NATIONAL GHG INVENTORY REPORT

SOUTH AFRICA

2000 - 2022

February 2024

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List of abbreviations

AFOLU	Agriculture, Forestry and Other Land Use
AGB	Above-ground biomass
ARC	Agricultural Research Council
Bbl/d	Barrels per day
BCEF	Biomass conversion and expansion factor
BEF	Biomass expansion factor
BNF	Biological nitrogen fixing
BOD	Biological oxygen demand
C	Carbon
C_2F_4	Tetrafluoroethylene
C_2F_6	Carbon hexafluoroethane
CF_4	Carbon tetrafluoromethane
CFC	Chlorofluorocarbons
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CRF	Common reporting format
DAFF	Department of Agriculture Affairs, Forestry and Fisheries
DEA	Department of Environmental Affairs
DFID	Department for International Development
DM	Dry matter
DMD	Dry matter digestibility
DMR	Department of Mineral Resources
DoE	Department of Energy
DOM	Dead organic matter
DTI	Department of Trade and Industry
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EF	Emission factor
F-gases	Flourinated gases: e.g., HFC, PFC, SF_6 and NF_3
FOD	First order decay
FOLU	Forestry and Other Land Use
FRA	Forest resource assessment
FSA	Forestry South Africa
GDP	Gross domestic product
GEI	Gross energy intake

GFRSA	Global Forest Resource Assessment for South Africa
Gg	Gigagram
GHG	Greenhouse gas
GHGI	Greenhouse Gas Inventory
GIS	Geographical Information Systems
GPG	Good Practice Guidance
GWH	Gigawatt hour
GWP	Global warming potential
HFC	Hydrofluorocarbons
HWP	Harvested wood products
IEF	Implied emission factor
INC	Initial National Communication
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
ISO	International Organization for Standardization
ISWC	Institute of Soil, Water and Climate
KCA	Key category analysis
LC	Land cover
LPG	Liquefied petroleum gas
LTO	Landing/take off
LULUCF	Land Use, Land Use Change and Forestry
MCF	Methane conversion factor
MEF	Manure emission factor
MW	Megawatt
MWH	Megawatt hours
MWTP	Municipal wastewater treatment plant
NAEIS	National Atmospheric Emissions Inventory System
N_2O	Nitrous oxide
NCCC	National Climate Change Committee
NCV	Net calorific value
NE	Not estimated
NERSA	National Energy Regulator of South Africa
NGHGIS	National Greenhouse Gas Inventory System
NIR	National Inventory Report
NIU	National Inventory Unit
NMVOC	Non-methane volatile organic compound
NO	Not occurring
NOx	Oxides of nitrogen
NTCSA	National Terrestrial Carbon Sinks Assessment
NWBIR	National Waste Baseline Information Report

PFC	Perfluorocarbons
PPM	Parts per million
PRP	Pastures, rangelands and paddocks
QA/QC	Quality assurance/quality control
RSA	Republic of South Africa
SAAQIS	South African Air Quality Information System
SAGERS	South African GHG Emissions Reporting System
SAISA	South African Iron and Steel Institute
SAMI	South African Minerals Industry
SAPIA	South African Petroleum Industry Association
SAR	Second Assessment Report
SASQF	South African Statistical Quality Assurance Framework
SADC	Southern African Development Community
SF_6	Sulphur hexafluoride
SNE	Single National Entity
SOC	Soil organic carbon
TAM	Typical animal mass
TAR	Third Assessment Report (IPCC)
TJ	Terajoule
TM	Tier method
TMR	Total mixed ratio
TOW	Total organics in wastewater
UN	United Nations
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
WRI	World Resources Institute
WWTP	Wastewater treatment plant-derived
VS	Volatile solids

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 (GHG) inventory for the year 2022. It also reports on the greenhouse gas trends for the period 2000 to 2022. 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 (IPCC, 2006), IPCC Good Practice Guidance (GPG) (IPCC, 2000; IPCC, 2003; IPCC, 2014) and the 2019 Refinement to the 2006 IPCC Guidelines (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 2017 (DEA, 2017), for 2013 to 2015 in 2019 (DEA, 2019), for 2017 in 2021 (DFFE, 2021), and for 2018, 2019 and 2020 in 2023 (DFFE, 2023).

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 – 2022 GHG emissions inventory.

