, or other surface-based mining activities.
22	Herbaceous Wetlands (currently mapped)	Natural or semi-natural wetlands covered in permanent or seasonal herbaceous vegetation. The class represents primarily riparian wetland areas, but can also include emergent aquatic vegetation in pans.
23	Herbaceous Wetlands (previous mapped extent)	Natural or semi-natural wetlands covered in permanent or seasonal herbaceous vegetation. The class represents primarily riparian wetland areas, but can also include emergent aquatic vegetation in pans.
24	Mangrove Wetlands	Naturally occurring mangrove community wetlands.
25	Natural Rock Surfaces	Naturally occurring areas of non-vegetated, exposed rock and consolidated substrate.
26	Dry Pans	Naturally occurring areas of non-vegetated, consolidated substrate, associated with permanent or long-term dry pans.
27	Eroded Lands	Permanent or semi-permanent, non-vegetated erosion surfaces, typically represented by gullies, dongas, and/or sheet erosion areas.
28	Sand Dunes (terrestrial)	*Non-vegetated*, naturally occurring inland (non-coastal) sand dunes, which are typically associated with arid, desert-like environments.
29	Coastal Dunes & Beach Sand	Non-vegetated, naturally occurring coastal sands, typically associated with both coastal dunes and beach environments.
30	Bare Riverbed Material	Natural or semi-natural, non-vegetated, consolidated or unnaturally occurring coastal sands, typically associated with both coastal dunes and beach environments.
31	Other Bare	Other natural, semi-natural or man-created non-vegetated areas.
32	Cultivated Commercial Permanent Orchards	Active or recently active cultivated lands used for the production of agricultural crops, in this case specifically associated with commercial orchards consisting of tree and/or bush based plants.
33	Cultivated Commercial Permanent Vines	Active or recently active cultivated lands used for the production of agricultural crops, in this case specifically associated with commercial viticulture.
34	Cultivated Commercial Sugarcane Pivot Irrigated	Active or recently active cultivated lands used for the production of agricultural crops, in this case specifically associated with commercial sugarcane. Grown in pivot irrigated fields.
35	Commercial Permanent (Pineapples)	Active or recently active cultivated lands used for the production of agricultural crops, in this case specifically associated with pineapples.
36	Cultivated Commercial Sugarcane Non-Pivot (all other)	Active or recently active cultivated lands used for the production of agricultural crops, in this case specifically associated with commercial sugarcane. Grown in rainfed or non-pivot irrigation fields.
37	Cultivated Emerging Farmer Sugarcane Non-Pivot (all other)	Active or recently active cultivated lands used for the production of agricultural crops, in this case specifically associated with small-scale / emerging farmer sugarcane.
38	Cultivated Commercial Annuals Pivot Irrigated	Active or recently active cultivated lands used for the production of agricultural crops, in this case specifically associated with commercial annual crops. Pivot irrigation.

39	Cultivated Commercial Annuals Non-Pivot Irrigated	Active or recently active cultivated lands used for the production of agricultural crops, in this case specifically associated with commercial annual crops. Non-pivot irrigation.
40	Cultivated Commercial Annuals Non-Pivot / Non-Irrigated	Active or recently active cultivated lands used for the production of agricultural crops, in this case specifically associated with commercial annual crops.
41	Subsistence Annual Crops	Active or recently active cultivated lands used for the production of agricultural crops, in this case specifically associated with small-scale commercial or subsistence-level annual crops.
42	Fallow Land & Old Fields (Trees)	Long-term, non-active, previously cultivated lands that are *now* overgrown with tree-dominated woody vegetation. Typically the cultivated land unit boundary is no longer image detectable.
43	Fallow Land & Old Fields (Bush)	Long-term, non-active, previously cultivated lands that are *now* overgrown with bush dominated woody vegetation.
44	Fallow Land & Old Fields (Grass)	Long-term, non-active, previously cultivated lands that are now overgrown with grass dominated woody vegetation.
45	Fallow Land & Old Fields (Bare)	Long-term, non-active, previously cultivated lands that are now predominately non-vegetated bare ground surfaces.
46	Fallow Land & Old Fields (Low Shrub)	Long-term, non-active, previously cultivated lands that are now overgrown with tree-dominated low shrub vegetation.
47	Residential Formal (Tree)	Built-up areas primarily containing formally planned and constructed residential structures and associated utilities. The dominant vegetation (in gardens etc) is tree-based.
48	Residential Formal (Bush)	Built-up areas primarily containing formally planned and constructed residential structures and associated utilities. The dominant vegetation (in gardens etc) is bush-based.
49	Residential Formal (low veg / grass)	Built-up areas primarily containing formally planned and constructed residential structures and associated utilities. The dominant vegetation (in gardens etc) is grass and/or low shrub based.
50	Residential Formal (Bare)	Built-up areas primarily containing formally planned and constructed residential structures and associated utilities. The surface is predominantly non-vegetated.
51	Residential Informal (Tree)	Built-up areas primarily containing informal, often unplanned residential structures and associated utilities. The dominant vegetation (in surrounding areas etc) is tree-based.
52	Residential Informal (Bush)	Built-up areas primarily containing informal, often unplanned residential structures and associated utilities. The dominant vegetation (in surrounding areas etc) is bush-based.
53	Residential Informal (low veg / grass)	Built-up areas primarily containing informal, often unplanned residential structures and associated utilities. The dominant vegetation (in surrounding areas etc) is grass and/or low shrub-based.
54	Residential Informal (Bare)	Built-up areas primarily containing informal, often unplanned residential structures and associated utilities. The surface is predominantly non-vegetated.
55	Village Scattered	Built-up areas primarily associated with scattered rural settlements and associated utilities. *Scattered villages* are defined as those represented by contiguous / adjacent village-classified cells which collectively *do not form the majority cover* in a surrounding 1 ha window.
56	Village Dense	Built-up areas primarily associated with scattered rural settlements and associated utilities. *Dense villages* are defined as those represented by contiguous / adjacent village-classified cells which collectively *do form the majority cover* in a surrounding 1 ha window.
57	Smallholdings (Tree)	Agricultural holdings typically located in peri-urban environments, where the dominant vegetation is tree-based.
58	Smallholdings (Bush)	Agricultural holdings typically located in peri-urban environments, where the dominant vegetation is bush-based.
59	Smallholdings (low veg / grass)	Agricultural holdings typically located in peri-urban environments, where the dominant vegetation is low shrub or grass based.
60	Smallholdings (Bare)	Agricultural holdings typically located in peri-urban environments, where the dominant cover is non-vegetation is bush-based.
61	Urban Recreational Fields (Tree)	Non-built-up, vegetated urban areas primarily associated with formally planned and established parks, sports fields, and golf courses.

62	Urban Recreational Fields (Bush)	Non-built-up, vegetated urban areas primarily associated with formally planned and established parks, sports fields, and golf courses.
63	Urban Recreational Fields (Grass)	Non-built-up, vegetated urban areas primarily associated with formally planned and established parks, sports fields, and golf courses.
64	Urban Recreational Fields (Bare)	Non-built-up, open urban areas primarily associated with formally planned and established parks, sports fields, and golf courses.
65	Commercial	Built-up areas primarily containing formally planned and constructed commercial structures and associated utilities. Includes shops, offices, schools, hospitals, and administration structures.
66	Industrial	Built-up areas primarily containing formally planned and constructed industrial structures and associated utilities. Includes both light and heavy industry, power generation, airports, rail terminals and ports.
67	Roads & Rail (Major Linear)	Built-up features represented by primary road and rail networks that are image-detectable (i.e. networks are non-contiguous), as well as smaller airfields and airstrips.
68	Mines: Surface Infrastructure	Built-up structures associated with the administration and/or industrial processing and extraction of mined resources.
69	Mines: Extraction Sites: Open Cast & Quarries *combined*	Non-vegetated, active and/or non-active extraction pits associated with surface-based mining activities, including open-cast mines, quarries, and road-side borrow pits etc.
70	Mines: Extraction Sites: Salt Mines	Non-vegetated, active or non-active extraction pits associated with evaporative salt-mining activities, typically associated with coastal or inland saline pan localities.
71	Mines: Waste (Tailings) & Resource Dumps	Non-vegetated, active or non-active mine generated material dumps or stockpiles, associated with both mine waste material (i.e. tailings dams) or mine generated resource stockpiles (i.e. coal stockpiles).
72	Land-fills	Primarily non-vegetated, active or non-active land-fill sites used for the large scale disposal of urban waste.
73	Fallow Land & Old Fields (wetlands)	Long-term, non-active, previously cultivated lands that are currently classified as wetland vegetation.

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" includes 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 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 remain applicable even to degraded woodlands.
  - Taking guidance from the Marrakesh Accord (2011) and adjusting the specific thresholds to be consistent with the NFA, the forest definition is given as "a minimum area of land of 0.05 hectares with tree crown cover of more than 10 per cent with trees with the potential to reach a minimum height of 2.5 metres at maturity in situ. A forest may consist either of closed forest formations where trees of various storeys and undergrowth cover a high portion of the ground open forest. Young natural stands and all plantations which have yet to reach a crown density of 10 per cent or tree height of 2.5 metres are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention such as harvesting or natural causes, but which are expected to revert to forest."
- *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.
- *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, smallholdings, commercial, residential and industrial areas.
  - 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 (2019a).
  - In the CALC 20 class maps (which are used in this inventory) Mangroves are classified under wetlands, which is different from the earlier 1990 and 2014 SANLC change maps where they were included in thickets (Forest lands). Mangroves fall within the definition of forests and so should be moved to the Forest land category. This correction should be included in the next inventory.
- *Other lands*:
  - Includes bare ground and rocks.

Table 5. 34: Relationship between SANLC, land change and IPCC categories in the 2020 inventory.

SANLC 1990 and 2013/14 Class		Category in 20 class change map		IPCC category	SANLC 2018 Class	
No.	Class	No.	Category	Category	No.	Class
4	Indigenous forest	1	Indigenous forest	Forest land	1	Contiguous forest
5	Thicket/ dense bush	2	Thicket/dense bush	Forest land	2	Contiguous low forest & thicket
6	Woodland/open bush	3	Natural woodland	Forest land	3 4 42 43	Dense forest and woodland Open woodland Fallow lands (trees) Fallow lands (bushes)
32 33 34	Plantations and woodlots	4	Planted forest	Forest land	5 6 7	Contiguous and dense plantation forest Open and sparse plantation forest Temporary unplanted plantation
8 9	Shrublands fynbos Low shrubland	5	Shrubland	Grassland	8 9 10 11 46	Low shrubland (other, fynbos, succulent karoo, nama karoo) Fallow lands and old fields (low shrub)
7	Grassland	6	Grassland	Grassland	12 13 44	Sparsely wooded grassland Natural grassland Fallow land (grass)
1 2 37	Water seasonal/permanent	7	Waterbodies	Wetland	14 15 16	Rivers Estuaries and lagoons

38	Mine water seasonal/permanent				17 18 19 20 21	Ocean and coastal Lakes Pans Artificial dams Artificial sewage ponds Artificial flooded mine pits
3	Wetlands	8	Wetlands	Wetlands	22 23 24 73	Herbaceous wetlands Mangrove wetlands Fallow land (wetlands)
41	Bare non vegetated	9	Barren land	Other land	25 26 28 29 30 31 45	Rock surfaces Dry pans Sand dunes Coastal sand dunes Bare riverbed Other bare Fallow land bare
40	Erosion (donga)	10	Eroded land	Grassland	27	Eroded land
16 17 18 22	Cultivated orchards Cultivated pineapples	11	Permanent orchards	Cropland	32 35	Permanent orchards Permanent pineapples
19 20 21	Cultivated vines	12	Permanent vines	Cropland	33	Permanent vines
13 14 15 26 27	Commercial pivot crops Cane pivots Cane pivot - fallow	13	Annual pivot irrigated	Cropland	34 38	Sugarcane pivot irrigated Annual crops pivot irrigated
10 11 12 28 29 30 31	Commercial non-pivot crops Cane crop Cane fallow Cane emerging crop Cane emerging fallow	14	Annual non-pivot crops	Cropland	36 37 39 40	Sugarcane non-pivot Sugarcane emerging non-pivot Non-pivot irrigated Rainfed dryland
23 24 25	Cultivated subsistence	15	Cultivated subsistence	Cropland	41	Subsistence annual crops
44-52, 57-72	Various types of urban classes (informal, residential, sport, township, village, built-up)	16	Built-up residential	Settlements	47–56, 61-64	Various types of residential (formal, informal, village, recreational, urban)
53 54 55 56	Various urban small holdings	17	Built-up smallholdings	Settlements	57 58 59 60	Various smallholdings

42						
42	Urban commercial	18	Built-up commercial	Settlements	65	Commercial
43	Urban industrial	19	Built-up industrial	Settlements	66	Industrial
35 36 39	Mine bare Mine semi-bare Mine buildings	20	Mines	Settlements	68 69 70 71 72	Mines Land-fills

5.4.2.3 Land use change

Land-use changes were mapped using an Approach 2 method as described in 2006 IPCC Guidelines. The 1990 and 2014 maps were produced using Landsat and 2018 using Sentinel data.

A 2018 South African National Land Cover Change Assessments report (GTI, 2020) was completed as part of the 2018 land cover mapping project to verify the natural land class (indigenous forest, thicket, woodlands, grasslands, low shrublands) changes between 1990/2014/2018. This assessment showed that most of the land changes between the natural land classes were not real changes but rather due to an improved classification resulting from the higher resolution of the 2018 map. It 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 (Table 5. 35). As similar assumptions would be made for the 2014 map, it was decided to use the 1990 to 2018 change map instead to reduce the number of assumptions, and after 2018 the more frequent maps (2020, 2022, etc) could be utilized. The 2020 map was not officially released at the time the inventory preparations began and therefore has not been included in this inventory. Extrapolations were made from 2018 to 2020 assuming the same rate of change between 1990 and 2018, but in the next inventory the 2020 map will be incorporated, and the data updated. In terms of the assumptions, the conversion areas where no conversion is considered to occur (i.e., where change was not real change but rather due to improved classification) were reverted to the 2018 land remaining land class.

Plantation areas from the land cover maps were compared to Forestry South Africa (FSA) data (FSA, 2018) and it was found that the LC maps had much larger plantation areas. Corrections were not included in the land change matrix, but rather in the calculation file. The *Plantation remaining plantation* area was adjusted to reflect the area provided by Forestry SA (FSA, 2018) and the excess area was allocated to thickets and dense bush, based on the information from the Department of Forestry.

Table 5. 35: Assumptions and corrections included in the 1990-2018 land change maps.

Conversion category	Assumption	Basis for assumption
Indigenous forest to Thicket/Dense bush	Assumption is that only 10% of the conversion of indigenous forest to thicket occurs and that the 2018 map is more accurate therefore 90% of the converted area is allocated back to the 2018 classification (Thicket/Dense bush).	The 2018 LC Assessment report (DEFF, 2019b) compared the new 2018 Sentinel LC maps with the older 1990/2014 Landsat LC maps and the assessment showed that these conversions were due to a change in interpretation and not due to real change.
Indigenous forest to Natural woodland	Assumption is that only 10% of the conversion of indigenous forest to natural woodland occurs and that the 2018 map is more accurate therefore 90% of the converted area is allocated back to the 2018 classification (Natural woodland).	The 2018 LC Assessment report (DEFF, 2019b) compared the new 2018 Sentinel LC maps with the older 1990/2014 Landsat LC maps and the assessment showed that these conversions were due to a change in interpretation and not due to real change.
Thicket/Dense bush to Natural woodland	Assumption is that only 25% of the original conversion area is due to real change and that the 2018 map is more accurate therefore 75% of the converted area is allocated back to the 2018 classification (Natural woodland).	The 2018 LC Assessment report (DEFF, 2019b) compared the new 2018 Sentinel LC maps with the older 1990/2014 Landsat LC maps. This assessment indicates this area is very large and the whole area could not be assessed but it was indicated that "it is difficult to locate areas of real change in a class that is so extensive and in which interpretation changes probably overwhelmingly dominate any possible real changes." For this reason, "overwhelmingly" was assumed to be 75%, however this assumption will need to be investigated in more detail in future.
Thicket/Dense bush to Shrubland	Assumption is that only 20% of the original conversion area is actually due to real change and that the 2018 map is more accurate therefore 80% of the converted area is allocated back to the 2018 classification (Shrubland).	The 2018 LC Assessment report (DEFF, 2019b) compared the new 2018 Sentinel LC maps with the older 1990/2014 Landsat LC maps. This assessment provides 6 examples of areas that were assessed and in one of these areas the change was assessed to be real whereas in the other examples the change was rather due to a change in interpretation as opposed to a real change. An assumption was therefore made that only 20% of the change may be due to real change while the rest was reallocated back to shrubland (to remain consistent with the assumption that the 2018 classification was better). There was, however, a lot of discussion as to whether "Shrubland" was the better classification an in many cases it was thought that Thicket was the better classification, so the assumption of reallocating the change back to "Shrubland" rather than "Thicket" should be revisited in future.

Thicket/Dense bush to Grassland	Assumption is that only 5% of the original conversion area is due to real change and that the 2018 map is more accurate therefore 95% of the converted area is allocated back to the 2018 classification (Grassland).	The 2018 LC Assessment report (DEFF, 2019b) compared the new 2018 Sentinel LC maps with the older 1990/2014 Landsat LC maps. This assessment provides 6 examples of areas that were assessed and in most cases, it was indicated the area was not due to real change but a change in interpretation. There was a small patch to the south of Polokwane where there may be a gradual loss of woody vegetation, therefore the assumption of 5% change was retained.
Natural woodland to Shrubland	Assumption is that only 10% of the original conversion of natural woodland to shrubland occurs and that the 2018 map is more accurate therefore 90% of the converted area is allocated back to the 2018 classification (Shrubland).	The 2018 LC Assessment report (DEFF, 2019b) compared the new 2018 Sentinel LC maps with the older 1990/2014 Landsat LC maps and the assessment showed that these conversions were due to a change in interpretation and not due to real change.
Natural woodland to Grassland	Assumption is that only 10% of the original conversion area is actually due to real change and that the 2018 map is more accurate therefore 90% of the converted area is allocated back to the 2018 classification (Grassland).	The 2018 LC Assessment report (DEFF, 2019b) compared the new 2018 Sentinel LC maps with the older 1990/2014 Landsat LC maps. This assessment indicates that most of the change is due to an improved interpretation/classification but there is mention that there is a possibility of some area around rural settlements where wood harvesting could be occurring, so it was assumed that 10% of the original change may be due to actual change.
Shrubland to Natural woodland	Assumption is that 5% of the conversion occurs while 95% is due to reclassification. It is assumed that the 2018 map is more accurate therefore the converted area is allocated back to the 2018 classification (Natural woodland).	The 2018 LC Assessment report (DEFF, 2019b) compared the new 2018 Sentinel LC maps with the older 1990/2014 Landsat LC maps and the assessment showed that these conversions were due to a change in interpretation and not due to real change.
Grassland to Natural woodland	Assumption is that 10% of the conversion of Shrubland to Natural woodland occurs and that the 2018 map is more accurate therefore 90% of the converted area is allocated back to the 2018 classification (Natural woodland).	The 2018 LC Assessment report (DEFF, 2019b) compared the new 2018 Sentinel LC maps with the older 1990/2014 Landsat LC maps and the assessment showed that these conversions were due to a change in interpretation and not due to real change.
Grassland to Shrubland	Assumption is that 5% of the conversion of Grassland to Shrubland occurs and that the 2018 map is more accurate therefore 95% of the converted area is allocated back to the 2018 classification (Shrubland).	The 2018 LC Assessment report (DEFF, 2019b) compared the new 2018 Sentinel LC maps with the older 1990/2014 Landsat LC maps and the assessment showed that these conversions were due to a change in interpretation and not due to real change.

Shrubland to grassland	Assumption is that 70% of the conversion of Shrubland to grassland occurs and that the 2018 map is more accurate therefore 20% of the converted area is allocated back to the 2018 classification (Grassland).	The 2018 LC Assessment report (DEFF, 2019b) compared the new 2018 Sentinel LC maps with the older 1990/2014 Landsat LC maps and the assessment showed that most of these conversions are actual conversions, however some of the conversions are suggested to possibly be due to fire. Losses due to fire are incorporated in the biomass losses so there could be some double counting so 30% of the conversion are assumed not to occur to account for this. This assumption will be improved in the next inventory with further investigation an overlay with burnt area maps.
Settlements to mines	These changes are "highly unlikely" so reverted back to the 2018 class as 2018 assumed to be more accurate.	GTI presentation on the 2020 SANLC map (2021).
Indigenous forest and thicket to plantation	These changes are assumed highly unlikely so reverted to back to the 2018 land cover (plantations).	Based on discussions with forestry industry.
Natural woodland to thicket	Assumption is that 50% of the conversion of Natural woodland to thicket occurs and that the 2018 map is more accurate therefore the other 50% of the converted area is allocated back to the 2018 classification (Thicket/dense bush).	GTI presentation on the 2020 SANLC map (2022) indicates that Natural woodland to thicket (code 43) and visa versa (code 62) are prone to seasonal changes. The 2018 LC Assessment report (DEFF, 2019b) compared the new 2018 Sentinel LC maps with the older 1990/2014 Landsat LC maps and indicated that the majority of the change was due to reclassification and not actual change. Therefore, is assumed that there is also classification issues with Natural woodland to thicket. To be more conservative only 50% of the change was assumed to be due to classification or seasonal changes and not real change.

In the previous inventory corrections were made to the wetland and degraded areas to try to account for the wet and dry years, however, to reduce the number of corrections and assumptions these corrections were not implemented in this inventory. These areas are relatively small, so these changes do not have a large impact on the emission outputs. The original land change matrix and the corrected land change matrix are shown in Table 5. 36 and Table 5. 37.

There is an urgent need to conduct further validation of the change data as this is the largest limitation to the LULUCF inventory. The previous review highlighted that validation data, perhaps using Collect Earth, was required however a new land mapping platform is being investigated. The land mapping platform should ideally be able to integrate various datasets and create a consistent time series across the entire time period and provide more accurate data on actual change. More frequent datasets would also provide further accuracy and DFFE Geographical Information Systems (GIS) Department has setup a system (Computer Automated Land Cover (CALC)) for generating the 20-class land cover maps every 2 years from Sentinel 2 data. A full detailed land cover map is expected to be produced every 4 years. As more maps are produced the natural variability will be distinguished from the permanent change. This system can be used in future to provide more quantitative data for excluding non-permanent changes.

5.4.2.4 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;
$LC_{i\ t-1}$ = area (ha) of land in land converted to land category *i* in year t-1;
$ALC_{i\ t}$ = annual total area (ha) converted to land category *i* in year t;
$ALC_{i\ (t-20)}$ = annual total area (ha) converted to land category *i* in year t-20;
$LRL_{i\ t}$ = area (ha) of land in the land remaining in the land category *i* in year t;
$LRL_{i\ t-1}$ = area (ha) of land in the land remaining in the land category *i* in year t-1;

$ACF_{i\,t}$ = annual total area (ha) converted from land category *i* to another land category in year t.

It was assumed that the annual change between 1990 and 2018 continued to 2020. This assumption will be corrected in the next inventory when the 2020 CALC map is incorporated into the inventory.

Table 5. 36: Annual land conversion areas (ha) for South Africa between 1990 and 2018.

Land categories		1990																			
		Indigenous Forest	Thicket / Dense Bush	Natural woodland	Planted Forest	Shrubland	Grassland	Waterbodies	Wetlands	Barren Land	Eroded Land	Cultivated Commercial Permanent Orchards	Cultivated Commercial Permanent Vines	Commercial Annuals Pivot Irrigated	Commercial Annuals Non-Pivot	Cultivated Subsistence	Built-Up Residential All	Built-Up Smallholdings	Built-Up Commercial	Built-Up Industrial	Mines
2018	Indigenous Forest		70	453	1 541	328	986	22	336	35	0	4	0	0	43	10	159	8	2	1	1
	Thicket / Dense Bush	2 811		4 105	2 255	2 848	12 875	165	1 204	237	2	160	17	12	591	305	683	34	17	20	5
	Natural woodland	1 278	115 595		2 523	55 107	158 586	782	6 350	1 429	811	897	147	395	13 015	6 055	2 367	230	126	107	545
	Planted Forest	99	1 606	1 756		756	14 054	57	846	23	4	80	11	7	1 436	57	194	50	2	4	95
	Shrubland	36	12 523	32 424	1 045		55 720	1 576	3 298	157 744	4 758	378	430	111	8 324	69	113	15	8	18	997
	Grassland	611	49 402	98 683	5 078	416 156		1 326	17 120	7 043	3 460	352	72	397	34 331	4 756	2 089	154	207	284	2 884
	Waterbodies	9	763	642	80	716	1 780		1 115	1 315	25	8	5	3	188	46	37	13	1	3	156
	Wetlands	28	2 309	1 165	619	1 109	9 728	674		157	60	26	12	13	1 107	72	161	35	5	10	78
	Barren Land	21	3 798	10 592	174	99 565	19 622	3 477	1 039		357	40	31	17	867	226	113	9	8	17	163
	Eroded Land	2	210	589	6	4 188	3 954	11	159	181		2	0	2	39	105	28	0	0	0	27
	Cultivated Commercial Permanent Orchards	8	609	271	206	399	249	9	71	11	0		368	147	1 104	53	19	29	0	1	0
	Cultivated Commercial Permanent Vines	0	91	36	11	375	45	4	58	124	0	40		26	175	0	4	17	0	1	0

	Commercial Annuals Pivot Irrigated	1	352	1 295	26	2 696	2 860	6	242	68	11	167	28		16 161	63	3	19	0	0	5
	Commercial Annuals Non-Pivot	38	2 372	2 181	654	8 279	17 902	110	1 359	100	17	1 890	547	756		898	127	486	1	5	37
	Cultivated Subsistence	89	1 410	2 380	139	2 290	4 233	31	548	6	146	168	0	23	727		831	80	0	0	11
	Built-Up Residential All	50	3 151	4 031	1 171	3 738	12 532	33	347	273	111	70	38	20	1 141	787		622	140	35	48
	Built-Up Smallholdings	0	65	341	339	113	466	3	12	1	5	2	3	0	352	6	113		2	5	2
	Built-Up Commercial	1	99	62	29	134	242	3	12	11	0	2	3	1	35	3	1 221	49		50	5
	Built-Up Industrial	1	143	120	30	372	421	34	20	119	2	78	8	27	223	3	358	40	20		52
	Mines	18	373	569	150	892	1 731	154	68	362	24	1	1	20	1 245	76	131	10	9	80	

Table 5. 37: Annual land conversion areas (ha) for South Africa between 1990 and 2018 after corrections.

Land categories		1990																			
		Indigenous Forest	Thicket / Dense Bush	Natural woodland	Planted Forest	Shrubland	Grassland	Waterbodies	Wetlands	Barren Land	Eroded Land	Cultivated Commercial Permanent Orchards	Cultivated Commercial Permanent Vines	Commercial Annuals Pivot Irrigated	Commercial Annuals Non-Pivot	Cultivated Subsistence	Built-Up Residential All	Built-Up Smallholdings	Built-Up Commercial	Built-Up Industrial	Mines
2018	Indigenous Forest		70	453	1 541	328	986	22	336	35	0	4	0	0	43	10	159	8	2	1	1
	Thicket / Dense Bush	281		2 052	2 255	2 848	12 875	165	1 204	237	2	160	17	12	591	305	683	34	17	20	5
	Natural woodland	128	28 899		2 523	2 755	15 859	782	6 350	1 429	811	897	147	395	13 015	6 055	2 367	230	126	107	545
	Planted Forest	0	0	1 756		756	14 054	57	846	23	4	80	11	7	1 436	57	194	50	2	4	95

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Shrubland	4	2 505	3 242	1 045		2 786	1 576	3 298	157 744	4 758	378	430	111	8 324	69	113	15	8	18	997
Grassland	61	2 470	9 868	5 078	291 309		1 326	17 120	7 043	3 460	352	72	397	34 331	4 756	2 089	154	207	284	2 884
Waterbodies	9	763	642	80	716	1 780		1 115	1 315	25	8	5	3	188	46	37	13	1	3	156
Wetlands	28	2 309	1 165	619	1 109	9 728	674		157	60	26	12	13	1 107	72	161	35	5	10	78
Barren Land	21	3 798	10 592	174	99 565	19 622	3 477	1 039		357	40	31	17	867	226	113	9	8	17	163
Eroded Land	2	210	589	6	4 188	3 954	11	159	181		2	0	2	39	105	28	0	0	0	27
Cultivated Commercial Permanent Orchards	8	609	271	206	399	249	9	71	11	0		368	147	1 104	53	19	29	0	1	0
Cultivated Commercial Permanent Vines	0	91	36	11	375	45	4	58	124	0	40		26	175	0	4	17	0	1	0
Commercial Annuals Pivot Irrigated	1	352	1 295	26	2 696	2 860	6	242	68	11	167	28		16 161	63	3	19	0	0	5
Commercial Annuals Non-Pivot	38	2 372	2 181	654	8 279	17 902	110	1 359	100	17	1 890	547	756		898	127	486	1	5	37
Cultivated Subsistence	89	1 410	2 380	139	2 290	4 233	31	548	6	146	168	0	23	727		831	80	0	0	11
Built-Up Residential All	50	3 151	4 031	1 171	3 738	12 532	33	347	273	111	70	38	20	1 141	787		622	140	35	48
Built-Up Smallholdings	0	65	341	339	113	466	3	12	1	5	2	3	0	352	6	113		2	5	2
Built-Up Commercial	1	99	62	29	134	242	3	12	11	0	2	3	1	35	3	1 221	49		50	5
Built-Up Industrial	1	143	120	30	372	421	34	20	119	2	78	8	27	223	3	358	40	20		52
Mines	18	373	569	150	892	1 731	154	68	362	24	1	1	20	1 245	76	0	0	0	0	

5.4.2.5 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. Although 4 climate types (Figure 5.17) are present in South Africa, the dominant climate is the warm, temperate dry climate. Incorporating all 4 climate types into the inventory adds a significant amount of additional calculations and therefore resources and time. Furthermore, this complexity does not lend itself to manual spreadsheet calculations and other options are being explored. The size of the emission impact of including the other three small climate zones was thought to be small relative to the amount of resources needed to incorporate all climates. Based on this it was decided that there were other more important aspects of the LULUCF inventory that needed attention before this. Therefore, for the purpose of this inventory the dominant climate type (warm, temperate, dry) was assumed for the whole area. This will be improved in the future inventories as the other issues are resolved or an improved data analysis system is brought on board.

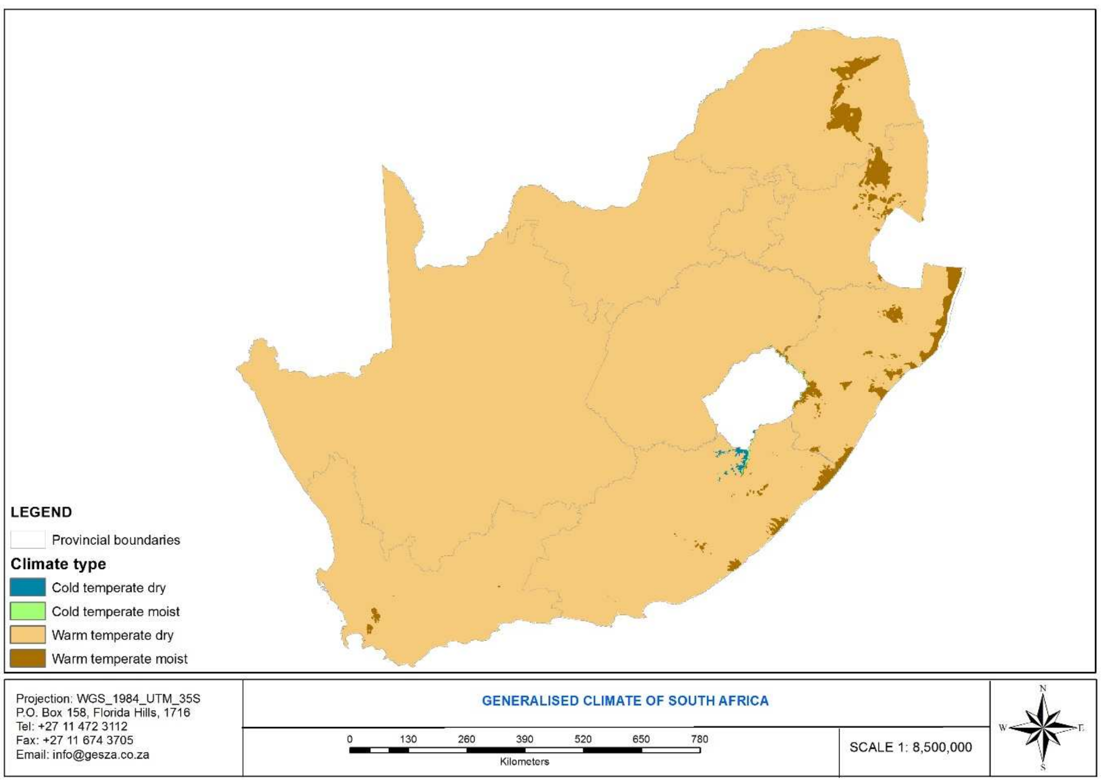

Figure 5.17: South Africa's long term climate map classified into the IPCC climate classes (Source: Moeletsi et al., 2015).

5.4.2.6 Soil

South Africa's detailed soils map was reclassified into the 7 soil classes provided by IPCC 2006 Guidelines (Moeletsi et al., 2015) (Figure 5.18). The map was derived from the 1:250 000-scale Land-type Survey of South Africa. This survey mapped over 7 000 unique land types, each of which has a specific combination of soil, terrain form and macroclimate. Within each land-type mapping unit, a number of different soil forms, as well as other land classes, such as rock, stream beds and pans, are recorded, and their percentage within the land type is used to allocate the land type to a specific broad soil pattern. Table 5. 38 indicates the soil categories and what criteria was used for their classification. Volcanic mineral soils are not found in South Africa, so this category was excluded. Organic soils were found to be insignificant, so these were also excluded.

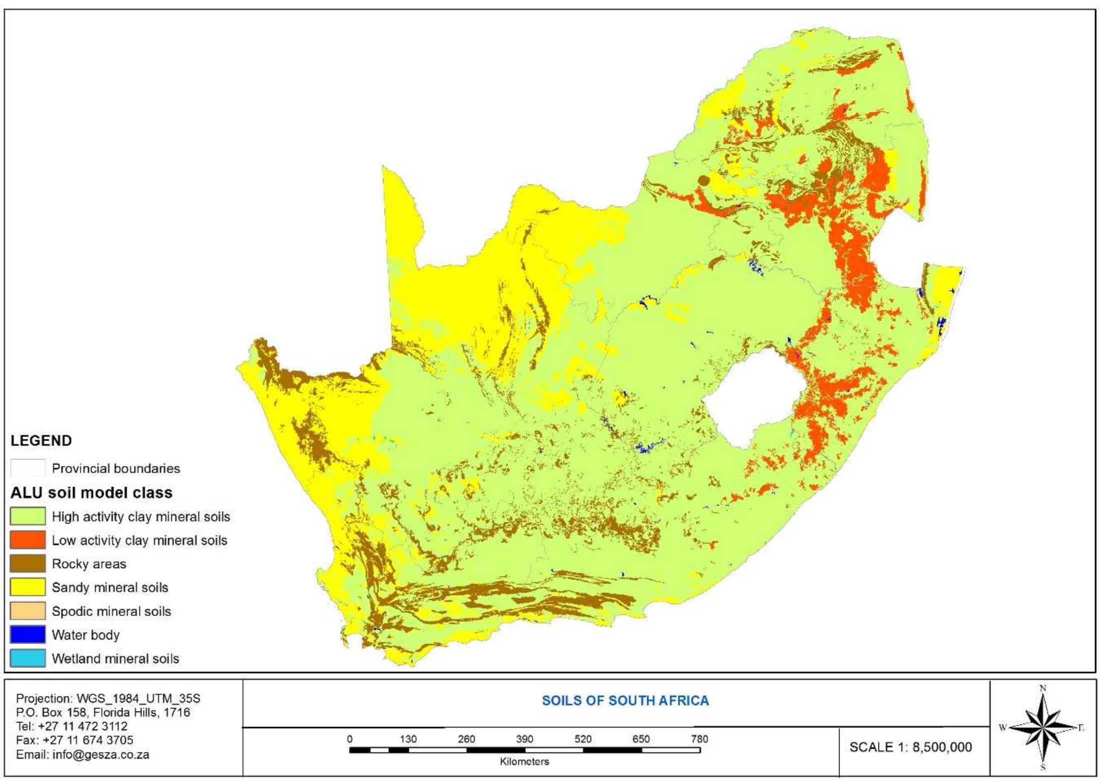

Figure 5.18: South African soils classified into the IPCC classes (Moeletsi et al., 2015).

Table 5. 38: Soil types and their description (Source: Moeletsi et al., 2015)

Soil Type	Description	Criteria
Sandy mineral soils	Sandy mineral soils comprise all soils where the texture class is sandy (***irrespective of taxonomy***). These areas generally have either sandy parent materials or have been subject to aeolian (wind-blown) deposition (such as the Kalahari sands of the Northern Cape).	Land types where soils with an average topsoil clay content less than 8% comprise more than 40%.
Wetland mineral soils	This map unit comprises all land types where soils with wetland characteristics are dominant. Most land types will have wetland soils in the lower parts of the landscape, but only a few land types have these soils as dominant, mainly in the north-east of KwaZulu-Natal.	Land types where Katspruit and Fernwood (series 30-42) soil forms, along with streambeds and pans, comprise more than 40%.
Organic soils	This map unit comprises all land types dominated by 'peat' soils. These soils typically occur in cool, often upland areas, so their distribution is limited to small zones in KwaZulu-Natal.	Land types where champagne soil forms comprise more than 40%.
Spodic mineral soils	This map unit comprises all land types where podzols (where leaching of iron/aluminium and organic matter has occurred) predominate. These areas are restricted to small zones in the south and south-west of the Western Cape.	Land types where Houwhoek and Lamotte soil forms comprise more than 30%.
Rocky areas		All I_b and I_c land types (rock outcrops more than 60%).
Low activity clay mineral soils	This map unit comprises all land types dominated by highly weathered, apedal (structureless) soils dominated by low activity (1:1) clay minerals such as kaolinite. Only soils where the base status is defined as part of the soil classification could be used, so it is very probable that the extent of such soils is larger than that shown on the map. These soils are found mainly in the warmer, higher rainfall areas,	Land types where Kranskop, Magwa, Inanda, Nomanci, Avalon (series 10–17), Glencoe (series 10–17), Pinedene (series 10–17), Griffin (10–13), Clovelly (series 10–18), Bainsvlei (series 10–17), Hutton (series 10–18) and Shortlands (all series) comprise more than 40%,

	such as KwaZulu-Natal and Mpumalanga.	and where average topsoil clay percentage is more than 8%.
High activity clay mineral soils	This map unit comprises all land types dominated by lightly to moderately weathered soils, dominated by 2:1 silicate clay minerals, including vertisols, mollisols, calcareous soils, shallow soils and various others. This group covers most of South Africa.	Land types not falling into one of the categories given above.

5.4.2.7 Annual change by soil and land type

To determine the area of each land class in a particular soil type, the soil datasets (Moeletsi et al., 2015) 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 2018 land cover datasets and the soil datasets were processed into the same projection and pixel size, they were merged to generate a land cover change dataset within each soil category. An output table was then generated, and annual areas calculated in a similar manner to that mentioned above. Annual change was assumed to have remained the same over the entire time series and land areas also incorporated the 20-year default conversion period as described in section 5.4.2.4 Since land parcels are not being tracked it was assumed that the land was always converted from a land remaining category. This assumption is a simplified assumption as in reality much of the converted land is likely to be converted from previously converted land. Ways of improving on this assumption are currently being sought.

5.4.3 Methodological issues

A summary of the methods used are provided in Table 5. 15. In the land category estimates the biomass (above-and below-ground), litter and soil carbon pools are included for each category, and in some cases (where data is available) the deadwood pool is also incorporated (Table 5. 39).