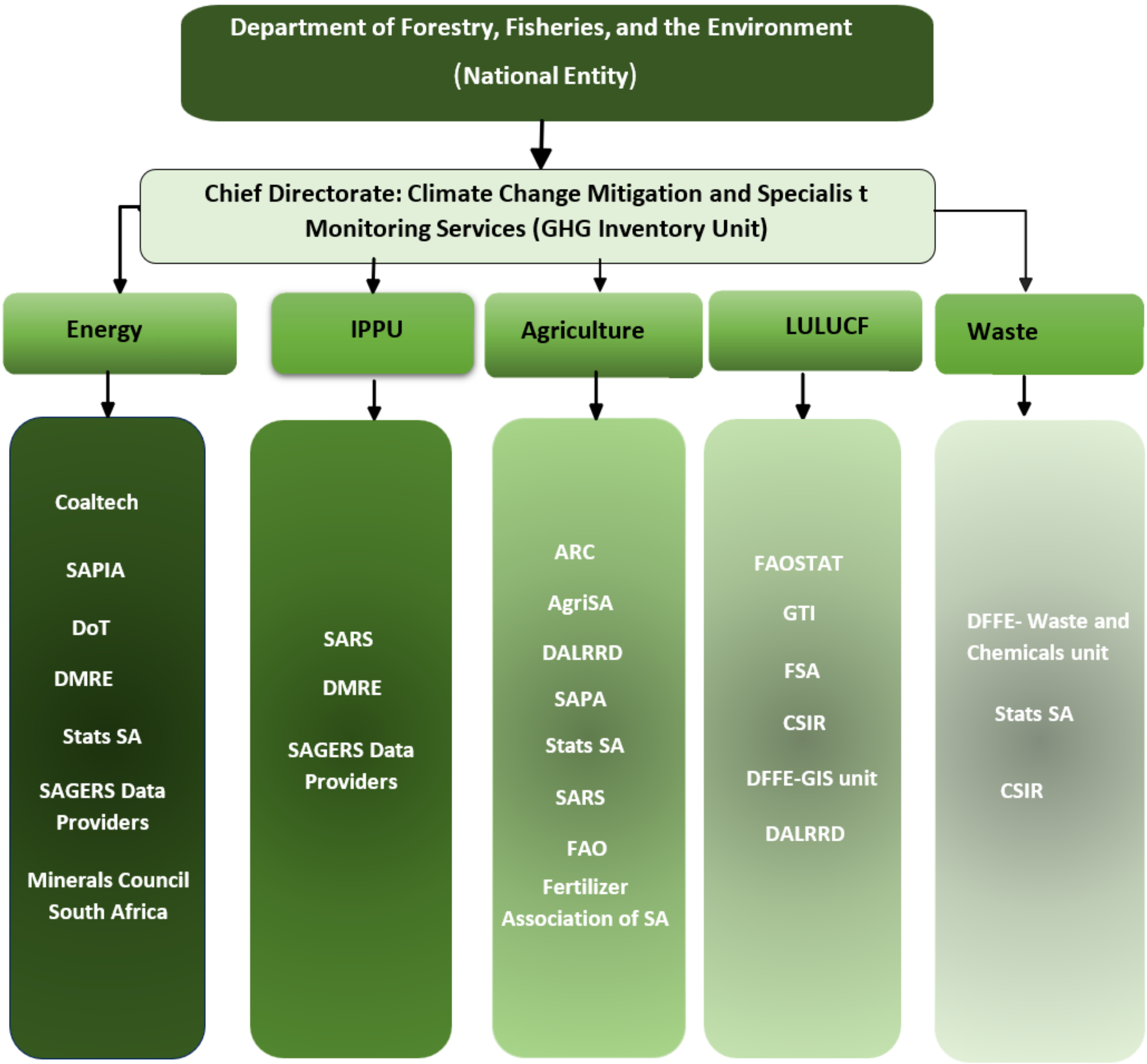

Figure ES 1: Institutional arrangements for the compilation of the 2000 – 2022 inventory for South Africa.

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 (DEA, 2017a). 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 National Greenhouse Gas Emissions Regulation came into effect on 03 April 2017. In accordance with regulation 7(1) of the regulation 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 Industrial Processes and Product Use (IPPU).

E.S.1.3. Organisation of report

This report follows a standard NIR format in line with the UNFCCC Reporting Guidelines or requirements under the enhanced transparency framework. 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 7 deal with detailed explanations of the emissions in the Energy; IPPU; Agriculture; Land Use, Land Use Change and Forestry (LULUCF) 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.

It should be noted that in the previous inventory Agriculture and LULUCF were grouped together under the *Agriculture, Forestry and Other Land Use* (AFOLU) sector as outlined in the 2006 IPCC Guidelines. However, in the Common Reporting Tables (CRT) under the Enhanced Transparency Framework (ETF) these two sectors are separated. South Africa is transitioning to the ETF CRT reporting format and therefore in this report Agriculture and LULUCF are treated as separate sectors with the categories and sub-categories following those outlined in the CRT formats.

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

GWP

In this inventory the emissions for each of the major GHGs are presented as carbon dioxide equivalents (CO_2e) using the 100- year global warming potentials (GWPs) from the 2014 IPCC Fifth Assessment Report (AR5) (IPCC, 2014b) in accordance with the Modalities, Procedures, and Guidelines (MPGs) for transparency framework for action and support referred to in Article 13 of the Paris Agreement. It should be noted that in the previous inventory for the years 2000 -2020 the 100 – year GWPs from the 1995 IPPC Second Assessment Report (AR2) (IPCC, 1996) were applied in line with the UNFCCC requirements for Non-Annex I Parties. Transitioning from the AR2 GWPs to AR5 GWPs led to a 2.9% and 3.7% increase in overall emissions in 2022 excluding and including LULUCF, respectively (Table ES 1).

Table ES 1: Impacts of transitioning from AR2 to AR5 GWPs on the overall emissions between 2000 and 2022.

	Emissions with AR2 GWPs		Emissions with AR5 GWPs		Impact of change in GWP	
	(excl. LULUCF)	(incl. LULUCF)	(excl. LULUCF)	(incl. LULUCF)	(excl. LULUCF)	(incl. LULUCF)
	Gg CO_2 e				%	
2000	476 861.9	446 961.4	489 747.5	462 205.4	2.7	3.4
2001	476 005.2	456 651.0	488 964.7	472 002.4	2.7	3.4
2002	484 725.3	468 360.2	497 651.3	483 692.9	2.7	3.3
2003	500 068.0	465 695.7	513 190.2	481 053.7	2.6	3.3
2004	511 790.2	485 929.7	524 902.7	501 254.4	2.6	3.2
2005	509 889.7	504 190.6	523 122.9	519 760.2	2.6	3.1
2006	500 850.5	489 020.8	514 091.2	504 500.4	2.6	3.2
2007	522 052.1	502 714.5	535 672.5	518 559.4	2.6	3.2
2008	518 440.6	512 877.7	532 320.7	529 003.6	2.7	3.1
2009	533 591.0	507 147.8	547 270.5	522 920.8	2.6	3.1
2010	513 118.4	497 009.7	526 971.4	512 987.3	2.7	3.2
2011	513 303.8	488 737.4	527 161.3	504 638.0	2.7	3.3
2012	521 851.5	496 005.2	536 003.0	512 196.6	2.7	3.3
2013	508 978.0	471 945.6	522 220.3	487 134.0	2.6	3.2
2014	509 474.4	481 452.6	522 899.6	496 835.8	2.6	3.2
2015	501 905.1	495 884.8	515 516.2	511 428.6	2.7	3.1
2016	496 339.9	473 786.2	509 870.0	489 254.4	2.7	3.3
2017	488 362.0	481 787.6	501 987.5	497 553.7	2.8	3.3
2018	489 041.8	487 530.8	502 130.2	502 893.9	2.7	3.2
2019	488 548.6	461 472.2	501 485.2	476 686.4	2.6	3.3
2020	459 358.9	420 560.5	472 437.8	435 918.6	2.8	3.7
2021	475 175.9	449 326.2	488 322.3	464 957.7	2.8	3.5
2022	465 609.9	420 146.1	478 887.5	435 827.7	2.9	3.7

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

E.S.3.1. Gas trends

Carbon dioxide

Carbon dioxide (CO_2) is the largest contributor to South Africa's emissions. CO_2 emissions contributed 81.9 % (excl. LULUCF) to South Africa's emissions in 2022 (Figure ES 2). Majority of CO_2 emissions are from the Energy sector, contributing an average of 92.7% (excl. LULUCF) to the total CO_2 emissions between 2000 and 2022 followed by the IPPU sector contribution (excl. LULUCF) an average of 6.8% between 2000 and 2022, while the Agriculture sector (excl. LULUCF) contributed an average of 0.6%.

Methane

Methane (CH_4) emissions have increased from 12.9% to 13.2% (excl. LULUCF) between 2000 and 2022 (Figure ES 2). The Agriculture (specifically *Enteric Fermentation*) and Waste (specifically *Solid Waste Disposal*) sectors are the major contributors to the total CH_4 emissions in 2022.

Nitrous oxide

Nitrous oxide (N_2O) emissions increased from 3.56% to 3.63% (excl. LULUCF) between 2000 and 2022 . The main contributor to N_2O emissions is the Agriculture sector followed by Energy sector, contributing 74.4% and 14.4% (excl. LULUCF) respectively.

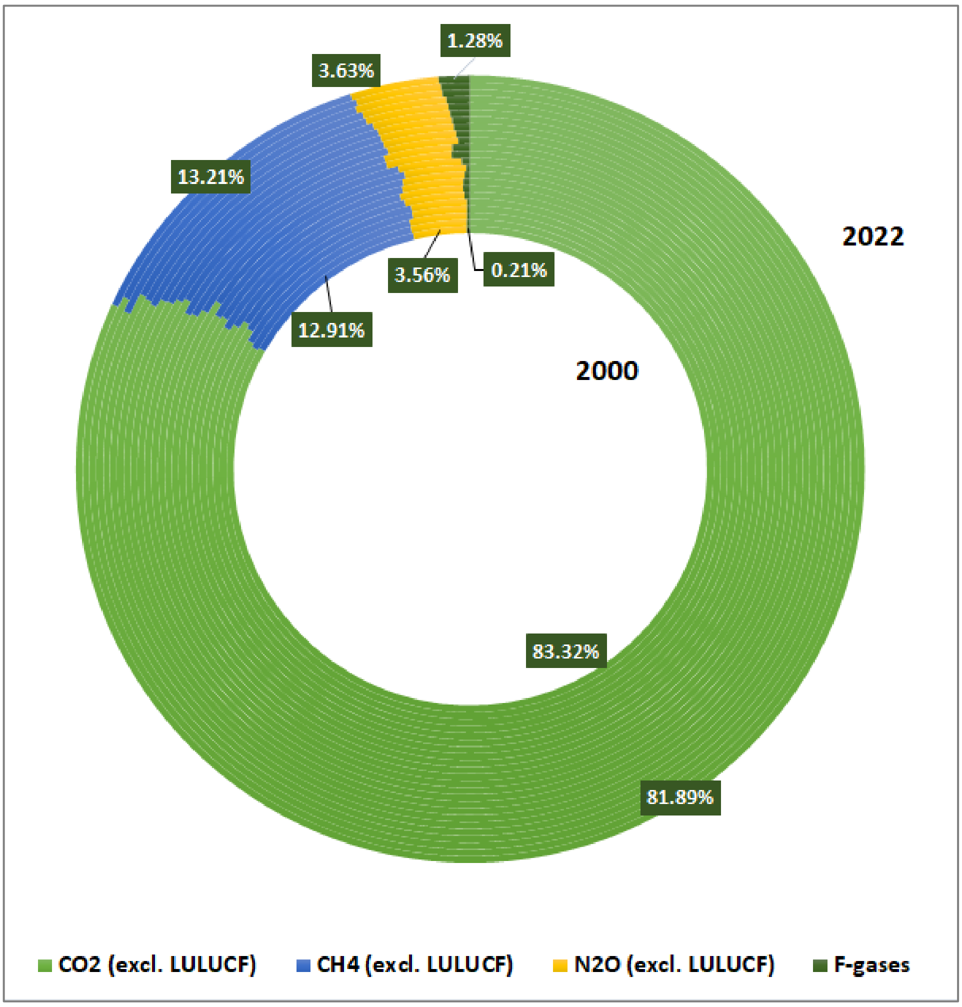

Figure ES 2: Gas contribution to South Africa's emissions (excl. LULUCF) between 2000 and 2022.

F-gases

Fluorinated gases (F-gases) emissions were only estimated for the IPPU sector in South Africa. Emissions for F-gases have increased from 0.2% to 1.3% (excl. LULUCF) between 2000 and 2022. Emissions increase from 2011 due to the addition of hydrofluorocarbons (HFCs) 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 replacement of ozone depleting substances did contribute to this increase.

Perfluorocarbons (PFCs) are produced during the production of aluminium.

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 414 Gg CO to 1 335 Gg CO between 2000 and 2022. The NOx emissions were between 31 Gg NOx and 60 Gg NOx, while NMVOCs were between 5 Gg NMVOCs and 90 Gg NMVOCs over the period 2000 to 2022. There is annual variability because the emissions include wildfires as well as controlled fires.

E.S.3.3. Sectoral trends

Energy

2022

Energy emissions in 2022 accounted for 78 % (excl. LULUCF) and 86 % (incl. LULUCF) of total emissions for South Africa (Figure ES 3). Majority of the Energy sector emissions were from *Energy Industries* (60 %) and *Transport* (14 %), while the least emissions were from *Solid Fuels* (0.6 %) and *Oil and Natural Gas* activities (0.03 %).

2000 – 2022

Since 2000, Energy sector emissions decreased by 2.5 % (Table ES 2). Emissions from the *Other Sectors* category decreased the most (by 62 %) during this period mainly because of the *Residential* sector. This is likely due to increased electrification over the years, as well as an increase in the use of renewable energy. Emissions from domestic aviation and petroleum refining also decreased significantly, 70 % and 73 % respectively since 2000. Although *Energy* sector emissions slightly decreased from 2000-2022 emissions from electricity production increased by 11.5 % due to an 8.7 % increase in power generation during that period. [1]

2020-2022

Energy emissions declined by 0.2% since 2020 (Table ES 2). In 2021 emissions increased by 3.5 % but then dropped again in 2022 to pandemic levels. This decrease is due to a 6.5% decrease in emissions from the *Energy Industries* sub-sector, which on average accounts for 67 % of the Energy sector emissions.

[1] *Electricity production data from Eskom's Annual Integrated reports 2000, 2011 – 2022. Integrated results - Eskom*