Table 5. 39: Carbon pool definitions (adapted from IPCC GPG)

Pool	Definition	Categories it is included in
Above-ground biomass	All living biomass above the soil including stem, stump, branches, bark, seeds, and foliage.	All
Below-ground biomass	All living biomass of live roots.	All
Litter	Includes all non-living biomass, lying dead, in various states of decomposition above the mineral or organic soil.	All
Deadwood	Includes all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil.	None, due to insufficient data
Soil organic carbon	Includes organic carbon in mineral soils to a depth of 30cm.	All

5.4.3.1 Biomass and Litter

General emission calculations

South Africa uses a combination of Tier 1, and Tier 2 methods for estimating emissions for the *Land* category.

There are two methods for estimating carbon stock changes in biomass, namely the Gain-loss method and the Stock-difference method. The Stock-difference method requires carbon stock inventories for a given land area, at two points in time. This method is applicable in countries that have national inventory systems for forests and other land-use categories where the stocks of different biomass pools are measured at periodic intervals (IPCC, 2006). South Africa does not have a forest inventory and so obtaining stock data for two time periods is challenging. The NTCSA (DEA, 2015; DEFF, 2020) was developed to produce carbon density maps (Tier 3) for South Africa to fill this gap. In 2015 the NTCA produced a map for above-ground (woody and herbaceous) and below-ground biomass for the year 2014. In 2020 the NTCSA was updated and the report (DEFF, 2020) indicated that the above-ground woody carbon pool was updated for 2015 and 2018, however the 2018 map was not available on the carbon sinks atlas database (https://ccis.environment.gov.za/carbon-sinks/#). Enquiries indicated the 2014 and 2018 data were the same, as is indicated in the Table 4 in the updated NTCSA report (DEFF, 2020). Without two years of data the carbon stock approach could not be applied, and emissions were therefore estimated using the process-based gain-loss method.

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 (IPCC, 2006; equation 2.10) 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 IPCC equations 2.11 to 2.14 (IPCC, 2006). 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 approach for *land remaining land* and a Tier 2 approach for *land converted to other land* (IPCC, 2006; equations 2.15 and 2.16) were applied. The dead organic matter pool only includes litter due to a lack of data on deadwood, and it is assumed that all litter pool carbon losses occur entirely in the year of transition (Tier 1).

The general equation for calculating emissions from biomass changes on land remaining land is the IPCC (2006) equation 2.4:

$$\Delta C_B = \Delta C_G - \Delta C_L$$

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:

$$\Delta C_B = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

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),

$$\Delta C_{CONVERSION} = \sum\{(B_{AFTERi} - B_{BEFOREi}) * \Delta A_{TO\_OTHERSi}\} * CF$$

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:

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

Where:

ΔC_{DOM} = annual change in carbon stocks in DOM (tonnes C yr^{-1})
C_n = DOM stock under the new land-use category (tonnes C yr^{-1})
C_o = DOM 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.

Activity data

The activity data for this sector is the land use change data which is described in detail under the land representation section (section 5.4.2). The burnt area data was obtained from MODIS (see section 5.3.2.2.). Forestry SA (FSA, 2018) supplies all the plantation data, while crop statistics are extracted from various sources (DAFF, 2020; Stats SA, 2007; FAOStats, 2020). Fuelwood consumption is determined from the number of households using fuel for cooking and heating (Statistics SA, 2019). Further specific details are provided in the sections below.

Emission factors

Biomass data is sourced from two main data sources, namely scientific literature and the carbon density maps from the NTCSA (DEFF, 2020). The carbon stocks for each land class type were determined from the NTCSA data by merging the carbon layers with the land cover to determine an average for each land class (methodology details provided in the Carbon density map data section below). If scientific literature was available then these values were applied and the NTCSA data was used as validation, but if there was no other data the NTCSA stock data was used. In general, the biomass data from the NTCSA overlay are much lower than the data from the literature and IPPC defaults, therefore it is recommended that further validation of the merged output data be conducted.

Carbon density data methodology

The NTCSA was initially conducted in 2015 (DEA, 2015) and updated in 2020 (DEFF, 2020). The technical reports provide the detailed methodology which is summarized below. The 2014 above-ground woody biomass[6] and the above-ground herbaceous biomass from 2018 were applied across the whole times series.

The size of each major carbon pool was estimated for every 1000 x 1000 m pixel across the range of different land-use and vegetation types in South Africa. The above-ground woody plant biomass was estimated using remotely sensed tree height (from ICESAT-GLAS) and canopy cover (MODIS). The woody biomass product was developed through the integration of ALOS PALSAR-1 synthetic aperture radar images, SRTM30m DEM parameters (elevation, slope and aspect), LiDAR tracks, and field data of woody biomass. The LiDAR tracks were processed to derive a canopy height model for woody vegetation above 0.5m at 1m pixel size. A detailed LiDAR (Above-ground biomass (AGB) woody), product was generated at 30m pixel size using LiDAR woody cover and height products and field data. The dual- polarized (HV, HH) SAR bands and DEM parameters were modelled using the LiDAR woody aboveground biomass as reference data for calibration and validation of the final woody aboveground biomass (AGB woody) map. Above-ground herbaceous and litter biomass in the NTCSA was calculated using published relationships between rainfall and annual grass and litter production.

A layer for below ground biomass was created through the NTCSA, but there were inconsistencies in the map output and the data reported in the technical report, so this will need further assessment before being incorporated. The corresponding below ground biomass was, therefore estimated using the root:shoot ratios provided in the report to set up the models and data from the literature

An above ground litter carbon density layer was also provided so DOM stocks could be determined for each land class. Again, litter data was supplemented with data from the literature where available.

Above ground woody biomass, above ground herbaceous and litter was determined for each land class by combining the biomass layers with the land cover maps. The biomass layers from DEFF (2020) were obtained from council for Scientific and Industrial Research (CSIR) and the land cover data for 2014 obtained from DFFE EGIS website, both

[6] The 2018 data for all carbon density layers were applied in the inventory to be consistent, it was only the woody biomass data that was not available for 2018 so the 2014 data was applied.

were reclassified to 20 classes. The land cover was converted to the same projection and datum as the biomass layers. The biomass layers' cell size was resampled from 1000m cell size to the same size as the relevant land cover layers (30m for the 2014). During the resampling the layers were also converted from the original .tiff format to .img (Imagine Image) format. Thereafter the biomass layers were converted from a floating-point pixel type to an unsigned integer to process it alongside the land cover data. Finally, the Combine (ESRI ArcGIS) function was used to get a combined attribute table to assess the biomass data per land cover class. The combine function combines multiple rasters so that a unique output value is assigned to each unique combination of the input values. The combine tool works on integer values and their associated attribute tables. A weighted average for each land class, along with the standard deviation, was determined. The resulting data is shown in Table 5. 40 where above ground woody and herbaceous biomass has been combined.

Forest land

DEFF (2020) indicated that the estimates for indigenous forests are likely underestimates due to the sensors saturating at densities higher than 130t/ha therefore data from the literature was applied for this category. Mucina and Rutherford (2011) indicates there are different forest types (Afrotemperate forests, Mistbelt forests, Scarp forest, Coastal forests, Sand forests and other forests). Literature provides values for the various forest types and then using the relative areas of these forest types in Mucina and Rutherford (2011) a weighted average for indigenous forests was calculated (Table 5. 40). A similar approach was applied to thickets. The thicket was determined from data from various literature applying the ratio of degraded to restored provided in DEA (2015). For woodlands and average value of various literature biomass data for woodlands, savannas and fynbos was applied. Plantation data was determined from the Timber Statistics data (DAFF, 2018) and supported by data from Alembong (2014).

In most cases the carbon density data from the NTCSA is lower than the literature data, but for indigenous forests and plantations this is expected due to the saturation of the sensor. The carbon density data for woodlands and thickets is at the low end of the IPCC defaults, while the literature data is within range. The carbon density data is averaged over the large woodland area, and it is recommended that in future inventories the carbon density data be determined for the various biomes to provide more specific data for comparison, particularly for the woodland category. Furthermore, a more detailed biome break down would also allow for easier comparison and validation with the outputs provided in the DFFE (2020) report. DFFE is currently exploring the option of including both woodland categories (dense forest and woodland, and open woodlands) in the 20-land class change map to improve the accuracy and detail of the forest land category.

Root to shoot ratios for the calculation of below ground biomass are provided in Table 5. 41, while litter and biomass accumulation rates are found in Table 5. 42Table 5. 42 and

Table 5. 43 Table 5. 43, respectively.

Croplands

The carbon density data value was applied to the annual crops as there is a wide variation in crop types and the NTCSA included more detail on annual crop types. For the perennial crops the input data provided for the original NTCSA (DEA, 2015) was applied. The data for all crops is low relative to the IPCC 2006 default values, however they are country specific data so are assumed to be more accurate.

Root to shoot ratios for the calculation of below ground biomass are provided in Table 5. 41 Table 5. 41, while litter and biomass accumulation rates are found in Table 5. 42 Table 5. 42 and

Table 5. 43 Table 5. 43, respectively.

Grasslands

Data from the literature was averaged and applied for grassland biomass. This value was in the range of the IPCC default data. The carbon density data for grasslands is very high, but this may be due to wooded grasslands being incorporated into the grassland area. Further investigation is required to understand the reason for the difference. For degraded land the carbon density data from the NTCSA was applied.

Root to shoot ratios for the calculation of below ground biomass are provided in Table 5. 41, while litter data is found in Table 5. 42.

Wetlands

Waterbodies were assumed to have no biomass, while wetland biomass data was sourced from the literature. Wetlands include mangroves in this inventory (which will be moved to Forest land in future inventories), so the biomass value is determined from literature on mangroves and non-woody wetlands

Root to shoot ratios for the calculation of below ground biomass are provided in Table 5. 41, while litter data is found in Table 5. 42.

Settlements

The carbon density data was applied for settlements, however the value was taken from the initial NTCSA (DEA, 2015) as the updated data indicated that the LiDAR sensor overestimated for settlements and was not suitable for estimating biomass in these landscapes. The value of 4.21 t C/ha is given in the DEA (2015) report, but this includes litter so 1.67 t C/ha of litter (obtained from the NTCSA overlay data) is removed from the number to obtain a value of 2.54 t C/ha (or 5.4 t dm/ha) as a total carbon value. For mines a value of zero is applied as mines are unvegetated.

Root to shoot ratios for the calculation of below ground biomass are provided in Table 5. 41 Table 5. 41, while litter and biomass accumulation rates are found in Table 5. 42 Table 5. 42 and

Table 5. 43 Table 5. 43, respectively.

Other land

Bare ground (or *Other land*) was assumed to have no biomass.

Table 5. 40: Above ground biomass factors for the various vegetation classes.

<table>
<tr><th rowspan="2"></th><th colspan="3">Data applied in the inventory</th><th colspan="3">Comparison to other data sets</th></tr>
<tr><th>Above ground biomass (t dm/ha)</th><th>SD</th><th>Reference</th><th>IPCC default</th><th>Above ground biomass from updated NTCSA (t dm/ha)</th><th>Spatial mapping deviation (%)</th></tr>
<tr><td>Indigenous forests</td><td>175.1 (Afrotemperate)
358.0 (Mistbelt)
103.4 (Scarp)
175.6 (Coastal)
80.0 (Sand)
71.86 (Other)
190.7 (Weighted average)</td><td>57.9</td><td>Adie et al. 2013
Mensah et al. 2016
Glenday, 2007
Glenday, 2007
Glenday, 2007
DEA, 2015</td><td rowspan="3">35.1 – 65.2
(subtropical Africa, IPCC 2019 Refinement)
20 – 200
(Subtropical Africa, IPCC 2006)</td><td>39.6</td><td>53.5</td></tr>
<tr><td>Thickets</td><td>35.9 (Thickets)</td><td>12.2</td><td>Glenday, 2007
Van der Vyver et al., 2013
Powel, 2009
Van der Vyver & Cowling, 2019</td><td>18.34</td><td>69.1</td></tr>
<tr><td>Woodlands</td><td>22.9 (Average)</td><td>3.3</td><td>Glenday, 2007
Mograbi et al. 2015
Wessels et al. 2013
Mills et al. 2012
Colgan et al. 2012
Scholes & Walker, 1993
Van Wilgen 1982
Shackleton and Scholes, 2011
Gander, 1994</td><td>11.07</td><td>63.2</td></tr>
</table>

Plantations	77.6		Calculated from Timber Statistics Reports (DAFF, 2018), supported by data from Alembong 2014	15 – 70 (subtropical Africa, IPCC 2019 Refinement) 10 – 150 (Subtropical Africa, IPCC 2006)	29.74	63
Annual non-pivot crops	No additional literature data so NTCSA data was applied		NA	10.63 (annual crops, IPCC 2006)	5.83	134
Annual pivot crops					9.94	112
Subsistence crops					7.20	97
Orchards	80.9		DEA, 2015	134.0 (temperate conditions, IPCC 2006)	17.45	65
Vineyards	29.8		DEA, 2015		12.89	68
Grasslands	2.0 (Average)	0.9	Snyman, 2006 Snyman & Fouche, 1991 Snyman, 2005 Mills et al., 2005a O'Connor et al. 2001 Gander, 1994	1.6 (warm temperate dry, IPCC 2006)	8.31	85
Low shrublands	7.6 (Average)	0.4	Milton, 1990 Rutherford and Westfall, 1986 Rutherford, 1978 Mills et al, 2005a Anderson et al., 2010	NA	3.83	150
Degraded land	No additional literature data therefore the NTCSA data was applied		NA	NA	6.4	86

Wetlands	14.2 (Salt marsh) 15.8 (reeds and sedges) 112.4 (Mangroves) 20.9 (Weighted average)	3.9	Glenday, 2007 Els, 2019 Johnson et al. 2020 Steinke et al. 1995		8.96	99
Waterbodies	0	NA	NA		0	0
Settlements – residential	5.4		DEA, 2015		11.63	71
Settlements – smallholdings					10.17	67
Settlements – commercial					12.33	71
Settlements – industrial					13.31	75
Mines	0		Assumed to be unvegetated		5.44	100
Bare ground	0	NA	NA		0.79	420

Table 5. 41: Root:shoot ratios for each of the land classes.

Land class	Root:shoot ratio	Reference	IPCC 2006 default
Indigenous forest	0.27	Glenday, 2007 Mangwale et al. 2017	0.24 – 0.56 (subtropical dry forests, IPCC 2006)
Plantations		Du Toit et al. (2016)	
Softwoods	0.28		
Euc. Grandis	0.24		
Other Euc.	0.24		
Wattle	0.28		
	0.26		

Other hardwoods			
Thicket/dense bush	0.34	Glenday, 2007 Powell, 2009	0.24 – 0.56 (subtropical dry forests, IPCC 2006)
Woodlands	0.25	DEA, 2015	
Annual crop (pivot)	0.2	DEA, 2015	None provided
Annual crop (non-pivot)	0.2	DEA, 2015	
Subsistence crop	0.2	DEA, 2015	
Perennial orchard	0.42	DEA, 2015	
Perennial vine	0.42	DEA, 2015	
Wetland	0.96	IPCC 2014 Wetland supplement (Mineral soils)	
Grassland	1	DEA, 2015	1.6 – 2.8 (subtropical to semi-arid grassland, IPCC 2006)
Low shrubland	2	DEA, 2015	
Settlements	0.5	DEA, 2015	Not provided
Mine	0.25	DEA, 2015	
Other land	0	Assumed	

Table 5. 42: Litter data applied in the inventory for each of the land classes.

	Data applied in the inventory		Comparison with other data	
	Litter (t dm/ha)	Reference	Litter from updated NTCSA (t dm/ha)	Spatial deviation (%)
Indigenous forests	8.4	Glenday, 2007 (average of coastal scarp, coastal lowland and dune forest)	9.93	59
Thickets	3.4	Glenday, 2007	4.99	114

Woodlands	2.4	Glenday, 2007 (average of woodland, bushclump grassland)	2.16	116
Plantations	2.38	Dames et al., 1998	4.81	107
Annual non-pivot crops	No additional data from literature therefore data from NTCSA was applied	NA	3.40	164
Annual pivot crops			2.72	158
Subsistence crops			1.36	190
Orchards			6.86	97
Vineyards			9.80	76
Grasslands			1.55	147
Low shrublands			2.72	198
Wetlands			2.48	167
Settlements – residential			2.96	160
Settlements – smallholdings			2.4	152
Settlements – commercial			2.35	182
Settlements – industrial			4.3	134
Mines			1.34	181
Eroded land			1.53	130
Bare ground			0	NA

Table 5. 43: Biomass growth or accumulation rates for the various woody land categories.

Land class	Forest type	Biomass growth rate (t C/ha/yr)	Reference	IPCC 2006 default (t C/ha/yr)
Indigenous forest	Primary (undisturbed)	0	Glenday, 2007	0.3 – 0.85 (subtropical dry forest in Africa >20yrs)
	Secondary (disturbed)	1.8	Glenday, 2007	1.1 – 1.2 (subtropical dry forest in Africa <20yrs)
Thicket/dense bush	Primary (undisturbed)	0	Glenday, 2007	0.3 – 0.85 (subtropical dry forest in Africa >20yrs)
	Secondary (disturbed)	1.3	Mills & Cowling, 2006 Van der Vyver et al. 2013 Smart, 2018 Glenday, 2007	1.1 – 1.2 (subtropical dry forest in Africa <20yrs)
Woodlands	Primary (undisturbed)	0	Glenday, 2007	0.3 – 0.85 (subtropical dry forest in Africa >20yrs)
	Secondary (disturbed)	0.9	Scholes & Walker, 1993 Hoffman & Franco, 2009	1.1 – 1.2 (subtropical dry forest in Africa <20yrs)
Perennial orchard	NA	2.16	Carbon stock divided by 25 yr harvest cycle	2.1 (temperate climate)
Perennial vine		0.80	Carbon stock divided by 25 yr harvest cycle	
Low shrubland		0.54	Carbon stock divided by default 20yrs	NA
Settlements		0.19	Carbon stock divided by default 20 yrs	NA

5.4.3.2 Mineral soils

Emission calculation

Formulation B was used to determine SOC changes. Soil carbon change was determined using the IPCC 2006 equation 2.25:

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

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 $_{(0\text{-}T)}$ = beginning of the inventory time period;
A = land area (ha);
D = time dependence of stock change factor.

Activity data

Activity data is the land cover area data and land change per soil type (section 5.4.2.7**Error! Reference source not found.**) and the soil stock change factors (Table 5. 44). Some default factors were obtained from the IPCC 2019 Refinement as the refinement has a better disaggregation (particularly between dry and wet conditions) of the stock change factors for croplands than the IPCC 2006 Guidelines.

Table 5. 44: Soil carbon stock change factors for the various land types.

Land class	F_{LU}	F_{MG}	F_I	Reference
Indigenous forest, thickets, woodlands, plantations, wetlands, grasslands, low shrublands	1	1	1	IPCC 2006
Degraded lands	1	0.85 (moderately degraded)	1	IPCC 2006
Orchards, vineyards	0.72	1 (full till)	1	IPCC 2006 IPCC 2019
Annual crops	0.76	Determined from Moeletsi et al. (2015)		F_{LU} – IPCC 2019 F_{MG}, F_I - Moeletsi et al. (2015)
Subsistence crops	0.58			NTCSA (DFFE 2020)
Settlements and mines	1	1	1	IPCC 2006

Table 5. 45: Stock change factors for the various crop types in South Africa (derived from Moeletsi et al., 2015)

Crop type	Stock change factors	
	Management (F_{MG})	Inputs (F_I)
	Dry climate	
Barley	1	0.98
Cabbage	1	1.04

Cotton	1	0.51
Drybeans	1.001	0.99
General vegetables	1	1.04
Groundnut	1	1.01
Legumes	1	1.01
Lucerne	1	0.92
Maize	1.003	0.95
Onions	1	1.03
Other field crops	1	0.96
Other fodder crops	1	0.53
Other oil seeds	1	0.99
Other summer cereal	1.003	0.95
Other winter cereals	1.001	0.99
Potato	1	1.04
Silage	1.002	0.95
Sorghum	1	1.00
Soybean	1	0.56
Sugarcane	1	0.96
Sunflower	1	0.87
Teff	1.002	0.53
Tobacco	1	1.02
Tomato	1	1.02
Wheat	1.001	1
General annual crop	1.003	0.95
Fallow land	1.13	0
Pasture	1.13	0.51

SOC reference data

The ISRIC (2017) soil organic carbon stock at 30 cm depth (https://data.isric.org/geonetwork/srv/eng/catalog.search;jsessionid=D59E70CBD401A199C806783D11B4B656#/metadata/ea80098c-bb18-44d8-84dc-a8a1fbadc061), which is based on many data points in South Africa, was used as the SOC reference data. A soil carbon value for each soil type was determined by extracting the ISRIC SOC to fit the South African boundary (South African Boundary shapefile (2018) obtained from the Municipal Demarcation Board (https://dataportal-mdb-sa.opendata.arcgis.com/search?tags=2018)). This was then re-projected to match the same co-ordinates as the land cover dataset (UTM 35 S). The SOC data set was re-sampled to change the cell size from 250 x 250 m to 100 x 100m to match the soil map. The soil data was sub-divided to create a standalone file for each soil type and the SOC data was extracted for each soil type to determine a SOC reference value for each soil type (weighted average SOC per soil type using the 'Value' (t/ha) and Counts or number of cells that match the value). The resulting SOC reference values are shown in Table 5. 46. Comparison was made with the IPCC data and this showed that the country specific values for wetlands mineral soils and spodic soils were lower than the IPCC default values, but for low activity clay the value was much higher. The values for sandy soil and high activity clay matched well with the IPCC data. These differences will need to be investigated further in the next inventory

Table 5. 46: SOC reference values for the various soil types (t C/ha).

Soil type	Country specific	IPCC 2006	IPCC 2019
Sandy mineral soils	20.85	19	10
Wetland mineral soils	40.53	88	74
Spodic mineral soils	71.65	115	NA
Low activity clay mineral soils	65.54	24	19
High activity clay mineral soils	35.21	38	24

SOC validation

The SOC data was validated by comparing the carbon stock data calculated using the Tier 1 and Tier 2 method. For 1990 these data sets were within 0.4% of each other and in 2020 they were within 1.1% of each other. The annual SOC change in 2020 was however found to be 32% lower with the Tier 2 method. The difference is due to the Tier 2 method incorporating the more detailed annual land use changes and accounting for the 20-year default period. The IPCC 2006 Guidelines indicates that incorporating the land use changes is likely to lead to annual variations between the two methods. The discrepancy between the two methods, which appears to be greater in grasslands due to the large area and area changes, will be investigated further and a more detailed assessment provided in the next inventory.

5.4.4 Recalculations since the 2017 inventory

Recalculations were performed for the entire time series for the *Land* sector due to several updates and improvements:

- Land areas:
  - Incorporation of 1990-2018 land change data.
  - Exclusion of corrections for wetlands and degraded lands.
  - Updated assumptions on land area changes based on land change assessment report (DEFF, 2020).
  - Inclusion of mineral wetland carbon stock changes.
- Biomass gains data:
  - Updated biomass data based on updated NTCSA data (DEFF, 2020) and scientific literature.
  - Inclusion of no growth for primary (or undisturbed) forest areas.
  - Updated BCEF factors for plantations.
  - Corrected plantation area to reflect the areas provided by Forestry SA.
- Biomass losses:
  - Burnt area data was updated to MODIS collection 6 data.
  - Fuelwood removals from woodlands were adjusted for charcoal and fuelwood from plantations.
  - Inclusion of mortality rate.
- Litter data:
  - Updated litter data based on the updated NTCSA data (DEFF, 2020).
- SOC data:
  - Country specific SOC reference data based on the ISRIC soil database.
  - Incorporation of more detailed SOC change data based on the development of land change matrix per soil type.

The recalculations produced a sink estimate that was 40% lower than the previous submission for the year 2017, however the change percentage varied across the time series. In 2000 and 2001 the sink in the current inventory was increased by 46%, and in 2016 it was increased by 8%. On the other hand, for all other years the sink was reduced, and between 2005 and 2008 the sink was shown to be a source in this inventory.

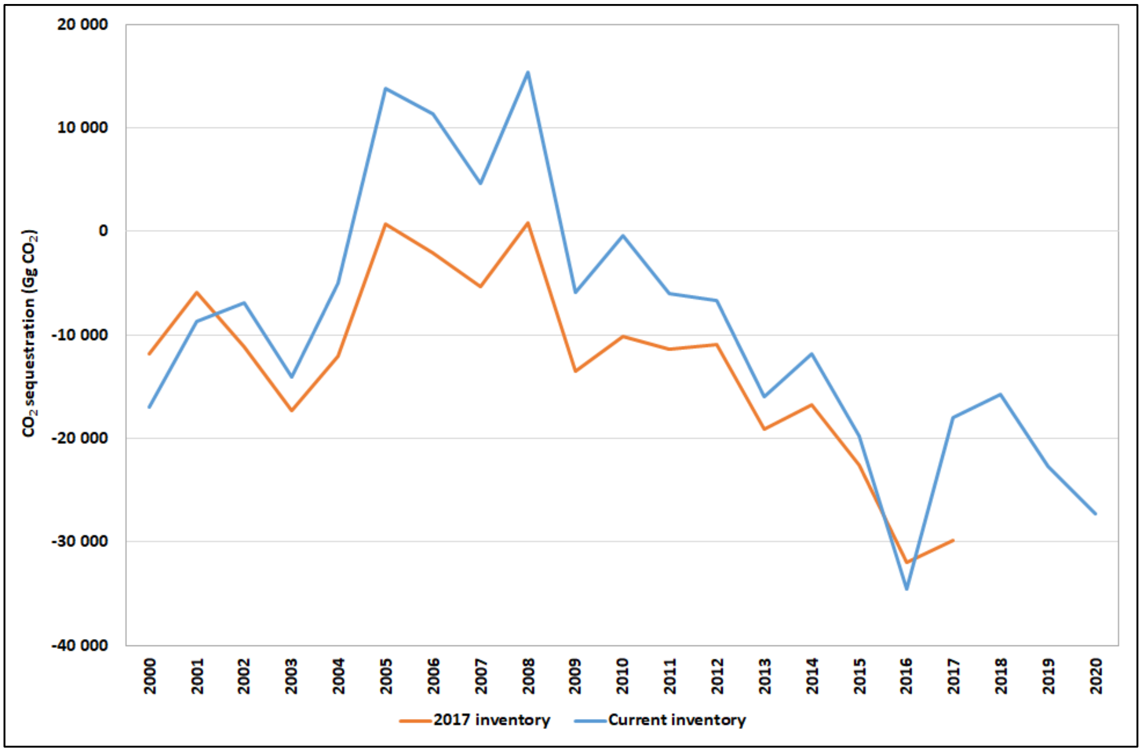

Figure 5.19: Recalculated Land category emissions in 2020 compared to 2017 submission data.

5.4.5 Uncertainties and time-series consistency

5.4.5.1 Uncertainties

Land cover maps

The 2018 South African National Land-Cover dataset was verified in terms of mapping accuracy to provide a measure of end user confidence in data use. The satellite image generated land-cover / land-use information was verified visually, as part of a desk-top only procedure, against equivalent date, high resolution imagery and photography in Google Earth ©. Accuracies are reported using industry standard error (confusion) matrices, and included Producer, User accuracies and Kappa values. The map accuracy results for the 2018 South African National Land-Cover CALC dataset, modelled from multi-seasonal Sentinel 2 imagery, based on the modified legend format, are provided in Figure 5.20.

Overall Summary	SANLC 2018	
Overall Map Accuracy %	91.32	
Mean Class Accuracy %	91.38	
90% confidence limits	90.87	91.78
	low	*high*
Kappa Index	91.12	
Number of classes present	47	
Number of sample sites	6570	

Figure 5.20: Mapping accuracies for the CALC generated 2018 SA National Land Cover dataset (Source: DFFE,2021).

The overall map accuracy for the 2018 South African National Land-Cover map is 91.32%, with a mean land-cover / land-use class accuracy of 91.38%. This has been determined from 6 570 sample points representing 47 land cover classes. A breakdown of individual class accuracies is provided in Figure 5.21.

Accuracy class name		User Acc %	Prod Acc %	90% C.I. low	90% C.I. high	Omm. Error	Comm. Error
Contiguous Forest (indigenous)	1	98.90	84.11	79.50	88.73	0.16	0.01
Contiguous Low Forest	2	80.74	93.16	90.06	96.27	0.07	0.19
Dense Forest & Woodland	3	77.25	93.59	90.97	96.21	0.06	0.23
Open Woodland	4	79.49	92.26	89.53	95.00	0.08	0.21
Plantation Forest	5	99.35	96.20	94.12	98.28	0.04	0.01
Low Shrubland (non-fynbos)	6	78.86	86.25	82.69	89.81	0.14	0.21
Low Shrubland (fynbos)	7	93.92	85.80	82.22	89.39	0.14	0.06
Low Shrubland (succulent karoo)	8	94.00	74.60	69.57	79.64	0.25	0.06
Low Shrubland (nama karoo)	9	86.45	87.58	84.09	91.08	0.12	0.14
Sparsely Wooded Grassland	10	91.18	88.57	84.49	92.65	0.11	0.09
Natural Grassland	11	48.36	88.08	84.62	91.54	0.12	0.52
Natural Rivers	12	99.36	99.36	98.26	100.00	0.01	0.01
Natural Estuaries & Lagoons	13	97.09	100.00	99.30	100.00	0.00	0.03
Natural Ocean	14	97.04	100.00	99.21	100.00	0.00	0.03
Natural Lakes	15	100.00	100.00	98.26	100.00	0.00	0.00
Natural Pans (flooded observation time)	16	93.33	97.67	95.80	99.55	0.02	0.07
Artificial Dams (including canals)	17	94.41	95.60	93.39	97.80	0.04	0.06
Artificial Sewage Ponds	18	100.00	96.15	93.58	98.73	0.04	0.00
Artificial Flooded Mine Pits	19	95.49	95.49	93.05	97.93	0.05	0.05
Herbaceous Wetlands	20	97.56	78.82	75.09	82.55	0.21	0.02
Mangrove Wetlands	21	100.00	88.79	84.78	92.79	0.11	0.00
Natural Rock Surfaces	22	97.22	82.84	79.06	86.62	0.17	0.03
Dry Pans	23	95.51	76.58	71.35	81.80	0.23	0.04
Eroded Lands	24	100.00	86.75	83.30	90.19	0.13	0.00
Sand Dunes	25	100.00	91.14	86.92	95.36	0.09	0.00
Coastal Dunes & Beach Sand	26	96.39	98.16	96.63	99.68	0.02	0.04
Bare Riverbed Material	27	98.15	95.50	92.83	98.16	0.05	0.02
Other Bare	28	84.52	82.91	79.01	86.82	0.17	0.15
Cultivated Commercial Permanent Orchards	29	96.20	95.00	92.68	97.32	0.05	0.04
Cultivated Commercial Permanent Vines	30	99.37	97.52	95.79	99.24	0.02	0.01
Cultivated Commercial Sugarcane Pivot Irrigated	31	96.81	86.67	82.32	91.01	0.13	0.03
Commercial Permanent (Pineapples)	32	100.00	92.80	89.73	95.87	0.07	0.00
Cultivated Commercial Sugarcane Non-Pivot (all other)	33	90.48	93.66	90.93	96.39	0.06	0.10
Cultivated Emerging Farmer Sugarcane Non-Pivot (all other)	34	100.00	82.91	78.37	87.45	0.17	0.00
Commercial Annuals Pivot Irrigated	35	92.44	96.95	95.09	98.81	0.03	0.08
Commercial Annuals Non-Pivot Irrigated	36	94.48	93.90	91.40	96.40	0.06	0.06
Commercial Annuals (Non-Pivot)	37	88.50	90.77	88.03	93.50	0.09	0.11
Subsistence Annual Crops	38	85.11	87.43	84.22	90.64	0.13	0.15
Residential Formal	39	84.21	100.00	99.28	100.00	0.00	0.16
Residential Informal	40	100.00	97.16	95.41	98.90	0.03	0.00
Village	41	95.24	68.97	63.39	74.54	0.31	0.05
Smallholdings	42	95.58	97.30	95.14	99.45	0.03	0.04
Urban Recreational Fields	43	98.95	94.95	91.98	97.91	0.05	0.01
Commercial	44	100.00	95.98	94.08	97.88	0.04	0.00
Industrial	45	95.65	98.72	97.35	100.00	0.01	0.04
Mines	46	91.56	90.38	87.27	93.50	0.10	0.08
Land-fills	47	100.00	97.78	94.65	100.00	0.02	0.00

Figure 5.21: Class accuracies for the 2018 CALC generated SA National Land Cover Map (Source: DFFE, 2021).

Carbon density data

The top-level products of the NTCSA are accompanied by error estimates, defined as the likely range for a given level of confidence (such as 80%). They take into account the error of estimation associated with uncertainty in the measurements and models. In order to estimate the top-level error, the underlying errors in each of the variables which went into the calculation must be known or estimated. Where possible, and especially for values which make a large contribution to the overall error, these are statistically rigorous, data-based derivatives of the variance. For factors where the data are sparse (n<5) or where the factor makes a small contributions to the overall error (<5%), an expert-based assessment of the variance (σ^2) has been made.

The propagation of error in the equations used in this study are mostly covered by the two rules outlined below, used alone or in combination.

For the sum (or subtraction) of statistically independent, normally distributed variables with a variance denoted σ^2, the overall error is given by:

Error = sqrt ($\sigma_1^2 + \sigma_2^2 + \sigma_3^2 + ... + \sigma_n^2$)

For the product of statistically independent, normally-distributed variables each with a variance denoted σ^2 and an expected value of q, where the overall expected value is Q, the overall error is given by

Error/|Q| = sqrt ($(\sigma_1/q_1)^2 + (\sigma_2/q_2)^2 + (\sigma_3/q_3)^2 + ... + (\sigma_4/q_4)^2$)

While these calculations could be completed for top-level products, individual sampling error was however not provided as the whole country is measured and therefore there is no statistical sampling error. The inherent spatial and temporal variability of carbon stocks and fluxes is rather reflected separately in the report tables as the spatial standard deviation (SD). The spatial deviation can be large as is seen in section 5.4.3.4. Without having an uncertainty on the spatial data, it is difficult to complete a full uncertainty analysis. Global carbon stock maps (Baccini et al., 2012) show an uncertainty of ±13% for Africa, and global AGB models (Saatchi et al. 2011), show an uncertainty of ±32% for Africa and therefore uncertainties could be expected to be less than this due to country specific data being used. A detailed uncertainty analysis needs to be conducted on all spatial data so that uncertainty data can be improved in the future.

5.4.5.2 Time-series consistency

The time series is consistent throughout the time-period.

5.4.6 Forest land (3.B.1)

5.4.6.1 Category description

Reporting in this category covers emissions and removals from above-ground and below-ground biomass, litter, 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 were 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 5.3.2.). 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.

5.4.6.2 Methodological issues

Forest land remaining forest land (3.B.1.a)

Living biomass

A Gain-loss approach is used to determine carbon stock changes in forest land remaining forest land. For plantations a Tier 2 approach was applied. The total carbon flux (ΔC) was calculated from the IPCC 2006 Guidelines (Equations 2.7 and 2.11) where carbon losses are subtracted from the carbon gains:

$$\Delta C = \Delta C_G - L_{wood\text{-}removals} - L_{fuelwood} - L_{disturbaNces}$$

<u>*Carbon gains*</u>

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):

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

where for G_{TOTAL} a Tier 1 approach was used for natural vegetation classes and a Tier 2 approach was applied for plantations.

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.

Natural forest lands remaining forest lands are classed as either undisturbed (or primary) or disturbed (secondary forest) to make use of different growth rates (

Table 5. 43 Table 5. 43). In the absence of data on specific areas of primary and secondary forests, it was assumed that primary forests are those that fall into protected areas. According to Statistics SA (StatsSA, 2021) 40%, 13% and 15% of indigenous forests, thickets and woodlands are protected. Annual above-ground biomass growth in primary indigenous forests, thickets and woodlands are considered to be zero (IPCC 2019), which is in line with the findings of Glenday (2007). For secondary forests the growth rates in Table 5. 43 were applied, and were assumed to grow until they reach their maximum biomass. A mortality factor was included due to a review comment, however there is no data on mortality rate fractions therefore and expert judgement of 10% was applied to natural forest land categories. DFFE (2020) indicates that 10% of above ground biomass is deadwood, which supports this assumption. Data needs to be collected on this and improved in future. Root to shoot ratios (Table 5. 41Table 5. 41) were utilized to include the below ground biomass.

For plantations a Tier 2 method is applied to calculate biomass gains. The plantation area provided in the land cover datasets is overestimated according to the FSA data, therefore in the calculation files a correction was made so that the FSA plantation area (FSA, 2019) is used for calculating gains. It should be noted that data for 2019 and 2020 was not available at the time of completing this inventory and these years were just assumed to be the same as for 2018. The data will be corrected in the next inventory.

The mean annual increments and biomass conversion and expansion factors required for this are provided in Table 5. 47

. A weighted value for each factor was determined based on the plantation species composition and these values were used with the area data to calculate gains and losses. A planned improvement is to determine the plantation stock each year and then use the stock change method for plantations as opposed to the gain-loss method. This data would decrease the uncertainty.

Table 5. 47: Factors applied for plantation data.

	Softwoods (e.g. Pines)	Eucalyptus grandis	Other Eucalyptus sp.	Acacia sp. (Wattles)	Other hardwood sp.
Mean annual increment (m^3/ha/yr)	Sawlogs: 11 Pulpwood: 15 Mining timber: 10.1 Poles: 10	Sawlogs: 27 Pulpwood: 23 Mining timber: 19 Poles: 18	Sawlogs: 16 Pulpwood: 17 Mining timber: 15 Poles: 16	Sawlogs: 8.8 Pulpwood: 9 Mining timber: 9 Poles: 8	Sawlogs: 16 Pulpwood: 16 Mining timber: 13 Poles: 13
BCEFs for growing stock: <20 21-40 41-100 101-200 >200)	 2.4 1.3 0.8 0.7 0.6	 1.5 1.0 0.8 0.7 0.6	 1.5 1.0 0.8 0.7 0.6	 2.2 1.3 1.0 0.8 0.8	 1.5 1.0 0.8 0.7 0.6
Ratio of below-ground biomass to above ground biomass	0.28	0.24	0.24	0.28	0.26

There are some conversions between forest types and for these areas the gains and loss are calculated as described above, but a Tier 2 approach is applied where the initial change in biomass carbon stocks on the converted land is added to the equation. The carbon stocks on the forest land before conversion are the values associated with the initial vegetation type (Table 5. 40). For values immediately after conversion are those associated with the final vegetation type. Carbon losses are assumed to occur within the year of conversion. It is assumed the change for natural forest systems is gradual (i.e., from natural vegetation carbon stock to new vegetation stock), while for plantations it is assumed the land is cleared, i.e., carbon stocks immediately after conversion are zero.

Carbon losses

The total carbon flux (ΔC) was calculated from the IPCC 2006 Guidelines (Equations 2.7 and 2.11) where carbon losses are subtracted from the carbon gains:

$$\Delta C = \Delta C_G - L_{wood\text{-}removals} - L_{fuelwood} - L_{disturbaNces}$$

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):

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

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) 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 determined from the $BCEF_S$ factors provided in Dovey et al. (2020) and the relationship between $BCEF_R$ and $BCEF_I$ provided in IPCC 2006 Guidelines. The harvested wood includes the fuelwood and charcoal as it is all removed as whole trees.