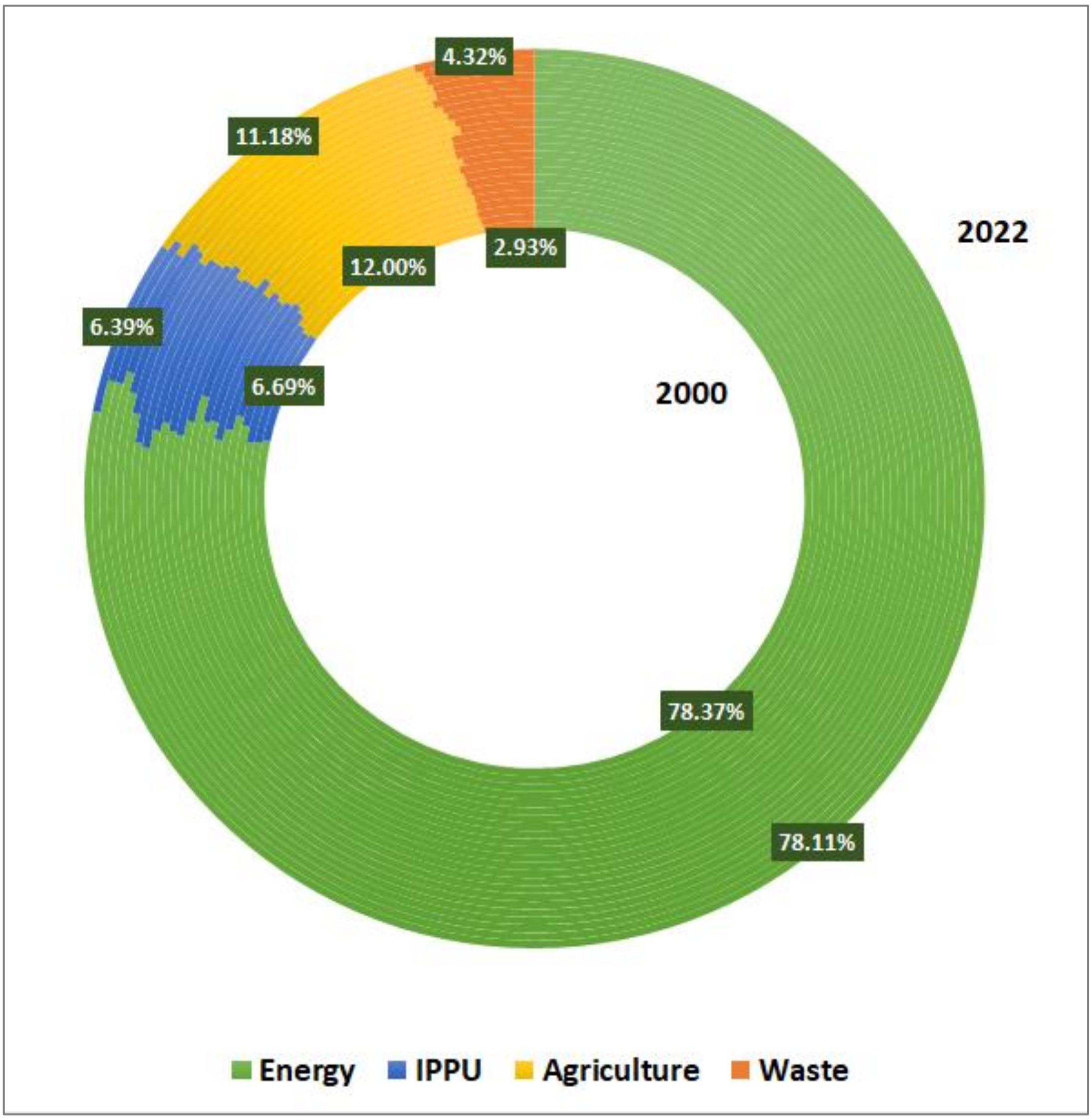

Figure ES 3: Sector contribution to total emissions (excluding LULUCF) in South Africa between 2000 and 2022.

Table ES 2: Change in sector emissions since 2000 and since the last inventory period (2000 - 2020).

	Emissions (Gg CO_2e)			Change 2000 to 2022		Change 2020 to 2022	
	2000	2020	2022	Gg CO2e	%	Gg CO2e	%
Energy	383 820.6	374 748.2	374 072.4	-9 748.2	-2.5	-675.7	-0.2
IPPU	32 781.3	24 857.6	30 598.0	-2 183.3	-6.7	5 740.4	23.1
Agriculture	58 782.9	53 830.0	53 518.7	-5 264.2	-9.0	-311.3	-0.6

LULUCF	-27 542.1	-36 519.2	-43 059.8	-15 517.7	56.3	-6 540.6	17.9
Waste	14 362.7	19 002.1	20 698.4	6 335.7	44.1	1 696.3	8.9

 # Calculated with AR5 GWP

Industrial processes and product use (IPPU)

2022

IPPU emissions for 2022, accounted 6.4% of South Africa's emissions (excl. LULUCF) (Figure ES 3). The largest source category is the *Metal industry* category, which contributes 51.2% to the total IPPU sector emissions. The *Mineral industry* and the *Product used as substitutes for ozone depleting substances* subsectors contribute 19.8% and 19.4%, respectively, to the IPPU sector emissions.

2000 - 2022

Since 2000, IPPU emissions have decreased by 6.7% (Table ES 2). The decline can be attributed to the decline in metals production (-39.0%), specifically Iron and Steel, and Aluminium. This can be ascribed to a decrease in global demand. The chemicals industry also declined (-31.4%). *Cement Production* and *Non-Energy Product Use from Fuels and Solvents* increased emissions from 2000 by 2 081 Gg CO_2e. The local demand for cement increased dramatically from 2000.

2020-2022

The IPPU sector emissions increased by 23.1% since 2020. This was mainly due to the restoration of production in the minerals (26.8%) and metals (26.83%) industry post covid. The year 2020 was used by some industries for maintenance during the covid period. A contribution was also made by the increased replacement of ozone depleting substances by fluorinated gases (12.5%). The chemicals industry had lower emissions (-22.5%) due to lower production.

Agriculture

2022

Agriculture emissions in 2022 accounted for 12% (excl. LULUCF) and 7% (incl. LULUCF) of total emissions for South Africa (Figure ES 3). Majority of the Agriculture sector emissions were from *Enteric fermentation* (68 %), *Agricultural soils* (19 %), and *Manure* *management* (8 %), while the least emissions were from *Field burning of agricultural residues* (0.1 %).

2000 - 2022

Since 2000, Agriculture sector emissions decreased by 8.9 % (Table ES 2). Emissions from *Enteric fermentation* decreased the most (by 14 %) during this period mainly because of the reduced non-dairy cattle total emissions. This is likely due to decreased livestock population numbers since 2000. Emissions from *Manure management* increased by 8% and this was due to the increase in N_2O emission from manure management. The rise in N_2O emissions from handling manure occurred primarily due to the practice of leaving most manure in dry lot/ kraals across various livestock categories. As a result, the storage of dry-based manure predominantly contributes to increased N_2O production.

2020-2022

Since 2020 the Agriculture sector emissions have declined by 0.6% and this is due mainly to declining livestock population.

LULUCF

2022

LULUCF sector was a sink of 43 060 Gg CO_2e in 2022. *Forest lands* were the largest contributors to this sink, while all other land sectors were estimated to be an overall source of emissions. The dominant *Forest land* sinks were thickets and woodlands. *Harvested wood products* (*HWP)* were a very small sink in 2022 (181 Gg CO_2e).

2000 - 2022

The LULUCF sector increased its sink by 56.3% between 2000 and 2022 (Table ES 2). *Forest lands* were the largest contributor to this increased sink. *Forest lands remaining forest lands* showed a general increase from 2009. Between 2014 and 2022 the was an increase in the conversion of grasslands to woodlands which contributed to the increasing sink during this time. *Grasslands* led to increased emissions between 2000 and 2022 due to land conversions between low shrublands and grasslands.

2020-2022

The LULUCF sink grew by a further 17.9% between 2020 and 2022 (Table ES 2), There was first a decline in 2021 due to increased losses from fires, but this then recovered in

2022 were an increase in the conversion of *Grassland* to *Forest land* produced an increased *Forest land* sink.

Waste

2022

In South Africa, Waste sector emissions for 2022 accounted 4.3% (excl. LULUCF) and 4.8% (incl. LULUCF) of the total emissions (Figure ES 3). Majority of Waste sector emissions are from *Wastewater treatment and discharge* which is contributing 44.7% to the total Waste sector emissions. This is, followed by *Solid waste disposal* which contributes 41.5%. *Biological treatment of solid waste* and *Incineration and Open Burning of Waste* contributed 12.2 % and 1.6 % of the total Waste emissions respectively.

2000 – 2022

Waste sector emissions have increased by 44.1% since 2000 (Table ES 2). *Solid waste disposal* emissions have increased by 47.6% since 2000. *Incineration and open burning of waste* emissions increased by 53.1% since 2000, while emissions from *Wastewater treatment and discharge* increased slightly throughout the time series. This is largely driven by increases of 35.6% in *Domestic wastewater treatment and discharge* emissions, whilst there was a 9.4% decline in *Industrial wastewater treatment and discharge* emissions.

E.S.4. Improvements and recalculations

Improvements introduced in the current inventory

Energy

The Energy sector emission estimates were improved through the use of country-specific emission factors, based on a study completed in 2022, for commonly used liquid and gas fuels; incorporation of data from SAGERS for categories 1A2a *Iron & Steel* and 1A2b *Non-ferrous Metals*; use of updated activity data from the 2020 DMRE energy balance; inclusion of emissions from charcoal and coke production under 1B1c; inclusion of emissions from natural gas activities under and the inclusion of other emissions from *Energy Production*.

IPPU

Tier 2 and Tier 3 estimates were introduced into the SAGERS data from 2022 onwards in the IPPU sector. Calculations with increased accuracy were achieved for *Other Chemicals and Product Use*, specifically ceramics, soda ash and dolomite usage. Verification of some selected production plants identified areas previously not included and increased accuracy.

Agriculture

Agriculture and LULUCF were split into separate chapters. All the other land category for non-CO_2 biomass burning emissions were removed from agriculture sector and it was incorporated into the LULUCF sector. Non-CO_2 biomass burning emissions in agriculture sector only included the cropland biomass burning of agricultural residues.

LULUCF

Several improvements were made in the LULUCF sector. The largest changes were to the land areas and land change data. Land change maps for 1990 to 2014, 2014 to 2018 and 2018 to 2020 were included in this inventory. Land change data was also improved by making corrections for changes in land classifications; removing potential seasonal variation for the conversions between *Forest lands* and *Grasslands*, and *Grasslands* and bare ground; and making corrections for the conversions from previously converted land. These improvements in the land change data had the biggest impact on the recalculations. Other improvements included updates to BCEF data for plantations, carbon stock data for all land categories, emission factors for wetlands and the incorporation on non-CO_2 biomass burning emissions into the LULUCF sector.

Waste

A change in the source of the population data to a more country-specific source led to changes in emission estimates in this sector. There were also further updates made to the COD values for various industries and this impacted the industrial wastewater treatment emissions.

Recalculations

The improvements led to recalculations of the emission estimates across the time-series. The 2020 inventory estimates were recalculated using the AR5 GWP to remove the impacts of the changing GWP. The overall improvements led to a reduction in emissions (excl. LULUCF) of 0.4% to 5.3% across the time-series. Including LULUCF in the total produced estimates that were between 0.2% and 4.9% lower than the 2020 estimates. The energy sector improvements are the largest contributors to the reduction.

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 LULUCF to determine the key categories for South Africa. For the 2000-2022 inventory the level of disaggregation for each sector was updated. However, as with the last two inventories the key categories were then ranked according to their combined contribution to the level and trend assessments. In the previous inventory there were 58 key categories, while in this inventory there are 53. Table ES 3 shows the top 30 key categories.

Forest land converted to grassland, *Direct N_2O emissions from managed soils* and *Ferroalloy production* are new to the top 10 key categories. In the previous inventory these categories were in 26th (as *Land converted to grassland*), 16th and 15th place, respectively.

Table ES 3: Key categories for South Africa for 2022 (including LULUCF) and their ranking.

Rank	IPCC code	IPCC Category	GHG#	Criteria
1	4.A.2.b	Grassland converted to forest land – all pools	CO_2	L,T
2	1.A.3.b	Road Transportation – Liquid Fuels	CO_2	L,T
3	4.A.1.a	Forest land remaining forest land – biomass	CO_2	L,T
4	1.A.1	Energy Industries – Solid Fuels	CO_2	L,T
5	3.D.1	Direct N_2O Emissions From Managed Soils	N_2O	L
6	4.C.1.a	Grassland remaining Grassland – biomass	CO_2	L,T
7	4.F.2.c	Grassland converted to other land – all pools	CO_2	L,T
8	1.A.5	Other – Solid Fuels	CO_2	L,T
9	2.C.2	Ferroalloys Production	C	L
10	1.B.3	Other emissions from energy production	CO_2	L,T
11	1.A.4	Other Sectors – Liquid Fuels	CO_2	L,T
12	3.A.1.a.ii	Non-dairy Cattle	CH_4	L,T
13	4.G	Harvested Wood Products	CO_2	T
14	5.D	Wastewater Treatment and Discharge – Industrial	CH_4	L
15	1.A.3.a	Domestic Aviation	CO_2	T

Rank	IPCC code	IPCC Category	GHG[#]	Criteria
16	1.A.1	Energy Industries – Gaseous Fuels	CO_2	T
17	1.A.5	Other – Liquid Fuels	CO_2	T
18	1.A.4	Other Sectors – Solid Fuels	CO_2	L,T
19	2.C.1	Iron and Steel Production	CO_2	L,T
20	3.A.1.a.i	Dairy Cattle	CH_4	L
21	4.A.1.b	Forest land remaining forest land – dead organic matter	CO_2	T
22	5.A	Solid Waste Disposal	CH_4	L,T
23	1.B.3	Other emissions from energy production	CH_4	L
24	2.B.2	Nitric Acid Production	N_2O	T
25	2.C.3	Aluminium Production	F-gases	T
26	1.A.2	Manufacturing Industries and Construction – Gaseous Fuels	CH_4	L,T
27	4.C.2.a	Forest land converted to Grassland – all pools	CO_2	L,T
28	1.B.2	Oil and Natural Gas	CO_2	T
29	4(V)	Biomass Burning	CH_4	L
30	4.B.2.b	Grassland converted to Cropland – all pools	CO_2	L

[#]C=Confidential

E.S.6. Indicator trends

The carbon intensity of the population (i.e. total net emissions per capita) has decreased by 33 % since 2000 (Figure ES 4) with 2020 experiencing the highest annual decrease of 10 %.