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):

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

Where:

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

The amount of fuelwood collected is determined from the number of households using fuelwood for cooking and heating (Statistics SA, 2019). It is assumed that there is overlap between the houses that use wood for heating and cooking and so the higher value (households for heating) is taken to be the total number of households using wood. An average household fuel wood consumption rate of 3.5 t per household per year (Twine and Holdo, 2016) is applied. This may be overestimated as it is indicated that the households that use wood but also have electricity use an average of 2.9 t per household per year. Some of the fuelwood comes from plantations and this removal is already accounted for under harvested wood, therefore the fuelwood and charcoal removals from plantations was subtracted from the determined fuelwood consumption. In a review it was suggested that losses due to charcoal production also be included. There is no national data on charcoal production, therefore the charcoal production data from FAOStat was utilised. The wood consumption in m^3 was determined based on the assumption that 6kg wood are required to make 1kg charcoal. This consumption was then added to the fuelwood consumption. Some fuelwood would also be coming from the harvesting of alien invasive species, however this is another complex issue which needs to be considered for incorporation in future inventories. A wood density of 0.65 t dm/m^3 (Glenday, 2007) is applied to convert the volume to mass.

The fuelwood consumption numbers are within the range of the value provided by the FAOStat and a UNEP report (UNEP, 2019). 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.

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 was calculated following IPCC Equation 2.14:

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

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

For fire disturbance losses the burnt area data is determined as described in section 5.4.2. Burnt area is provided for the total area of each land class and in order to split this into land remaining land and land converted to forests the fraction of burnt area was calculated and then applied to the land remaining and the converted land areas. Carbon biomass is taken to be the carbon density for each land type (section 5.4.5.). There is no country specific data on the fraction of fuelwood lost during the fire disturbance, so the combustion fractions provided by IPCC 2006 are used as a proxy. The Tier 1 assumption that all the disturbance losses are emitted in the year of the disturbance is applied.

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. FSA data reports on the severity of the fire disturbance, so it was assumed that for severe damage fd=1, moderate damage fd=0.6 and slight damage fd=0.1. Based on the fraction of each the fd for plantation hardwoods and softwoods were determined to be 0.63 and 0.68, respectively for fire disturbance, and 0.29 and 0.36, respectively for other disturbances. The AGB (B_W) data are provided in section 5.4.3.4.

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.

Litter

A Tier 1 approach is applied to litter for forest land where it is assumed there is no change in DOM in forest land remaining forest land. For areas that are converted from one forest type to another, the litter from the initial and final land types is utilized and if there is a gain in litter this is assumed to occur over the 20-year default period, while losses are assumed to occur within the year of conversion. A Tier 1 assumption that all carbon contained in biomass killed during a land-use conversion event is emitted directly to the atmosphere and none is added to the deadwood and litter pools.

Mineral soils

Calculations and outputs for mineral SOC in *Forest land remaining forest land* is described in section 5.4.3.2.

Land converted to forest land (3.B.1.b)

Living biomass

The biomass changes in land converted to forest lands involves the determination of gains and losses, but also initial biomass changes due to the conversion. Biomass gains and losses for and converted from other land types to forest lands are calculated as for forest lands remaining forest lands. For the initial change in biomass due to the conversion the carbon stock of the initial land use (calculated from the biomass data; see section 5.4.3.2), is subtracted from the biomass immediately after the conversion. For natural land types the conversion is assumed to be gradual, thus biomass transitions from the initial to the final biomass, but for conversion to plantations the land is assumed to be cleared first. All carbon gains are assumed to occur gradually over the default 20-year period, while losses are assumed to be emitted in the year of conversion.

Litter

For areas that are converted from another land type to a forest land, the litter from the initial and final land types is utilized and if there is a gain in litter this is assumed to occur over the 20-year default period, while losses are assumed to occur within the year of conversion. A Tier 1 assumption that all carbon contained in biomass killed during a land-use conversion event is emitted directly to the atmosphere and none is added to the deadwood and litter pools.

Mineral soils

Calculations and outputs for mineral SOC in *Land converted to Forest land* is described in section 5.4.3.2.

5.4.6.3 Uncertainties and time series consistency

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 2018 land cover map was determined to be 91.3% (GTI, 2020). No uncertainty was provided for the soil maps. There is a large number of statistics for plantations and the FSA statistics have a high confidence rating (80% (Vorster, 2008) with an uncertainty range from -11% to 3%. For data from the carbon density maps, although error was calculated the error on specific point data could not be provided and only an overall spatial standard deviation was provided. A full uncertainty assessment on the carbon density maps needs to be conducted.

IPCC 2006 provides default uncertainties which are applied for now. Growing stock or gains are indicated to have a ±30% uncertainty for non-industrialised countries. Fuelwood losses are shown to have a ±20% uncertainty in industrialized countries, so in South Africa this is expected to be higher, particularly due to the way the fuelwood consumption is estimated. An uncertainty of ±30% is applied. Disturbance losses in industrialised countries have a default uncertainty of ±15%, so a ±20% uncertainty is assumed. Land conversions are assumed to have a ±5% greater uncertainty on the area. Since the litter and SOC data have greater uncertainty than the biomass data an uncertainty of ±35% is assigned to these categories.

5.4.6.4 Category specific QA/QC and verification

All general QC listed in Table 1.8 were completed for this category. Land areas were checked. Carbon emission factors were compared to literature, and to IPCC values. Where possible outputs were compared to the NTCSA (DEA, 2015; DEFF, 2020). Data could not be compared at the land class level as the land class information in the DEFF (2020) report was based on biomes as opposed to the land categories in the SANLC, but the total data for the various biomass pools was compared and shown to be similar in range.

Plantation area and fuelwood consumption data was compared to FAO data.

Soil stocks were compared to the NTCSA SOC data and for stock change validation a Tier 1 Approach 1 was used as a comparison (section 5.4.3.2). In terms of the calculation files, 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.

5.4.6.5 Category-specific recalculations

Recalculations were completed for the forest land category for the full time series due to a number of improvements:

a) Inclusion of 1990 to 2018 change data and updated area conversion assumptions.
b) Updated assumptions regarding land change between natural forest classes based on the land change assessment report.
c) Inclusion of carbon stock changes due to conversion of wetlands to forest lands.
d) Updated biomass, biomass accumulation rates and litter data.
e) Country specific SOC reference data.
f) Updated Tier 2 SOC data based on land change data per soil type.
g) Updated BCEF factors for plantations.
h) Addition of mortality rate.
i) Addition of separate growth rates for primary and secondary forests; and
j) Inclusion of charcoal losses.

Overall, the forest land recalculation led to a decrease in the sink compared to the previous inventory (Figure 5.22) and this varied across the years, for example 43.5% in 2014, 23.7% in 2015, 1.9% in 2016 and 47.2% in 2017. *Forest land remaining forest land* showed a decrease in the sink in 2017 (91.8%) compared to the previous inventory, while the *land converted to Forest land* showed an increase in the sink (87.7%) and the majority of this change is related to the update in the land change map data and conversion assumptions based on the change assessment report. Changes in the conversion of grasslands and wetlands to forest lands were the greatest contributors to this increased sink, while the changes in the conversion of *Other land* to *Forest land* contributed the most to decrease in the sink.

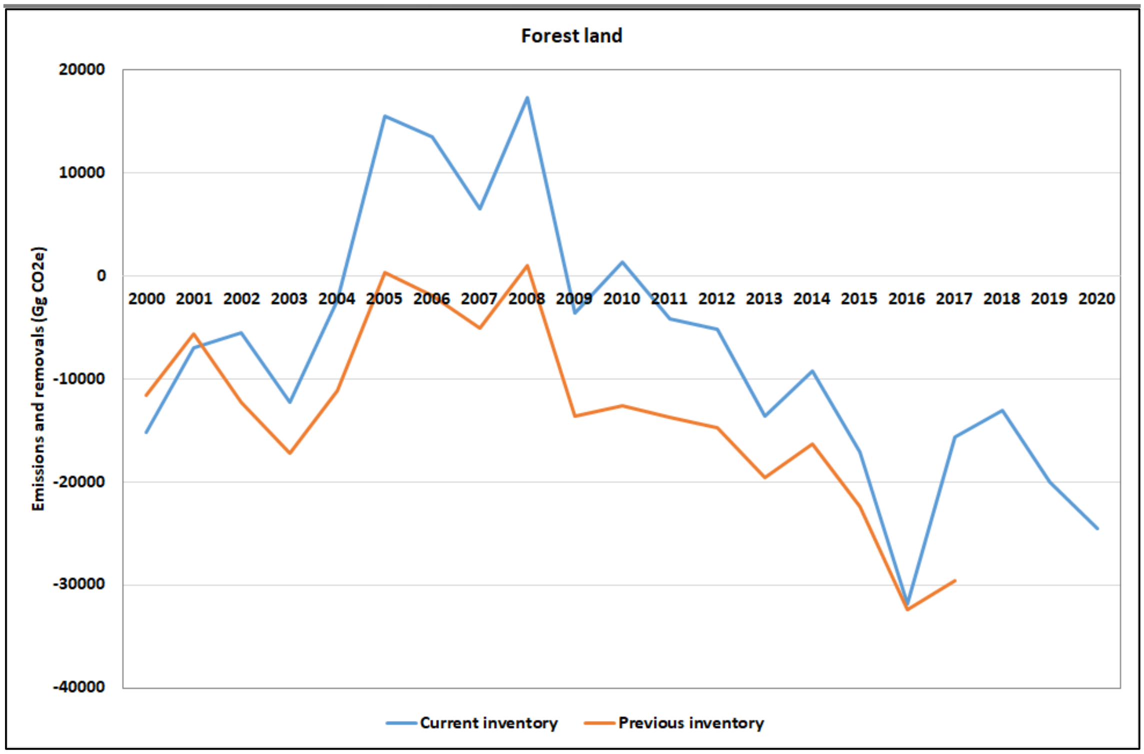

Figure 5.22: Recalculations for Forest lands.

5.4.6.6 Category-specific planned improvements

Several improvements are planned for the Forest land category:

- Removal of natural, seasonal change between natural land classes using annual 8 class land cover maps.
- Addition of another woodland class (further disaggregation) to improve accuracy.
- Inclusion of mangroves in Forest land.
- Assessment of overlap between burnt area and land change to ensure the losses are not being double counted.
- More detailed assessment of the forest land biomass factors.
- Complete a comparison between the stock-difference and gain-loss method for plantation data.

5.4.7 Croplands (3.B.2)

5.4.7.1 Category description

The *Cropland* category covers perennial crops (orchards and vineyards) and annual crops (pivot irrigation, non-pivot, and subsistence crops). 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.

5.4.7.2 Methodological issues

Cropland remaining cropland (3.B.2.a)

Living biomass

A Tier 1 approach is applied where annual crops are assumed to be in equilibrium, so biomass gains and losses are only accounted for in perennial crops. The area of perennial crops is multiplied by a biomass accumulation rate (Table 5. 43)

Losses accounted are those from biomass burning and harvest losses. Harvest losses were not included previously but have been incorporated as per UNFCCC reviewer suggestion. For harvest losses the maturity cycle is 25 years and so the area is divided by 25 to divide the crops into age classes. Every year it is assumed then that the oldest age class is harvested. These calculations are as provided in the review. Burnt area is determined as for forest lands, with the fraction of biomass lost to disturbance being assumed to equal the combustion factor for croplands (IPCC 2006).

There is some conversion between cropland types and for these areas the gains and losses are calculated as described above, but a Tier 2 approach is applied where the initial change in biomass carbon stocks on the converted land is added to the equation. The carbon stocks on the croplands before conversion are the values associated with the initial vegetation type (see section 5.4.3.1). The biomass stocks immediately after conversion are assumed to be zero, as it is assumed all land is cleared before being converted to cropland. A default period of 20 years is applied to carbon stock increases for perennial crops (i.e., it is assumed the carbon stock will increase from the initial carbon stock to the final carbon stock over a period of 20 years). For annual crop only 1 years' worth of growth is accounted for, after which the biomass is assumed to be at equilibrium. This is also the case for losses in annual crops. Carbon losses are assumed to occur within the year of conversion. For perennial crop the loss occurs across the total converted land area instead of the annual converted area.

Litter

The Tier 1 assumption for the litter pool is that the stocks in *Cropland remaining cropland* are not changing over time, therefore litter 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 litter were calculated for these areas using Eq.5.4. For *land converted to croplands* the changes in litter are determined from the data provided in Table 5. 42 and Eq.5.4. It is assumed that the change occurs slowly over the 20-year default transition period.

Mineral soils

Annual change in carbon stocks in mineral soils for *Croplands* was calculated as described in section 5.4.3.2.

Land converted to cropland (3.B.2.b)

Living biomass

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 in subsequent years it is zero.

Litter

For areas that are converted from another land to cropland, the litter from the initial and final land types is utilized and if there is a gain in litter this is assumed to occur over the 20-year default period, while losses are assumed to occur within the year of conversion. A Tier 1 assumption that all carbon contained in biomass killed during a land-use conversion event is emitted directly to the atmosphere and none is added to the deadwood and litter pools.

Calculations and outputs for mineral SOC in *Land converted to Cropland* is described in section 5.4.3.2.

5.4.7.3 Uncertainties and time series consistency

The time series is consistent.

Uncertainties on land areas is discussed in section 5.4.5.1. Since there is no specific uncertainty data on the carbon biomass data a value of ±20% was assigned to biomass changes as the uncertainty on global maps is between 13% and 32% (Baccini et al., 2012; Saatchi et al. 2011) and since country specific data is applied the uncertainty is expected to be less. As indicated for Forest lands, the uncertainty on litter and SOC data is assumed to be ±30% and ±35% respectively.

5.4.7.4 Category specific QA/QC and verification

All general QC listed in Table 1.8 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 other outputs were compared to the NTCSA (DEA, 2015; DEFF, 2020).

In terms of the calculation files, 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.

5.4.7.5 Category-specific recalculations

Recalculations were completed for the *Cropland* land category for the full time series due to several improvements:

a) Inclusion of 1990 to 2018 land change data.
b) Updated biomass and litter data based on the updated NTCSA (DEFF, 2020).
c) Country specific SOC reference data and updated Tier 2 methods using land change data per soil type.
d) Inclusion of stock changes for conversion of wetlands to croplands.

e) Inclusion of harvest losses of perennial crops.

Recalculations in the Cropland category led to a 33.1% increase in the source in 2017 compared to the previous inventory. Between 2000 and 2006 the recalculations are slightly higher or lower than in the previous inventory (1.3% in 2006), and from then the recalculated values tend to show an increasing source compared to the previous inventory. The recalculations in the *Cropland remaining Cropland* category contribute less over time while converted lands contribute more to the increasing sink. This indicates that it is the updated changes in areas and assumptions that contribute the most to the changes. As with forest lands it is the conversion of grasslands and wetlands to croplands that contribute the most to the increase in the source. Wetland carbon stock changes were not included in the last inventory, hence the contribution to recalculations.

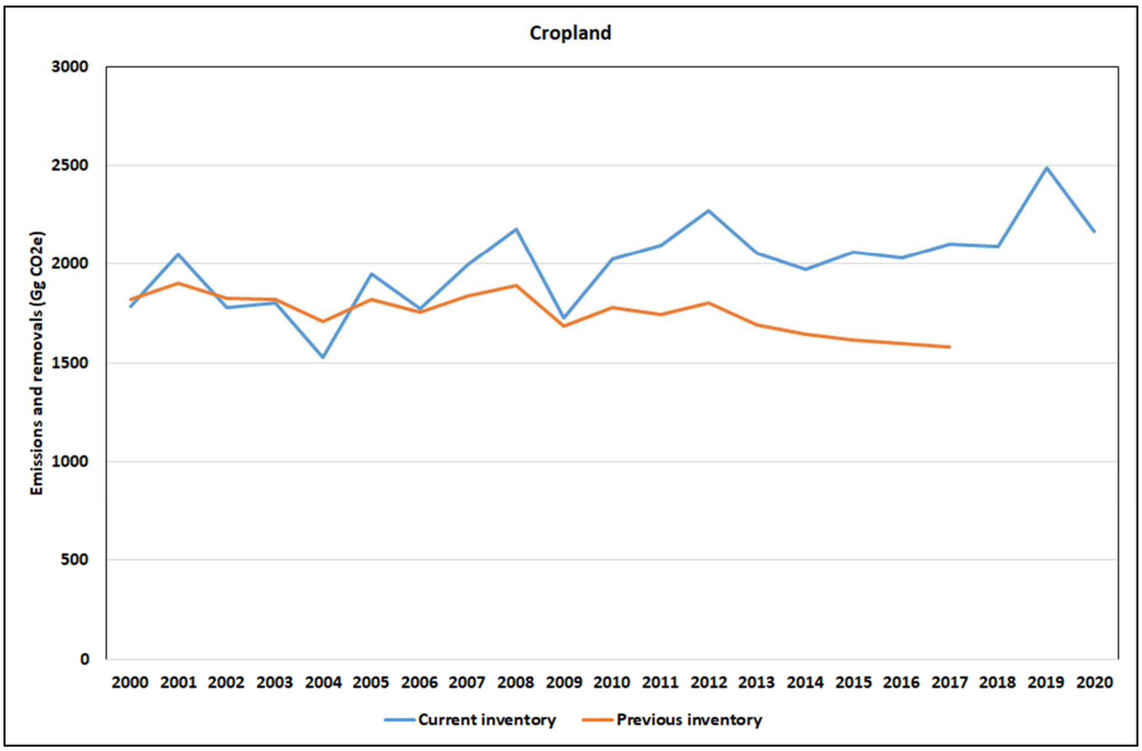

Figure 5.23: Recalculations for Croplands

5.4.7.6 Category-specific planned improvements

There are no major improvements planned for the cropland category, however one improvement planned is the incorporation of crop specific detail (e.g., sugar cane and pineapple) from the detailed land cover maps into the inventory by incorporating more specific biomass data.

5.4.8 Grasslands (3.B.3)

5.4.8.1 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.

This section deals with emissions and removals of CO_2 in the biomass, litter, and mineral soil carbon pools. 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. Emissions were only reported for the change area in the first year.

5.4.8.2 Methodological issues

Grassland remaining grassland (3.B.3.a)

Living biomass

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. In the IPCC review it was recommended that, since the growth and low shrublands is very low, it should be considered in equilibrium, as are the grasslands, therefore, in this inventory gains and losses in low shrubland were not included in land remaining land. The carbon losses from fire disturbance in annual grasses and low shrublands is not reported, as the carbon released during combustion is assumed to be reabsorbed by the vegetation during the next growing season. Where there has been land-use change between the grasslands and low shrublands, carbon stock changes are reported under *Grasslands remaining grasslands.*

Litter

The Tier 1 assumption for the litter pool is that the stocks in *grasslands remaining grasslands* are not changing over time, therefore litter 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 litter were calculated for these areas as discussed in section 5.4.3.1. For land converted to grasslands the changes in litter are determined from the data provided in **Table 5. 42** It is assumed that the change occurs slowly over the 20-year default transition period.

Mineral soils

Annual change in carbon stocks in mineral soils for *Grasslands remaining grasslands* are calculated as discussed in section 5.4.3.2.

Land converted to grasslands (3.B.3.b)

Living biomass

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 methods provided in section 5.4.3.1.

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.

Litter

Calculated as discussed in section 5.4.3.1.

Mineral soils

Calculations and outputs for mineral SOC in *Land converted to Grasslands* is described in section 5.4.3.2.

5.4.8.3 Uncertainties and time series consistency

The time series is consistent. Uncertainties on land areas is discussed in section 5.4.5.1. Since there is no specific uncertainty data on the biomass a value of ±20% was assigned to biomass changes as the uncertainty on global maps is between 13% and 32% (Baccini et al., 2012; Saatchi et al. 2011) and since country specific data is applied the uncertainty is expected to be less. As indicated for Forest lands, the uncertainty on DOM and SOC data is assumed to be ±30% and ±35% respectively.

5.4.8.4 Category specific QA/QC and verification

All general QC listed in Table 1.8 were completed for this category. Land areas were checked. Carbon emission factors were compared to literature, and to IPCC values. Where possible outputs were compared to the NTCSA (DEA, 2015; DEFF, 2020). SOC estimates were compared against a Tier 1 approach (see section 5.4.3.2).

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.

5.4.8.5 Category-specific recalculations

Recalculations were completed for the *Grassland* category for the full time series due to several improvements:

a) Inclusion of 1990 to 2018 land change data and updated land change assumptions.
b) Updated biomass and litter data based on the updated NTCSA (DEFF, 2020).
c) Country specific SOC reference data and updated Tier 2 methods using land change data per soil type.
d) Exclusion of low shrubland gains and losses from *Grasslands remaining grasslands*.

The recalculated sink was on average 30.2% less than estimated in the previous inventory. This recalculation impact was constant across the time series. *Grasslands remaining grasslands* contributed the most to the decreased sink, while the conversion of wetlands to grasslands contributed the most from the land conversion category. As mentioned previously, mineral wetland carbon stock changes were not included in the last inventory and so is a new addition in this inventory.

5.4.8.6 Category-specific planned improvements

No specific plans have been put in place for this category.

5.4.9 Wetlands (3.B.4)

5.4.9.1 Category description

Waterbodies and wetlands are the two sub-divisions in the wetland category and are defined in GTI (2015). The wetlands are not separated into coastal or inland wetlands and since organic soils were assumed to be insignificant the wetlands were assumed to be on mineral soils. It is noted that this is a broad assumption and that a recent Blue Carbon Study (Raw et al., 2020) indicated there is a small amount of organic soils, this assumption and data will be updated in the next inventory.

In this inventory the CO_2 emissions as well as the N_2O emissions from wetlands was determined. This is in addition to the CH_4 emissions that were previously estimated.

5.4.9.2 Methodological issues

Wetlands on mineral soils are calculated as per Chapter 2, Volume 4 of the IPCC 2006 Guidelines (IPCC, 2013; Chapter 5). This methodology is the same as for the other land types which are also on mineral soils

Wetlands remaining wetlands (3.B.4.a)

Living biomass

According to IPCC Tier 1 gains and losses are in equilibrium in annual vegetation, so there are no changes in *Wetlands remaining wetlands* unless there is a change from a waterbody with no vegetation to a wetland which has vegetation.

Litter

Calculated as discussed in section 5.4.3.1.

Mineral soils

Calculated as discussed in section 5.4.3.2.

CH_4 and N_2O emissions

CH_4 emissions from wetlands were calculated following equation 5.1. of the IPCC Wetland Supplement (IPCC, 2014; Chapter 5) which is the wetland area multiplied by the emission factor. N_2O was calculated in the same way. Emission factors of 55.9 kg CH_4/ha/yr and 1.4 kg N_2O/ha/yr (Kruger et al., 2012) were applied. The CH_4 emission factor is lower than the 235 kg CH_4/ha/yr that provided by the IPCC Guidelines (IPCC, 2014) but is a country specific factor. The paper indicates that some of the values were comparable in magnitude to that of other international studies, but maximum values appeared to be higher in other studies reported in the literature. It was suggested that this was possibly due to the strong seasonality of the Drakensberg sites. The seasonality of wetlands in South Africa needs to be examined more closely in the next inventory to determine if this emission factor is representative of wetlands in South Africa in general or if the emissions factor needs to be adjusted. A more in-depth investigation of the data will be completed in the next inventory.

Land converted to wetlands (3.B.4.b)

Living biomass

For land conversions a Tier 2 approach was applied. The annual increase in carbon stocks in biomass due to land conversions was estimated following methods describe in section 5.4.3.1. For *land converted to wetlands* the annual wetland growth and losses are only accounted for on the annual change area, even though the area remains in the land converted category for 20 years.

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 are cleared before being converted to a wetland, while all other conversions are slow transitions and not abrupt changes.

Litter

Calculated as discussed in section 5.4.3.1.

Mineral soils

Calculations and outputs for mineral SOC in *Land converted to Wetlands* is described in section 5.4.3.2. The rewetting default stock change factor of 0.8 was applied.

5.4.9.3 Uncertainties and time series consistency

Uncertainties on land areas is discussed in section 5.4.5.1. Since there is no specific uncertainty data on the biomass data a value of ±20% was assigned to biomass changes as the uncertainty on global maps is between 13% and 32% (Baccini et al., 2012; Saatchi et al. 2011) and since country specific data is applied the uncertainty is expected to be less. As indicated for Forest lands, the uncertainty on DOM and SOC data is assumed to be ±30% and ±35% respectively.

5.4.9.4 Category specific QA/QC and verification

All general QC listed in Table 1.8 were completed for this category. Land areas were checked. Carbon emission factors were compared to literature, and to IPCC values. Where possible outputs were compared to the NTCSA (DEA, 2015; DEFF, 2020). SOC change values were compared to a Tier 1 approach (see section 5.4.3.2).

5.4.9.5 Category-specific recalculations

CH_4 emissions were recalculated due to the inclusion of a country specific factor. Emissions were 125% higher than in the previous submission. There were no recalculations for the CO_2 or N_2O as these were not included in the previous inventory.

5.4.9.6 Category-specific planned improvements

It is planned that in the future the data from the Blue Carbon Study (Raw et al., 2020) be included, along with organic soils. In addition, the CH_4 and N_2O emission factors will be further investigated to ensure they are representative of all wetlands.

5.4.10 Settlements (3.B.5)

5.4.10.1 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 2020 (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.

5.4.10.2 Methodological issues

Settlements remaining settlements (3.B.5.a)

Living biomass

In the previous inventory the percentage wooded area was determined for the settlement category by using the percentage woodland and shrubland area of settlements from Fairbanks et al. (2000). This was not done in this inventory since carbon density data was being applied it is assumed that the carbon biomass value determined for settlements would be an average over the settlement area since it is spatial data. Biomass gains and losses were determined as for *Forest land remaining forest land*.

Litter

The Tier 1 assumption for the litter pool is that the stocks in *Settlements remaining settlements* are not changing over time, therefore litter changes are reported to be zero.

Mineral soils

Annual change in carbon stocks in mineral soils for *settlements remaining settlements* were calculated as discussed in section 5.4.3.2.

Land converted to settlements (3.B.5.b)

Living biomass

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.

Litter

The changes in litter are determined from the data provided in **Table 5. 42**. It is assumed that change occurs slowly over the 20-year default transition period.

Mineral soils

Calculations and outputs for mineral SOC in *Land converted to Settlements* is described in section 5.4.3.2.

5.4.10.3 Uncertainties and time series consistency

The time series is consistent. Uncertainties on land areas is discussed in section 5.4.5.1. Since there is no specific uncertainty data on the carbon density data a value of ±20% was assigned to biomass changes as the uncertainty on global maps is between 13% and 32% (Baccini et al., 2012; Saatchi et al. 2011) and since country specific data is applied the uncertainty is expected to be less. As indicated for Forest lands, the uncertainty on DOM and SOC data is assumed to be ±30% and 35% respectively.

5.4.10.4 Category specific QA/QC and verification

All general QC listed in Table 1.8 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.

5.4.10.5 Category-specific recalculations

Recalculations were completed for the *Settlements* land category for the full time series due to several improvements:

a) Inclusion of 1990 to 2018 land change data and updated land change assumptions.
b) Inclusion of wetlands converted to settlements.
c) Updated biomass and litter data based on the updated NTCSA (DEFF, 2020).

d) Country specific SOC reference data and updated Tier 2 methods using land change data per soil type.

In the previous inventory Settlements were estimated to be a small source of emissions between 2000 and 2010, after which it became a sink. This sink increased from 2010 to 2017. The recalculated estimates now show Settlements to be a larger sink. In 2017 the previous inventory estimated a sink of 397 Gg CO_2e, while the recalculated estimate is 1 166 Gg CO_2e. The trend is still the same with the sink increasing over time (Figure 5.24). *Settlements remaining settlements* and *Wetlands converted to settlements* are the major contributors to the increased sink.

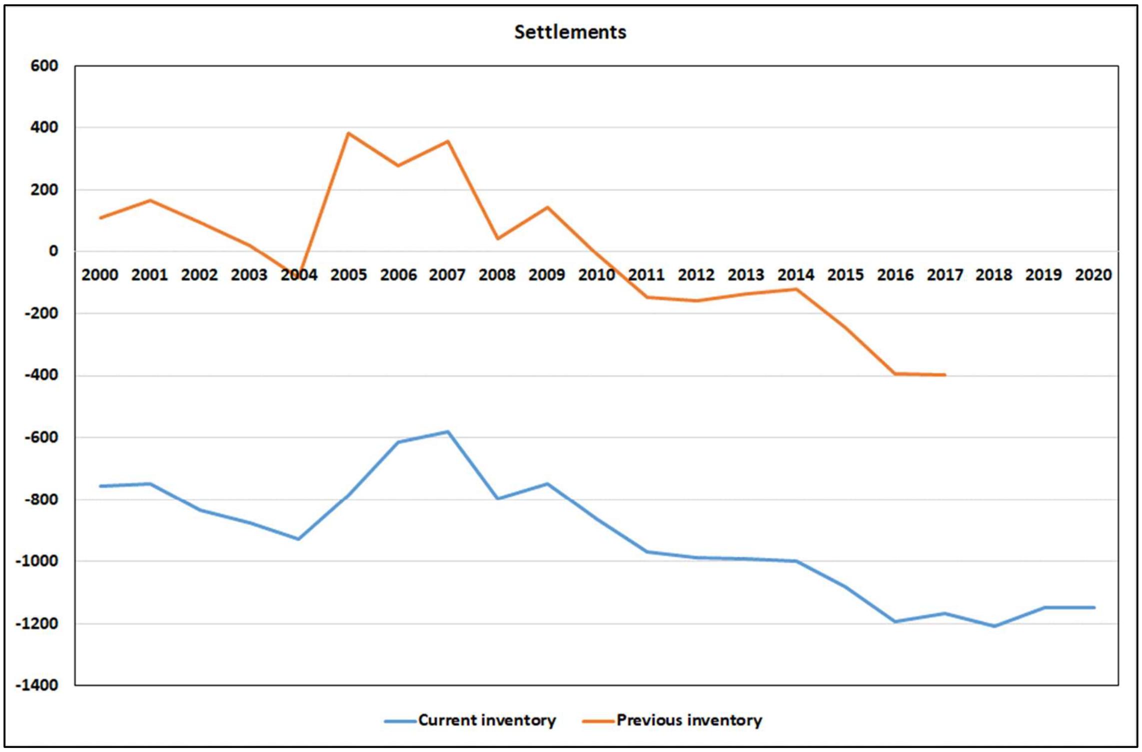

Figure 5.24: Recalculations for Settlements.

5.4.10.6 Category-specific planned improvements

The detailed SANLC maps contain much greater detail than the 20 land class change maps in terms of settlements. This data will be incorporated to determine an improved biomass value for each of the 20 class settlement categories.

5.4.11 Other lands (3.B.6)

5.4.11.1 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.

5.4.11.2 Methodological issues

Other lands remaining other lands (3.B.6.a)

Living biomass

Tier 1 of IPCC 2006 assumes that there are no carbon gains or losses on *other lands remaining other lands*.

Litter

The Tier 1 assumption for the litter pool is that the stocks in *Other lands remaining other lands* are zero.

Mineral soils

It is assumed that there are no changes in the SOC in *Other land remaining Other land*.

Land converted to other lands (3.B.6.b)

Living biomass

For this a Tier 2 approach was applied. The change in carbon stocks in biomass due to land conversions was estimated following the methodology provided in section 5.4.3.1. 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.

Litter

The changes in litter are determined from the data provided in Table 5. 42 and it assumes that the change occurs slowly over the 20-year default transition period.

Mineral soils

Annual change in carbon stocks in mineral soils for *land converted to other lands* were calculated as discussed in section 5.4.3.2. The Tier 1 assumption that the final carbon stock is zero was adjusted based on review comments.

5.4.11.3 Uncertainties and time series consistency

The time series is consistent. Uncertainties on land areas is discussed in section 5.4.5.1. *Other land* is assumed not to have any biomass or litter. As indicated for Forest lands, the uncertainty on SOC data is assumed to be ±35% respectively.

5.4.11.4 Category specific QA/QC and verification

All general QC listed in Table 1.8 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.

5.4.11.5 Category-specific recalculations

Recalculations were completed for the *Other land* category for the full time series due to a number of improvements:

a) Inclusion of 1990 to 2018 land change data and updated land change assumptions.
b) Updated biomass and litter for other land categories being converted to *Other lands*.
c) Inclusion of stock changes for wetlands being converted to other lands.
d) Soil stock change factor adjust to 0.7 so final soil carbon not assumed to be zero.

Other land recalculations led to a 54.7% decline in the *Other land* source due to land changes with conversions from wetlands and settlements contributing the most.

5.4.11.6 Category-specific planned improvements

No category specific improvements are planned for this category.

5.5 Other (3.D)

5.5.1 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 HWPs to annual CO_2 emissions or removals. HWPs include all wood material that leaves harvest sites.

5.5.2 Harvested wood products (3.D.1)

5.5.2.1 Methodological issues

All the data on production was obtained from Forestry SA (FSA, 2018) from 1990, while export data was obtained from the SARS website at https://tools.sars.gov.za/tradestatsportal/data_download.aspx. The production data was split into sawlogs and veneer logs, and pulpwood. Sawlogs and veneer data then had to be split into sawnwood and wood-based panels and this was done using the fraction sales of timber to sawn timber and panel products (FSA, 2019).

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 5.2 and 5.3 (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.

$$f_{IRW}(i) = (IRW_P(i) - IRW_{EX}(i)) / (IRW_P(i) + IRW_{IM}(i) - IRW_{EX}(i) \qquad (Eq.\ 5.1)$$

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})

$$f_{PULP}(i) = (PULP_P(i) - PULP_{EX}(i)) / (PULP_P(i) + PULP_{IM}(i) - PULP_{EX}(i)) \qquad (Eq.\ 5.2)$$

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 5.4 (Eq 2.8.4 KP Supplement) to estimate the HWP contribution of the aggregate commodities sawnwood, wood-based panels and paper and paperboard.

$$HWP_j(i) = HWP_P(i) * f_{DP}(i) * f_j(i) \qquad (Eq.\ 5.3)$$

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 5.5 (Eq 12.1 in 2006 IPCC Guidelines)) was applied to estimate the HWP contribution:

$$C(i+1) = e^{-k} * C(i) + ((1 - e^{-k})/k) * Inflow(i) \qquad (Eq.\ 5.4)$$

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 5.6 (Eq 2.8.6 KP Supplement):

$$C(t_0) = Inflow_{average}/k \qquad (Eq.\ 5.5)$$

Where:

$$Inflow_{average} = (\sum_{i=t0}^{t4} Inflow(i))/5 \qquad (Eq.\ 5.6)$$

$C(t_0)$ was taken to be 1990 (S. Ruter, pers. comm.) and was substituted into Eq 5.5 so that $C(i)$ and $\Delta C(i)$ in the sequential time instants can be calculated.

5.5.2.2 Uncertainties and time series consistency

The activity data was obtained from Forestry SA from 1990 and is consistent over the time-series. Uncertainties for activity data and parameters associated with HWP variables are provided in the IPCC Guidelines (IPCC 2006, Volume 4, p. 12.22). Production and trade data have an uncertainty of ±50% since 1961, while the product volume to product weight factors and oven-dry product weight to carbon weight have uncertainties of ±25% and ±10%, respectively. There was also a ±50% uncertainty on the half-life values.

5.5.2.3 Category specific QA/QC and verification

In the previous inventory the data was run through the Wood Carbon Monitor model and the outputs correlated well which meant the calculation file is set up correctly. In this inventory the country specific data was populated into the same file.

5.5.2.4 Category-specific recalculations

Recalculations were performed for the entire time series due to the inclusion of country specific data. There was a 24% decrease in the sink for 2017, however this data varied from year to year with an increase in some years and a decrease in others.

5.5.2.5 Category-specific planned improvements

A more detailed assessment of HWP is proposed, one which includes a wider range of products. In addition, as indicated in the review, the production data outputs should be compared to other approaches, such as the atmospheric approach, as a quality checking process.

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Chapter 6: Waste

6.1 Sector overview

Methane is generated during anaerobic fermentation of degradable organic waste deposited in landfill sites (IPCC, 2006). If waste were not disposed of in landfill sites, the degradation would take place in aerobic conditions without the formation of methane. Methane emissions from waste disposal in Landfill sites are thus of anthropogenic origin and, consequently, a constituent part of national GHG inventories in accordance with the 2006 IPCC guidelines.

This chapter highlights the GHG emissions into the atmosphere from managed landfill sites, open burning of waste, biological treatment of solid waste and wastewater treatment systems in South Africa, estimated using the IPCC 2006 Guidelines and 2019 refinements for National Greenhouse Gas Inventories. In South Africa, CH_4 emissions from solid waste disposal sites (landfill sites) are the largest source of greenhouse gas emissions in the Waste Sector, followed by CH_4 emissions from wastewater treatment and discharge.

Various improvements have been made in the current waste sector inventory covering the period 2000 - 2020 to enhance the accuracy of emissions estimates and take into account national circumstances. These are discussed in detail under category-specific improvements.

In the past GHG inventories, the waste sector only covered three sources. In the current 2000 – 2020 GHG inventory, the waste sector considers the following sources:

- 4A Solid waste disposal;
  - CH_4 emissions from Managed Solid Waste Disposal Sites
- 4B Biological Treatment of Solid Waste, CH_4 and N_2O emissions from:
  - from Composting (*New Source*)
  - Anaerobic Digestion at Biogas Facilities (*New Source*)
- 4C Open burning of waste; and
- 4D Wastewater treatment and discharge, CH_4 and indirect N_2O emissions from treatment of wastewater.
  - Domestic Wastewater treatment and discharge.
  - Industrial Wastewater treatment and discharge (*New Source*)

For completeness in this sector, emissions from incineration still need to be addressed. Emissions from use of solid waste as fuel for combustion in Energy Industries and Manufacturing Industries are reported in the *Energy* Sector.

6.1.1 Overview of shares and trends in emissions

In South Africa the total *Waste* sector emissions for 2020 were 23 046 Gg CO_2e (Table 6.1) of total net national emissions*.* The majority of these emissions are from *Solid waste disposal* contributing 18 253 Gg CO_2e (79.2%) of the total *Waste* sector emissions. *Wastewater treatment and discharge* contributed a further 4 458 Gg CO_2e (19.3%) of waste emissions while *open burning* of waste contributed 335 Gg CO_2e (1.5%). Emissions from the *biological treatment of solid waste were estimated to be insignificant* (0.0019 Gg CO_2e). *Solid waste disposal* increased its contribution to the total *Waste* sector emissions by 4.5% (from 74.6% to 79.2%) since 2000. *Incineration and open burning of waste* increased its contribution since 2000 by 0.5% (1.0% to 1.5%), while the contribution from *Wastewater treatment and discharge* declined from 24.4% to 19.3% by 2020. This is largely driven by a 54.2% decline in Industrial wastewater treatment and discharge.

A detailed summary table of the 2020 Waste sector emissions is provided in Appendix C.

6.1.1.1 2020

In 2020 the *Waste* sector produced 23 046 Gg CO_2e. The largest source category is the *Solid waste disposal* which contributed 79.2% (18 253 Gg CO_2e) towards the total sector emissions.

Table 6.1: Summary of the estimated emissions from the Waste sector in 2020.

Categories	Emissions [Gg]							Total emissions
	CO_2	CH_4	N_2O	NOx	CO	NM VOCs	SO_2	(Gg CO_2e)
4. WASTE	**35.4**	**1 055.1**	**2.8**	**NE**	**NE**	**NE**	**NE**	**23 045.8**
4A Solid Waste Disposal		869.2		0.0	0.0	0.0	0.0	18 252.8
4A1 Managed Waste Disposal Sites				*NE*	*NE*	*NE*	*NE*	*NE*
4A2 Unmanaged Waste Disposal Sites				*NE*	*NE*	*NE*	*NE*	*NE*
4A3 Uncategorised Waste Disposal Sites				*NE*	*NE*	*NE*	*NE*	*NE*
4B Biological Treatment of Solid Waste		0.0	0.0	NE	NE	NE	NE	0.0
4C Incineration and Open Burning of Waste	35.4	10.6	0.2	0.0	0.0	0.0	0.0	334.9
4C1 Waste Incineration	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*
4C2 Open Burning of Waste	*35.4*	*10.6*	*0.2*	*NE*	*NE*	*NE*	*NE*	*334.9*

Categories	Emissions [Gg]							Total emissions
	CO_2	CH_4	N_2O	NOx	CO	NM VOCs	SO_2	(Gg CO_2e)
4D Wastewater Treatment and Discharge	0.00	175.3	2.5	0.0	0.0	0.0	0.0	4 458.1
4D1 Domestic Wastewater Treatment and Discharge		*132.5*	*2.5*	*NE*	*NE*	*NE*	*NE*	*3 560.8*
4D2 Industrial Wastewater Treatment and Discharge		*42.7*		*NE*	*NE*	*NE*	*NE*	*897.3*
4E Other (please specify)				0.0	0.0	0.0	0.0	0.0

Numbers may not sum exactly due to rounding off.

6.1.1.2 2000 – 2020

In the 2000 – 2020 GHG inventory, waste sector emissions have been recalculated to reflect changes in the 2019 IPCC Refinement, and from addition of new sources in particular biological treatment of solid waste and emissions from industrial wastewater treatment and discharge.

Waste sector emissions have increased by 26.3% from the 18 241 Gg CO_2e in 2000 (Table 6.2). Emissions increased steadily between 2000 and 2020 (Figure 6.1; Table 6.3). There are two likely reasons for the increase observed in the waste sector:

- The first being that the FOD methodology has an in-built lag-effect and, as a result, the reported emissions from solid waste in managed landfills in a given year are likely to be due to solid waste disposed of over the previous 10 to 15 years.
- Secondly, in South Africa the expected growth in the provision of sanitation services, particularly with respect to collecting and managing solid waste streams in managed landfills, is likely to result in an increase in emissions of more than 5% annually. In addition, at present very little methane is captured at the country's landfills and the percentages of recycled organic waste are low. Intervention mechanisms designed to reduce GHG emissions from solid waste are likely to yield significant reductions in the waste sector.

The key driver for the increase of emissions is the increase in the amount of biodegradable part of the municipal waste deposited on the SWDS. This has been adjusted in the FOD methodology by adjusting the waste composition quantities deposited in SWDS. These are discussed in detail in category specific sections.

Emissions from *Solid waste disposal* increased by 34.1% (13 610 Gg CO_2e) since 2000 to 18 253 Gg CO_2e in 2020. Emissions from *Incineration and open burning of waste* increased by 90.2% while the trend in emissions from *Wastewater treatment and discharge* remained stable over this period.

Table 6.2: GHG emissions from South Africa's Waste sector between 2000 and 2020.

IPCC Code	Source Category	Gas	2000	2020	Change (%)
4	**TOTAL WASTE**	**All**	**18 241.2**	**23 045.8**	**26.3**
4A	Solid Waste Disposal	CH_4	13 610.5	18 252.8	34.1
4B	Biological treatment of solid waste	All	0.00132	0.00.0019	-46.4
4B	Biological Treatment of Solid Waste	CH_4	0.0008	0.0011	40.2
4B	Biological Treatment of Solid Waste	N_2O	0.0005	0.0008	56.5
4C	Incineration and open burning of waste	All	176.1	334.9	90.2
4C2	*Open Burning of Waste*	CO_2	*18.6*	*35.4*	*90.2*
4C2	*Open Burning of Waste*	CH_4	*117.5*	*223.4*	*90.2*
4C2	*Open Burning of Waste*	N_2O	*40.0*	*76.1*	*90.2*
4D	Wastewater Treatment and Discharge	All	4 454.6	4 458.1	0.08
4D1	*Wastewater Treatment and Discharge*	CH_4	*1 951.2*	*2 782.9*	*42.6*
4D1	*Wastewater Treatment and Discharge*	N_2O	*545.4*	*777.9*	*42.6*
4D2	Wastewater Treatment and Discharge	CH_4	1 958.1	897.3	-54.2

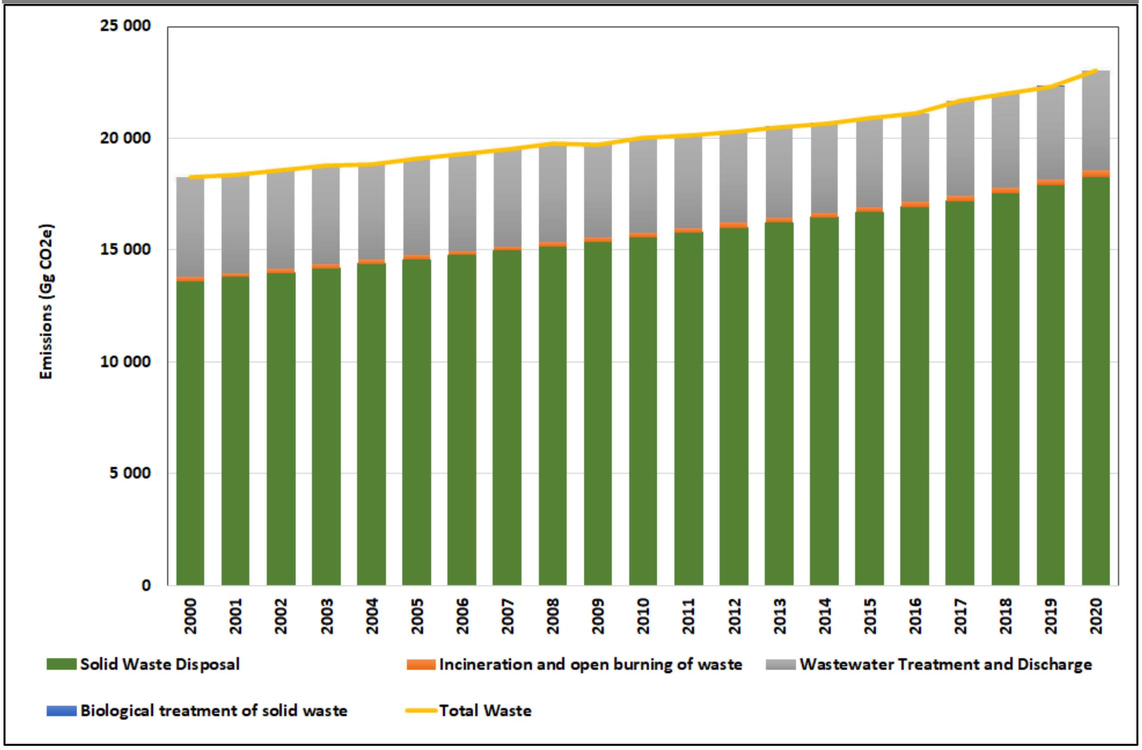

Figure 6.1: Trend in emissions from Waste sector, 2000 - 2020.

Table 6.3: Trend in Waste sector category emissions between 2000 and 2020.

	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	13 610.5	0.0	176.1	4 454.6	18 241.2
2001	13 782.7	0.0	179.7	4 381.2	18 343.6
2002	13 965.2	0.0	185.7	4 415.5	18 566.4
2003	14 175.1	0.0	187.5	4 440.5	18 803.2
2004	14 379.1	0.0	189.5	4 290.2	18 858.8
2005	14 579.6	0.0	191.7	4 314.2	19 085.5
2006	14 778.3	0.0	194.0	4 323.6	19 295.9
2007	14 976.3	0.0	196.4	4 329.0	19 501.8
2008	15 175.3	0.0	199.1	4 367.7	19 742.1
2009	15 376.6	0.0	201.9	4 153.7	19 732.3
2010	15 581.4	0.0	205.0	4 220.7	20 007.0
2011	15 791.9	0.0	208.1	4 114.0	20 113.9
2012	16 008.4	0.0	211.4	4 087.2	20 306.9
2013	16 230.9	0.0	214.7	4 045.6	20 491.1
2014	16 462.4	0.0	218.0	3 980.0	20 660.4
2015	16 698.7	0.0	221.4	3 976.2	20 896.3
2016	16 939.0	0.0	224.9	3 959.5	21 123.4
2017	17 183.9	0.0	250.7	4 264.7	21 699.3
2018	17 551.8	0.0	254.1	4 183.2	21 989.0
2019	17 908.7	0.0	257.5	4 133.1	22 299.3
2020	18 252.8	0.0	334.9	4 458.1	23 045.8

6.1.2 Overview of methodology and completeness

The emissions for the *Waste* sector were derived by either using available data or estimates based on accessible surrogate data sourced from the scientific literature. Table 6.4 shows the methods and emission factors applied in this sector. For the waste sector, among the chief limitations of quantifying the GHG emissions from different waste streams was the lack of a periodically updated national inventory on the quantities of organic waste deposited in well-managed landfills; the annual recovery of methane from landfills; quantities generated from anaerobically decomposed organic matter from wastewater treated; and per capita annual protein consumption in South Africa.

Table 6.4: Summary of methods and emission factors for the Waste sector and an assessment of the completeness of the Waste sector emissions.

GHG Source and sink category		CO_2		CH_4		N_2O		Details
		Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	
A	Solid waste disposal			T1	DF			Tier 1 FOD model was used.
B	Biological treatment of solid waste			T1	DF	T1	DF	2006 IPCC GL
C	Incineration and open burning of waste	T1	DF	T1	DF	T1	DF	2006 IPCC GL
D	Waste water treatment and discharge			T1	DF, CS	T1	DF	2006 IPCC GL

6.1.2.1 Data sources

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

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

Sub-category	Activity data	Data source
Solid waste disposal	Population data	Statistics SA (2015);
		UN (2012)
	Waste composition	IPCC 2006, and 2019 IPCC Refinement
	Waste generation rate for each component	State of Waste Report (2018)
	GDP	World bank
Biological treatment of solid waste	Mass of organic waste by biological treatment type	SAWIC, DFFE (wastewater treatment and biological treatment of solid waste study)
Open burning of waste	Population data	Statistics SA (2015);
		UN (2012)
	Fraction of population burning waste	Assumption based on population without access to waste collection services
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

6.1.3 Key categories in the Waste sector

The key categories in the Waste sector were determined to be:

Table 6.6: Key categories in the Waste sector.

IPCC Code	Category	GHG	Criteria
4A	Solid Waste Disposal	CH_4	L, T
4D1	Domestic Wastewater Treatment and Discharge	CH_4	L, T

6.1.4 Recalculations and improvements since the 2017 submission

Recalculations were performed for the category *Solid waste disposal* for all years between 2000 to the latest inventory year (2020) due to the following changes:

- Waste generation rate per person was adjusted from 578 kg/cap/yr in previous submissions to 398 kg/cap/yr in the current submission and this is consistent with the waste generation rates per capita provided in the 2019 refinement to the 2006 IPCC guidelines. This is used from the base year of 2000 until 2020.
- Waste generation rate per GDP value, for purposes of estimating the amount of industrial waste generated was adjusted from 8Gg waste/GDP/yr in previous submissions to 0.4 waste/GDP/yr in the current submission (calculated based on data contained in the 2018 state of waste report). This is used from the base year of 2000 until 2020.
- Amount sent to SWDS adjusted to 76% for MSW and 85% for Industrial waste to reflect changes in penetration of recycling and the evolution of other forms of waste management and/or treatment.

6.1.5 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, therefore, margins of error were large. No specific improvements are planned; however South Africa has identified the following areas to be considered in the improvement plan:

(i) Obtain data on the quantities of waste disposed of into managed and unmanaged landfills including its composition.
(ii) Improve the classification of landfill sites
(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.
(vi) Collect data on CH_4 recovery at SWDS based on metering data.

6.2 Solid Waste Disposal (4.A)

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. The types of waste included are bulk municipal waste, industrial waste, and sewage sludge waste. 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.

Methane flaring is an activity that occurs at a few Solid Waste Disposal Sites. Currently the projects[7] highlighted below are known to be in place to generate electricity from SWDS:

- EThekwini Municipality has two major sites, Mariannhilll and Bisasar Road (generating approx. 45 000 MWh/year).

[7] http://www.sustainable.org.za/userfiles/waste%20to%20energy%202(2).pdf

- Ekurhuleni Metropolitan Municipality with installed capacity of 1 MW Landfill Gas to electricity plant at its Simmer and Jack landfill site in Germiston.

According to the 2006 IPCC guidelines, emissions from flaring are however not significant, as the CO_2 emissions are of biogenic origin and the CH_4 and N_2O emissions are very small, so good practice in the waste sector does not require their estimation. In addition, according to the guidelines, it is good practice to only estimate and report CH_4 recovery when references documenting the amount of CH_4 recovery are available. Reporting based on metering of all gas recovered for energy and flaring or reporting of gas recovery based on the monitoring of produced amount of electricity from the gas (considering the availability of load factors, heating value and corresponding heat rate, and other factors impacting the amount of gas used to produce the monitored amount of electricity) is consistent with good practice.

6.2.1.1 Overview of shares and trends in emissions

2020

Solid waste disposal was estimated to produce 18 253 Gg CO_2e in 2020, which was all from CH_4 emissions. It contributes 79.2% to the total *Waste* sector emissions.

2000 – 2020

Emissions in this category increased by 34.1% (from 13 610 Gg CO_2e in 2000 to 18 253 Gg CO_2e in 2020). The main driver of this increase is the population numbers and therefore the amount of waste being generated.

6.2.2 Methodology

The methodology for calculating GHG emissions from solid waste is consistent with the IPCC Tier 1 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 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 2020, 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 2019.

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	
	Sewage sludge	0.06	
Methane correction factor (MCF)	Unmanaged, shallow	0.4	Unitless
	Unmanaged, deep	0.8	
	Managed	1	
	Managed, semi-aerobic	0.5	
	Uncategorized	0.6	
Fraction of methane in generated landfill gas (F)		0.5	Fraction
Oxidation factor (OF)		0	Unitless

In addition, the inventory compilers noted that the information on national waste composition presented in the National Waste Baseline Information Report (DEA, 2012) was not compatible with the approach set out in the 2006 IPCC Guidelines, therefore, even though domestic information on waste composition was available, it could not be used for the purposes of this inventory. Instead, default IPCC waste composition values were used. The National Waste Information Baseline Report (DEA, 2012) indicated that 11% of waste was recycled in 2011 and then a further 9% went to open burning. Due to a lack of data for other years, these values were assumed to be constant over the period and so the percentage of generated waste which goes to solid waste disposal sites was set at 76%.

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 DFFE has implemented the National Climate Change Response Database, which captures valuable data from mitigation and adaptation projects for future GHG estimates from landfills. This tool will be used in the future to identify and implement methane recovery projects. However, at present there are limited publicly accessible data on the quantities of methane recovered annually from managed landfills in South Africa.

The key assumptions applied in this method were:

- waste generation rate per capita was assumed to be constant (578 kg/cap/yr) (calculated based on the 2018 State of Waste Report) throughout the time series 2000 – 2020.
- percentage of MSW going into landfills was assumed to be constant (76%) throughout the time series 2000 – 2020.
- percentage of Industrial Solid Waste going into landfills was assumed to be constant (85%) throughout the time series 2000 – 2020.
- Composition of waste going into SWDS was assumed to be 26 % food, 17% garden, 18% paper, 2% wood, 0% textile, 0% nappies and 37% plastic or other inert substance (default IPCC Regional values – 2019 Refinement).
- waste generation rate per GDP (Gg/$m GDP/yr) was assumed to be constant (0,4 tonnes/per unit of GDP in US dollar) throughout the time series (calculated based on the 2018 State of Waste Report).

6.2.3 Uncertainty and time series consistency

6.2.3.1 Uncertainty

Among the chief limitations of the FOD methodology is that even if activity data improved considerably, the limitations of the data, or lack thereof, of previous years will still introduce a considerable degree of uncertainty. On the other hand, the estimated waste generations derived from previous years, back to 1950, will remain useful in future estimations of GHGs as they will aid in taking into account half-lives.

Uncertainty in this category is due mainly to the lack of data on the characterization of landfills, as well as of the quantities of waste disposed in them over the medium to long term. An uncertainty of ±30% is typical for countries that collect waste-generation data on a regular basis (IPCC 2006 Guidelines, Table 3.5). Another source of uncertainty is that methane production is calculated using bulk waste because of a lack of data on waste composition, therefore, uncertainty is more than a factor of two (DEAT, 2009). For the purpose of the bulk waste estimates, the whole of South Africa is classified as a "warm temperate dry" climate zone, even though some landfills are located in dry tropical climatic conditions. Other uncertainties are provided in Table 6.8.

6.2.3.2 Time series consistency

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

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	
	DOC_f	±20	
	MCF	±10	
	Fraction of CH_4 in generated landfill gas	±5	
	Methane recovery	±50	

6.2.4 Planned improvements

Planned improvements include:

- Collection of actual quantities of waste disposed into landfill sites for period 2000 – 2020.
- Collection of wastewater related activity data for period 2000 – 2020 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 Biological Treatment of Solid Waste (4.B)

6.3.1 Category information

In this source category only the emissions from biological treatment of Industrial Solid Waste have been taken into account. This category excludes biological treatment of Municipal Solid Waste. The GHG emissions from biological treatment of solid waste were calculated using the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. These guidelines provide default methane and nitrous oxide emission factors that were used in conjunction with the mass of waste estimated to be treated by composting or anaerobic digestion, on a dry-weight basis.

6.3.1.1 Overview of shares and trends in emissions

2020

Emissions from Biological Treatment of Solid Waste were estimated to produce 0.0019 Gg CO_2e in 2020. Emissions were considered to be insignificant as they are below 500 Gg CO_2e of the national total.

However, in the current inventory, the only waste covered that undergoes biological treatment is industrial waste and no MSW is taken into account. It is envisaged that as more data is collected on the amount of MSW that undergoes biological treatment, emissions for this category are likely to increase.

6.3.2 Methodology

A Tier 1 approach, with default IPCC 2006 emission factors, was applied in the calculation of CH_4 and N_2O emissions from biological treatment of solid waste. The amount of Industrial waste undergoing biological treatment on a dry weight basis is shown below. Emissions were estimated using Equation 4.1 of the IPCC 2006 Guidelines (IPCC, 2006; vol 5, chapt. 4; pg. 4.5).

6.3.2.1 Activity data

Activity data used to estimate emissions from this category are show in Table 6.9.

Table 6.9: Activity data for biological treatment systems.

Period	Biological Treatment System	Types of Waste	Total Annual amount treated by biological treatment facilities (Gg)	CH_4 Recovered
2000	Composting	Industrial	2677	
2001		Industrial	2781	
2002		Industrial	2955	
2003		Industrial	2866	
2004		Industrial	3096	
2005		Industrial	3215	
2006		Industrial	3333	
2007		Industrial	3622	
2008		Industrial	3957	
2009		Industrial	3803	
2010		Industrial	4052	
2011		Industrial	4156	
2012		Industrial	4315	
2013		Industrial	4386	
2014		Industrial	4409	
2015		Industrial	4335	
2016		Industrial	4357	
2017		Industrial	4099	
2018		Industrial	4741	
2019		Industrial	4842	
2020		Industrial	4189	
2000	Anaerobic digestion at biogas facilities	Industrial	5662	10.8
2001		Industrial	5732	10.9
2002		Industrial	5838	11.1
2003		Industrial	5808	11.0
2004		Industrial	5923	11.3
2005		Industrial	5888	11.2

Period	Biological Treatment System	Types of Waste	Total Annual amount treated by biological treatment facilities (Gg)	CH_4 Recovered
2006		Industrial	5729	10.9
2007		Industrial	5980	11.4
2008		Industrial	5415	10.3
2009		Industrial	7118	13.5
2010		Industrial	8324	15.8
2011		Industrial	5631	10.7
2012		Industrial	5726	10.9
2013		Industrial	5691	10.8
2014		Industrial	6260	11.9
2015		Industrial	5698	10.8
2016		Industrial	5753	10.9
2017		Industrial	5683	10.8
2018		Industrial	6078	11.5
2019		Industrial	6054	11.5
2020		Industrial	5753	10.9

6.3.2.2 Emission factors

Emission factors are shown in Table 6.10 on a dry weight basis.

Table 6.10: Emission Factors for Biological Treatment of Solid Waste

	CH_4 Emission Factors (g CH_4/kg waste treated)	N_2O Emission Factors (g N_2O/kg waste treated)
Composting	10	0.6
Anaerobic Digestion at Biogas Facilities	2	Assumed negligible

6.4 Incineration and open burning of waste (4.C)

6.4.1 Category information

According to the IPCC guidelines, open burning of waste can be defined as the combustion of unwanted combustible materials 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. Open burning can also include incineration devices that do not control the combustion air to maintain an adequate temperature and do not provide sufficient residence time for complete combustion.

In South Africa open burning of waste is considered in two cases,

- Where population do not have access to formal waste collection services. It is assumed that this portion of the population burn its waste openly.
- Small percentage of formal landfill sites who practice open burning as a means to manage waste volumes at SWDS.

In this source category only the emissions from *Open burning* have been included and emissions associated with incineration of waste are not yet considered.

Overview of shares and trends in emissions

2020

Open burning was estimated to produce 335 Gg CO_2e in 2020. Emissions were 10.4% CO_2 (35 Gg CO_2e), 66.6% CH_4 (223 Gg CO_2e) and 22.7% N_2O (76 Gg CO_2e).

2000 – 2020

Emissions in this category increased by 90.2% (159 Gg CO_2e) between 2000 and 2020 (Table 6.2).

6.4.2 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).

6.4.2.1 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% (Expert Judgement). CO_2 emissions were calculated for the different waste types using the IPCC default breakdown.

6.4.2.2 Emission factors

Emission factors are shown in Table 6.11.

Table 6.11: 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

6.4.3 Uncertainty and time series consistency

6.4.3.1 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 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%.

6.4.3.2 Time series consistency

The time series is consistent as the activity data source is the same throughout the time series.

6.4.4 Planned improvements

As a planned improvement for this sector, collection of activity data on amounts of waste incinerated, by category of waste and the technologies used to incinerate waste in South Africa.

6.5 Wastewater Treatment and Discharge (4.D)

6.5.1 Domestic wastewater treatments and discharge (4.D.1)

6.5.1.1 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.

6.5.1.2 Overview of shares and trends in emissions

2020

Wastewater treatment and discharge were estimated to produce 4 458 Gg CO_2e in 2020, of which 80% (3 561 Gg CO_2e) is from *Domestic Wastewater treatment* and 20% (897 Gg CO_2e) is from *Industrial wastewater treatment*.

2000 - 2020

Emissions from *Domestic wastewater treatment* increased by 42.6% and emissions from *Industrial wastewater treatment* and discharge decreased by 54.1% between 2000 and 2020 (Table 6.2), resulting in an overall increase of 0.08% for the entire category.

6.5.1.3 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 Biological Oxygen Demand (BOD) generated from domestic and commercial sources in South Africa annually, the yearly estimates were determined using the IPPC 2006 default Tier 1 method.

The projected methane emissions from the wastewater follow the same methodology described in the 2012 National GHG Inventory Report (DEA, 2016). The estimated methane emissions reported are from domestic and commercial sources of wastewater because the IPPC 2006 Guidelines do not stipulate a different set of equations or differentiated computational approaches for the two sources, as was previously stipulated in 1996 IPCC Guidelines. It should be noted that the data on quantities of wastewater from specific industrial sources with high organic content are largely lacking in South Africa and, therefore, the estimated values in this report are assumed to be due to domestic and industrial sources treated in municipal wastewater treatment systems. However, wastewater from commercial and industrial sources discharged into sewers is accounted for, so the term “domestic wastewater” in this inventory refers to the total wastewater discharged into sewers from all sources. This is achieved by employing the default IPCC correction factor of 1.25 used to account for commercial and industrial wastewater. It is highly likely that the I value for South Africa ranges between 1.2 and 1.4.

Activity data

To be consistent, the specific-category data described in Section 6.4.1 of the National GHG Inventory Report for 2000 (DEAT, 2009) and its underlying assumptions were adopted. In determining the total quantity of kg BOD yr^{-1}, population data was sourced from Statistics South Africa. This is the same population data as used in the FOD model.

Emission factors

Default population distribution trends between rural and urban settlements as a function of income, as well as a default average South African BOD production value of 37 g $person^{-1}$ day^{-1} were sourced from the 2006 IPCC Guidelines. Generally, it is good practice to express BOD product as a function of income, however, this information is not readily available in South Africa, therefore, it could not be included in the waste sector model. In this case, a default IPCC correction factor of 1.25 was applied in order to take into account the industrial wastewater treated in sewage treatment systems. The emissions factors for different wastewater treatment and discharge systems were taken from the 2006 IPCC Guidelines (Table 6.12) as was the data on distribution and utilization of different treatment and discharge systems (Table 6.13).

Table 6.12: Emission factors for different wastewater treatment and discharge systems

Type of treatment or discharge	Maximum CH_4 producing capacity (BOD)	CH_4 correction factor for each treatment system	Emission factor
	(kg CH_4/kg BOD)	(MCF)	(kg CH_4/kg BOD)
Septic system	0.6	0.5	0.30
Latrine – rural	0.6	0.1	0.06
Latrine – urban low income	0.6	0.5	0.30
Stagnant sewer (open and warm)	0.6	0.5	0.30
Flowing sewer	0.6	0.0	0.00
Other	0.6	0.1	0.06
None	0.6	0.0	0.00

Table 6.13: Distribution and utilization of different treatment and discharge systems

Income group	Fraction of population income group	Type of treatment or discharge pathway	Degree of utilization
		(kg CH_4/kg BOD)	(T_{ij})
Rural	0.39	Septic tank	0.10
		Latrine – rural	0.28
		Sewer stagnant	0.10
		Other	0.04
		None	0.48
Urban high-income	0.12	Sewer closed	0.70
		Septic tank	0.15
		Other	0.15
Urban low-income	0.49	Latrine – urban low income	0.24
		Septic tank	0.17
		Sewer (open and warm)	0.34
		Sewer (flowing)	0.20
		Other	0.05

Nitrous oxide emissions from Domestic and Wastewater Treatment

The default values provided by the IPCC Guidelines were used in estimating the potential growing trends of N_2O emissions from the wastewater treatment systems. This was due to the lack of specific-activity data for South Africa. For instance, a default value for per capita protein consumption of 27.96 kg/person/yr was applied in the model (FAO, 2017).

N_2O emissions from discharge of effluent

The per capita protein consumption value of 27.96 kg/person/yr was used consistently throughout the time series (sourced from the 2006 IPCC GLs). Indirect N_2O emissions were then estimated by multiplying the N effluent by the N_2O emission factor to estimate indirect N_2O emissions.

6.5.1.4 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 20-year time series and default IPCC emission factors used.

6.5.1.5 Planned improvements

There are no planned improvements for this category.

6.5.2 Industrial wastewater treatment and discharge (4.D.2)

6.5.2.1 Category information

In South Africa, it is common practice for major industrial facilities to have comprehensive in-plant or on-site wastewater treatment systems for purposes of compliance with regulatory standards for wastewater treatment and discharge.

Industrial and commercial wastewater treated anaerobically on-site (uncollected) or sewered (co-discharged) to a centralized plant (collected) or disposed untreated nearby waterbodies, generates and is a source of methane (CH_4) (IPCC 2006).

In the previous GHG inventories, South Africa has always accounted for Industrial wastewater treated in Wastewater treatment and Discharge systems using a default IPCC correction factor of 1.25 to account for commercial and industrial wastewater that is co-discharged in domestic wastewater treatment systems. This has been done because the IPCC methodology is on a per person basis and emissions from commercial wastewater are estimated as part of domestic wastewater in accordance with the 2006 IPCC guidelines.

In accordance with the 2006 IPCC guidelines, the addition to the inventory of a new category or subcategory requires the calculation of an entire time series and emissions were estimate for the period 2000 – 2020.

6.5.2.2 Overview of shares and trends in emissions

2020

Emissions from industrial wastewater treatment and discharge were estimated to produce 897 Gg CO2e in 2020. CH_4 from industrial wastewater treatment in 2020 are 54.2% lower than the level of 2000. The trend in emissions in this source category is highly dependent on changes in output in various sectors of industry.

2000 - 2020

CH_4 emissions from industrial wastewater treatment and discharge were estimated to decrease by 54.2% since 2000 levels. Emissions from category 4D2 were 1958 Gg CO2e in the year 2000 and they have declined over the time series to 897 Gg CO2e in 2020.

6.5.2.3 Methodology

The Tier 1 default IPCC methodology was used to estimate CH_4 emissions from industrial wastewater treatment using national parameters on production tonnage per sector; wastewater generated per ton of production; average concentration of Chemical Oxygen Demand (COD); and discharge pathways for the period 2000-2017 (IPCC, 2006, equation

6.4). Emissions of methane from wastewater and their sludge generated in treatment systems were considered.

A waste improvement study implemented in the year 2019, collected actual activity data for the period 2000-2017 for all the sectors of wastewater and biological solid waste, followed by developing a forecasting model for the period 2018-2035 for industrial wastewater.

Activity data

The collected data for the industrial wastewater sectors included the following parameters:

- Production tonnage per sector.
- Wastewater generated per ton of production.
- Average concentration of COD; and
- Discharge pathways

The input activity data were quantities of production per sector for the period; wastewater generated per production tonne; COD concentration in wastewater for the period 2000 – 2017 this activity data was then extrapolated to cover the entire time series. South Africa is using Sanitation Pathways study for industrial wastewater activity data.

Methane recovery in the calculation was not taken into account in view of the lack of information on projects for the collection and utilization of methane in facilities for the treatment of industrial wastewater.

The maximum methane producing capacity of CH_4 (Bo)

The calculation used the value of B_0 by default 0.25 g CH_4 / g COD (IPCC, 2006).

Methane Correction Factor

The following MCF values and emission factors were were used:

Table 6.14: MCF values and emission factors

Type of treatment or discharge	CH_4 correction factor for each treatment system	Emission factor
	(MCF)	(kg CH_4/kg BOD)
Aerobic treatment plant	0.1	0,025
Sea River	0.1	0,025

Anaerobic Lagoon (shallow)	0.2	0,05
Aerobic Lagoon (ATP not well managed)	0.3	0,075
Sea River Untreated	0.1	0,025
Anaerobic Reactor	0.8	0,2
Anaerobic Lagoon	0.2	0,05

Chemical Oxygen Demand

The content of degradable organic substances in industrial wastewater (COD). The content of organic contaminants in industrial effluents were calculated from the chemical needs for oxygen (COD) of sewage. The table below provides the COD values used.

Table 6.15: Average COD values used to estimate CH_4 emissions from industrial wastewater

Type of treatment or discharge	Chemical Oxygen Demand (COD)
Alcohol Refining	11
Starch Production	1
Beer and Malt	11
Vegetable Oils	52
Dairy Products	3
Fish Processing	2.5
Vegetables Fruits and Juices	1.5
Meat and Poultry	4.1
Organic Chemicals	3
Petroleum Refining	1
Plastic and Resins	2.9
Soap and Detergents	0.85
Pulp and Paper	17.3
Sugar	6
Wine & vinegar	6.8

6.5.2.4 Uncertainty and time series consistency

Uncertainties

The estimation of the uncertainties of CH emissions from industrial wastewater was carried out using the IPCC level 1 method (IPCC, 2000, 2006).

Time series consistency

Data was collected from industries and existing databases on industrial wastewater for the period 2000-2017. This collected data gave a better estimation of national greenhouse gas (GHG) emissions in the waste sector thereby improving the accuracy in compilation of the national GHG emissions inventory for South Africa. A baseline and forecasting model was developed for the years 2018-2020 using collected activity data (2000-2017) from the previous waste improvement study.

6.5.2.5 Planned improvements

In future inventories, it is planned to continue collecting more detailed data on the applied technologies of wastewater treatment in various industries the use of the mandatory GHG reporting regime. Work will also continue the analysis and assessment of the data reported through the SAGERS to enhance the accuracy of the emissions from this category.

6.6 References

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Appendix A: Key category analysis

Table A.1: Level assessment on emissions excluding FOLU for South Africa (2000) with the key categories highlighted in green.

IPCC Category code	IPCC Category	Fuel type	GHG	2020 Ex,t (Gg CO_2e)	Lx,t	Cumulative Total
1A1a	Electricity and Heat Production	Solid	CO_2	185027.4	0.398	0.398
1A3b	Road Transport	Liquid	CO_2	36302.9	0.078	0.476
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	CO_2	30454.7	0.065	0.541
1B3	Other Emissions from Energy Production		CO_2	28146.6	0.061	0.602
3A1a	Enteric fermentation - cattle		CH_4	23901.0	0.051	0.653
1A2	Manufacturing Industries and Construction	Solid	CO_2	19545.0	0.042	0.695
1A4a	Commercial/Institutional	Solid	CO_2	18248.1	0.039	0.735
2C1	Iron and Steel Production		CO_2	15334.4	0.033	0.768
1A5a	Stationary	Solid	CO_2	14272.3	0.031	0.798
4A	Solid Waste Disposal		CH_4	13610.5	0.029	0.828
2C2	Ferroalloys Production		CO_2	8079.1	0.017	0.845
1A2	Manufacturing Industries and Construction	Gas	CO_2	6520.2	0.014	0.859
3A1c	Enteric fermentation - sheep		CH_4	5837.3	0.013	0.872
3C4	Direct N_2O emissions from managed soils		N_2O	4093.0	0.009	0.880
2A1	Cement Production		CO_2	3870.6	0.008	0.889
1A4b	Residential	Solid	CO_2	3604.2	0.008	0.896
1A5a	Stationary	Liquid	CO_2	2888.6	0.006	0.903
1A4b	Residential	Liquid	CO_2	2868.4	0.006	0.909
1A2	Manufacturing Industries and Construction	Liquid	CO_2	2564.8	0.006	0.914
1B1a	Coal mining and handling		CH_4	2338.1	0.005	0.919
1B3	Other Emissions from Energy Production		CH_4	2318.6	0.005	0.924

1A1b	Petroleum Refining	Gas	CO_2	2307.1	0.005	0.929
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	CO_2	2251.0	0.005	0.934
1A3a	Civil Aviation	Liquid	CO_2	2249.1	0.005	0.939
1A4a	Commercial/Institutional	Liquid	CO_2	2028.6	0.004	0.943
4D2	Industrial Wastewater Treatment and Discharge		CH_4	1958.1	0.004	0.948
4D1	Wastewater Treatment and Discharge		CH_4	1951.2	0.004	0.952
1A1b	Petroleum Refining	Liquid	CO_2	1735.5	0.004	0.956
2B	Chemical industry		C	C	0.004	0.959
3A1d	Enteric fermentation - goats		CH_4	1493.1	0.003	0.962
3A2a	Manure management - cattle		N_2O	1249.4	0.003	0.965
2C3	Aluminium Production		CO_2	1091.3	0.002	0.967
2C3	Aluminium Production		PFCs	983.2	0.002	0.969
1A1a	Electricity and Heat Production	Solid	N_2O	893.9	0.002	0.971
3A2a	Manure management - cattle		CH_4	881.6	0.002	0.973
1B2a	Oil		CO_2	752.0	0.002	0.975
3C5	Indirect N_2O emissions from managed soils		N_2O	737.5	0.002	0.976
3A2i	Manure management - poultry		N_2O	651.9	0.001	0.978
1A4a	Commercial/Institutional	Gas	CO_2	631.0	0.001	0.979
3C1c	Biomass burning in grasslands		N_2O	557.4	0.001	0.980
1A3c	Railways	Liquid	CO_2	551.5	0.001	0.982
4D1	Wastewater Treatment and Discharge		N_2O	545.4	0.001	0.983
1A3b	Road Transport	Liquid	N_2O	545.1	0.001	0.984
2B	Chemical industry		C	C	0.001	0.985
1A4b	Residential	Solid	N_2O	439.1	0.001	0.986
2B	Chemical industry		C	C	0.001	0.987
2A2	Lime Production		CO_2	426.1	0.001	0.988
3C1c	Biomass burning in grasslands		CH_4	413.5	0.001	0.989

3C2	Liming		CO_2	384.1	0.001	0.990
3C1a	Biomass burning in forest land		N_2O	298.7	0.001	0.990
3C3	Urea application		CO_2	297.3	0.001	0.991
3C1a	Biomass burning in forest land		CH_4	293.6	0.001	0.991
1A3b	Road Transport	Liquid	CH_4	247.9	0.001	0.992
3C1b	Biomass burning in croplands		CH_4	235.6	0.001	0.992
1A3d	Water-Borne Navigation	Liquid	CO_2	222.2	0.000	0.993
1A2	Manufacturing Industries and Construction	Solid	N_2O	216.6	0.000	0.993
1A4b	Residential	Solid	CH_4	206.2	0.000	0.994
3C6	Indirect N_2O emissions from manure management		N_2O	201.4	0.000	0.994
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	CO_2	199.5	0.000	0.995
3A2h	Manure management - swine		CH_4	192.0	0.000	0.995
2D1	Lubricant Use		CO_2	188.5	0.000	0.996
3A2c	Manure management - sheep		N_2O	185.3	0.000	0.996
1A4a	Commercial/Institutional	Solid	N_2O	176.3	0.000	0.996
2B	Chemical industry		C	C	0.000	0.997
1A1a	Electricity and Heat Production	Liquid	CO_2	121.3	0.000	0.997
4C2	Open Burning of Waste		CH_4	117.5	0.000	0.997
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	N_2O	110.3	0.000	0.997
2C6	Zinc Production		CO_2	108.4	0.000	0.998
3A1f	Enteric fermentation - horses		CH_4	102.1	0.000	0.998
3C1b	Biomass burning in croplands		N_2O	90.2	0.000	0.998
3A2i	Manure management - poultry		CH_4	84.2	0.000	0.998
2A3	Glass Production		CO_2	74.4	0.000	0.998
3A2d	Manure management - goats		N_2O	69.2	0.000	0.998
1A5a	Stationary	Solid	N_2O	69.0	0.000	0.999
1A2	Manufacturing Industries and Construction	Solid	CH_4	66.4	0.000	0.999

1A3c	Railways	Liquid	N_2O	66.0	0.000	0.999
2B	Chemical industry		C	C	0.000	0.999
1A1a	Electricity and Heat Production	Solid	CH_4	40.4	0.000	0.999
4C2	Open Burning of Waste		N_2O	40.0	0.000	0.999
3A1h	Enteric fermentation - swine		CH_4	39.8	0.000	0.999
3A2h	Manure management - swine		N_2O	34.7	0.000	0.999
3A1g	Enteric fermentation - mules and asses		CH_4	34.4	0.000	0.999
1B1a	Coal mining and handling		CO_2	30.6	0.000	1.000
3A2c	Manure management - sheep		CH_4	22.1	0.000	1.000
4C2	Open Burning of Waste		CO_2	18.6	0.000	1.000
3C1d	Biomass burning in wetlands		N_2O	16.7	0.000	1.000
2C5	Lead Production		CO_2	15.1	0.000	1.000
3C1d	Biomass burning in wetlands		CH_4	12.4	0.000	1.000
3A2d	Manure management - goats		CH_4	11.3	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	CH_4	10.6	0.000	1.000
3C1e	Biomass burning in settlements		N_2O	10.5	0.000	1.000
3C1e	Biomass burning in settlements		CH_4	7.8	0.000	1.000
2D2	Paraffin Wax Use		CO_2	7.4	0.000	1.000
1A5a	Stationary	Liquid	N_2O	7.4	0.000	1.000
1A2	Manufacturing Industries and Construction	Liquid	N_2O	6.4	0.000	1.000
1A3a	Civil Aviation	Liquid	N_2O	5.9	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	N_2O	5.6	0.000	1.000
1A4b	Residential	Liquid	N_2O	5.4	0.000	1.000
1A4a	Commercial/Institutional	Liquid	N_2O	4.9	0.000	1.000
1A2	Manufacturing Industries and Construction	Gas	N_2O	4.2	0.000	1.000
1A4a	Commercial/Institutional	Solid	CH_4	4.0	0.000	1.000
1A1b	Petroleum Refining	Liquid	N_2O	3.6	0.000	1.000

1A3b	Road Transport	Gas	CO_2	3.4	0.000	1.000
2C2	Ferroalloys Production		CH_4	3.3	0.000	1.000
1A5a	Stationary	Solid	CH_4	3.1	0.000	1.000
1A2	Manufacturing Industries and Construction	Gas	CH_4	2.8	0.000	1.000
1A5a	Stationary	Liquid	CH_4	2.5	0.000	1.000
1A2	Manufacturing Industries and Construction	Liquid	CH_4	2.2	0.000	1.000
1A4b	Residential	Liquid	CH_4	2.0	0.000	1.000
1A3a	Civil Aviation	Liquid	CH_4	2.0	0.000	1.000
2B	Chemical industry		C	C	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	N_2O	1.9	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	CH_4	1.9	0.000	1.000
1A4a	Commercial/Institutional	Liquid	CH_4	1.7	0.000	1.000
1A3d	Water-Borne Navigation	Liquid	N_2O	1.3	0.000	1.000
1A1b	Petroleum Refining	Gas	N_2O	1.2	0.000	1.000
1A1b	Petroleum Refining	Liquid	CH_4	1.2	0.000	1.000
1A1b	Petroleum Refining	Gas	CH_4	0.8	0.000	1.000
1A3c	Railways	Liquid	CH_4	0.6	0.000	1.000
1A3d	Water-Borne Navigation	Liquid	CH_4	0.4	0.000	1.000
1A4a	Commercial/Institutional	Gas	N_2O	0.3	0.000	1.000
1A1a	Electricity and Heat Production	Liquid	N_2O	0.3	0.000	1.000
1A4a	Commercial/Institutional	Gas	CH_4	0.2	0.000	1.000
1A1a	Electricity and Heat Production	Liquid	CH_4	0.1	0.000	1.000
1A3b	Road Transport	Gas	CH_4	0.1	0.000	1.000
2B	Chemical industry		C	C	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	CH_4	0.0	0.000	1.000
1A3b	Road Transport	Gas	N_2O	0.0	0.000	1.000
4B	Biological Treatment of Solid Waste - Industrial Waste		CH_4	0.0	0.000	1.000

4B	Biological Treatment of Solid Waste - Industrial Waste		N_2O	0.0	0.000	1.000
1A1a	Electricity and Heat Production	Gas	CO_2	0.0	0.000	1.000
1A1b	Petroleum Refining	Solid	CO_2	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	CO_2	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	CO_2	0.0	0.000	1.000
1A1a	Electricity and Heat Production	Gas	CH_4	0.0	0.000	1.000
1A1b	Petroleum Refining	Solid	CH_4	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	CH_4	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	CH_4	0.0	0.000	1.000
1A1a	Electricity and Heat Production	Gas	N_2O	0.0	0.000	1.000
1A1b	Petroleum Refining	Solid	N_2O	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	N_2O	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	N_2O	0.0	0.000	1.000
1A3a	Civil Aviation	Gas	CO_2	0.0	0.000	1.000
1A3c	Railways	Gas	CO_2	0.0	0.000	1.000
1A3d	Water-Borne Navigation	Gas	CO_2	0.0	0.000	1.000
1A3a	Civil Aviation	Gas	CH_4	0.0	0.000	1.000
1A3c	Railways	Gas	CH_4	0.0	0.000	1.000
1A3d	Water-Borne Navigation	Gas	CH_4	0.0	0.000	1.000
1A3a	Civil Aviation	Gas	N_2O	0.0	0.000	1.000
1A3c	Railways	Gas	N_2O	0.0	0.000	1.000
1A3d	Water-Borne Navigation	Gas	N_2O	0.0	0.000	1.000
2A4	Other Process Uses of Carbonates		CO_2	0.0	0.000	1.000
2B	Chemical industry		C	C	0.000	1.000
2B	Chemical industry		C	C	0.000	1.000
2B	Chemical industry		C	C	0.000	1.000
2B	Chemical industry		C	C	0.000	1.000

2C1	Iron and Steel Production		CH_4	0.0	0.000	1.000
2F1	Refrigeration and Air Conditioning		HFCs	0.0	0.000	1.000
2F2	Foam Blowing Agents		HFCs	0.0	0.000	1.000
2F3	Fire Protection		HFCs	0.0	0.000	1.000
2F4	Aerosols		HFCs	0.0	0.000	1.000
3A1j	Enteric fermentation - other game		CH_4	0.0	0.000	1.000
3A2f	Manure management - horses		CH_4	0.0	0.000	1.000
3A2g	Manure management - mules and asses		CH_4	0.0	0.000	1.000
3A2j	Manure management - other game		CH_4	0.0	0.000	1.000
3C1f	Biomass burning in other lands		CH_4	0.0	0.000	1.000
3C1f	Biomass burning in other lands		N_2O	0.0	0.000	1.000

**C=Confidential data*

Table A.2: Level assessment on emissions including FOLU for South Africa (2000) with the key categories highlighted in green.