Similarly, both the carbon intensity of economy and the carbon intensity of the energy supply have decreased, by 42 % and 35 % respectively, since 2000.

These carbon intensity indicators show that overall South Africa’s carbon intensity is decreasing overtime.

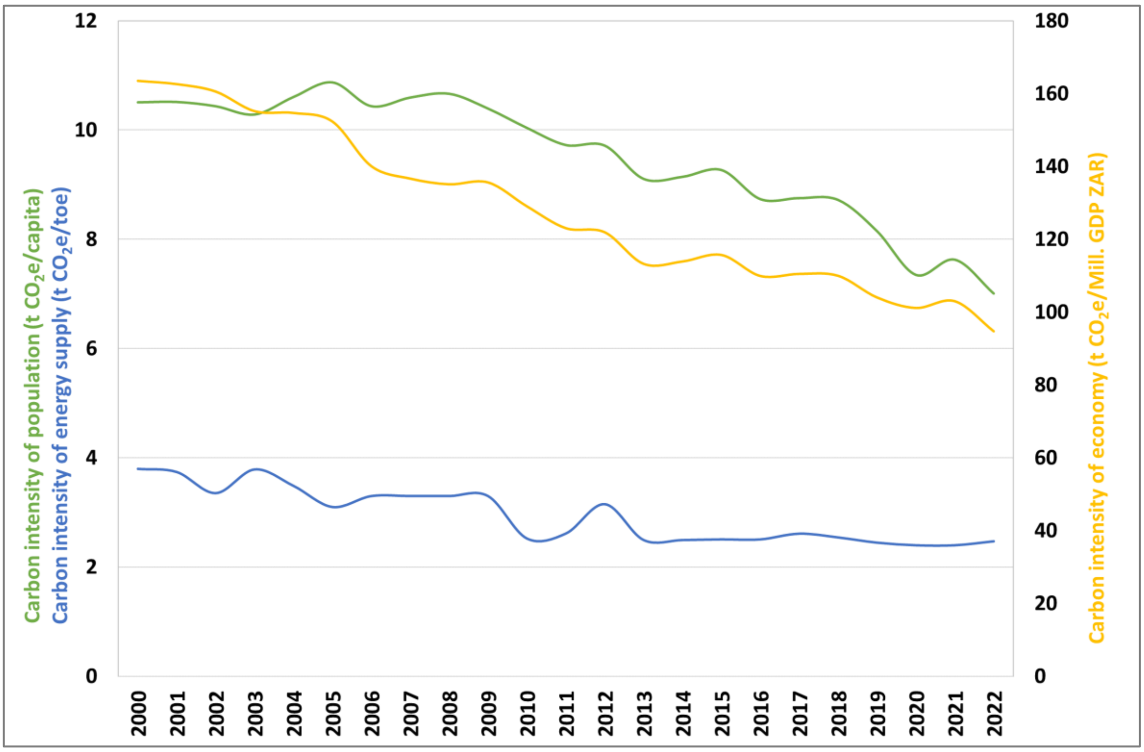

Figure ES 4: Trend in carbon intensity indicators for South Africa between 2000 - 2022

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. This inventory included some updated uncertainty data for various categories within all sectors, and a more detailed uncertainty analysis was included for the LULUCF sector A trend uncertainty between the base year and 2022, 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 12.1% and 12.5% including LULUCF, with an uncertainty of 8.9% introduced into the trends. Excluding LULUCF reduced the overall uncertainty to 5.7%-6.4% with the trend uncertainty dropping to 4.4%.

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..

Completeness of the national inventory

The South African GHG emission inventory for the period 2000 – 2022 is not complete, mainly due to the lack of sufficient data. Table ES 4 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 4: Activities in the 2022 inventory which are not estimated (NE), included elsewhere (IE) or not occurring (NO).

NE, IE or NO	IPCC Category	Activity	Comments
NE	1B1b	CO_2, CH_4 and N_2O from spontaneous combustion of coal seams	Research to be initiated in future, depended on availability of funding to initiate a study.
	1B1ai2	CH_4 emissions from abandoned mines	Research to be initiated in future, depended on availability of funding to initiate a study.
	1C1	CO_2 transport	Insufficient data to include
	1C2	Injection and storage	Insufficient data to include

	2B7	CH_4 and N_2O emissions from Soda Ash Production	CO_2 included in this inventory. CH_4 and N_2O is not anticipated to be included in future inventories.
	2C1	N_2O emissions from iron and steel production	Insufficient data to include
	2C2	N_2O emissions from ferroalloy production	Insufficient data to include
	2D2	CH_4 and N_2O emissions from paraffin wax use	Insufficient data to include
	2E	Electronics industry	Insufficient data to include
	2F5	PFCs and HFCs from solvents	Insufficient data to include
	2G1	PFCs from electrical equipment	Insufficient data to include
	2G2	PFCs from other product uses	Insufficient data to include
	2G3	N_2O from product uses	Insufficient data to include
	3D1f	Cultivation of organic soils	Organis soils are assumed to be insignificant, but incorporating detail on organic soils is included in the improvement plan
	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.
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	Non-specified mobile	Included under Non-specified Mobile (1A3b)
	3E	Prescribed burning of savannas	Emissions are included under LULUCF Forest land (4A)
	4B	Non-CO_2 emissions from cropland burning	These are included under Field burning of agricultural residues (3F).
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	
	3C7	Rice cultivation	

Planned improvements

Table ES 5: Improvements that are currently in progress and improvements planned or proposed

Sector	Improvement	Barriers and constraints
Tasks in progress		
Cross-cutting	Improve uncertainty data for all sectors by incorporating more country specific uncertainty values	Lack of uncertainty data constrains this activity. As data becomes available it will be incorporated. In this inventory a more detailed analysis of uncertainty for LULUCF sector was completed.
	Improve QA/QC process by addressing all issues in external review	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 working through them. It is an ongoing process.
Energy	Improve the improvement plan by incorporating all review activities not addressed in current 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.
	Improve explanation of large changes in trends	Partly resolved. Additional explanations have been provided, but there are still areas where this can be improved further. Ongoing process.
Agriculture	Incorporate all background data and equations for the Tier 2 calculations of enteric fermentation	Partly completed. All the background equations have been included, but average data is still being used for some of the factors (instead of annual data) due to a lack of a sustainable data source. This will be further investigated in the 2021 inventory.
LULUCF	Complete a full uncertainty analysis for the Land sector, including area bias corrections	A more detailed uncertainty analysis was included for biomass, DOM and SOC data in the LULUCF sector. Mapping uncertainties were improved, however these will be improved further during the land change improvement plan.