IPCC Category code	IPCC Category	Fuel type	GHG	2000 Ex,t (Gg CO_2e)	Lx,t	Cumulative Total
1A1a	Electricity and Heat Production	Solid	CO_2	185027.4	0.364	0.364
1A3b	Road Transport	Liquid	CO_2	36 302.9	0.071	0.435
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	CO_2	30 454.7	0.060	0.495
1B3	Other Emissions from Energy Production		CO_2	28 146.6	0.055	0.550
3A1a	Enteric fermentation - cattle		CH_4	23 901.0	0.047	0.597
1A2	Manufacturing Industries and Construction	Solid	CO_2	19 545.0	0.038	0.635
1A4a	Commercial/Institutional	Solid	CO_2	18 248.1	0.036	0.671
2C1	Iron and Steel Production		CO_2	15 334.4	0.030	0.701
1A5a	Stationary	Solid	CO_2	14 272.3	0.028	0.729
4A	Solid Waste Disposal		CH_4	13 610.5	0.027	0.756
3B1b	Land converted to forest land - Net CO_2		CO_2	-13 471.5	0.026	0.783
3B3b	Land converted to grassland - Net CO_2		CO_2	-9 697.1	0.019	0.802
2C2	Ferroalloys Production		CO_2	8 079.1	0.016	0.818
1A2	Manufacturing Industries and Construction	Gas	CO_2	6 520.2	0.013	0.830
3B6b	Land converted to other lands - Net CO_2		CO_2	6 126.9	0.012	0.842
3A1c	Enteric fermentation - sheep		CH_4	5 837.3	0.011	0.854
3C4	Direct N_2O emissions from managed soils		N_2O	4 093.0	0.008	0.862
2A1	Cement Production		CO_2	3 870.6	0.008	0.869
1A4b	Residential	Solid	CO_2	3 604.2	0.007	0.877
3B2b	Land converted to cropland - Net CO_2		CO_2	3 314.2	0.007	0.883
1A5a	Stationary	Liquid	CO_2	2 888.6	0.006	0.889
1A4b	Residential	Liquid	CO_2	2 868.4	0.006	0.894
1A2	Manufacturing Industries and Construction	Liquid	CO_2	2 564.8	0.005	0.899

1B1a	Coal mining and handling		CH_4	2 338.1	0.005	0.904
1B3	Other Emissions from Energy Production		CH_4	2 318.6	0.005	0.909
1A1b	Petroleum Refining	Gas	CO_2	2 307.1	0.005	0.913
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	CO_2	2 251.0	0.004	0.918
1A3a	Civil Aviation	Liquid	CO_2	2 249.1	0.004	0.922
3D1	Harvested wood products		CO_2	-2 106.2	0.004	0.926
1A4a	Commercial/Institutional	Liquid	CO_2	2 028.6	0.004	0.930
4D2	Industrial Wastewater Treatment and Discharge		CH_4	1 958.1	0.004	0.934
4D1	Wastewater Treatment and Discharge		CH_4	1 951.2	0.004	0.938
1A1b	Petroleum Refining	Liquid	CO_2	1 735.5	0.003	0.941
3B1a	Forest land remaining forest land - Net CO_2		CO_2	-1 704.8	0.003	0.945
2B	Chemical industry		C	C	0.003	0.948
3B4	Wetland		CH_4	1 587.9	0.003	0.951
3B5a	Settlements remaining settlements - Net CO_2		CO_2	-1 554.0	0.003	0.954
3B2a	Cropland remaining cropland - Net CO_2		CO_2	-1 527.0	0.003	0.957
3A1d	Enteric fermentation - goats		CH_4	1 493.1	0.003	0.960
3A2a	Manure management - cattle		N_2O	1 249.4	0.002	0.962
2C3	Aluminium Production		CO_2	1 091.3	0.002	0.964
3B3a	Grassland remaining grassland - Net CO_2		CO_2	-1 001.1	0.002	0.966
2C3	Aluminium Production		PFCs	983.2	0.002	0.968
1A1a	Electricity and Heat Production	Solid	N_2O	893.9	0.002	0.970
3A2a	Manure management - cattle		CH_4	881.6	0.002	0.972
3B5b	Land converted to settlements - Net CO_2		CO_2	798.1	0.002	0.973
1B2a	Oil		CO_2	752.0	0.001	0.975
3C5	Indirect N_2O emissions from managed soils		N_2O	737.5	0.001	0.976
3A2i	Manure management - poultry		N_2O	651.9	0.001	0.978
1A4a	Commercial/Institutional	Gas	CO_2	631.0	0.001	0.979

3B4	Wetland		N_2O	581.4	0.001	0.980
3C1c	Biomass burning in grasslands		N_2O	557.4	0.001	0.981
1A3c	Railways	Liquid	CO_2	551.5	0.001	0.982
4D1	Wastewater Treatment and Discharge		N_2O	545.4	0.001	0.983
1A3b	Road Transport	Liquid	N_2O	545.1	0.001	0.984
2B	Chemical industry		C	C	0.001	0.985
3B4b	Land converted to wetland		CO_2	-481.1	0.001	0.986
1A4b	Residential	Solid	N_2O	439.1	0.001	0.987
2B	Chemical industry		C	C	0.001	0.988
2A2	Lime Production		CO_2	426.1	0.001	0.989
3C1c	Biomass burning in grasslands		CH_4	413.5	0.001	0.990
3C2	Liming		CO_2	384.1	0.001	0.990
3C1a	Biomass burning in forest land		N_2O	298.7	0.001	0.991
3C3	Urea application		CO_2	297.3	0.001	0.992
3C1a	Biomass burning in forest land		CH_4	293.6	0.001	0.992
1A3b	Road Transport	Liquid	CH_4	247.9	0.000	0.993
3C1b	Biomass burning in croplands		CH_4	235.6	0.000	0.993
1A3d	Water-Borne Navigation	Liquid	CO_2	222.2	0.000	0.993
1A2	Manufacturing Industries and Construction	Solid	N_2O	216.6	0.000	0.994
1A4b	Residential	Solid	CH_4	206.2	0.000	0.994
3C6	Indirect N_2O emissions from manure management		N_2O	201.4	0.000	0.995
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	CO_2	199.5	0.000	0.995
3A2h	Manure management - swine		CH_4	192.0	0.000	0.995
2D1	Lubricant Use		CO_2	188.5	0.000	0.995
3A2c	Manure management - sheep		N_2O	185.3	0.000	0.995
1A4a	Commercial/Institutional	Solid	N_2O	176.3	0.000	0.996
2B	Chemical industry		C	C	0.000	0.996

1A1a	Electricity and Heat Production	Liquid	CO_2	121.3	0.000	0.996
4C2	Open Burning of Waste		CH_4	117.5	0.000	0.997
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	N_2O	110.3	0.000	0.997
2C6	Zinc Production		CO_2	108.4	0.000	0.997
3A1f	Enteric fermentation - horses		CH_4	102.1	0.000	0.997
3C1b	Biomass burning in croplands		N_2O	90.2	0.000	0.997
3A2i	Manure management - poultry		CH_4	84.2	0.000	0.997
2A3	Glass Production		CO_2	74.4	0.000	0.998
3A2d	Manure management - goats		N_2O	69.2	0.000	0.998
1A5a	Stationary	Solid	N_2O	69.0	0.000	0.998
1A2	Manufacturing Industries and Construction	Solid	CH_4	66.4	0.000	0.998
1A3c	Railways	Liquid	N_2O	66.0	0.000	0.998
2B	Chemical industry		C	C	0.000	0.998
1A1a	Electricity and Heat Production	Solid	CH_4	40.4	0.000	0.998
4C2	Open Burning of Waste		N_2O	40.0	0.000	0.998
3A1h	Enteric fermentation - swine		CH_4	39.8	0.000	0.999
3B4a	Wetland remaining wetland		CO_2	39.1	0.000	0.999
3A2h	Manure management - swine		N_2O	34.7	0.000	0.999
3A1g	Enteric fermentation - mules and asses		CH_4	34.4	0.000	0.999
1B1a	Coal mining and handling		CO_2	30.6	0.000	0.999
3A2c	Manure management - sheep		CH_4	22.1	0.000	0.999
4C2	Open Burning of Waste		CO_2	18.6	0.000	0.999
3C1d	Biomass burning in wetlands		N_2O	16.7	0.000	0.999
2C5	Lead Production		CO_2	15.1	0.000	0.999
3C1d	Biomass burning in wetlands		CH_4	12.4	0.000	0.999
3A2d	Manure management - goats		CH_4	11.3	0.000	0.999
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	CH_4	10.6	0.000	0.999

3C1e	Biomass burning in settlements		N_2O	10.5	0.000	0.999
3C1e	Biomass burning in settlements		CH_4	7.8	0.000	0.999
2D2	Paraffin Wax Use		CO_2	7.4	0.000	0.999
1A5a	Stationary	Liquid	N_2O	7.4	0.000	0.999
1A2	Manufacturing Industries and Construction	Liquid	N_2O	6.4	0.000	0.999
1A3a	Civil Aviation	Liquid	N_2O	5.9	0.000	0.999
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	N_2O	5.6	0.000	0.999
1A4b	Residential	Liquid	N_2O	5.4	0.000	0.999
1A4a	Commercial/Institutional	Liquid	N_2O	4.9	0.000	0.999
1A2	Manufacturing Industries and Construction	Gas	N_2O	4.2	0.000	0.999
1A4a	Commercial/Institutional	Solid	CH_4	4.0	0.000	0.999
1A1b	Petroleum Refining	Liquid	N_2O	3.6	0.000	0.999
1A3b	Road Transport	Gas	CO_2	3.4	0.000	0.999
2C2	Ferroalloys Production		CH_4	3.3	0.000	0.999
1A5a	Stationary	Solid	CH_4	3.1	0.000	0.999
1A2	Manufacturing Industries and Construction	Gas	CH_4	2.8	0.000	0.999
1A5a	Stationary	Liquid	CH_4	2.5	0.000	0.999
1A2	Manufacturing Industries and Construction	Liquid	CH_4	2.2	0.000	0.999
1A4b	Residential	Liquid	CH_4	2.0	0.000	0.999
1A3a	Civil Aviation	Liquid	CH_4	2.0	0.000	0.999
2B	Chemical industry		C	C	0.000	0.999
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	N_2O	1.9	0.000	0.999
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	CH_4	1.9	0.000	0.999
1A4a	Commercial/Institutional	Liquid	CH_4	1.7	0.000	0.999
1A3d	Water-Borne Navigation	Liquid	N_2O	1.3	0.000	0.999
1A1b	Petroleum Refining	Gas	N_2O	1.2	0.000	0.999
1A1b	Petroleum Refining	Liquid	CH_4	1.2	0.000	0.999

1A1b	Petroleum Refining	Gas	CH_4	0.8	0.000	0.999
1A3c	Railways	Liquid	CH_4	0.6	0.000	0.999
1A3d	Water-Borne Navigation	Liquid	CH_4	0.4	0.000	0.999
1A4a	Commercial/Institutional	Gas	N_2O	0.3	0.000	0.999
1A1a	Electricity and Heat Production	Liquid	N_2O	0.3	0.000	0.999
1A4a	Commercial/Institutional	Gas	CH_4	0.2	0.000	0.999
1A1a	Electricity and Heat Production	Liquid	CH_4	0.1	0.000	0.999
1A3b	Road Transport	Gas	CH_4	0.1	0.000	0.999
2B	Chemical industry		C	C	0.000	0.999
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	CH_4	0.0	0.000	0.999
1A3b	Road Transport	Gas	N_2O	0.0	0.000	0.999
4B	Biological Treatment of Solid Waste - Industrial Waste		CH_4	0.0	0.000	0.999
4B	Biological Treatment of Solid Waste - Industrial Waste		N_2O	0.0	0.000	0.999
1A1a	Electricity and Heat Production	Gas	CO_2	0.0	0.000	0.999
1A1b	Petroleum Refining	Solid	CO_2	0.0	0.000	0.999
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	CO_2	0.0	0.000	0.999
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	CO_2	0.0	0.000	0.999
1A1a	Electricity and Heat Production	Gas	CH_4	0.0	0.000	0.999
1A1b	Petroleum Refining	Solid	CH_4	0.0	0.000	0.999
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	CH_4	0.0	0.000	0.999
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	CH_4	0.0	0.000	0.999
1A1a	Electricity and Heat Production	Gas	N_2O	0.0	0.000	0.999
1A1b	Petroleum Refining	Solid	N_2O	0.0	0.000	0.999
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	N_2O	0.0	0.000	0.999
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	N_2O	0.0	0.000	0.999
1A3a	Civil Aviation	Gas	CO_2	0.0	0.000	0.999
1A3c	Railways	Gas	CO_2	0.0	0.000	0.999

1A3d	Water-Borne Navigation	Gas	CO_2	0.0	0.000	0.999
1A3a	Civil Aviation	Gas	CH_4	0.0	0.000	0.999
1A3c	Railways	Gas	CH_4	0.0	0.000	0.999
1A3d	Water-Borne Navigation	Gas	CH_4	0.0	0.000	0.999
1A3a	Civil Aviation	Gas	N_2O	0.0	0.000	0.999
1A3c	Railways	Gas	N_2O	0.0	0.000	0.999
1A3d	Water-Borne Navigation	Gas	N_2O	0.0	0.000	0.999
2A4	Other Process Uses of Carbonates		CO_2	0.0	0.000	0.999
2B	Chemical industry		C	C	0.000	0.999
2B	Chemical industry		C	C	0.000	0.999
2B	Chemical industry		C	C	0.000	0.999
2B	Chemical industry		C	C	0.000	0.999
2C1	Iron and Steel Production		CH_4	0.0	0.000	0.999
2F1	Refrigeration and Air Conditioning		HFCs	0.0	0.000	0.999
2F2	Foam Blowing Agents		HFCs	0.0	0.000	0.999
2F3	Fire Protection		HFCs	0.0	0.000	0.999
2F4	Aerosols		HFCs	0.0	0.000	0.999
3A1j	Enteric fermentation - other game		CH_4	0.0	0.000	0.999
3A2f	Manure management - horses		CH_4	0.0	0.000	0.999
3A2g	Manure management - mules and asses		CH_4	0.0	0.000	0.999
3A2j	Manure management - other game		CH_4	0.0	0.000	0.999
3B6a	Other land remaining other land		CO_2	0.0	0.000	0.999
3C1f	Biomass burning in other lands		CH_4	0.0	0.000	0.999
3C1f	Biomass burning in other lands		N_2O	0.0	0.000	0.999

**C=Confidential data*

Table A.3: Level assessment on emissions excluding FOLU for South Africa (2020) with the key categories highlighted in green.

IPCC Category code	IPCC Category	Fuel type	GHG	2020 Ex,t (Gg CO_2e)	Lx,t	Cumulative Total
1A1a	Electricity and Heat Production	Solid	CO_2	201332.7	0.429	0.429
1A3b	Road Transport	Liquid	CO_2	43 949.2	0.094	0.523
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	CO_2	28 454.1	0.061	0.584
1B3	Other Emissions from Energy Production		CO_2	25 644.5	0.055	0.639
3A1a	Enteric fermentation - cattle		CH_4	21 554.6	0.046	0.685
1A2	Manufacturing Industries and Construction	Solid	CO_2	21 220.0	0.045	0.730
4A	Solid Waste Disposal		CH_4	18 252.8	0.039	0.769
1A5a	Stationary	Solid	CO_2	16 969.3	0.036	0.805
1A2	Manufacturing Industries and Construction	Gas	CO_2	6 830.2	0.015	0.820
2C2	Ferroalloys Production		CO_2	6 576.5	0.014	0.834
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	CO_2	5 822.5	0.012	0.846
3C4	Direct N_2O emissions from managed soils		N_2O	5 276.0	0.011	0.857
1A2	Manufacturing Industries and Construction	Liquid	CO_2	5 016.0	0.011	0.868
2F1	Refrigeration and Air Conditioning		HFCs	4 846.9	0.010	0.878
3A1c	Enteric fermentation - sheep		CH_4	4 653.5	0.010	0.888
2C1	Iron and Steel Production		CO_2	3 849.9	0.008	0.896
2A1	Cement Production		CO_2	3 795.7	0.008	0.905
1A1a	Electricity and Heat Production	Liquid	CO_2	3 234.0	0.007	0.911
1B1a	Coal mining and handling		CH_4	2 892.8	0.006	0.918
4D1	Wastewater Treatment and Discharge		CH_4	2 783.0	0.006	0.924
1B3	Other Emissions from Energy Production		CH_4	2 218.2	0.005	0.928
1A3d	Water-Borne Navigation	Liquid	CO_2	1 970.6	0.004	0.932
1A4a	Commercial/Institutional	Liquid	CO_2	1 865.6	0.004	0.936

1A1b	Petroleum Refining	Gas	CO_2	1 745.0	0.004	0.940
3A2a	Manure management - cattle		N_2O	1 360.3	0.003	0.943
1A4b	Residential	Liquid	CO_2	1 334.1	0.003	0.946
3A1d	Enteric fermentation - goats		CH_4	1 190.0	0.003	0.948
2C3	Aluminium Production		CO_2	1 134.8	0.002	0.951
1A1a	Electricity and Heat Production	Solid	N_2O	998.8	0.002	0.953
1A4b	Residential	Solid	CO_2	990.0	0.002	0.955
3A2i	Manure management - poultry		N_2O	977.1	0.002	0.957
1A4a	Commercial/Institutional	Gas	CO_2	947.4	0.002	0.959
3C2	Liming		CO_2	942.3	0.002	0.961
1A4a	Commercial/Institutional	Solid	CO_2	928.5	0.002	0.963
4D2	Industrial Wastewater Treatment and Discharge		CH_4	897.3	0.002	0.965
3A2a	Manure management - cattle		CH_4	859.0	0.002	0.967
2B	Chemical industry		C	C	0.002	0.969
4D1	Wastewater Treatment and Discharge		N_2O	777.9	0.002	0.970
2B	Chemical industry		C	C	0.002	0.972
3C5	Indirect N_2O emissions from managed soils		N_2O	723.3	0.002	0.974
2A2	Lime Production		CO_2	714.9	0.002	0.975
1A3a	Civil Aviation	Liquid	CO_2	693.4	0.001	0.977
1A3b	Road Transport	Liquid	N_2O	677.9	0.001	0.978
2D1	Lubricant Use		CO_2	667.3	0.001	0.979
1A1b	Petroleum Refining	Liquid	CO_2	665.6	0.001	0.981
1B2a	Oil		CO_2	641.8	0.001	0.982
2D2	Paraffin Wax Use		CO_2	627.4	0.001	0.984
3C3	Urea application		CO_2	584.7	0.001	0.985
1A3c	Railways	Liquid	CO_2	501.8	0.001	0.986
2C2	Ferroalloys Production		CH_4	492.5	0.001	0.987

3C1c	Biomass burning in grasslands		N_2O	471.6	0.001	0.988
1A5a	Stationary	Liquid	CO_2	423.3	0.001	0.989
2B	Chemical industry		C	C	0.001	0.990
3C1c	Biomass burning in grasslands		CH_4	349.9	0.001	0.990
3C1a	Biomass burning in forest land		CH_4	288.6	0.001	0.991
3C1a	Biomass burning in forest land		N_2O	265.6	0.001	0.992
1A4b	Residential	Solid	N_2O	260.3	0.001	0.992
3C6	Indirect N_2O emissions from manure management		N_2O	227.5	0.000	0.993
4C2	Open Burning of Waste		CH_4	223.4	0.000	0.993
1A3b	Road Transport	Liquid	CH_4	221.3	0.000	0.994
1A2	Manufacturing Industries and Construction	Solid	N_2O	195.1	0.000	0.994
3A2c	Manure management - sheep		N_2O	182.5	0.000	0.994
3C1b	Biomass burning in croplands		CH_4	167.0	0.000	0.995
3A2h	Manure management - swine		CH_4	158.2	0.000	0.995
2A3	Glass Production		CO_2	154.5	0.000	0.995
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	N_2O	143.8	0.000	0.996
3A2i	Manure management - poultry		CH_4	128.2	0.000	0.996
1A4b	Residential	Solid	CH_4	127.6	0.000	0.996
3A1f	Enteric fermentation - horses		CH_4	124.7	0.000	0.996
2C3	Aluminium Production		PFCs	120.4	0.000	0.997
2A4	Other Process Uses of Carbonates		CO_2	109.3	0.000	0.997
1A3b	Road Transport	Gas	CO_2	108.6	0.000	0.997
2B	Chemical industry		C	C	0.000	0.997
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	CO_2	83.0	0.000	0.998
1A5a	Stationary	Solid	N_2O	82.0	0.000	0.998
2B	Chemical industry		C	C	0.000	0.998
4C2	Open Burning of Waste		N_2O	76.1	0.000	0.998

2F3	Fire Protection		HFCs	65.9	0.000	0.998
3C1b	Biomass burning in croplands		N_2O	63.9	0.000	0.998
2B	Chemical industry		C	C	0.000	0.999
3A2d	Manure management - goats		N_2O	57.9	0.000	0.999
1A2	Manufacturing Industries and Construction	Solid	CH_4	51.7	0.000	0.999
1A3c	Railways	Liquid	N_2O	51.3	0.000	0.999
1A1a	Electricity and Heat Production	Solid	CH_4	45.1	0.000	0.999
1B1a	Coal mining and handling		CO_2	37.9	0.000	0.999
2C6	Zinc Production		CO_2	36.6	0.000	0.999
4C2	Open Burning of Waste		CO_2	35.4	0.000	0.999
3A1g	Enteric fermentation - mules and asses		CH_4	33.9	0.000	0.999
3A1h	Enteric fermentation - swine		CH_4	32.8	0.000	0.999
2B	Chemical industry		C	C	0.000	0.999
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	CH_4	29.1	0.000	0.999
3A2h	Manure management - swine		N_2O	28.6	0.000	1.000
3A2c	Manure management - sheep		CH_4	21.1	0.000	1.000
2B	Chemical industry		C	C	0.000	1.000
2F4	Aerosols		HFCs	18.2	0.000	1.000
3C1d	Biomass burning in wetlands		N_2O	16.6	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	N_2O	14.7	0.000	1.000
1A2	Manufacturing Industries and Construction	Liquid	N_2O	12.4	0.000	1.000
3C1d	Biomass burning in wetlands		CH_4	12.3	0.000	1.000
1A3d	Water-Borne Navigation	Liquid	N_2O	11.8	0.000	1.000
3A2d	Manure management - goats		CH_4	9.4	0.000	1.000
1A4a	Commercial/Institutional	Solid	N_2O	9.0	0.000	1.000
1A1a	Electricity and Heat Production	Liquid	N_2O	8.1	0.000	1.000
3C1e	Biomass burning in settlements		N_2O	7.8	0.000	1.000

2C5	Lead Production		CO_2	6.6	0.000	1.000
3C1e	Biomass burning in settlements		CH_4	5.8	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	CH_4	5.0	0.000	1.000
2B	Chemical industry		C	C	0.000	1.000
1A4a	Commercial/Institutional	Liquid	N_2O	4.7	0.000	1.000
1A2	Manufacturing Industries and Construction	Liquid	CH_4	4.2	0.000	1.000
1A2	Manufacturing Industries and Construction	Gas	N_2O	3.9	0.000	1.000
1A3d	Water-Borne Navigation	Liquid	CH_4	3.7	0.000	1.000
1A5a	Stationary	Solid	CH_4	3.7	0.000	1.000
2C1	Iron and Steel Production		CH_4	3.2	0.000	1.000
2B	Chemical industry		C	C	0.000	1.000
1A1a	Electricity and Heat Production	Liquid	CH_4	2.7	0.000	1.000
1A2	Manufacturing Industries and Construction	Gas	CH_4	2.7	0.000	1.000
2F2	Foam Blowing Agents		HFCs	2.1	0.000	1.000
1A4b	Residential	Liquid	N_2O	2.1	0.000	1.000
1A3a	Civil Aviation	Liquid	N_2O	1.8	0.000	1.000
1A4a	Commercial/Institutional	Liquid	CH_4	1.6	0.000	1.000
1A1b	Petroleum Refining	Liquid	N_2O	1.3	0.000	1.000
1A5a	Stationary	Liquid	N_2O	1.1	0.000	1.000
1A1b	Petroleum Refining	Gas	N_2O	0.9	0.000	1.000
1A4b	Residential	Liquid	CH_4	0.8	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	N_2O	0.8	0.000	1.000
1A1b	Petroleum Refining	Gas	CH_4	0.6	0.000	1.000
1A3a	Civil Aviation	Liquid	CH_4	0.6	0.000	1.000
1A3c	Railways	Liquid	CH_4	0.5	0.000	1.000
1A4a	Commercial/Institutional	Gas	N_2O	0.5	0.000	1.000
1A1b	Petroleum Refining	Liquid	CH_4	0.4	0.000	1.000

1A5a	Stationary	Liquid	CH_4	0.4	0.000	1.000
1A4a	Commercial/Institutional	Gas	CH_4	0.3	0.000	1.000
1A4a	Commercial/Institutional	Solid	CH_4	0.2	0.000	1.000
1A3b	Road Transport	Gas	N_2O	0.1	0.000	1.000
2B	Chemical industry		C	C	0.000	1.000
1A3b	Road Transport	Gas	CH_4	0.0	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	CH_4	0.0	0.000	1.000
4B	Biological Treatment of Solid Waste - Industrial Waste		CH_4	0.0	0.000	1.000
4B	Biological Treatment of Solid Waste - Industrial Waste		N_2O	0.0	0.000	1.000
1A1a	Electricity and Heat Production	Gas	CO_2	0.0	0.000	1.000
1A1b	Petroleum Refining	Solid	CO_2	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	CO_2	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	CO_2	0.0	0.000	1.000
1A1a	Electricity and Heat Production	Gas	CH_4	0.0	0.000	1.000
1A1b	Petroleum Refining	Solid	CH_4	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	CH_4	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	CH_4	0.0	0.000	1.000
1A1a	Electricity and Heat Production	Gas	N_2O	0.0	0.000	1.000
1A1b	Petroleum Refining	Solid	N_2O	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	N_2O	0.0	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	N_2O	0.0	0.000	1.000
1A3a	Civil Aviation	Gas	CO_2	0.0	0.000	1.000
1A3c	Railways	Gas	CO_2	0.0	0.000	1.000
1A3d	Water-Borne Navigation	Gas	CO_2	0.0	0.000	1.000
1A3a	Civil Aviation	Gas	CH_4	0.0	0.000	1.000
1A3c	Railways	Gas	CH_4	0.0	0.000	1.000
1A3d	Water-Borne Navigation	Gas	CH_4	0.0	0.000	1.000

1A3a	Civil Aviation	Gas	N_2O	0.0	0.000	1.000
1A3c	Railways	Gas	N_2O	0.0	0.000	1.000
1A3d	Water-Borne Navigation	Gas	N_2O	0.0	0.000	1.000
3A1j	Enteric fermentation - other game		CH_4	0.0	0.000	1.000
3A2f	Manure management - horses		CH_4	0.0	0.000	1.000
3A2g	Manure management - mules and asses		CH_4	0.0	0.000	1.000
3A2j	Manure management - other game		CH_4	0.0	0.000	1.000
3C1f	Biomass burning in other lands		CH_4	0.0	0.000	1.000
3C1f	Biomass burning in other lands		N_2O	0.0	0.000	1.000

**C=Confidential data*

Table A.4: Level assessment on emissions including FOLU for South Africa (2020) with the key categories highlighted in green.

IPCC Category code	IPCC Category	Fuel type	GHG	2020 Ex,t (Gg CO_2e)	Lx,t	Cumulative Total
1A1a	Electricity and Heat Production	Solid	CO_2	201 332.7	0.386	0.386
1A3b	Road Transport	Liquid	CO_2	43 949.2	0.084	0.471
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	CO_2	28 454.1	0.055	0.525
1B3	Other Emissions from Energy Production		CO_2	25 644.5	0.049	0.575
3A1a	Enteric fermentation - cattle		CH_4	21 554.6	0.041	0.616
1A2	Manufacturing Industries and Construction	Solid	CO_2	21 220.0	0.041	0.657
4A	Solid Waste Disposal		CH_4	18 252.8	0.035	0.692
1A5a	Stationary	Solid	CO_2	16 969.3	0.033	0.724
3B1b	Land converted to forest land - Net CO_2		CO_2	-14 032.4	0.027	0.751

3B1a	Forest land remaining forest land - Net CO_2		CO_2	-10 542.8	0.020	0.771
3B3b	Land converted to grassland - Net CO_2		CO_2	-10 027.3	0.019	0.791
1A2	Manufacturing Industries and Construction	Gas	CO_2	6 830.2	0.013	0.804
2C2	Ferroalloys Production		CO_2	6 576.5	0.013	0.816
3B6b	Land converted to other lands - Net CO_2		CO_2	6 125.2	0.012	0.828
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	CO_2	5 822.5	0.011	0.839
3C4	Direct N_2O emissions from managed soils		N_2O	5 276.0	0.010	0.850
1A2	Manufacturing Industries and Construction	Liquid	CO_2	5 016.0	0.010	0.859
2F1	Refrigeration and Air Conditioning		HFCs	4 846.9	0.009	0.868
3A1c	Enteric fermentation - sheep		CH_4	4 653.5	0.009	0.877
2C1	Iron and Steel Production		CO_2	3 849.9	0.007	0.885
2A1	Cement Production		CO_2	3 795.7	0.007	0.892
3B2b	Land converted to cropland - Net CO_2		CO_2	3 558.7	0.007	0.899
1A1a	Electricity and Heat Production	Liquid	CO_2	3 234.0	0.006	0.905
1B1a	Coal mining and handling		CH_4	2 892.8	0.006	0.911
4D1	Wastewater Treatment and Discharge		CH_4	2 783.0	0.005	0.916
1B3	Other Emissions from Energy Production		CH_4	2 218.2	0.004	0.920
1A3d	Water-Borne Navigation	Liquid	CO_2	1 970.6	0.004	0.924
3B5a	Settlements remaining settlements - Net CO_2		CO_2	-1 914.2	0.004	0.928
1A4a	Commercial/Institutional	Liquid	CO_2	1 865.6	0.004	0.931
1A1b	Petroleum Refining	Gas	CO_2	1 745.0	0.003	0.935
3B2a	Cropland remaining cropland - Net CO_2		CO_2	-1 391.3	0.003	0.937
3A2a	Manure management - cattle		N_2O	1 360.3	0.003	0.940
1A4b	Residential	Liquid	CO_2	1 334.1	0.003	0.942
3B4	Wetland		CH_4	1 192.5	0.002	0.945
3A1d	Enteric fermentation - goats		CH_4	1 190.0	0.002	0.947
2C3	Aluminium Production		CO_2	1 134.8	0.002	0.949

3B3a	Grassland remaining grassland - Net CO_2		CO_2	-1 057.2	0.002	0.951
1A1a	Electricity and Heat Production	Solid	N_2O	998.8	0.002	0.953
1A4b	Residential	Solid	CO_2	990.0	0.002	0.955
3A2i	Manure management - poultry		N_2O	977.1	0.002	0.957
1A4a	Commercial/Institutional	Gas	CO_2	947.4	0.002	0.959
3C2	Liming		CO_2	942.3	0.002	0.961
1A4a	Commercial/Institutional	Solid	CO_2	928.5	0.002	0.962
4D2	Industrial Wastewater Treatment and Discharge		CH_4	897.3	0.002	0.964
3A2a	Manure management - cattle		CH_4	859.0	0.002	0.966
2B	Chemical industry		C	C	0.002	0.967
4D1	Wastewater Treatment and Discharge		N_2O	777.9	0.001	0.969
3B5b	Land converted to settlements - Net CO_2		CO_2	766.8	0.001	0.970
2B	Chemical industry		C	C	0.001	0.972
3C5	Indirect N_2O emissions from managed soils		N_2O	723.3	0.001	0.973
2A2	Lime Production		CO_2	714.9	0.001	0.974
1A3a	Civil Aviation	Liquid	CO_2	693.4	0.001	0.976
1A3b	Road Transport	Liquid	N_2O	677.9	0.001	0.977
2D1	Lubricant Use		CO_2	667.3	0.001	0.978
1A1b	Petroleum Refining	Liquid	CO_2	665.6	0.001	0.980
1B2a	Oil		CO_2	641.8	0.001	0.981
3D1	Harvested wood products		CO_2	635.2	0.001	0.982
2D2	Paraffin Wax Use		CO_2	627.4	0.001	0.983
3C3	Urea application		CO_2	584.7	0.001	0.984
1A3c	Railways	Liquid	CO_2	501.8	0.001	0.985
2C2	Ferroalloys Production		CH_4	492.5	0.001	0.986
3B4b	Land converted to wetland		CO_2	-475.6	0.001	0.987
3C1c	Biomass burning in grasslands		N_2O	471.6	0.001	0.988

3B4	Wetland		N_2O	436.6	0.001	0.989
1A5a	Stationary	Liquid	CO_2	423.3	0.001	0.990
2B	Chemical industry		C	C	0.001	0.991
3C1c	Biomass burning in grasslands		CH_4	349.9	0.001	0.991
3C1a	Biomass burning in forest land		CH_4	288.6	0.001	0.992
3C1a	Biomass burning in forest land		N_2O	265.6	0.001	0.992
1A4b	Residential	Solid	N_2O	260.3	0.000	0.993
3C6	Indirect N_2O emissions from manure management		N_2O	227.5	0.000	0.993
4C2	Open Burning of Waste		CH_4	223.4	0.000	0.994
1A3b	Road Transport	Liquid	CH_4	221.3	0.000	0.994
1A2	Manufacturing Industries and Construction	Solid	N_2O	195.1	0.000	0.994
3A2c	Manure management - sheep		N_2O	182.5	0.000	0.994
3C1b	Biomass burning in croplands		CH_4	167.0	0.000	0.994
3A2h	Manure management - swine		CH_4	158.2	0.000	0.995
2A3	Glass Production		CO_2	154.5	0.000	0.995
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	N_2O	143.8	0.000	0.995
3A2i	Manure management - poultry		CH_4	128.2	0.000	0.995
1A4b	Residential	Solid	CH_4	127.6	0.000	0.996
3A1f	Enteric fermentation - horses		CH_4	124.7	0.000	0.996
2C3	Aluminium Production		PFCs	120.4	0.000	0.996
2A4	Other Process Uses of Carbonates		CO_2	109.3	0.000	0.996
1A3b	Road Transport	Gas	CO_2	108.6	0.000	0.997
2B	Chemical industry		C	C	0.000	0.997
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	CO_2	83.0	0.000	0.997
1A5a	Stationary	Solid	N_2O	82.0	0.000	0.997
2B	Chemical industry		C	C	0.000	0.997
4C2	Open Burning of Waste		N_2O	76.1	0.000	0.997

2F3	Fire Protection		HFCs	65.9	0.000	0.997
3C1b	Biomass burning in croplands		N_2O	63.9	0.000	0.998
2B	Chemical industry		C	C	0.000	0.998
3A2d	Manure management - goats		N_2O	57.9	0.000	0.998
1A2	Manufacturing Industries and Construction	Solid	CH_4	51.7	0.000	0.998
1A3c	Railways	Liquid	N_2O	51.3	0.000	0.998
1A1a	Electricity and Heat Production	Solid	CH_4	45.1	0.000	0.998
3B4a	Wetland remaining wetland		CO_2	39.1	0.000	0.998
1B1a	Coal mining and handling		CO_2	37.9	0.000	0.998
2C6	Zinc Production		CO_2	36.6	0.000	0.998
4C2	Open Burning of Waste		CO_2	35.4	0.000	0.998
3A1g	Enteric fermentation - mules and asses		CH_4	33.9	0.000	0.998
3A1h	Enteric fermentation - swine		CH_4	32.8	0.000	0.999
2B	Chemical industry		C	C	0.000	0.999
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	CH_4	29.1	0.000	0.999
3A2h	Manure management - swine		N_2O	28.6	0.000	0.999
3A2c	Manure management - sheep		CH_4	21.1	0.000	0.999
2B	Chemical industry		C	C	0.000	0.999
2F4	Aerosols		HFCs	18.2	0.000	0.999
3C1d	Biomass burning in wetlands		N_2O	16.6	0.000	0.999
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	N_2O	14.7	0.000	0.999
1A2	Manufacturing Industries and Construction	Liquid	N_2O	12.4	0.000	0.999
3C1d	Biomass burning in wetlands		CH_4	12.3	0.000	0.999
1A3d	Water-Borne Navigation	Liquid	N_2O	11.8	0.000	0.999
3A2d	Manure management - goats		CH_4	9.4	0.000	0.999
1A4a	Commercial/Institutional	Solid	N_2O	9.0	0.000	0.999
1A1a	Electricity and Heat Production	Liquid	N_2O	8.1	0.000	0.999

3C1e	Biomass burning in settlements		N_2O	7.8	0.000	0.999
2C5	Lead Production		CO_2	6.6	0.000	0.999
3C1e	Biomass burning in settlements		CH_4	5.8	0.000	0.999
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	CH_4	5.0	0.000	0.999
2B	Chemical industry		C	C	0.000	0.999
1A4a	Commercial/Institutional	Liquid	N_2O	4.7	0.000	0.999
1A2	Manufacturing Industries and Construction	Liquid	CH_4	4.2	0.000	0.999
1A2	Manufacturing Industries and Construction	Gas	N_2O	3.9	0.000	0.999
1A3d	Water-Borne Navigation	Liquid	CH_4	3.7	0.000	0.999
1A5a	Stationary	Solid	CH_4	3.7	0.000	0.999
2C1	Iron and Steel Production		CH_4	3.2	0.000	0.999
2B	Chemical industry		C	C	0.000	0.999
1A1a	Electricity and Heat Production	Liquid	CH_4	2.7	0.000	0.999
1A2	Manufacturing Industries and Construction	Gas	CH_4	2.7	0.000	0.999
2F2	Foam Blowing Agents		HFCs	2.1	0.000	0.999
1A4b	Residential	Liquid	N_2O	2.1	0.000	0.999
1A3a	Civil Aviation	Liquid	N_2O	1.8	0.000	0.999
1A4a	Commercial/Institutional	Liquid	CH_4	1.6	0.000	0.999
1A1b	Petroleum Refining	Liquid	N_2O	1.3	0.000	0.999
1A5a	Stationary	Liquid	N_2O	1.1	0.000	0.999
1A1b	Petroleum Refining	Gas	N_2O	0.9	0.000	0.999
1A4b	Residential	Liquid	CH_4	0.8	0.000	0.999
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	N_2O	0.8	0.000	0.999
1A1b	Petroleum Refining	Gas	CH_4	0.6	0.000	0.999
1A3a	Civil Aviation	Liquid	CH_4	0.6	0.000	0.999
1A3c	Railways	Liquid	CH_4	0.5	0.000	0.999
1A4a	Commercial/Institutional	Gas	N_2O	0.5	0.000	0.999

1A1b	Petroleum Refining	Liquid	CH_4	0.4	0.000	0.999
1A5a	Stationary	Liquid	CH_4	0.4	0.000	0.999
1A4a	Commercial/Institutional	Gas	CH_4	0.3	0.000	0.999
1A4a	Commercial/Institutional	Solid	CH_4	0.2	0.000	0.999
1A3b	Road Transport	Gas	N_2O	0.1	0.000	0.999
2B	Chemical industry		C	C	0.000	0.999
1A3b	Road Transport	Gas	CH_4	0.0	0.000	0.999
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	CH_4	0.0	0.000	0.999
4B	Biological Treatment of Solid Waste - Industrial Waste		CH_4	0.0	0.000	0.999
4B	Biological Treatment of Solid Waste - Industrial Waste		N_2O	0.0	0.000	0.999
1A1a	Electricity and Heat Production	Gas	CO_2	0.0	0.000	0.999
1A1b	Petroleum Refining	Solid	CO_2	0.0	0.000	0.999
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	CO_2	0.0	0.000	0.999
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	CO_2	0.0	0.000	0.999
1A1a	Electricity and Heat Production	Gas	CH_4	0.0	0.000	0.999
1A1b	Petroleum Refining	Solid	CH_4	0.0	0.000	0.999
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	CH_4	0.0	0.000	0.999
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	CH_4	0.0	0.000	0.999
1A1a	Electricity and Heat Production	Gas	N_2O	0.0	0.000	0.999
1A1b	Petroleum Refining	Solid	N_2O	0.0	0.000	0.999
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	N_2O	0.0	0.000	0.999
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	N_2O	0.0	0.000	0.999
1A3a	Civil Aviation	Gas	CO_2	0.0	0.000	0.999
1A3c	Railways	Gas	CO_2	0.0	0.000	0.999
1A3d	Water-Borne Navigation	Gas	CO_2	0.0	0.000	0.999
1A3a	Civil Aviation	Gas	CH_4	0.0	0.000	0.999
1A3c	Railways	Gas	CH_4	0.0	0.000	0.999

1A3d	Water-Borne Navigation	Gas	CH_4	0.0	0.000	0.999
1A3a	Civil Aviation	Gas	N_2O	0.0	0.000	0.999
1A3c	Railways	Gas	N_2O	0.0	0.000	0.999
1A3d	Water-Borne Navigation	Gas	N_2O	0.0	0.000	0.999
3A1j	Enteric fermentation - other game		CH_4	0.0	0.000	0.999
3A2f	Manure management - horses		CH_4	0.0	0.000	0.999
3A2g	Manure management - mules and asses		CH_4	0.0	0.000	0.999
3A2j	Manure management - other game		CH_4	0.0	0.000	0.999
3B6a	Other land remaining other land		CO_2	0.0	0.000	0.999
3C1f	Biomass burning in other lands		CH_4	0.0	0.000	0.999
3C1f	Biomass burning in other lands		N_2O	0.0	0.000	0.999

**C=Confidential data*

forestry, fisheries & the environment

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Table A.5: Trend assessment on emissions excluding FOLU for South Africa (2000 - 2020) with the key categories highlighted in green.

IPCC Category code	IPCC Category	Fuel type	Greenhouse gas	2000 Ex,t (Gg CO_2e)	2020 Ex,t (Gg CO_2e)	Tx,t	% Contribution to trend	Cumulative total (%)
1A4a	Commercial/Institutional	Solid	CO_2	18 248.1	928.5	0.038	0.161	0.161
1A1a	Electricity and Heat Production	Solid	CO_2	185 027.4	201 332.7	0.032	0.136	0.297
2C1	Iron and Steel Production		CO_2	15 334.4	3 849.9	0.025	0.107	0.404
1A3b	Road Transport	Liquid	CO_2	36 302.9	43 949.2	0.016	0.068	0.471
2F1	Refrigeration and Air Conditioning		HFCs	0.0	4 846.9	0.010	0.045	0.516
4A	Solid Waste Disposal		CH_4	13 610.5	18 252.8	0.010	0.042	0.558
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	CO_2	2 251.0	5 822.5	0.008	0.033	0.591
1A1a	Electricity and Heat Production	Liquid	CO_2	121.3	3 234.0	0.007	0.029	0.619
1B3	Other Emissions from Energy Production		CO_2	28 146.6	25 644.5	0.006	0.025	0.644
1A4b	Residential	Solid	CO_2	3 604.2	990.0	0.006	0.024	0.669
1A5a	Stationary	Solid	CO_2	14 272.3	16 969.3	0.006	0.024	0.692
3A1a	Enteric fermentation - cattle		CH_4	23 901.0	21 554.6	0.005	0.023	0.716
1A5a	Stationary	Liquid	CO_2	2 888.6	423.3	0.005	0.023	0.739
1A2	Manufacturing Industries and Construction	Liquid	CO_2	2 564.8	5 016.0	0.005	0.022	0.761
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	CO_2	30 454.7	28 454.1	0.005	0.021	0.782
1A3d	Water-Borne Navigation	Liquid	CO_2	222.2	1 970.6	0.004	0.016	0.798
1A3a	Civil Aviation	Liquid	CO_2	2 249.1	693.4	0.003	0.014	0.812
2C2	Ferroalloys Production		CO_2	8 079.1	6 576.5	0.003	0.014	0.827
1A4b	Residential	Liquid	CO_2	2 868.4	1 334.1	0.003	0.014	0.841
1A2	Manufacturing Industries and Construction	Solid	CO_2	19 545.0	21 220.0	0.003	0.014	0.855
3A1c	Enteric fermentation - sheep		CH_4	5 837.3	4 653.5	0.003	0.011	0.867
3C4	Direct N_2O emissions from managed soils		N_2O	4 093.0	5 276.0	0.002	0.011	0.877

1A1b	Petroleum Refining	Liquid	CO_2	1 735.5	665.6	0.002	0.010	0.887
4D2	Industrial Wastewater Treatment and Discharge		CH_4	1 958.1	897.3	0.002	0.010	0.897
2C3	Aluminium Production		PFCs	983.2	120.4	0.002	0.008	0.905
2B	Chemical industry		C	C	C	0.002	0.008	0.913
4D1	Wastewater Treatment and Discharge		CH_4	1 951.2	2 783.0	0.002	0.008	0.920
2D2	Paraffin Wax Use		CO_2	7.4	627.4	0.001	0.006	0.926
1A1b	Petroleum Refining	Gas	CO_2	2 307.1	1 745.0	0.001	0.005	0.931
3C2	Liming		CO_2	384.1	942.3	0.001	0.005	0.936
1B1a	Coal mining and handling		CH_4	2 338.1	2 892.8	0.001	0.005	0.941
2C2	Ferroalloys Production		CH_4	3.3	492.5	0.001	0.005	0.946
2D1	Lubricant Use		CO_2	188.5	667.3	0.001	0.004	0.950
3A2i	Manure management - poultry		N_2O	651.9	977.1	0.001	0.003	0.953
3A1d	Enteric fermentation - goats		CH_4	1 493.1	1 190.0	0.001	0.003	0.956
1A4a	Commercial/Institutional	Gas	CO_2	631.0	947.4	0.001	0.003	0.959
2B	Chemical industry		C	C	C	0.001	0.003	0.962
2A2	Lime Production		CO_2	426.1	714.9	0.001	0.003	0.964
3C3	Urea application		CO_2	297.3	584.7	0.001	0.003	0.967
1A2	Manufacturing Industries and Construction	Gas	CO_2	6 520.2	6 830.2	0.001	0.002	0.969
4D1	Wastewater Treatment and Discharge		N_2O	545.4	777.9	0.000	0.002	0.971
1A4b	Residential	Solid	N_2O	439.1	260.3	0.000	0.002	0.973
1A4a	Commercial/Institutional	Liquid	CO_2	2 028.6	1 865.6	0.000	0.002	0.975
1A4a	Commercial/Institutional	Solid	N_2O	176.3	9.0	0.000	0.002	0.976
1A3b	Road Transport	Liquid	N_2O	545.1	677.9	0.000	0.001	0.977
1B3	Other Emissions from Energy Production		CH_4	2 318.6	2 218.2	0.000	0.001	0.978
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	CO_2	199.5	83.0	0.000	0.001	0.980
1B2a	Oil		CO_2	752.0	641.8	0.000	0.001	0.981
2A4	Other Process Uses of Carbonates		CO_2	0.0	109.3	0.000	0.001	0.982

2A1	Cement Production		CO_2	3 870.6	3 795.7	0.000	0.001	0.983
1A3b	Road Transport	Gas	CO_2	3.4	108.6	0.000	0.001	0.984
4C2	Open Burning of Waste		CH_4	117.5	223.4	0.000	0.001	0.985
3A2a	Manure management - cattle		N_2O	1 249.4	1 360.3	0.000	0.001	0.985
1A1a	Electricity and Heat Production	Solid	N_2O	893.9	998.8	0.000	0.001	0.986
2B	Chemical industry		C	C	C	0.000	0.001	0.987
3C1c	Biomass burning in grasslands		N_2O	557.4	471.6	0.000	0.001	0.988
1A4b	Residential	Solid	CH_4	206.2	127.6	0.000	0.001	0.989
2A3	Glass Production		CO_2	74.4	154.5	0.000	0.001	0.990
2C6	Zinc Production		CO_2	108.4	36.6	0.000	0.001	0.990
3C1b	Biomass burning in croplands		CH_4	235.6	167.0	0.000	0.001	0.991
3C1c	Biomass burning in grasslands		CH_4	413.5	349.9	0.000	0.001	0.991
2F3	Fire Protection		HFCs	0.0	65.9	0.000	0.001	0.992
2B	Chemical industry		C	C	C	0.000	0.001	0.993
1A3c	Railways	Liquid	CO_2	551.5	501.8	0.000	0.000	0.993
2B	Chemical industry		C	C	C	0.000	0.000	0.994
3A2i	Manure management - poultry		CH_4	84.2	128.2	0.000	0.000	0.994
4C2	Open Burning of Waste		N_2O	40.0	76.1	0.000	0.000	0.994
3C1a	Biomass burning in forest land		N_2O	298.7	265.6	0.000	0.000	0.995
3A2h	Manure management - swine		CH_4	192.0	158.2	0.000	0.000	0.995
2C3	Aluminium Production		CO_2	1 091.3	1 134.8	0.000	0.000	0.995
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	N_2O	110.3	143.8	0.000	0.000	0.996
3A2a	Manure management - cattle		CH_4	881.6	859.0	0.000	0.000	0.996
1A3b	Road Transport	Liquid	CH_4	247.9	221.3	0.000	0.000	0.996
2B	Chemical industry		C	C	C	0.000	0.000	0.996
3C1b	Biomass burning in croplands		N_2O	90.2	63.9	0.000	0.000	0.997
3C6	Indirect N_2O emissions from manure management		N_2O	201.4	227.5	0.000	0.000	0.997

1A2	Manufacturing Industries and Construction	Solid	N_2O	216.6	195.1	0.000	0.000	0.997
3A1f	Enteric fermentation - horses		CH_4	102.1	124.7	0.000	0.000	0.997
3C5	Indirect N_2O emissions from managed soils		N_2O	737.5	723.3	0.000	0.000	0.997
2B	Chemical industry		C	C	C	0.000	0.000	0.998
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	CH_4	10.6	29.1	0.000	0.000	0.998
2F4	Aerosols		HFCs	0.0	18.2	0.000	0.000	0.998
4C2	Open Burning of Waste		CO_2	18.6	35.4	0.000	0.000	0.998
1A3c	Railways	Liquid	N_2O	66.0	51.3	0.000	0.000	0.998
1A2	Manufacturing Industries and Construction	Solid	CH_4	66.4	51.7	0.000	0.000	0.998
1A5a	Stationary	Solid	N_2O	69.0	82.0	0.000	0.000	0.998
3A2d	Manure management - goats		N_2O	69.2	57.9	0.000	0.000	0.999
2B	Chemical industry		C	C	C	0.000	0.000	0.999
1A3d	Water-Borne Navigation	Liquid	N_2O	1.3	11.8	0.000	0.000	0.999
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	N_2O	5.6	14.7	0.000	0.000	0.999
2C5	Lead Production		CO_2	15.1	6.6	0.000	0.000	0.999
1A1a	Electricity and Heat Production	Liquid	N_2O	0.3	8.1	0.000	0.000	0.999
3C1a	Biomass burning in forest land		CH_4	293.6	288.6	0.000	0.000	0.999
3A1h	Enteric fermentation - swine		CH_4	39.8	32.8	0.000	0.000	0.999
1B1a	Coal mining and handling		CO_2	30.6	37.9	0.000	0.000	0.999
3A2h	Manure management - swine		N_2O	34.7	28.6	0.000	0.000	0.999
1A5a	Stationary	Liquid	N_2O	7.4	1.1	0.000	0.000	0.999
1A2	Manufacturing Industries and Construction	Liquid	N_2O	6.4	12.4	0.000	0.000	0.999
2B	Chemical industry		C	C	C	0.000	0.000	0.999
1A1a	Electricity and Heat Production	Solid	CH_4	40.4	45.1	0.000	0.000	0.999
3A2c	Manure management - sheep		N_2O	185.3	182.5	0.000	0.000	1.000
1A3a	Civil Aviation	Liquid	N_2O	5.9	1.8	0.000	0.000	1.000
1A4a	Commercial/Institutional	Solid	CH_4	4.0	0.2	0.000	0.000	1.000

1A4b	Residential	Liquid	N_2O	5.4	2.1	0.000	0.000	1.000
1A3d	Water-Borne Navigation	Liquid	CH_4	0.4	3.7	0.000	0.000	1.000
2C1	Iron and Steel Production		CH_4	0.0	3.2	0.000	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	CH_4	1.9	5.0	0.000	0.000	1.000
3C1e	Biomass burning in settlements		N_2O	10.5	7.8	0.000	0.000	1.000
2B	Chemical industry		C	C	C	0.000	0.000	1.000
1A1a	Electricity and Heat Production	Liquid	CH_4	0.1	2.7	0.000	0.000	1.000
1A1b	Petroleum Refining	Liquid	N_2O	3.6	1.3	0.000	0.000	1.000
1A5a	Stationary	Liquid	CH_4	2.5	0.4	0.000	0.000	1.000
2F2	Foam Blowing Agents		HFCs	0.0	2.1	0.000	0.000	1.000
3C1e	Biomass burning in settlements		CH_4	7.8	5.8	0.000	0.000	1.000
1A2	Manufacturing Industries and Construction	Liquid	CH_4	2.2	4.2	0.000	0.000	1.000
3A2d	Manure management - goats		CH_4	11.3	9.4	0.000	0.000	1.000
1A3a	Civil Aviation	Liquid	CH_4	2.0	0.6	0.000	0.000	1.000
1A4b	Residential	Liquid	CH_4	2.0	0.8	0.000	0.000	1.000
3A2c	Manure management - sheep		CH_4	22.1	21.1	0.000	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	N_2O	1.9	0.8	0.000	0.000	1.000
1A1b	Petroleum Refining	Liquid	CH_4	1.2	0.4	0.000	0.000	1.000
3A1g	Enteric fermentation - mules and asses		CH_4	34.4	33.9	0.000	0.000	1.000
1A5a	Stationary	Solid	CH_4	3.1	3.7	0.000	0.000	1.000
1A1b	Petroleum Refining	Gas	N_2O	1.2	0.9	0.000	0.000	1.000
1A2	Manufacturing Industries and Construction	Gas	N_2O	4.2	3.9	0.000	0.000	1.000
3C1d	Biomass burning in wetlands		N_2O	16.7	16.6	0.000	0.000	1.000
1A4a	Commercial/Institutional	Liquid	N_2O	4.9	4.7	0.000	0.000	1.000
1A1b	Petroleum Refining	Gas	CH_4	0.8	0.6	0.000	0.000	1.000
1A2	Manufacturing Industries and Construction	Gas	CH_4	2.8	2.7	0.000	0.000	1.000
3C1d	Biomass burning in wetlands		CH_4	12.4	12.3	0.000	0.000	1.000

1A4a	Commercial/Institutional	Gas	N_2O	0.3	0.5	0.000	0.000	1.000
1A3c	Railways	Liquid	CH_4	0.6	0.5	0.000	0.000	1.000
1A4a	Commercial/Institutional	Gas	CH_4	0.2	0.3	0.000	0.000	1.000
1A4a	Commercial/Institutional	Liquid	CH_4	1.7	1.6	0.000	0.000	1.000
1A3b	Road Transport	Gas	N_2O	0.0	0.1	0.000	0.000	1.000
1A3b	Road Transport	Gas	CH_4	0.1	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
4B	Biological Treatment of Solid Waste - Industrial Waste		CH_4	0.0	0.0	0.000	0.000	1.000
4B	Biological Treatment of Solid Waste - Industrial Waste		N_2O	0.0	0.0	0.000	0.000	1.000
1A1a	Electricity and Heat Production	Gas	CO_2	0.0	0.0	0.000	0.000	1.000
1A1b	Petroleum Refining	Solid	CO_2	0.0	0.0	0.000	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	CO_2	0.0	0.0	0.000	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	CO_2	0.0	0.0	0.000	0.000	1.000
1A1a	Electricity and Heat Production	Gas	CH_4	0.0	0.0	0.000	0.000	1.000
1A1b	Petroleum Refining	Solid	CH_4	0.0	0.0	0.000	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	CH_4	0.0	0.0	0.000	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	CH_4	0.0	0.0	0.000	0.000	1.000
1A1a	Electricity and Heat Production	Gas	N_2O	0.0	0.0	0.000	0.000	1.000
1A1b	Petroleum Refining	Solid	N_2O	0.0	0.0	0.000	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	N_2O	0.0	0.0	0.000	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	N_2O	0.0	0.0	0.000	0.000	1.000
1A3a	Civil Aviation	Gas	CO_2	0.0	0.0	0.000	0.000	1.000
1A3c	Railways	Gas	CO_2	0.0	0.0	0.000	0.000	1.000
1A3d	Water-Borne Navigation	Gas	CO_2	0.0	0.0	0.000	0.000	1.000
1A3a	Civil Aviation	Gas	CH_4	0.0	0.0	0.000	0.000	1.000
1A3c	Railways	Gas	CH_4	0.0	0.0	0.000	0.000	1.000

1A3d	Water-Borne Navigation	Gas	CH_4	0.0	0.0	0.000	0.000	1.000
1A3a	Civil Aviation	Gas	N_2O	0.0	0.0	0.000	0.000	1.000
1A3c	Railways	Gas	N_2O	0.0	0.0	0.000	0.000	1.000
1A3d	Water-Borne Navigation	Gas	N_2O	0.0	0.0	0.000	0.000	1.000
3A1j	Enteric fermentation - other game		CH_4	0.0	0.0	0.000	0.000	1.000
3A2f	Manure management - horses		CH_4	0.0	0.0	0.000	0.000	1.000
3A2g	Manure management - mules and asses		CH_4	0.0	0.0	0.000	0.000	1.000
3A2j	Manure management - other game		CH_4	0.0	0.0	0.000	0.000	1.000
3C1f	Biomass burning in other lands		CH_4	0.0	0.0	0.000	0.000	1.000
3C1f	Biomass burning in other lands		N_2O	0.0	0.0	0.000	0.000	1.000

**C=Confidential data*

Table A.6: Trend assessment on emissions including FOLU for South Africa (2000 - 2020) with the key categories highlighted in green.

IPCC Category code	IPCC Category	Fuel type	Greenhouse gas	2000 Ex,t (Gg CO_2e)	2020 Ex,t (Gg CO_2e)	Tx,t	% Contribution to trend	Cumulative total
1A1a	Electricity and Heat Production	Solid	CO_2	185 027.4	201 332.7	0.035	0.145	0.145
1A4a	Commercial/Institutional	Solid	CO_2	18 248.1	928.5	0.034	0.139	0.284
2C1	Iron and Steel Production		CO_2	15 334.4	3 849.9	0.022	0.092	0.376
3B1a	Forest land remaining forest land - Net CO_2		CO_2	-1 704.8	-10 542.8	0.017	0.071	0.447
1A3b	Road Transport	Liquid	CO_2	36 302.9	43 949.2	0.016	0.064	0.512
2F1	Refrigeration and Air Conditioning		HFCs	0.0	4 846.9	0.010	0.039	0.551
4A	Solid Waste Disposal		CH_4	13 610.5	18 252.8	0.009	0.039	0.590
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	CO_2	2 251.0	5 822.5	0.007	0.029	0.619
1A1a	Electricity and Heat Production	Liquid	CO_2	121.3	3 234.0	0.006	0.025	0.644
1A5a	Stationary	Solid	CO_2	14 272.3	16 969.3	0.006	0.023	0.667
3D1	Harvested wood products		CO_2	-2 106.2	635.2	0.005	0.022	0.689
1A4b	Residential	Solid	CO_2	3 604.2	990.0	0.005	0.021	0.710
1A2	Manufacturing Industries and Construction	Liquid	CO_2	2 564.8	5 016.0	0.005	0.020	0.730
1A5a	Stationary	Liquid	CO_2	2 888.6	423.3	0.005	0.020	0.750
1B3	Other Emissions from Energy Production		CO_2	28 146.6	25 644.5	0.004	0.018	0.768
3A1a	Enteric fermentation - cattle		CH_4	23 901.0	21 554.6	0.004	0.017	0.786
1A2	Manufacturing Industries and Construction	Solid	CO_2	19 545.0	21 220.0	0.004	0.015	0.800
1A3d	Water-Borne Navigation	Liquid	CO_2	222.2	1 970.6	0.003	0.014	0.815
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	CO_2	30 454.7	28 454.1	0.003	0.014	0.829
1A3a	Civil Aviation	Liquid	CO_2	2 249.1	693.4	0.003	0.012	0.841
1A4b	Residential	Liquid	CO_2	2 868.4	1 334.1	0.003	0.012	0.853
2C2	Ferroalloys Production		CO_2	8 079.1	6 576.5	0.003	0.012	0.865

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3C4	Direct N_2O emissions from managed soils		N_2O	4 093.0	5 276.0	0.002	0.010	0.875
3A1c	Enteric fermentation - sheep		CH_4	5 837.3	4 653.5	0.002	0.009	0.884
1A1b	Petroleum Refining	Liquid	CO_2	1 735.5	665.6	0.002	0.009	0.893
2C3	Aluminium Production		PFCs	983.2	120.4	0.002	0.007	0.900
4D1	Wastewater Treatment and Discharge		CH_4	1 951.2	2 783.0	0.002	0.007	0.906
2B	Chemical industry		C	C	C	0.002	0.006	0.913
2D2	Paraffin Wax Use		CO_2	7.4	627.4	0.001	0.005	0.918
1B1a	Coal mining and handling		CH_4	2 338.1	2 892.8	0.001	0.005	0.923
3C2	Liming		CO_2	384.1	942.3	0.001	0.005	0.927
1A1b	Petroleum Refining	Gas	CO_2	2 307.1	1 745.0	0.001	0.004	0.932
2C2	Ferroalloys Production		CH_4	3.3	492.5	0.001	0.004	0.936
2D1	Lubricant Use		CO_2	188.5	667.3	0.001	0.004	0.939
3B1b	Land converted to forest land - Net CO_2		CO_2	-13 471.5	-14 032.4	0.001	0.004	0.943
3B4	Wetland		CH_4	1 587.9	1 192.5	0.001	0.003	0.946
1A2	Manufacturing Industries and Construction	Gas	CO_2	6 520.2	6 830.2	0.001	0.003	0.949
3B5a	Settlements remaining settlements - Net CO_2		CO_2	-1 554.0	-1 914.2	0.001	0.003	0.952
3A2i	Manure management - poultry		N_2O	651.9	977.1	0.001	0.003	0.955
1A4a	Commercial/Institutional	Gas	CO_2	631.0	947.4	0.001	0.003	0.957
2B	Chemical industry		C	C	C	0.001	0.002	0.960
2A2	Lime Production		CO_2	426.1	714.9	0.001	0.002	0.962
3A1d	Enteric fermentation - goats		CH_4	1 493.1	1 190.0	0.001	0.002	0.964
3C3	Urea application		CO_2	297.3	584.7	0.001	0.002	0.967
3B2b	Land converted to cropland - Net CO_2		CO_2	3 314.2	3 558.7	0.001	0.002	0.969
3B3b	Land converted to grassland - Net CO_2		CO_2	-9 697.1	-10 027.3	0.000	0.002	0.971
4D1	Wastewater Treatment and Discharge		N_2O	545.4	777.9	0.000	0.002	0.973
1A4b	Residential	Solid	N_2O	439.1	260.3	0.000	0.001	0.974
1A4a	Commercial/Institutional	Solid	N_2O	176.3	9.0	0.000	0.001	0.976

3B2a	Cropland remaining cropland - Net CO_2		CO_2	-1 527.0	-1 391.3	0.000	0.001	0.977
1A4a	Commercial/Institutional	Liquid	CO_2	2 028.6	1 865.6	0.000	0.001	0.978
3B4	Wetland		N_2O	581.4	436.6	0.000	0.001	0.979
1A3b	Road Transport	Liquid	N_2O	545.1	677.9	0.000	0.001	0.980
3A2a	Manure management - cattle		N_2O	1 249.4	1 360.3	0.000	0.001	0.981
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	CO_2	199.5	83.0	0.000	0.001	0.982
1A1a	Electricity and Heat Production	Solid	N_2O	893.9	998.8	0.000	0.001	0.983
2A4	Other Process Uses of Carbonates		CO_2	0.0	109.3	0.000	0.001	0.984
4C2	Open Burning of Waste		CH_4	117.5	223.4	0.000	0.001	0.985
1A3b	Road Transport	Gas	CO_2	3.4	108.6	0.000	0.001	0.986
1B2a	Oil		CO_2	752.0	641.8	0.000	0.001	0.987
2B	Chemical industry		C	C	C	0.000	0.001	0.987
3C1c	Biomass burning in grasslands		N_2O	557.4	471.6	0.000	0.001	0.988
1B3	Other Emissions from Energy Production		CH_4	2 318.6	2 218.2	0.000	0.001	0.989
2A3	Glass Production		CO_2	74.4	154.5	0.000	0.001	0.989
1A4b	Residential	Solid	CH_4	206.2	127.6	0.000	0.001	0.990
2C6	Zinc Production		CO_2	108.4	36.6	0.000	0.001	0.990
3C1b	Biomass burning in croplands		CH_4	235.6	167.0	0.000	0.001	0.991
2F3	Fire Protection		HFCs	0.0	65.9	0.000	0.001	0.991
3C1c	Biomass burning in grasslands		CH_4	413.5	349.9	0.000	0.000	0.992
2B	Chemical industry		C	C	C	0.000	0.000	0.992
2C3	Aluminium Production		CO_2	1 091.3	1 134.8	0.000	0.000	0.993
3B6b	Land converted to other lands - Net CO_2		CO_2	6 126.9	6 125.2	0.000	0.000	0.993
3B3a	Grassland remaining grassland - Net CO_2		CO_2	-1 001.1	-1 057.2	0.000	0.000	0.994
1A3c	Railways	Liquid	CO_2	551.5	501.8	0.000	0.000	0.994
3A2i	Manure management - poultry		CH_4	84.2	128.2	0.000	0.000	0.994
2B	Chemical industry		C	C	C	0.000	0.000	0.995

2A1	Cement Production		CO_2	3 870.6	3 795.7	0.000	0.000	0.995
4C2	Open Burning of Waste		N_2O	40.0	76.1	0.000	0.000	0.995
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	N_2O	110.3	143.8	0.000	0.000	0.996
3A2h	Manure management - swine		CH_4	192.0	158.2	0.000	0.000	0.996
3C1a	Biomass burning in forest land		N_2O	298.7	265.6	0.000	0.000	0.996
3C6	Indirect N_2O emissions from manure management		N_2O	201.4	227.5	0.000	0.000	0.996
2B	Chemical industry		C	C	C	0.000	0.000	0.997
3C1b	Biomass burning in croplands		N_2O	90.2	63.9	0.000	0.000	0.997
3B5b	Land converted to settlements - Net CO_2		CO_2	798.1	766.8	0.000	0.000	0.997
1A3b	Road Transport	Liquid	CH_4	247.9	221.3	0.000	0.000	0.997
3A1f	Enteric fermentation - horses		CH_4	102.1	124.7	0.000	0.000	0.997
1A2	Manufacturing Industries and Construction	Solid	N_2O	216.6	195.1	0.000	0.000	0.998
2B	Chemical industry		C	C	C	0.000	0.000	0.998
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Liquid	CH_4	10.6	29.1	0.000	0.000	0.998
2F4	Aerosols		HFCs	0.0	18.2	0.000	0.000	0.998
4C2	Open Burning of Waste		CO_2	18.6	35.4	0.000	0.000	0.998
3A2a	Manure management - cattle		CH_4	881.6	859.0	0.000	0.000	0.998
1A3c	Railways	Liquid	N_2O	66.0	51.3	0.000	0.000	0.998
1A2	Manufacturing Industries and Construction	Solid	CH_4	66.4	51.7	0.000	0.000	0.998
1A5a	Stationary	Solid	N_2O	69.0	82.0	0.000	0.000	0.999
2B	Chemical industry		C	C	C	0.000	0.000	0.999
3A2d	Manure management - goats		N_2O	69.2	57.9	0.000	0.000	0.999
1A3d	Water-Borne Navigation	Liquid	N_2O	1.3	11.8	0.000	0.000	0.999
3B4b	Land converted to wetland		CO_2	-481.1	-475.6	0.000	0.000	0.999
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	N_2O	5.6	14.7	0.000	0.000	0.999
2C5	Lead Production		CO_2	15.1	6.6	0.000	0.000	0.999
3C5	Indirect N_2O emissions from managed soils		N_2O	737.5	723.3	0.000	0.000	0.999

1A1a	Electricity and Heat Production	Liquid	N_2O	0.3	8.1	0.000	0.000	0.999
1B1a	Coal mining and handling		CO_2	30.6	37.9	0.000	0.000	0.999
3A1h	Enteric fermentation - swine		CH_4	39.8	32.8	0.000	0.000	0.999
1A5a	Stationary	Liquid	N_2O	7.4	1.1	0.000	0.000	0.999
1A2	Manufacturing Industries and Construction	Liquid	N_2O	6.4	12.4	0.000	0.000	0.999
3A2h	Manure management - swine		N_2O	34.7	28.6	0.000	0.000	0.999
1A1a	Electricity and Heat Production	Solid	CH_4	40.4	45.1	0.000	0.000	1.000
2B	Chemical industry		C	C	C	0.000	0.000	1.000
1A3a	Civil Aviation	Liquid	N_2O	5.9	1.8	0.000	0.000	1.000
1A4a	Commercial/Institutional	Solid	CH_4	4.0	0.2	0.000	0.000	1.000
1A3d	Water-Borne Navigation	Liquid	CH_4	0.4	3.7	0.000	0.000	1.000
1A4b	Residential	Liquid	N_2O	5.4	2.1	0.000	0.000	1.000
2C1	Iron and Steel Production		CH_4	0.0	3.2	0.000	0.000	1.000
1A4c	Agriculture/Forestry/Fishing/Fish Farms	Liquid	CH_4	1.9	5.0	0.000	0.000	1.000
2B	Chemical industry		C	C	C	0.000	0.000	1.000
1A1a	Electricity and Heat Production	Liquid	CH_4	0.1	2.7	0.000	0.000	1.000
3C1e	Biomass burning in settlements		N_2O	10.5	7.8	0.000	0.000	1.000
3C1a	Biomass burning in forest land		CH_4	293.6	288.6	0.000	0.000	1.000
1A1b	Petroleum Refining	Liquid	N_2O	3.6	1.3	0.000	0.000	1.000
1A5a	Stationary	Liquid	CH_4	2.5	0.4	0.000	0.000	1.000
2F2	Foam Blowing Agents		HFCs	0.0	2.1	0.000	0.000	1.000
1A2	Manufacturing Industries and Construction	Liquid	CH_4	2.2	4.2	0.000	0.000	1.000
3C1e	Biomass burning in settlements		CH_4	7.8	5.8	0.000	0.000	1.000
3A2d	Manure management - goats		CH_4	11.3	9.4	0.000	0.000	1.000
1A3a	Civil Aviation	Liquid	CH_4	2.0	0.6	0.000	0.000	1.000
3A2c	Manure management - sheep		N_2O	185.3	182.5	0.000	0.000	1.000
1A4b	Residential	Liquid	CH_4	2.0	0.8	0.000	0.000	1.000

1A4c	Agriculture/Forestry/Fishing/Fish Farms	Solid	N_2O	1.9	0.8	0.000	0.000	1.000
3A2c	Manure management - sheep		CH_4	22.1	21.1	0.000	0.000	1.000
1A1b	Petroleum Refining	Liquid	CH_4	1.2	0.4	0.000	0.000	1.000
1A5a	Stationary	Solid	CH_4	3.1	3.7	0.000	0.000	1.000
3B4a	Wetland remaining wetland		CO_2	39.1	39.1	0.000	0.000	1.000
1A1b	Petroleum Refining	Gas	N_2O	1.2	0.9	0.000	0.000	1.000
3A1g	Enteric fermentation - mules and asses		CH_4	34.4	33.9	0.000	0.000	1.000
1A2	Manufacturing Industries and Construction	Gas	N_2O	4.2	3.9	0.000	0.000	1.000
1A1b	Petroleum Refining	Gas	CH_4	0.8	0.6	0.000	0.000	1.000
1A4a	Commercial/Institutional	Gas	N_2O	0.3	0.5	0.000	0.000	1.000
1A4a	Commercial/Institutional	Liquid	N_2O	4.9	4.7	0.000	0.000	1.000
1A2	Manufacturing Industries and Construction	Gas	CH_4	2.8	2.7	0.000	0.000	1.000
1A3c	Railways	Liquid	CH_4	0.6	0.5	0.000	0.000	1.000
1A4a	Commercial/Institutional	Gas	CH_4	0.2	0.3	0.000	0.000	1.000
1A3b	Road Transport	Gas	N_2O	0.0	0.1	0.000	0.000	1.000
1A4a	Commercial/Institutional	Liquid	CH_4	1.7	1.6	0.000	0.000	1.000
3C1d	Biomass burning in wetlands		N_2O	16.7	16.6	0.000	0.000	1.000
1A3b	Road Transport	Gas	CH_4	0.1	0.0	0.000	0.000	1.000
3C1d	Biomass burning in wetlands		CH_4	12.4	12.3	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
4B	Biological Treatment of Solid Waste - Industrial Waste		CH_4	0.0	0.0	0.000	0.000	1.000
4B	Biological Treatment of Solid Waste - Industrial Waste		N_2O	0.0	0.0	0.000	0.000	1.000
1A1a	Electricity and Heat Production	Gas	CO_2	0.0	0.0	0.000	0.000	1.000
1A1b	Petroleum Refining	Solid	CO_2	0.0	0.0	0.000	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	CO_2	0.0	0.0	0.000	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	CO_2	0.0	0.0	0.000	0.000	1.000

1A1a	Electricity and Heat Production	Gas	CH_4	0.0	0.0	0.000	0.000	1.000
1A1b	Petroleum Refining	Solid	CH_4	0.0	0.0	0.000	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	CH_4	0.0	0.0	0.000	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	CH_4	0.0	0.0	0.000	0.000	1.000
1A1a	Electricity and Heat Production	Gas	N_2O	0.0	0.0	0.000	0.000	1.000
1A1b	Petroleum Refining	Solid	N_2O	0.0	0.0	0.000	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Solid	N_2O	0.0	0.0	0.000	0.000	1.000
1A1c	Manufacture of Solid Fuels and Other Energy Industries	Gas	N_2O	0.0	0.0	0.000	0.000	1.000
1A3a	Civil Aviation	Gas	CO_2	0.0	0.0	0.000	0.000	1.000
1A3c	Railways	Gas	CO_2	0.0	0.0	0.000	0.000	1.000
1A3d	Water-Borne Navigation	Gas	CO_2	0.0	0.0	0.000	0.000	1.000
1A3a	Civil Aviation	Gas	CH_4	0.0	0.0	0.000	0.000	1.000
1A3c	Railways	Gas	CH_4	0.0	0.0	0.000	0.000	1.000
1A3d	Water-Borne Navigation	Gas	CH_4	0.0	0.0	0.000	0.000	1.000
1A3a	Civil Aviation	Gas	N_2O	0.0	0.0	0.000	0.000	1.000
1A3c	Railways	Gas	N_2O	0.0	0.0	0.000	0.000	1.000
1A3d	Water-Borne Navigation	Gas	N_2O	0.0	0.0	0.000	0.000	1.000
3A1j	Enteric fermentation - other game		CH_4	0.0	0.0	0.000	0.000	1.000
3A2f	Manure management - horses		CH_4	0.0	0.0	0.000	0.000	1.000
3A2g	Manure management - mules and asses		CH_4	0.0	0.0	0.000	0.000	1.000
3A2j	Manure management - other game		CH_4	0.0	0.0	0.000	0.000	1.000
3B6a	Other land remaining other land		CO_2	0.0	0.0	0.000	0.000	1.000
3C1f	Biomass burning in other lands		CH_4	0.0	0.0	0.000	0.000	1.000
3C1f	Biomass burning in other lands		N_2O	0.0	0.0	0.000	0.000	1.000
4D2	Industrial Wastewater Treatment and Discharge		CH_4	1 958.1	897.3	0.000	0.000	1.000

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Appendix B: Uncertainty analysis

Table B.1: Overall uncertainty analysis for 2000 to 2020.