	Improvement of land change data through detailed assessment of maps and tracking of land parcels	This 2022 inventory incorporated a more detailed assessment of the land change data and identified the most important land change categories that need attention. The assessment also identified improvements that need to be done moving forward and the priority of these improvements. Removing changes due to seasonality is top priority and this will be improved as more land change maps are obtained. The 2022 SANLC map will already assist with making improvements. Tracking of land parcels over time is the second most important issue and training on Collect Earth to assist in this process is underway.
	Include deadwood in the DOM pool for all land categories	Deadwood has been included for the forest land category. The other land categories with woody components are settlements and perennial crops, but data is very limited for these land categories. Deadwood in these categories is assumed to be very small, but an explanation of this will be included in the next inventory.
	Move to a higher tier level for DOM in forest lands	This was considered in the 2022 inventory and more detailed disturbance matrix data was included to determine the amount of biomass entering the DOM pool, however there were still one or two pieces of data misisng which requires further investigation. This will be completed and included in the next inventory.
Waste	Data collection on quantities of waste disposed of into managed and unmanaged landfills	Project is underway so data will be included in 2024 inventory.
Tasks outstanding		
Cross cutting	Investigate inconsistencies in lime activity data (for lime production in IPPU and lime application emission in Agriculture), explore alternative data sources or improve consistency.	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.
	Incorporate NOx, CO, NMVOC, and SOx emissions	Not resolved.
Energy	Further disaggregation of 1A2	Current inventory breaks down 1A2 into 1A2a, 1A2b and 1A2-ab. Further work is require to further disaggregate this sector and have emissions calculated per sub-sector.
	More activity data for estimating emissions associated with non-energy fuel use	Research to be initiated in future.

	Inclusion of methodology documentation/summary/approval process for tier 3 methods	To be collated and included in future.
	CO_2, CH_4 and N_2O from spontaneous combustion of coal seams	Research to be initiated in future.
	CH_4 emissions from abandoned mines	Research to be initiated in future.
	Investigate pipeline transport	Proposed
	Investigate ground activities at airports and harbours	Proposed
	Update of the VKT study, including segregation of on-road/off-road	Proposed
	Comparison of next VKT approach with fuel statistics	Proposed
	Segregation of military energy use.	Proposed
	Incorporate emissions from biogas	This would require a study and so should be recommended as a project under the GHGIP.
	CO_2 transport and storage	Proposed
	CO_2, CH_4 and N_2O emissions from combined heat and power (CHP) combustion systems	Proposed
	Development of T3 methods for CTL-GTC and GTL	Resources and funding are required to complete this study so it will be incorporated into the GHGIP.
IPPU	Update the fluorinated gasses with higher accuracy figures from SARS	Access to all data and ensuring that the data is accurate.
	Include emissions from electronics industry	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	Lack of data is still a challenge.
Agriculture	Improve manure management data, including biogas digesters as a management system	Proposed project as there is a high variability in this dataset.

LULUCF	Incorporate organic soils study to include emissions from organic soils	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	This was partially investigated in this inventory; however a proper assessment will be included in the land use change improvement plan that will run over the next few years.
	Perform a more detailed assessment of HWP to include a wider range of products	Proposed project that could be considered under the GHGIP. For future evaluation.
	Report activity data and parameters (e.g. half-life) used for HWP emission estimation for the whole time-series	This will be included in the 2024 inventory.
	Report on the frequency of the HWP activity data collection	This will be included in the 2024 inventory.
	Assess if the emissions/removals in the overseas territories are significant	Currently these emissions are assumed insignificant as the area of these territories is extremely small, but an assessment of possible emissions still needs to be explored.
	Collect data on other disturbances besides fire in forest lands	This would require a study so will be recommended as a project under the GHGIP.
	Develop a spatial map of fuel wood consumption based on litertarure to further improve fuel wood consumption	This would require a study so will be recommended as a project under the GHGIP.
	Assess the significance of peatlands	Asessing the areas of peatlands would be the first step and this part could be done as part of the land use improvement plan.
Waste	Improve MCF and rate constants	This would require a study so will be recommended as a project under the GHGIP.
	Include economic data for different population groups	Will be included in the 2024 inventory
	Include information on population distribution in rural and urban areas as a function of income	Insufficient data.
	Include HWP in solid waste	Insufficient data.
	Obtain data on waste streams and the bucket system	Insufficient data.

	CH_4, N_2O emissions from biological treatment of waste	Insufficient data.
	CO_2, CH_4 and N_2O from waste incineration	Insufficient data.

E.S.8. Conclusions

The 2000 to 2022 GHG emissions results revealed that emissions have decreased since 2000 from the Energy and IPPU and Agriculture sector. Even though the South African economy recovered after the COVID-19 pandemic, estimated emissions from the IPPU sector are lower than the emissions in 2000. The decline in emissions in the IPPU sector can be attributed to the decline in metals production (-39.0%), specifically Iron and Steel, and Aluminium. This can be ascribed to a decrease in global demand. The chemicals industry also declined (-31.4%).

The energy sector continued to be the main contributor of GHG emissions as was found in previous inventories. The estimated emissions for the Energy sector are lower than the emissions in 2000, this decline in emissions is attributed to significant reductions in other energy sub sectors, particularly in the residential sector, driven by increased electrification and renewable energy use. Notably, domestic aviation and petroleum refining emissions decreased by 70% and 73%, respectively. Despite an overall decrease in Energy sector emissions since 2000, emissions from electricity production increased by 11.5% due to a rise in power generation.

Improvements in the current inventory were implemented across different categories for the energy sector. These included the introduction of country-specific emission factors for liquid and gas fuels based on a 2022 study, incorporation of data from SAGERS for Iron & Steel and Non-ferrous Metals categories, and the utilisation of updated activity data from the 2020 DMRE energy balance. Charcoal and coke production emissions were included under category 1B1c and emissions from natural gas activities and other emissions from Energy Production were also included. For the IPPU sector Tier 2 and Tier 3 estimates from SAGERS data were introduced from 2020 onwards.