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	(-)%	(+)%	(-)%	(+)%	(-)%	(+)%	(%)	%	%	%
1A1a	Electricity and Heat Production	CO_2	185 148.7	204 566.7	3.00%	5.00%	7.00%	7.00%	7.62%	8.60%	0.1560%	0.31%	3.24%	0.11%
1A1b	Petroleum Refining	CO_2	4 042.6	2 410.6	3.00%	5.00%	7.00%	7.00%	7.62%	8.60%	0.0000%	0.03%	0.04%	0.00%
1A1c	Manufacture of Solid Fuels and Other Energy Industries	CO_2	30 454.7	28 454.1	3.00%	5.00%	7.00%	7.00%	7.62%	8.60%	0.0030%	0.03%	0.45%	0.00%
1A1a	Electricity and Heat Production	CH_4	40.5	47.8	3.00%	5.00%	75.00%	75.00%	75.06%	75.17%	0.0000%	0.00%	0.00%	0.00%
1A1b	Petroleum Refining	CH_4	2.1	1.1	3.00%	5.00%	75.00%	75.00%	75.06%	75.17%	0.0000%	0.00%	0.00%	0.00%
1A1c	Manufacture of Solid Fuels and Other Energy Industries	CH_4	10.6	29.1	3.00%	5.00%	75.00%	75.00%	75.06%	75.17%	0.0000%	0.00%	0.00%	0.00%
1A1a	Electricity and Heat Production	N_2O	894.2	1 006.9	3.00%	5.00%	75.00%	75.00%	75.06%	75.17%	0.0003%	0.02%	0.02%	0.00%
1A1b	Petroleum Refining	N_2O	4.9	2.2	3.00%	5.00%	75.00%	75.00%	75.06%	75.17%	0.0000%	0.00%	0.00%	0.00%
1A1c	Manufacture of Solid Fuels and Other Energy Industries	N_2O	110.3	143.8	3.00%	5.00%	75.00%	75.00%	75.06%	75.17%	0.0000%	0.01%	0.00%	0.00%
1A2	Manufacturing Industries and Construction	CO_2	28 630.0	33 066.2	5.00%	10.00%	7.00%	7.00%	8.60%	12.21%	0.0082%	0.07%	1.05%	0.01%
1A2	Manufacturing Industries and Construction	CH_4	9.2	11.5	5.00%	10.00%	75.00%	75.00%	75.17%	75.66%	0.0000%	0.00%	0.00%	0.00%
1A2	Manufacturing Industries and Construction	N_2O	104.8	118.7	5.00%	10.00%	75.00%	75.00%	75.17%	75.66%	0.0000%	0.00%	0.00%	0.00%

1A3a	Civil Aviation	CO_2	2 249.1	693.4	5.00%	5.00%	1.50%	1.50%	5.22%	5.22%	0.0000%	0.01%	0.01%	0.00%
1A3b	Road Transport	CO_2	36 306.3	44 057.9	5.00%	5.00%	2.00%	2.00%	5.39%	5.39%	0.0028%	0.03%	0.70%	0.00%
1A3c	Railways	CO_2	551.5	501.8	5.00%	5.00%	5.00%	5.00%	7.07%	7.07%	0.0000%	0.00%	0.01%	0.00%
1A3d	Water-Borne Navigation	CO_2	222.2	1 970.6	5.00%	5.00%	5.00%	5.00%	7.07%	7.07%	0.0000%	0.02%	0.03%	0.00%
1A3a	Civil Aviation	CH_4	2.0	0.6	5.00%	5.00%	50.00%	50.00%	50.25%	50.25%	0.0000%	0.00%	0.00%	0.00%
1A3b	Road Transport	CH_4	248.0	221.4	5.00%	5.00%	9.00%	9.00%	10.30%	10.30%	0.0000%	0.00%	0.00%	0.00%
1A3c	Railways	CH_4	0.6	0.5	5.00%	5.00%	9.00%	9.00%	10.30%	10.30%	0.0000%	0.00%	0.00%	0.00%
1A3d	Water-Borne Navigation	CH_4	0.4	3.7	5.00%	5.00%	50.00%	50.00%	50.25%	50.25%	0.0000%	0.00%	0.00%	0.00%
1A3a	Civil Aviation	N_2O	5.9	1.8	5.00%	5.00%	50.00%	50.00%	50.25%	50.25%	0.0000%	0.00%	0.00%	0.00%
1A3b	Road Transport	N_2O	545.1	678.0	5.00%	5.00%	70.00%	72.00%	70.18%	72.17%	0.0001%	0.02%	0.01%	0.00%
1A3c	Railways	N_2O	66.0	51.3	5.00%	5.00%	70.00%	72.00%	70.18%	72.17%	0.0000%	0.00%	0.00%	0.00%
1A3d	Water-Borne Navigation	N_2O	1.3	11.8	5.00%	5.00%	40.00%	140.00%	40.31%	140.09%	0.0000%	0.00%	0.00%	0.00%
1A4a	Commercial/Institutional	CO_2	20 907.7	3 741.5	5.00%	10.00%	7.00%	7.00%	8.60%	12.21%	0.0001%	0.27%	0.12%	0.00%
1A4b	Residential	CO_2	6 472.7	2 324.1	5.00%	10.00%	7.00%	7.00%	8.60%	12.21%	0.0000%	0.06%	0.07%	0.00%
1A4c	Agriculture/Forestry/Fishing/Fish Farms	CO_2	2 450.5	5 905.5	5.00%	10.00%	7.00%	7.00%	8.60%	12.21%	0.0003%	0.05%	0.19%	0.00%
1A4a	Commercial/Institutional	CH_4	5.9	2.1	5.00%	10.00%	75.00%	75.00%	75.17%	75.66%	0.0000%	0.00%	0.00%	0.00%
1A4b	Residential	CH_4	208.2	128.4	5.00%	10.00%	75.00%	75.00%	75.17%	75.66%	0.0000%	0.01%	0.00%	0.00%
1A4c	Agriculture/Forestry/Fishing/Fish Farms	CH_4	1.9	5.0	5.00%	10.00%	75.00%	75.00%	75.17%	75.66%	0.0000%	0.00%	0.00%	0.00%
1A4a	Commercial/Institutional	N_2O	181.6	14.2	5.00%	10.00%	75.00%	75.00%	75.17%	75.66%	0.0000%	0.03%	0.00%	0.00%
1A4b	Residential	N_2O	444.6	262.4	5.00%	10.00%	75.00%	75.00%	75.17%	75.66%	0.0000%	0.03%	0.01%	0.00%
1A4c	Agriculture/Forestry/Fishing/Fish Farms	N_2O	7.5	15.5	5.00%	10.00%	75.00%	75.00%	75.17%	75.66%	0.0000%	0.00%	0.00%	0.00%
1A5a	Stationary	CO_2	17 261.4	18 056.5	3.00%	5.00%	7.00%	7.00%	7.62%	8.60%	0.0012%	0.01%	0.29%	0.00%
1A5a	Stationary	CH_4	5.6	4.2	3.00%	5.00%	75.00%	75.00%	75.06%	75.17%	0.0000%	0.00%	0.00%	0.00%
1A5a	Stationary	N_2O	76.9	86.3	3.00%	5.00%	75.00%	75.00%	75.06%	75.17%	0.0000%	0.00%	0.00%	0.00%
1B1a	Coal mining and handling	CO_2	30.6	37.9	10.00%	10.00%	63.00%	63.00%	63.79%	63.79%	0.0000%	0.00%	0.00%	0.00%
1B1a	Coal mining and handling	CH_4	2 338.1	2 892.8	10.00%	10.00%	63.00%	63.00%	63.79%	63.79%	0.0017%	0.08%	0.09%	0.00%
1B2a	Oil	CO_2	752.0	641.8	25.00%	25.00%	75.00%	75.00%	79.06%	79.06%	0.0001%	0.02%	0.05%	0.00%
1B3	Other Emissions from Energy Production	CO_2	28 146.6	25 644.5	25.00%	25.00%	75.00%	75.00%	79.06%	79.06%	0.2070%	0.41%	2.03%	0.04%
1B3	Other Emissions from Energy Production	CH_4	2 318.6	2 218.2	25.00%	25.00%	75.00%	75.00%	79.06%	79.06%	0.0015%	0.02%	0.18%	0.00%

2A1	Cement Production	CO_2	3 870.6	3 357.2	30.00%	30.00%	35.00%	35.00%	46.10%	46.10%	0.0012%	0.04%	0.32%	0.00%
2A2	Lime Production	CO_2	426.1	714.9	30.00%	30.00%	6.00%	6.00%	30.59%	30.59%	0.0000%	0.00%	0.07%	0.00%
2A3	Glass Production	CO_2	74.4	154.5	1.00%	3.00%	1.00%	3.00%	1.41%	4.24%	0.0000%	0.00%	0.00%	0.00%
2A4	OPUC	CO_2	0.0	94.5	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.0000%	0.00%	0.00%	0.00%
2B1	Ammonia Production	CO_2	485.3	398.2	15.00%	85.00%	1.00%	5.00%	15.03%	85.15%	0.0001%	0.00%	0.11%	0.00%
2B1	Ammonia Production	CH_4	65.6	77.7	15.00%	85.00%	1.00%	5.00%	15.03%	85.15%	0.0000%	0.00%	0.02%	0.00%
2B3	Nitric Acid Production	N_2O	1 644.5	835.5	2.00%	2.00%	2.00%	2.00%	2.83%	2.83%	0.0000%	0.00%	0.01%	0.00%
2B5	Carbide Production	CO_2	2.0	29.5	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.0000%	0.00%	0.00%	0.00%
2B5	Carbide Production	CH_4	0.0	2 743.1	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.0000%	0.00%	0.00%	0.00%
2B6	Titanium Dioxide Production	CO_2	437.6	742.1	5.00%	5.00%	10.00%	10.00%	11.18%	11.18%	0.0000%	0.01%	0.01%	0.00%
2B7	Soda Ash Production	CO_2	0.0	4.8	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.0000%	0.00%	0.00%	0.00%
2B8f	Petrochemical and Carbon Black Production	CO_2	138.6	93.7	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.0000%	0.00%	0.00%	0.00%
2B8f	Petrochemical and Carbon Black Production	CH_4	0.1	0.0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.0000%	0.00%	0.00%	0.00%
2B8g	Hydrogen production	CO_2	0.0	59.7	10.00%	10.00%	15.00%	15.00%	18.03%	18.03%	0.0000%	0.00%	0.00%	0.00%
2C1	Iron and Steel Production	CO_2	15 334.4	3 853.1	10.00%	10.00%	85.00%	85.00%	85.59%	85.59%	0.0055%	2.18%	0.12%	0.05%
2C1	Iron and Steel Production	CH_4	0.0	3.2	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.0000%	0.00%	0.00%	0.00%
2C2	Ferroalloys Production	CO_2	8 079.1	5 457.3	10.00%	110.00%	25.00%	25.00%	26.93%	112.81%	0.0191%	0.15%	1.90%	0.04%
2C2	Ferroalloys Production	CH_4	3.3	496.2	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.0000%	0.00%	0.00%	0.00%
2C3	Aluminium Production	CO_2	1 091.3	1 134.8	5.00%	5.00%	25.00%	25.00%	25.50%	25.50%	0.0000%	0.00%	0.02%	0.00%
2C3	Aluminium Production	PFCs	983.2	120.4	5.00%	5.00%	25.00%	25.00%	25.50%	25.50%	0.0000%	0.05%	0.00%	0.00%
2C5	Lead Production	CO_2	15.1	6.6	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.0000%	0.00%	0.00%	0.00%
2C6	Zinc Production	CO_2	108.4	36.6	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.0000%	0.00%	0.00%	0.00%
2D1	Lubricant Use	CO_2	188.5	855.0	10.00%	10.00%	50.00%	50.00%	50.99%	50.99%	0.0001%	0.07%	0.03%	0.00%
2D2	Paraffin Wax Use	CO_2	7.4	393.2	10.00%	10.00%	50.00%	50.00%	50.99%	50.99%	0.0000%	0.04%	0.01%	0.00%
2F1	Refrigeration and Air Conditioning	HFCs	0.0	4 846.9	10.00%	10.00%	50.00%	50.00%	50.99%	50.99%	0.0031%	0.54%	0.15%	0.00%
2F2	Foam Blowing Agents	HFCs	0.0	2.1	10.00%	10.00%	50.00%	50.00%	50.99%	50.99%	0.0000%	0.00%	0.00%	0.00%
2F3	Fire Protection	HFCs	0.0	65.9	25.00%	25.00%	25.00%	25.00%	35.36%	35.36%	0.0000%	0.00%	0.01%	0.00%
2F4	Aerosols	HFCs	0.0	18.2	50.00%	50.00%	25.00%	25.00%	55.90%	55.90%	0.0000%	0.00%	0.00%	0.00%
3A1a	Enteric fermentation - cattle	CH_4	23 901.0	21 554.6	5.10%	22.36%	15.00%	27.80%	15.84%	35.68%	0.0298%	0.14%	1.53%	0.02%
3A1c	Enteric fermentation - sheep	CH_4	5 837.3	4 653.5	11.18%	20.62%	32.00%	32.00%	33.90%	38.07%	0.0016%	0.08%	0.30%	0.00%

3A1d	Enteric fermentation - goats	CH_4	1 493.1	1 190.0	20.63%	20.62%	39.80%	39.80%	44.83%	44.82%	0.0001%	0.03%	0.08%	0.00%
3A1f	Enteric fermentation - horses	CH_4	102.1	124.7	7.07%	7.07%	40.00%	40.00%	40.62%	40.62%	0.0000%	0.00%	0.00%	0.00%
3A1g	Enteric fermentation - mules and asses	CH_4	34.4	33.9	11.18%	11.18%	40.00%	40.00%	41.53%	41.53%	0.0000%	0.00%	0.00%	0.00%
3A1h	Enteric fermentation - swine	CH_4	39.8	32.8	50.20%	50.20%	20.00%	20.00%	54.04%	54.04%	0.0000%	0.00%	0.01%	0.00%
3A1j	Enteric fermentation - other game	CH_4	0.0	0.0					0.00%	0.00%	0.0000%	0.00%	0.00%	0.00%
3A2a	Manure management - cattle	CH_4	881.6	859.0	5.10%	22.36%	10.00%	19.00%	11.23%	29.34%	0.0000%	0.00%	0.06%	0.00%
3A2c	Manure management - sheep	CH_4	22.1	21.1	11.18%	20.62%	18.70%	18.70%	21.79%	27.84%	0.0000%	0.00%	0.00%	0.00%
3A2d	Manure management - goats	CH_4	11.3	9.4	20.63%	20.62%	50.40%	50.40%	54.46%	54.45%	0.0000%	0.00%	0.00%	0.00%
3A2f	Manure management - horses	CH_4	0.0	0.0	7.07%	7.07%	30.80%	30.80%	31.60%	31.60%	0.0000%	0.00%	0.00%	0.00%
3A2g	Manure management - mules and asses	CH_4	0.0	0.0	11.18%	11.18%	30.00%	30.00%	32.02%	32.02%	0.0000%	0.00%	0.00%	0.00%
3A2h	Manure management - swine	CH_4	192.0	158.2	50.20%	50.20%	20.00%	20.00%	54.04%	54.04%	0.0000%	0.00%	0.03%	0.00%
3A2i	Manure management - poultry	CH_4	84.2	128.2	20.60%	20.60%	20.00%	20.00%	28.71%	28.71%	0.0000%	0.00%	0.01%	0.00%
3A2j	Manure management - other game	CH_4	0.0	0.0					0.00%	0.00%	0.0000%	0.00%	0.00%	0.00%
3A2a	Manure management - cattle	N_2O	1 249.4	1 360.3	30.84%	60.37%	58.70%	116.30%	66.31%	131.04%	0.0016%	0.03%	0.26%	0.00%
3A2c	Manure management - sheep	N_2O	185.3	182.5	32.10%	32.10%	59.40%	105.00%	67.52%	109.80%	0.0000%	0.00%	0.02%	0.00%
3A2d	Manure management - goats	N_2O	69.2	57.9	36.50%	36.50%	61.90%	106.40%	71.86%	112.49%	0.0000%	0.00%	0.01%	0.00%
3A2h	Manure management - swine	N_2O	34.7	28.6	59.40%	59.40%	77.60%	116.30%	97.72%	130.59%	0.0000%	0.00%	0.01%	0.00%
3A2i	Manure management - poultry	N_2O	651.9	977.1	44.20%	44.20%	66.70%	109.30%	80.02%	117.90%	0.0007%	0.08%	0.14%	0.00%
3B1a	Forest land remaining forest land - Net CO_2	CO_2	-8 439.3	-15 330.1	30.70%	30.70%	44.70%	44.70%	54.23%	54.23%	0.0348%	0.69%	1.49%	0.03%
3B1b	Land converted to forest land - Net CO_2	CO_2	-10 508.4	-10 896.0	35.70%	35.70%	44.70%	44.70%	57.21%	57.21%	0.0196%	0.04%	1.23%	0.02%
3B2a	Cropland remaining cropland - Net CO_2	CO_2	-3 955.8	-3 817.1	8.40%	8.40%	90.00%	90.00%	90.39%	90.39%	0.0060%	0.03%	0.10%	0.00%
3B2b	Land converted to cropland - Net CO_2	CO_2	1 000.1	1 002.4	13.40%	13.40%	90.00%	90.00%	90.99%	90.99%	0.0004%	0.00%	0.04%	0.00%
3B3a	Grassland remaining grassland - Net CO_2	CO_2	-11 302.5	-11 309.4	21.70%	21.70%	90.00%	90.00%	92.58%	92.58%	0.0552%	0.01%	0.78%	0.01%
3B3b	Land converted to grassland - Net CO_2	CO_2	-4 971.7	-5 167.3	26.70%	26.70%	90.00%	90.00%	93.88%	93.88%	0.0119%	0.04%	0.44%	0.00%
3B4a	Wetland remaining wetland	CO_2	3 828.7	3 828.7	7.00%	7.00%	90.00%	90.00%	90.27%	90.27%	0.0060%	0.00%	0.08%	0.00%
3B4b	Land converted to wetland	CO_2	-1 169.2	-1 155.2	12.00%	12.00%	90.00%	90.00%	90.80%	90.80%	0.0006%	0.00%	0.04%	0.00%

3B4	Wetland	CH_4	1 587.9	1 192.5	7.00%	7.00%	90.00%	90.00%	90.27%	90.27%	0.0006%	0.08%	0.03%	0.00%
3B4	Wetland	N_2O	581.4	436.6	7.00%	7.00%	90.00%	90.00%	90.27%	90.27%	0.0001%	0.03%	0.01%	0.00%
3B5a	Settlements remaining settlements - Net CO_2	CO_2	-1 728.2	-2 088.4	6.60%	6.60%	90.00%	90.00%	90.24%	90.24%	0.0018%	0.07%	0.04%	0.00%
3B5b	Land converted to settlements - Net CO_2	CO_2	967.3	940.5	11.60%	11.60%	90.00%	90.00%	90.74%	90.74%	0.0004%	0.01%	0.03%	0.00%
3B6a	Other land remaining other land	CO_2	2 385.6	2 385.6	0.00%	0.00%	90.00%	90.00%	90.00%	90.00%	0.0023%	0.00%	0.00%	0.00%
3B6b	Land converted to other lands - Net CO_2	CO_2	6 273.4	6 273.4	22.00%	22.00%	90.00%	90.00%	92.65%	92.65%	0.0170%	0.00%	0.44%	0.00%
3C1a	Biomass burning in forest land	CH_4	293.6	288.6	60.51%	60.51%	72.53%	72.53%	94.46%	94.46%	0.0000%	0.00%	0.06%	0.00%
3C1b	Biomass burning in croplands	CH_4	235.6	167.0	22.36%	22.36%	45.83%	45.83%	50.99%	50.99%	0.0000%	0.01%	0.01%	0.00%
3C1c	Biomass burning in grasslands	CH_4	413.5	349.9	76.72%	76.72%	86.52%	86.52%	115.64%	115.64%	0.0001%	0.01%	0.09%	0.00%
3C1d	Biomass burning in wetlands	CH_4	12.4	12.3	76.19%	76.19%	86.05%	86.05%	114.93%	114.93%	0.0000%	0.00%	0.00%	0.00%
3C1e	Biomass burning in settlements	CH_4	7.8	5.8	41.23%	41.23%	57.45%	57.45%	70.71%	70.71%	0.0000%	0.00%	0.00%	0.00%
3C1f	Biomass burning in other lands	CH_4	0.0	0.0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.0000%	0.00%	0.00%	0.00%
3C1a	Biomass burning in forest land	N_2O	298.7	265.6	60.51%	60.51%	72.53%	72.53%	94.46%	94.46%	0.0000%	0.01%	0.05%	0.00%
3C1b	Biomass burning in croplands	N_2O	90.2	63.9	22.36%	22.36%	45.83%	45.83%	50.99%	50.99%	0.0000%	0.00%	0.00%	0.00%
3C1c	Biomass burning in grasslands	N_2O	557.4	471.6	76.72%	76.72%	86.52%	86.52%	115.64%	115.64%	0.0001%	0.02%	0.11%	0.00%
3C1d	Biomass burning in wetlands	N_2O	16.7	16.6	76.19%	76.19%	86.05%	86.05%	114.93%	114.93%	0.0000%	0.00%	0.00%	0.00%
3C1e	Biomass burning in settlements	N_2O	10.5	7.8	41.23%	41.23%	57.45%	57.45%	70.71%	70.71%	0.0000%	0.00%	0.00%	0.00%
3C1f	Biomass burning in other lands	N_2O	0.0	0.0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.0000%	0.00%	0.00%	0.00%
3C2	Liming	CO_2	384.1	942.3	75.00%	75.00%	90.10%	90.10%	117.23%	117.23%	0.0006%	0.11%	0.22%	0.00%
3C3	Urea application	CO_2	297.3	584.7	10.00%	10.00%	51.00%	51.00%	51.97%	51.97%	0.0000%	0.03%	0.02%	0.00%
3C4	Direct N_2O emissions from managed soils	N_2O	12 363.6	12 825.3	5.00%	91.20%	100.10%	100.10%	100.22%	135.42%	0.1519%	0.11%	3.71%	0.14%
3C5	Indirect N_2O emissions from managed soils	N_2O	1 256.4	1 200.3	5.00%	207.00%	97.90%	97.90%	98.03%	228.98%	0.0038%	0.01%	0.79%	0.01%
3C6	Indirect N_2O emissions from manure management	N_2O	347.1	387.5	58.70%	116.30%	116.10%	116.10%	130.10%	164.33%	0.0002%	0.01%	0.14%	0.00%
3D1	Harvested wood products	CO_2	-2 106.2	635.2	10.00%	10.00%	10.00%	10.00%	14.14%	14.14%	0.0000%	0.06%	0.02%	0.00%
4A	Solid Waste Disposal	CH_4	13 610.5	18 252.8	50.00%	50.00%	40.00%	40.00%	64.03%	64.03%	0.0688%	0.42%	2.89%	0.09%
4B	Biological treatment of waste	CH_4	0.0	0.0	50.00%	50.00%	50.00%	50.00%	70.71%	70.71%	0.0000%	0.00%	0.00%	0.00%
4B	Biological treatment of waste	N_2O	0.0	0.0	50.00%	50.00%	50.00%	50.00%	70.71%	70.71%	0.0000%	0.00%	0.00%	0.00%

4C2	Open Burning of Waste	CO_2	18.6	35.4	50.00%	50.00%	40.00%	40.00%	64.03%	64.03%	0.0000%	0.00%	0.01%	0.00%
4C2	Open Burning of Waste	CH_4	117.5	223.4	50.00%	50.00%	100.00%	100.00%	111.80%	111.80%	0.0000%	0.02%	0.04%	0.00%
4C2	Open Burning of Waste	N_2O	40.0	76.1	50.00%	50.00%	100.00%	100.00%	111.80%	111.80%	0.0000%	0.01%	0.01%	0.00%
4D1	Wastewater Treatment and Discharge	CH_4	1 951.2	2 783.0	50.00%	50.00%	40.00%	40.00%	64.03%	64.03%	0.0016%	0.07%	0.44%	0.00%
4D1	Wastewater Treatment and Discharge	N_2O	545.4	777.9	50.00%	50.00%	90.00%	90.00%	102.96%	102.96%	0.0003%	0.05%	0.12%	0.00%
4D2	Industrial Wastewater Treatment and Discharge	CH_4	1 958.1	897.3	50.00%	50.00%	40.00%	40.00%	64.03%	64.03%	0.0002%	0.09%	0.14%	0.00%
			446 275.1	445 565.6							0.83%			0.57%
										Uncertainty in total inventory	9.11%		**Trend uncertainty**	7.54%

C = Confidential

Appendix C: Summary emission tables for 2020

Table C.1: Summary emission table for South Africa for 2020.

IPCC 2006 category	Emissions and Removals (Gg)								
	Net CO_2	CH_4	N_2O	HFCs	PFCs	NOx	CO	NMVOC	Total GHGs
	(Gg)			Gg CO_2e		(Gg)			Gg CO_2e
Emissions (incl. FOLU)	**363 676,9**	**2 815,6**	**46,0**	**4 933,1**	**120,4**	**48,7**	**1 093,9**	**53,4**	**442 125,1**
Emissions (excl. FOLU)	**391 992,6**	**2 758,8**	**44,6**	**4 933,1**	**120,4**	**48,7**	**1 093,9**	**53,4**	**468 811,7**
1 - Energy	**371 409,3**	**267,3**	**8,0**						**379 505,2**
1.A - Fuel Combustion Activities	**345 085,1**	**23,9**	**8,0**			NE	NE	NE	**348 069,9**
1.A.1 - Energy Industries	235 431,4	3,7	3,7			NE	NE	NE	236 662,3
1.A.2 - Manufacturing Industries and Construction	33 066,2	2,8	0,7			NE	NE	NE	33 336,2
1.A.3 - Transport	47 223,7	10,8	2,4			NE	NE	NE	48 192,9
1.A.4 - Other Sectors	11 971,2	6,5	0,9			NE	NE	NE	12 398,8
1.A.5 - Non-Specified	17 392,6	0,2	0,3			NE	NE	NE	17 479,7
1.B - Fugitive emissions from fuels	**26 324,3**	**243,4**	NE			NE	NE	NE	**31 435,2**
1.B.1 - Solid Fuels	37,9	137,8	NE			NE	NE	NE	2 930,7
1.B.2 - Oil and Natural Gas	641,8	NE	NE			NE	NE	NE	641,8
1.B.3 - Other emissions from Energy Production	25 644,5	105,6	NE			NE	NE	NE	27 862,7
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

IPCC 2006 category	Emissions and Removals (Gg)								
	Net CO_2	CH_4	N_2O	HFCs	PFCs	NOx	CO	NMVOC	Total GHGs
	(Gg)			Gg CO_2e		(Gg)			Gg CO_2e
2 - Industrial Processes and Product Use	**19 021,0**	**27,4**	**2,7**	**4 933,1**	**120,4**				**25 486,1**
2.A - Mineral Industry	4 774,3	NE				NE	NE	NE	4 774,3
2.B - Chemical Industry	1 347,5	3,8	2,7			NE	NE	NE	2 263,5
2.C - Metal Industry	11 604,3	23,6	NE	NE	120,4	NE	NE	NE	12 220,4
2.D - Non-Energy Products from Fuels and Solvent Use	1 294,8	NE	NE			NE	NE	NE	1 294,8
2.E - Electronics Industry	NE		NE	NE	NE	NE	NE	NE	0,0
2.F - Product Uses as Substitutes for Ozone Depleting Substances	NE			4 933,1	NE	NE	NE	NE	4 933,1
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	**-26 788,8**	**1 465,8**	**32,6**			**48,7**	**1 093,9**	**53,4**	**14 088,0**
3.A - Livestock		**1 369,8**	**8,4**			NA	NA	NA	**31 371,7**
3.A.1 - Enteric Fermentation		1 313,8				NA	NA	NA	27 589,5
3.A.2 - Manure Management		56,0	8,4			NA	NA	NA	3 782,2
3.B - Land	**-28 951,0**	**56,8**	**1,4**			NA	NA	NA	**-27 321,9**
3.B.1 - Forest land	-24 575,2	NE	NE			NA	NA	NA	-24 575,2
3.B.2 - Cropland	2 167,3	NE	NE			NA	NA	NA	2 167,3
3.B.3 - Grassland	-11 084,5	NE	NE			NA	NA	NA	-11 084,5
3.B.4 - Wetlands	-436,5	56,8	1,4			NA	NA	NA	1 192,6
3.B.5 - Settlements	-1 147,3	NE	NE			NA	NA	NA	-1 147,3
3.B.6 - Other Land	6 125,2	NE	NE			NA	NA	NA	6 125,2

IPCC 2006 category	Emissions and Removals (Gg)								
	Net CO_2	CH_4	N_2O	HFCs	PFCs	NOx	CO	NMVOC	Total GHGs
	(Gg)			Gg CO_2e		(Gg)			Gg CO_2e
3.C - Aggregate sources and non-CO_2 emissions sources on land	**1 526,9**	**39,2**	**22,7**			**48,7**	**1 093,9**	**53,4**	**9 402,9**
3.C.1 - Emissions from biomass burning	IE	39,2	2,7			48,7	1 093,9	53,4	1 649,2
3.C.2 - Liming	942,3					NA	NA	NA	942,3
3.C.3 - Urea application	584,7					NA	NA	NA	584,7
3.C.4 - Direct N_2O Emissions from managed soils			17,0			NA	NA	NA	5 276,0
3.C.5 - Indirect N_2O Emissions from managed soils			2,3			NA	NA	NA	723,3
3.C.6 - Indirect N_2O Emissions from manure management			0,7			NA	NA	NA	227,5
3.C.7 - Rice cultivations	NO	NO	NO			NA	NA	NA	0,0
3.C.8 - Other	NO	NO	NO			NA	NA	NA	0,0
3.D - Other	**635,2**	NA	NA			NA	NA	NA	**635,2**
3.D.1 - Harvested Wood Products	635,2					NA	NA	NA	635,2
3.D.2 - Other	NO	NO	NO			NA	NA	NA	0,0
4 - Waste	**35,4**	**1 055,1**	**2,8**						**23 045,8**
4.A - Solid Waste Disposal		869,2	NE			NA	NA	NA	18 252,8
4.B - Biological Treatment of Solid Waste		0,0	0,0			NA	NA	NA	0,0
4.C - Incineration and Open Burning of Waste	35,4	10,6	0,2			NA	NA	NA	334,9
4.D - Wastewater Treatment and Discharge		175,3	2,5			NA	NA	NA	4 458,1
4.E - Other	NO	NO	NO	NO	NO	NO	NO	NO	

IPCC 2006 category	Emissions and Removals (Gg)								
	Net CO_2	CH_4	N_2O	HFCs	PFCs	NOx	CO	NMVOC	Total GHGs
	(Gg)			Gg CO_2e		(Gg)			Gg CO_2e
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	**5 283,1**	**0,3**	**0,1**	NA	NA	NA	NA	NA	5 331,4
International aviation	2 268,8	0,1	0,0	NA	NA	NA	NA	NA	2 276,7
International water-borne transport	3 014,4	0,2	0,1	NA	NA	NA	NA	NA	3 054,7
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 C.2: Summary Energy sector emission table for South Africa for 2020.

Categories	Emissions (Gg)							Emissions
	CO_2	CH_4	N_2O	NOx	CO	NMVOCs	SO_2	(Gg CO_2e)
1 - Energy	**371 409**	**267**	**8**	**0**	**0**	**0**	**0**	**379 505**
1.A - Fuel Combustion Activities	**345 085**	**24**	**8**	**0**	**0**	**0**	**0**	**348 070**
1.A.1 - Energy Industries	**235 431**	**4**	**4**	**0**	**0**	**0**	**0**	**236 662**
1.A.1.a - Main Activity Electricity and Heat Production	204 567	2	3	NE	NE	NE	NE	205 621
1.A.1.a.i - Electricity Generation	*204 567*	*2*	*3*	NE	NE	NE	NE	205 621

Categories	Emissions (Gg)							Emissions
	CO_2	CH_4	N_2O	NOx	CO	NMVOCs	SO_2	(Gg CO_2e)
1.A.1.a.ii - Combined Heat and Power Generation (CHP)	IE	IE	IE	NE	NE	NE	NE	0
1.A.1.a.iii - Heat Plants	IE	IE	IE	NE	NE	NE	NE	0
1.A.1.b - Petroleum Refining	2 411	0	0	NE	NE	NE	NE	2 414
1.A.1.c - Manufacture of Solid Fuels and Other Energy Industries	28 454	1	0	NE	NE	NE	NE	28 627
1.A.1.c.i - Manufacture of Solid Fuels	*28 454*	*1*	*0*	NE	NE	NE	NE	28 627
1.A.1.c.ii - Other Energy Industries	*NE*	*NE*	*NE*	NE	NE	NE	NE	NE
1.A.2 - Manufacturing Industries and Construction	**33 066**	**3**	**1**	**0**	**0**	**0**	**0**	**33 336**
1.A.2.a - Iron and Steel				NE	NE	NE	NE	0
1.A.2.b - Non-Ferrous Metals				NE	NE	NE	NE	0
1.A.2.c - Chemicals				NE	NE	NE	NE	0
1.A.2.d - Pulp, Paper and Print				NE	NE	NE	NE	0
1.A.2.e - Food Processing, Beverages and Tobacco				NE	NE	NE	NE	0
1.A.2.f - Non-Metallic Minerals				NE	NE	NE	NE	0
1.A.2.g - Transport Equipment				NE	NE	NE	NE	0
1.A.2.h - Machinery				NE	NE	NE	NE	0
1.A.2.i - Mining (excluding fuels) and Quarrying				NE	NE	NE	NE	0
1.A.2.j - Wood and wood products				NE	NE	NE	NE	0
1.A.2.k - Construction				NE	NE	NE	NE	0
1.A.2.l - Textile and Leather				NE	NE	NE	NE	0
1.A.2.m - Non-specified Industry				NE	NE	NE	NE	0
1.A.3 - Transport	**47 224**	**11**	**2**	**0**	**0**	**0**	**0**	**48 193**
1.A.3.a - Civil Aviation	693	0	0	NE	NE	NE	NE	696
1.A.3.a.i - International Aviation (International Bunkers) (1)								*0*
1.A.3.a.ii - Domestic Aviation	*693*	*0*	*0*	*NE*	*NE*	*NE*	*NE*	*696*

Categories	Emissions (Gg)							Emissions
	CO_2	CH_4	N_2O	NOx	CO	NMVOCs	SO_2	(Gg CO_2e)
1.A.3.b - Road Transportation	44 058	11	2	NE	NE	NE	NE	44 957
1.A.3.b.i - Cars				*NE*	*NE*	*NE*	*NE*	*0*
1.A.3.b.i.1 - Passenger cars with 3-way catalysts				*NE*	*NE*	*NE*	*NE*	*0*
1.A.3.b.i.2 - Passenger cars without 3-way catalysts				*NE*	*NE*	*NE*	*NE*	*0*
1.A.3.b.ii - Light-duty trucks				*NE*	*NE*	*NE*	*NE*	*0*
1.A.3.b.ii.1 - Light-duty trucks with 3-way catalysts				*NE*	*NE*	*NE*	*NE*	*0*
1.A.3.b.ii.2 - Light-duty trucks without 3-way catalysts				*NE*	*NE*	*NE*	*NE*	*0*
1.A.3.b.iii - Heavy-duty trucks and buses				*NE*	*NE*	*NE*	*NE*	*0*
1.A.3.b.iv - Motorcycles				*NE*	*NE*	*NE*	*NE*	*0*
1.A.3.b.v - Evaporative emissions from vehicles				*NE*	*NE*	*NE*	*NE*	*0*
1.A.3.b.vi - Urea-based catalysts				*NE*	*NE*	*NE*	*NE*	*0*
1.A.3.c - Railways	502	0	0	NE	NE	NE	NE	554
1.A.3.d - Water-borne Navigation	1 971	0	0	NE	NE	NE	NE	1 986
1.A.3.d.i - International water-borne navigation (International bunkers) (1)								*0*
1.A.3.d.ii - Domestic Water-borne Navigation	*1 971*	*0*	*0*	*NE*	*NE*	*NE*	*NE*	*1 986*
1.A.3.e - Other Transportation				*NE*	*NE*	*NE*	*NE*	*0*
1.A.3.e.i - Pipeline Transport	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*
1.A.3.e.ii - Off-road	*IE*	*IE*	*IE*	*NE*	*NE*	*NE*	*NE*	*NE*
1.A.4 - Other Sectors	**11 971**	**6**	**1**	**0**	**0**	**0**	**0**	**12 399**
1.A.4.a - Commercial/Institutional	3 742	0	0	NE	NE	NE	NE	3 758
1.A.4.b - Residential	2 324	6	1	NE	NE	NE	NE	2 715
1.A.4.c - Agriculture/Forestry/Fishing/Fish Farms	5 906	0	0	NE	NE	NE	NE	5 926
1.A.4.c.i - Stationary	*5 906*	*0*	*0*	NE	NE	NE	NE	5 926
1.A.4.c.ii - Off-road Vehicles and Other Machinery	*IE*	*IE*	*IE*	*NE*	*NE*	*NE*	*NE*	*NE*

Categories	Emissions (Gg)							Emissions
	CO_2	CH_4	N_2O	NOx	CO	NMVOCs	SO_2	(Gg CO_2e)
1.A.4.c.iii - Fishing (mobile combustion)	*IE*	*IE*	*IE*	*NE*	*NE*	*NE*	*NE*	*NE*
1.A.5 - Non-Specified	**17 393**	**0**	**0**	**0**	**0**	**0**	**0**	**17 480**
1.A.5.a - Stationary	17 393	0	0	NE	NE	NE	NE	17 480
1.A.5.b - Mobile				NE	NE	NE	NE	0
1.A.5.b.i - Mobile (aviation component)	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*
1.A.5.b.ii - Mobile (water-borne component)	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*
1.A.5.b.iii - Mobile (Other)	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*
1.A.5.c - Multilateral Operations								0
1.B - Fugitive emissions from fuels	**26 324**	**243**	**0**	**0**	**0**	**0**	**0**	**31 435**
1.B.1 - Solid Fuels	**38**	**138**		**0**	**0**	**0**	**0**	**2 931**
1.B.1.a - Coal mining and handling	38	138	NE	NE	NE	NE	NE	2 931
1.B.1.a.i - Underground mines	*38*	*138*	NE	*NE*	*NE*	*NE*	*NE*	*2 931*
1.B.1.a.i.1 - Mining	*31*	*112*	NE	*NE*	*NE*	*NE*	*NE*	*2 375*
1.B.1.a.i.2 - Post-mining seam gas emissions	*7*	*26*	NE	*NE*	*NE*	*NE*	*NE*	*555*
1.B.1.a.i.3 - Abandoned underground mines	*NE*	*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*	*NE*
1.B.1.a.ii - Surface mines	*0*	*0*	NE	*NE*	*NE*	*NE*	*NE*	*0*
1.B.1.a.ii.1 - Mining	*0*	*0*	NE	*NE*	*NE*	*NE*	*NE*	*0*
1.B.1.a.ii.2 - Post-mining seam gas emissions	*0*	*0*	NE	*NE*	*NE*	*NE*	*NE*	*0*
1.B.1.b - Uncontrolled combustion and burning coal dumps	NE	NE	NE	NE	NE	NE	NE	NE
1.B.1.c - Solid fuel transformation	NE	NE	NE	NE	NE	NE	NE	NE
1.B.2 - Oil and Natural Gas	**642**	**0**	**0**	**0**	**0**	**0**	**0**	**642**
1.B.2.a - Oil	642	0	0	NE	NE	NE	NE	642

Categories	Emissions (Gg)							Emissions
	CO_2	CH_4	N_2O	NOx	CO	NMVOCs	SO_2	(Gg CO_2e)
1.B.2.a.i - Venting	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*
1.B.2.a.ii - Flaring	*642*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*
1.B.2.a.iii - All Other	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.a.iii.1 - Exploration	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.a.iii.2 - Production and Upgrading	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.a.iii.3 - Transport	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.a.iii.4 - Refining	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.a.iii.5 - Distribution of oil products	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.a.iii.6 - Other	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.b - Natural Gas	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.b.i - Venting	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.b.ii - Flaring	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.b.iii - All Other	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.b.iii.1 - Exploration	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.b.iii.2 - Production	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.b.iii.3 - Processing	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.b.iii.4 - Transmission and Storage	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.b.iii.5 - Distribution	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.b.iii.6 - Other	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*0*
1.B.3 - Other emissions from Energy Production	**25 645**	**106**	**0**	**0**	**0**	**0**	**0**	**27 863**
1.C - Carbon dioxide Transport and Storage	0			0	0	0	0	0
1.C.1 - Transport of CO_2	0			0	0	0	0	0
1.C.1.a - Pipelines	NE			NE	NE	NE	NE	NE
1.C.1.b - Ships	NE			NE	NE	NE	NE	NE

Categories	Emissions (Gg)							Emissions
	CO_2	CH_4	N_2O	NOx	CO	NMVOCs	SO_2	(Gg CO_2e)
1.C.1.c - Other (please specify)	NE			NE	NE	NE	NE	NE
1.C.2 - Injection and Storage	0			0	0	0	0	0
1.C.2.a - Injection	NE			NE	NE	NE	NE	NE
1.C.2.b - Storage	NE			NE	NE	NE	NE	NE
1.C.3 - Other	0			0	0	0	0	0

Table C.3: Summary IPPU sector emission table for South Africa for 2020.

Categories	Gg			Gg CO_2e			Gg CO_2e				
	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	NOx	CO	NMVOCs	SO_2	Total
2 - Industrial Processes and Product Use	**19 021,0**	**27,4**	**2,7**	**4 933,1**	**120,4**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**25 486,1**
2.A - Mineral Industry	**4 774,3**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**4 774,3**
2.A.1 - Cement production	3 795,7	NE					NE	NE	NE	NE	3 795,7
2.A.2 - Lime production	714,9	NE					NE	NE	NE	NE	714,9
2.A.3 - Glass Production	154,5	NE					NE	NE	NE	NE	154,5
2.A.4 - Other Process Uses of Carbonates	109,3	NE					NE	NE	NE	NE	109,3
2.A.5 - Other	NE	NE					NE	NE	NE	NE	NE
2.B - Chemical Industry	**1 347,5**	**3,8**	**2,7**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**2 263,5**
2.B.1 - Ammonia Production	C	C	NE				NE	NE	NE	NE	C
2.B.2 - Nitric Acid Production		NA	C				NE	NE	NE	NE	C
2.B.3 - Adipic Acid Production	NO	NO	NO				NO	NO	NO	NO	NO
2.B.4 - Caprolactam, Glyoxal and Glyoxylic Acid Production	NO	NO	NO				NO	NO	NO	NO	NO
2.B.5 - Carbide Production	C	C	NA				NE	NE	NE	NE	C
2.B.6 - Titanium Dioxide Production	C	NA	NA				NE	NE	NE	NE	C
2.B.7 - Soda Ash Production	C	NA	NA				NE	NE	NE	NE	C
2.B.8 - Petrochemical and Carbon Black Production	C	C	NA				NE	NE	NE	NE	C
2.B.8.a - Methanol	*NO*	*NO*	*NO*				*NO*	*NO*	*NO*	*NO*	*NO*
2.B.8.b - Ethylene	*NO*	*NO*	*NO*				*NO*	*NO*	*NO*	*NO*	*NO*
2.B.8.c - Ethylene Dichloride and Vinyl Chloride Monomer	*NO*	*NO*	*NO*				*NO*	*NO*	*NO*	*NO*	*NO*
2.B.8.d - Ethylene Oxide	*NO*	*NO*	*NO*				*NO*	*NO*	*NO*	*NO*	*NO*
2.B.8.e - Acrylonitrile	*NO*	*NO*	*NO*				*NO*	*NO*	*NO*	*NO*	*NO*

Categories	Gg			Gg CO_2e			Gg CO_2e				
	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	NOx	CO	NMVOCs	SO_2	Total
2.B.8.f - Carbon Black	*C*	*C*	*NA*				*NE*	*NE*	*NE*	*NE*	*C*
2.B.8.g - Hydrogen Production	*C*	*NA*	*NA*				*NE*	*NE*	*NE*	*NE*	*C*
2.B.9 - Fluorochemical Production				NO	NO	NO	NO	NO	NO	NO	NO
2.B.9.a - By-product emissions				NO	NO	NO	*NO*	*NO*	*NO*	*NO*	*NO*
2.B.9.b - Fugitive Emissions				NO	NO	NO	*NO*	*NO*	*NO*	*NO*	*NO*
2.B.10 - Other	C						NE	NE	NE	NE	C
2.C - Metal Industry	**11 604,3**	**23,6**	**0,0**	**0,0**	**120,4**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**12 220,4**
2.C.1 - Iron and Steel Production	3 849,9	0,2	NE				NE	NE	NE	NE	3 853,1
2.C.2 - Ferroalloys Production	6 576,5	23,5	NE				NE	NE	NE	NE	7 069,0
2.C.3 - Aluminium production	1 134,8	NE			120,4		NE	NE	NE	NE	1 255,2
2.C.4 - Magnesium production	NO			NO	NO	NO	NO	NO	NO	NO	NO
2.C.5 - Lead Production	6,6						NE	NE	NE	NE	6,6
2.C.6 - Zinc Production	36,6						NE	NE	NE	NE	36,6
2.C.7 - Other	0,0						NE	NE	NE	NE	0,0
2.D - Non-Energy Products from Fuels and Solvent Use	**1 294,8**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**1 294,8**
2.D.1 - Lubricant Use	667,3						NE	NE	NE	NE	667,3
2.D.2 - Paraffin Wax Use	627,4	NE	NE				NE	NE	NE	NE	627,4
2.D.3 - Solvent Use							NE	NE	NE	NE	0,0
2.D.4 - Other	NE	NE	NE				NE	NE	NE	NE	0,0
2.E - Electronics Industry	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**
2.E.1 - Integrated Circuit or Semiconductor	NE		NE	NE	NE	NE	NE	NE	NE	NE	NE
2.E.2 - TFT Flat Panel Display				NE	NE	NE	NE	NE	NE	NE	NE
2.E.3 - Photovoltaics				NE	NE		NE	NE	NE	NE	NE
2.E.4 - Heat Transfer Fluid					NE		NE	NE	NE	NE	NE
2.E.5 - Other	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE

Categories	Gg			Gg CO_2e			Gg CO_2e				
	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	NOx	CO	NMVOCs	SO_2	Total
2.F - Product Uses as Substitutes for Ozone Depleting Substances	**0,0**	**0,0**	**0,0**	**4 933,1**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**4 933,1**
2.F.1 - Refrigeration and Air Conditioning	0,0	0,0	0,0	4 846,9	NE		NE	NE	NE	NE	4 846,9
2.F.1.a - Refrigeration and Stationary Air Conditioning	*NE*			*2 524,1*	NE		*NE*	*NE*	*NE*	*NE*	*2 524,1*
2.F.1.b - Mobile Air Conditioning	*NE*			*2 322,7*	NE		*NE*	*NE*	*NE*	*NE*	*2 322,7*
2.F.2 - Foam Blowing Agents	NE			2,1	NE		NE	NE	NE	NE	2,1
2.F.3 - Fire Protection	NE			65,9	NE		NE	NE	NE	NE	65,9
2.F.4 - Aerosols				18,2	NE		NE	NE	NE	NE	18,2
2.F.5 - Solvents				NE	NE		NE	NE	NE	NE	NE
2.F.6 - Other Applications	NO	NO	NO	NO	NO		NO	NO	NO	NO	NO
2.G - Other Product Manufacture and Use	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,00**
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 - SF_6 and PFCs from Other Product Uses					NE	NE	NE	NE	NE	NE	NE
2.G.2.a - Military Applications					*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*
2.G.2.b - Accelerators					*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*
2.G.2.c - Other					*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*
2.G.3 - N_2O from Product Uses			NE				NE	NE	NE	NE	NE
2.G.3.a - Medical Applications			*NE*				*NE*	*NE*	*NE*	*NE*	*NE*
2.G.3.b - Propellant for pressure and aerosol products			*NE*				*NE*	*NE*	*NE*	*NE*	*NE*
2.G.3.c - Other			NE				NE	NE	NE	NE	NE
2.G.4 - Other	NO	NO		NO			NO	NO	NO	NO	NO
2.H - Other	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**

Categories	Gg			Gg CO_2e			Gg CO_2e				
	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	NOx	CO	NMVOCs	SO_2	Total
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	NO	NO	NO				NO	NO	NO	NO	NO

Table C.4: Summary AFOLU sector emission table for South Africa for 2020.

	Net CO_2 emissions / removals	Emissions					Total emissions
		(Gg)					(Gg CO_2e)
		CH_4	N_2O	NOx	CO	NMVOCs	
3 - Agriculture, Forestry, and Other Land Use	**-26 788,80**	**1 465,79**	**32,57**	**1 093,91**	**47,70**	**53,40**	**14 087,98**
3 - AFOLU (excluding FOLU)	**1 526,92**	**1 409,00**	**31,16**	**1 093,91**	**47,70**	**53,40**	**40 774,60**
3.A - Livestock	**0,00**	**1 369,78**	**8,41**	**0,00**	**0,00**	**0,00**	**31 371,68**
3.A.1 - Enteric Fermentation	**0,00**	**1 313,78**	**0,00**	**0,00**	**0,00**	**0,00**	**27 589,47**
3.A.1.a - Cattle		1 026,41					21 554,63
3.A.1.a.i - Dairy Cows		*134,01*					*2 814,28*
3.A.1.a.ii - Other Cattle		*892,40*					*18 740,35*
3.A.1.b - Buffalo		*NO*					NO
3.A.1.c - Sheep		*221,59*					4 653,47
3.A.1.d - Goats		*56,67*					1 189,97
3.A.1.e - Camels		*NO*					NO
3.A.1.f - Horses		*5,94*					124,74
3.A.1.g - Mules and Asses		*1,62*					33,92
3.A.1.h - Swine		*1,56*					32,75
3.A.1.j - Other		*NO*					NO
3.A.2 - Manure Management	**0,00**	**56,00**	**8,41**	**0,00**	**0,00**	**0,00**	**3 782,21**
3.A.2.a - Cattle		40,90	4,39				2 219,26
3.A.2.a.i - Dairy cows		*19,65*	*0,90*				*692,05*
3.A.2.a.ii - Other cattle		*21,26*	*3,49*				*1 527,20*

	Net CO_2 emissions / removals	Emissions					Total emissions
		(Gg)					(Gg CO_2e)
		CH_4	N_2O	NOx	CO	NMVOCs	
3.A.2.b - Buffalo		*NO*	*NO*				NO
3.A.2.c - Sheep		*1,01*	*0,59*				21,11
3.A.2.d - Goats		*0,45*	*0,19*				9,41
3.A.2.e - Camels		*NO*	*NO*				NO
3.A.2.f - Horses		*0.0*	*0.0*				0.0
3.A.2.g - Mules and Asses		*0.0*	*0.0*				0.0
3.A.2.h - Swine		*7,53*	*0,09*				158,20
3.A.2.i - Poultry		*6,11*	*3,15*				128,22
3.A.2.j - Other		*NO*	*NO*				NO
3.B - Land	**-28 950,96**	**56,78**	**1,41**	**0,00**	**0,00**	**0,00**	**-27 321,86**
3.B.1 - Forest land	**-24 575,18**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**-24 575,18**
3.B.1.a - Forest land Remaining Forest land	-10 542,80						-10 542,80
3.B.1.b - Land Converted to Forest land	-14 032,39						-14 032,39
3.B.1.b.i - Cropland converted to Forest Land	*-2 867,92*						*-2 867,92*
3.B.1.b.ii - Grassland converted to Forest Land	*-9 817,54*						*-9 817,54*
3.B.1.b.iii - Wetlands converted to Forest Land	*-810,44*						*-810,44*
3.B.1.b.iv - Settlements converted to Forest Land	*-421,33*						*-421,33*
3.B.1.b.v - Other Land converted to Forest Land	*-115,16*						*-115,16*
3.B.2 - Cropland	**2 167,31**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**2 167,31**
3.B.2.a - Cropland Remaining Cropland	-1 391,35						-1 391,35
3.B.2.b - Land Converted to Cropland	3 558,66						3 558,66
3.B.2.b.i - Forest Land converted to Cropland	*1 290,45*						*1 290,45*

	Net CO_2 emissions / removals	Emissions					Total emissions
		(Gg)					(Gg CO_2e)
		CH_4	N_2O	NOx	CO	NMVOCs	
3.B.2.b.ii - Grassland converted to Cropland	*2 101,63*						*2 101,63*
3.B.2.b.iii - Wetlands converted to Cropland	*184,72*						*184,72*
3.B.2.b.iv - Settlements converted to Cropland	*-4,49*						*-4,49*
3.B.2.b.v - Other Land converted to Cropland	*-13,64*						*-13,64*
3.B.3 - Grassland	**-11 084,48**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**-11 084,48**
3.B.3.a - Grassland Remaining Grassland	-1 057,18						-1 057,18
3.B.3.b - Land Converted to Grassland	-10 027,30						-10 027,30
3.B.3.b.i - Forest Land converted to Grassland	*1 596,14*						*1 596,14*
3.B.3.b.ii - Cropland converted to Grassland	*-3 231,73*						*-3 231,73*
3.B.3.b.iii - Wetlands converted to Grassland	*584,01*						*584,01*
3.B.3.b.iv - Settlements converted to Grassland	*-74,94*						*-74,94*
3.B.3.b.v - Other Land converted to Grassland	*-8 900,77*						*-8 900,77*
3.B.4 - Wetlands	**-436,50**	**56,78**	**1,41**	**0,00**	**0,00**	**0,00**	**1 192,60**
3.B.4.a - Wetlands Remaining Wetlands	39,10	38,11	0,95				1 132,57
3.B.4.b - Land Converted to Wetlands	-475,60	18,67	0,46				60,03
3.B.5 - Settlements	**-1 147,33**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**-1 147,33**
3.B.5.a - Settlements Remaining Settlements	-1 914,17						-1 914,17
3.B.5.b - Land Converted to Settlements	766,84						766,84
3.B.5.b.i - Forest Land converted to Settlements	*813,90*						*813,90*
3.B.5.b.ii - Cropland converted to Settlements	*-22,85*						*-22,85*
3.B.5.b.iii - Grassland converted to Settlements	*3,10*						*3,10*
3.B.5.b.iv - Wetlands converted to Settlements	*15,40*						*15,40*

	Net CO_2 emissions / removals	Emissions					Total emissions
		(Gg)					(Gg CO_2e)
		CH_4	N_2O	NOx	CO	NMVOCs	
3.B.5.b.v - Other Land converted to Settlements	*-42,70*						*-42,70*
3.B.6 - Other Land	**6 125,21**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**6 125,21**
3.B.6.a - Other land Remaining Other land	0,00						0,00
3.B.6.b - Land Converted to Other land	6 125,21						6 125,21
3.B.6.b.i - Forest Land converted to Other Land	*1 275,22*						*1 275,22*
3.B.6.b.ii - Cropland converted to Other Land	*30,36*						*30,36*
3.B.6.b.iii - Grassland converted to Other Land	*4 043,08*						*4 043,08*
3.B.6.b.iv - Wetlands converted to Other Land	*738,57*						*738,57*
3.B.6.b.v - Settlements converted to Other Land	*37,98*						*37,98*
3.C - Aggregate sources and non-CO_2 emissions sources on land	**1 526,92**	**39,22**	**22,75**	**1 093,91**	**47,70**	**53,40**	**9 402,92**
3.C.1 - Emissions from biomass burning	**0,00**	**39,22**	**2,66**	**1 093,91**	**47,70**	**53,40**	**1 649,23**
3.C.1.a - Biomass burning in forest lands	IE	13,74	0,86	327,61	11,61	27,49	554,22
3.C.1.b - Biomass burning in croplands	IE	7,95	0,21	271,03	7,36	NO	230,96
3.C.1.c - Biomass burning in grasslands	IE	16,66	1,52	470,88	28,25	24,63	821,50
3.C.1.d - Biomass burning in wetlands	IE	0,59	0,05	16,61	0,00	0,87	28,97
3.C.1.e - Biomass burning in settlements	IE	0,28	0,03	7,78	0,47	0,41	13,57
3.C.1.f - Biomass burning in otherlands	NO	NO	NO	NO	NO	NO	NO
3.C.2 - Liming	942,26						942,26
3.C.3 - Urea application	584,66						584,66
3.C.4 - Direct N_2O Emissions from managed soils			17,02				5 275,95
3.C.5 - Indirect N_2O Emissions from managed soils			2,33				723,31
3.C.6 - Indirect N_2O Emissions from manure management			0,73				227,50

	Net CO_2 emissions / removals	Emissions					Total emissions
		(Gg)					(Gg CO_2e)
		CH_4	N_2O	NOx	CO	NMVOCs	
3.C.7 - Rice cultivations	NO	NO	NO				NO
3.C.8 - Other	NO	NO	NO				0,00
3.D - Other	**635,24**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**635,24**
3.D.1 - Harvested Wood Products	635,24						635,24
3.D.2 - Other	NO	NO	NO				0,00

Table C.5: Summary Land sector emission table for South Africa for 2020.[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 (Gg C)	Net carbon stock change (Gg C)	Carbon stock change (Gg C)	Carbon emitted as CH_4 and CO from fires (Gg C)	Net carbon stock change (Gg C)	Net carbon stock change in mineral soils (Gg C)	Carbon loss from drained organic soils (Gg C)		
3.B - Land	**123 562 851,0**	**NE**	**26 187,2**	**17 707,4**	**IE**	**4 763,4**	**0,0**	**IE**	**326,3**	**520,4**	**NE**		**-28 951,0**
3.B.1 - Forest land	**21 037 901,6**	**NE**	**28 028,1**	**21 717,4**	**IE**	**6 310,6**	**143,6**	**IE**	**143,6**	**248,1**	**NE**		**-24 575,2**

[8] Excludes CH_4 and N_2O emissions from *Wetlands*.

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 (Gg C)	Net carbon stock change (Gg C)	Carbon stock change (Gg C)	Carbon emitted as CH_4 and CO from fires (Gg C)	Net carbon stock change (Gg C)	Net carbon stock change in mineral soils (Gg C)	Carbon loss from drained organic soils (Gg C)	
3.B.1.a - Forest land Remaining Forest land	19 224 763,3	NE	23 766,0	20 876,3		2 889,7	-14,4		-14,4	0,0	NE	-10 542,8
3.B.1.b - Land Converted to Forest land	1 813 138,3	NE	4 262,1	841,1	IE	3 421,0	158,0	IE	158,0	248,1	NE	-14 032,4
3.B.1.b.i - Cropland converted to Forest Land	*464 837,8*	NE	*647,8*	*133,3*		*514,5*	*24,0*		*24,0*	*243,7*	*NE*	*-2 867,9*
3.B.1.b.ii - Grassland converted to Forest Land	*1 025 540,3*	NE	*3 119,2*	*551,7*		*2 567,5*	*105,7*		*105,7*	*4,3*	*NE*	*-9 817,5*
3.B.1.b.iii - Wetlands converted to Forest Land	*195 236,4*	NE	*317,8*	*113,5*		*204,3*	*16,8*		*16,8*	*0,0*	*NE*	*-810,4*
3.B.1.b.iv - Settlements converted to Forest Land	*93 030,2*	NE	*140,6*	*32,7*		*107,9*	*7,0*		*7,0*	*0,0*	*NE*	*-421,3*
3.B.1.b.v - Other Land converted to Forest Land	*34 493,5*	NE	*36,7*	*9,9*		*26,8*	*4,6*		*4,6*	*0,0*	*NE*	*-115,2*
3.B.2 - Cropland	**13 459 383,9**	**NE**	**1 038,5**	**852,9**	**IE**	**185,6**	**-2,4**	**IE**	**-2,4**	**-774,3**	**NE**	**2 167,3**
3.B.2.a - Cropland Remaining Cropland	12 337 548,0	NE	742,3	357,9		384,4	-7,9		-7,9	3,0	NE	-1 391,3
3.B.2.b - Land Converted to Cropland	1 121 835,9	NE	296,2	495,0	IE	-198,9	5,6	IE	5,6	-777,3	NE	3 558,7
3.B.2.b.i - Forest Land converted to Cropland	*243 335,1*	NE	*92,3*	*268,4*		*-176,1*	*-17,6*		*-17,6*	*-158,3*	*NE*	*1 290,4*
3.B.2.b.ii - Grassland converted to Cropland	*790 022,8*	NE	*179,1*	*174,2*		*4,9*	*20,9*		*20,9*	*-598,9*	*NE*	*2 101,6*
3.B.2.b.iii - Wetlands converted to Cropland	*48 748,4*	NE	*13,0*	*45,0*		*-31,9*	*1,7*		*1,7*	*-20,1*	*NE*	*184,7*

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 (Gg C)	Net carbon stock change (Gg C)	Carbon stock change (Gg C)	Carbon emitted as CH_4 and CO from fires (Gg C)	Net carbon stock change (Gg C)	Net carbon stock change in mineral soils (Gg C)	Carbon loss from drained organic soils (Gg C)	
3.B.2.b.iv - Settlements converted to Cropland	*33 558,0*	NE	*8,6*	*7,1*		*1,4*	*-0,2*		*-0,2*	*0,0*	*NE*	*-4,5*
3.B.2.b.v - Other Land converted to Cropland	*6 171,5*	NE	*3,2*	*0,4*		*2,8*	*0,9*		*0,9*	*0,0*	*NE*	*-13,6*
3.B.3 - Grassland	**69 551 594,7**	**NE**	**2 401,4**	**1 674,9**	**IE**	**726,5**	**-37,0**	**IE**	**-37,0**	**2 333,5**	**NE**	**-11 084,5**
3.B.3.a - Grassland Remaining Grassland	64 156 998,1	NE	1 119,2	687,6		431,6	-158,8		-158,8	15,5	NE	-1 057,2
3.B.3.b - Land Converted to Grassland	5 394 596,6	NE	1 282,2	987,3	IE	294,9	121,8	IE	121,8	2 318,0	NE	-10 027,3
3.B.3.b.i - Forest Land converted to Grassland	*501 596,8*	NE	*104,1*	*493,9*		*-389,8*	*-43,9*		*-43,9*	*-1,6*	*NE*	*1 596,1*
3.B.3.b.ii - Cropland converted to Grassland	*987 359,3*	NE	*186,0*	*59,5*		*126,5*	*-35,7*		*-35,7*	*790,6*	*NE*	*-3 231,7*
3.B.3.b.iii - Wetlands converted to Grassland	*469 804,1*	NE	*90,1*	*323,9*		*-233,8*	*-4,3*		*-4,3*	*78,8*	*NE*	*584,0*
3.B.3.b.iv - Settlements converted to Grassland	*136 469,8*	NE	*25,7*	*4,0*		*21,6*	*-1,0*		*-1,0*	*-0,2*	*NE*	*-74,9*
3.B.3.b.v - Other Land converted to Grassland	*3 299 366,6*	NE	*876,3*	*105,9*		*770,4*	*206,8*		*206,8*	*1 450,3*	*NE*	*-8 900,8*
3.B.4 - Wetlands	**3 164 895,4**	**NE**	**333,6**	**175,2**	**IE**	**158,4**	**-11,4**	**IE**	**-11,4**	**-27,9**	**NE**	**-436,5**
3.B.4.a - Wetlands Remaining Wetlands	2 715 182,1	NE	12,9	21,4		-8,5	-0,5		-0,5	-1,7	NE	39,1
3.B.4.b - Land Converted to Wetlands	449 713,3	NE	320,6	153,8	IE	166,9	-10,9	IE	-10,9	-26,2	NE	-475,6

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 (Gg C)	Net carbon stock change (Gg C)	Carbon stock change (Gg C)	Carbon emitted as CH_4 and CO from fires (Gg C)	Net carbon stock change (Gg C)	Net carbon stock change in mineral soils (Gg C)	Carbon loss from drained organic soils (Gg C)	
3.B.4.b.i - Forest Land converted to wetlands	*112 339,3*	NE	*79,2*	*130,3*		*-51,1*	*-12,0*		*-12,0*	*-15,9*	*NE*	*289,6*
3.B.4.b.ii - Cropland converted to wetlands	*29 598,6*	NE	*23,6*	*3,3*		*20,3*	*-0,9*		*-0,9*	*3,8*	*NE*	*-85,1*
3.B.4.b.iii - Grasslands converted to wetlands	*268 364,6*	NE	*209,3*	*19,1*		*190,2*	*2,0*		*2,0*	*-20,8*	*NE*	*-628,3*
3.B.3.b.iv - Settlements converted to wetlands	*9 969,2*	NE	*5,5*	*1,0*		*4,5*	*-0,2*		*-0,2*	*-1,2*	*NE*	*-11,5*
3.B.3.b.v - Other Land converted to wetlands	*29 441,6*	NE	*3,0*	*0,1*		*2,9*	*0,2*		*0,2*	*7,9*	*NE*	*-40,3*
3.B.5 - Settlements	**3 712 351,5**	**NE**	**707,2**	**412,5**	**IE**	**294,7**	**-6,8**	**IE**	**-6,8**	**25,0**	**NE**	**-1 147,3**
3.B.5.a - Settlements Remaining Settlements	2 969 850,3	NE	565,8	42,4		523,3	-1,3		-1,3	0,0	NE	-1 914,2
3.B.5.b - Land Converted to Settlements	742 501,2	NE	141,4	370,1	IE	-228,6	-5,5	IE	-5,5	25,0	NE	766,8
3.B.5.b.i - Forest Land converted to Settlements	*214 883,5*	NE	*40,9*	*247,0*		*-206,0*	*-16,0*		*-16,0*	*0,0*	*NE*	*813,9*
3.B.5.b.ii - Cropland converted to Settlements	*82 918,8*	NE	*15,8*	*24,5*		*-8,7*	*0,1*		*0,1*	*14,8*	*NE*	*-22,9*
3.B.5.b.iii - Grassland converted to Settlements	*415 663,4*	NE	*79,2*	*89,4*		*-10,3*	*9,2*		*9,2*	*0,2*	*NE*	*3,1*
3.B.5.b.iv - Wetlands converted to Settlements	*13 710,5*	NE	*2,6*	*9,0*		*-6,4*	*0,3*		*0,3*	*1,9*	*NE*	*15,4*
3.B.5.b.v - Other Land converted to Settlements	*15 325,0*	NE	*2,9*	*0,2*		*2,7*	*0,9*		*0,9*	*8,0*	*NE*	*-42,7*
3.B.6 - Other Land	**12 636 723,9**	**NE**	**0,0**	**873,2**	**IE**	**-873,2**	**-324,0**	**IE**	**-324,0**	**-473,3**	**NE**	**6 125,2**

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 (Gg C)	Net carbon stock change (Gg C)	Carbon stock change (Gg C)	Carbon emitted as CH_4 and CO from fires (Gg C)	Net carbon stock change (Gg C)	Net carbon stock change in mineral soils (Gg C)	Carbon loss from drained organic soils (Gg C)	
3.B.6.a - Other land Remaining Other land	9 833 999,5	NE				0,0			0,0	0,0	NE	0,0
3.B.6.b - Land Converted to Other land	2 802 724,4	NE	0,0	873,2	IE	-873,2	-324,0	IE	-324,0	-473,3	NE	6 125,2
3.B.6.b.i - Forest Land converted to Other Land	*291 705,6*	NE	*0,0*	*238,6*		*-238,6*	*-38,9*		*-38,9*	*-70,2*	*NE*	*1 275,2*
3.B.6.b.ii - Cropland converted to Other Land	*23 612,8*	NE	*0,0*	*6,6*		*-6,6*	*-1,8*		*-1,8*	*0,2*	*NE*	*30,4*
3.B.6.b.iii - Grassland converted to Other Land	*2 390 879,2*	NE	*0,0*	*606,7*		*-606,7*	*-141,5*		*-141,5*	*-354,4*	*NE*	*4 043,1*
3.B.6.b.iv - Wetlands converted to Other Land	*90 330,6*	NE	*0,0*	*20,0*		*-20,0*	*-141,5*		*-141,5*	*-40,0*	*NE*	*738,6*
3.B.6.b.v - Settlements converted to Other Land	*6 196,2*	NE	*0,0*	*1,2*		*-1,2*	*-0,3*		*-0,3*	*-8,9*	*NE*	*38,0*

Table C.6: Summary Waste sector emission table for South Africa for 2020.

Categories	Emissions [Gg]							Total emissions
	CO_2	CH_4	N_2O	NOx	CO	NMVOCs	SO_2	(Gg CO_2e)
4. WASTE	**35.4**	**1 055.1**	**2.8**	**NE**	**NE**	**NE**	**NE**	**23 045.8**
4A Solid Waste Disposal		**869.2**		**0.0**	**0.0**	**0.0**	**0.0**	**18 252.8**
4A1 Managed Waste Disposal Sites				NE	NE	NE	NE	NE
4A2 Unmanaged Waste Disposal Sites				NE	NE	NE	NE	NE
4A3 Uncategorised Waste Disposal Sites				NE	NE	NE	NE	NE
4B Biological Treatment of Solid Waste		**0.0**	**0.0**	**NE**	**NE**	**NE**	**NE**	**0.0**
4C Incineration and Open Burning of Waste	**35.4**	**10.6**	**0.2**	**0.0**	**0.0**	**0.0**	**0.0**	**334.9**
4C1 Waste Incineration	NE	NE	NE	NE	NE	NE	NE	NE
4C2 Open Burning of Waste	35.4	10.6	0.2	NE	NE	NE	NE	334.9
4D Wastewater Treatment and Discharge	**0.0**	**175.3**	**2.5**	**0.0**	**0.0**	**0.0**	**0.0**	**4 458.1**
4D1 Domestic Wastewater Treatment and Discharge		132.5	2.5	NE	NE	NE	NE	3 560.8
4D2 Industrial Wastewater Treatment and Discharge		42.7	*NE*	NE	NE	NE	NE	897.3
4E Other (please specify)				**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Appendix D: Reference and sectoral fuel consumption

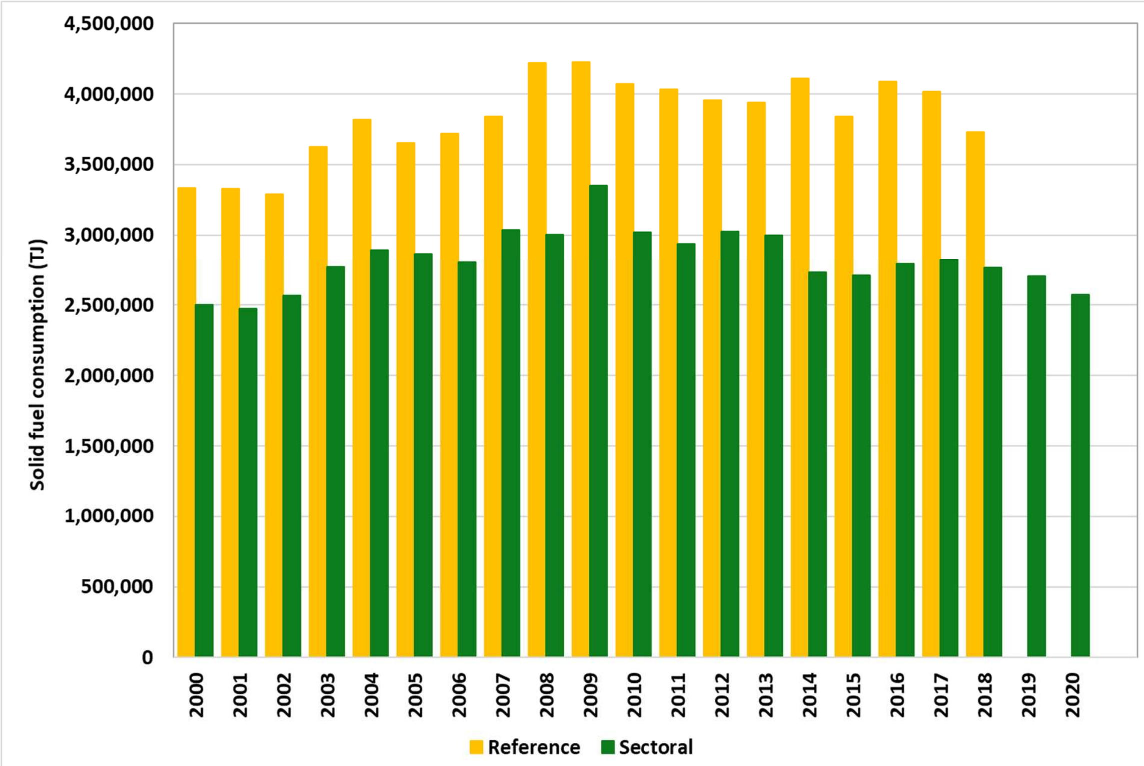

Figure D.1: Comparisons between the solid fuel consumption determined by the reference and sectoral approaches, 2000 – 2020.

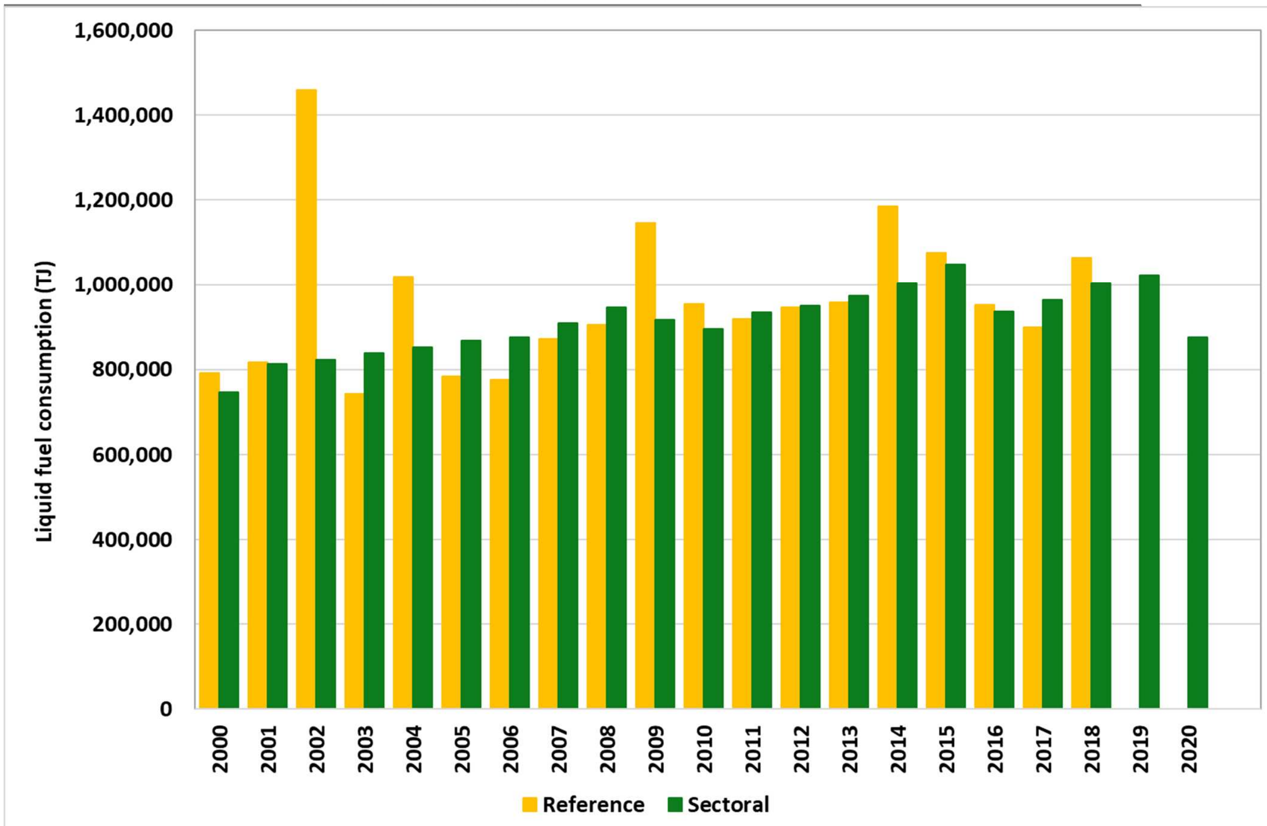

Figure D.2: Comparisons between the liquid fuel consumption determined by the reference and sectoral approaches, 2000 – 2020[9].

[9] 2018 is the latest year in which there is an Energy Balance

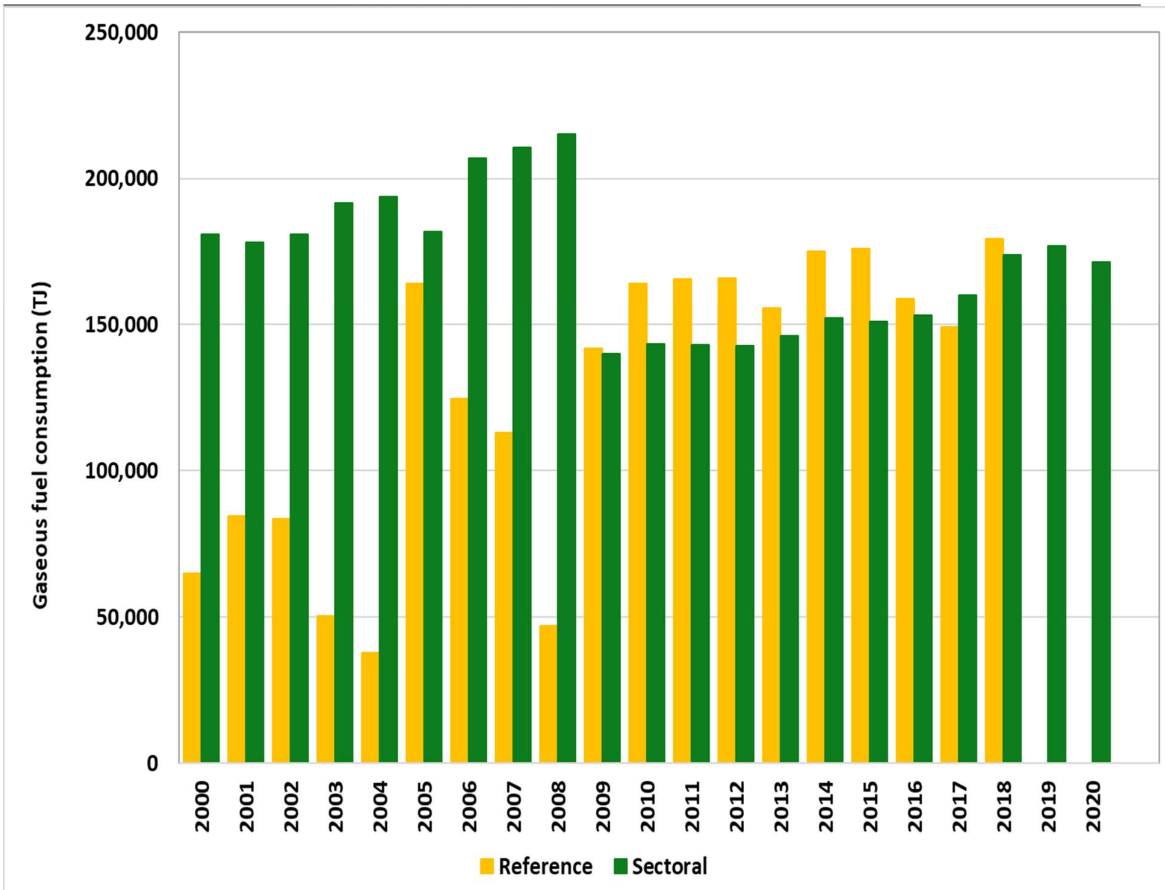

Figure D.3: Comparisons between the gaseous fuel consumption determined by the reference and sectoral approaches, 2000 – 2020[10].

[10] 2018 is the latest year in which there is an Energy Balance

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