Agriculture and LULUCF were separated into distinct chapters. Non-CO_2 biomass burning emissions, excluding cropland biomass burning of agricultural residues, were transferred from the agriculture sector to the LULUCF sector. Significant improvements were made in the LULUCF sector, particularly in land areas and land change data. Land change maps for different periods were included, corrections were made for changes in land classifications and potential seasonal variations. For the Waste sector the source of population data was changed to a more country-specific one. Further updates were made to COD values for various industries, impacting industrial wastewater treatment emissions.

Contents

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Department:
Forestry, Fisheries and the Environment
REPUBLIC OF SOUTH AFRICA

Figures

Chapter 1: Introduction

1.1 Structure of the report

1.1.1 Overall structure

This National Inventory Report (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, Agriculture, LULUCF, Waste).
- **Chapters 3 to 7** deal with detailed explanations of the emissions in the Energy, IPPU, Agriculture, LULUCF 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 category (Appendix A) and uncertainty analysis results (Appendix B), all summary tables in the IPCC prescribed format (Appendix C), and the energy sector reference approach data (Appendix D).

1.1.2 Structure of sectoral chapters

In this submission the Agriculture and LULUCF sectors have been split into two chapters to bring the report in alignment with the required Common Reporting Tables (CRT) that have to be submitted as part of the Enhanced Transparency Framework (ETF) reporting. The layout and structure of the detailed sectoral chapters (chapters 3 to 7) is as follows:

- **Sector overview** is at the front 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 quality assurance and quality control (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 Agriculture 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 LULUCF sector also has additional information at the beginning to provide detail on the land classifications and approaches for determining land areas and land use change that is used throughout the section.

1.2 National circumstances

1.2.1 Background information on climate change

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

1.2.2 Background information on GHG inventories

In August 1997, the Republic of South Africa joined the majority of countries in the international community in ratifying the UNFCCC. The first national GHG inventory 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 2017 (DEA, 2017), for 2013 to 2015 in 2019 (DEA, 2019), for 2017 in 2021 (DFFE, 2021), and for 2018, 2019 and 2020 in 2023 (DFFE, 2023).

1.2.3 Global warming potentials

As greenhouse gases (GHG) 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, emissions are presented as CO_2e using the 100- year global warming potentials (GWPs) from the 2014 IPCC Fifth Assessment Report (AR5) in accordance with the Modalities, Procedures, and Guidelines (MPGs) for transparency framework for action and support referred to in Article 13 of the Paris Agreement (Table 1.1).

Table 1.1: Global warming potential (GWP) of greenhouse gases used in this report and taken from AR5 (IPCC, 2014b).

Greenhouse gas	Chemical formula	AR5 GWP
Carbon dioxide	CO_2	1
Methane	CH_4	28
Nitrous oxide	N_2O	265
Hydrofluorocarbons (HFCs)		
HFC-23	CHF_3	12 400
HFC-32	CH_2F_2	677
HFC-125	CHF_2CF_3	3170
HFC-134a	CH_2FCF_3	1300
HFC-143a	CF_3CH_3	4 800
HFC-227ea	C_3HF_7	3350
HFC-365mfc	$C_4H_5F_5$	804
HFC-152a	CH_3CHF_2	138
Perfluorocarbons (PFCs)		
PFC-14	CF_4	6 630
PF-116	C_2F_6	11 100

Inventories prior to the 2000 – 2020 inventory were prepared using the IPCC Second Assessment Report (AR2) (IPCC, 1996) GWPs. For purposes of comparison with past inventories, and due to the use of the IPCC Third Assessment Report (AR3) (IPCC, 2001) GWPs in other national regulations, the national emissions trends are presented using GWPs from AR2, AR3 and AR5 in Table 1.2. All text references, tables and graphs throughout the report refer to the AR5 GWP estimates, unless it is otherwise stated.

Table 1.2: Trends in national GHG emissions (excluding and including LULUCF) between 2000 and 2022 based on the three different GWPs

	National emissions (Gg CO_2e)					
	AR2 GWP		AR3 GWP		AR5 GWP	
	(excl. LULUCF)	(incl. LULUCF)	(excl. LULUCF)	(incl. LULUCF)	(excl. LULUCF)	(incl. LULUCF)
2000	476 861.9	446 961.4	480 384.7	451 149.8	489 747.5	462 205.4
2001	476 005.2	456 651.0	479 546.4	460 866.0	488 964.7	472 002.4
2002	484 725.3	468 360.2	488 264.0	472 575.8	497 651.3	483 692.9
2003	500 068.0	465 695.7	503 666.1	469 925.2	513 190.2	481 053.7
2004	511 790.2	485 929.7	515 384.5	490 148.5	524 902.7	501 254.4
2005	509 889.7	504 190.6	513 517.9	508 475.4	523 122.9	519 760.2
2006	500 850.5	489 020.8	504 508.7	493 309.3	514 091.2	504 500.4
2007	522 052.1	502 714.5	525 791.8	507 080.9	535 672.5	518 559.4
2008	518 440.6	512 877.7	522 289.4	517 358.0	532 320.7	529 003.6
2009	533 591.0	507 147.8	537 416.2	511 562.8	547 270.5	522 920.8
2010	513 118.4	497 009.7	517 007.1	501 495.5	526 971.4	512 987.3
2011	513 303.8	488 737.4	517 020.8	493 029.0	527 161.3	504 638.0
2012	521 851.5	496 005.2	525 694.8	500 422.0	536 003.0	512 196.6
2013	508 978.0	471 945.6	512 741.3	476 257.3	522 220.3	487 134.0
2014	509 474.4	481 452.6	513 287.3	485 816.5	522 899.6	496 835.8
2015	501 905.1	495 884.8	505 793.3	500 318.6	515 516.2	511 428.6
2016	496 339.9	473 786.2	500 222.5	478 217.8	509 870.0	489 254.4
2017	488 362.0	481 787.6	492 288.7	486 318.6	501 987.5	497 553.7
2018	489 041.8	487 530.8	492 825.3	491 956.2	502 130.2	502 893.9
2019	488 548.6	461 472.2	492 302.3	465 869.3	501 485.2	476 686.4
2020	459 358.9	420 560.5	463 172.7	425 018.2	472 437.8	435 918.6
2021	475 175.9	449 326.2	479 020.9	453 870.1	488 322.3	464 957.7
2022	465 609.9	420 146.1	469 510.1	424 724.2	478 887.5	435 827.7

1.3 Institutional arrangements

1.3.1 National Entity

In South Africa the Department of Forestry, Fisheries and the Environment (DFFE) is the central co-ordinating and policy-making authority with respect to environmental conservation. The DFFE is mandated by the Air Quality Act (Act 39 of 2004) (RSA, 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 (RSA) 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.

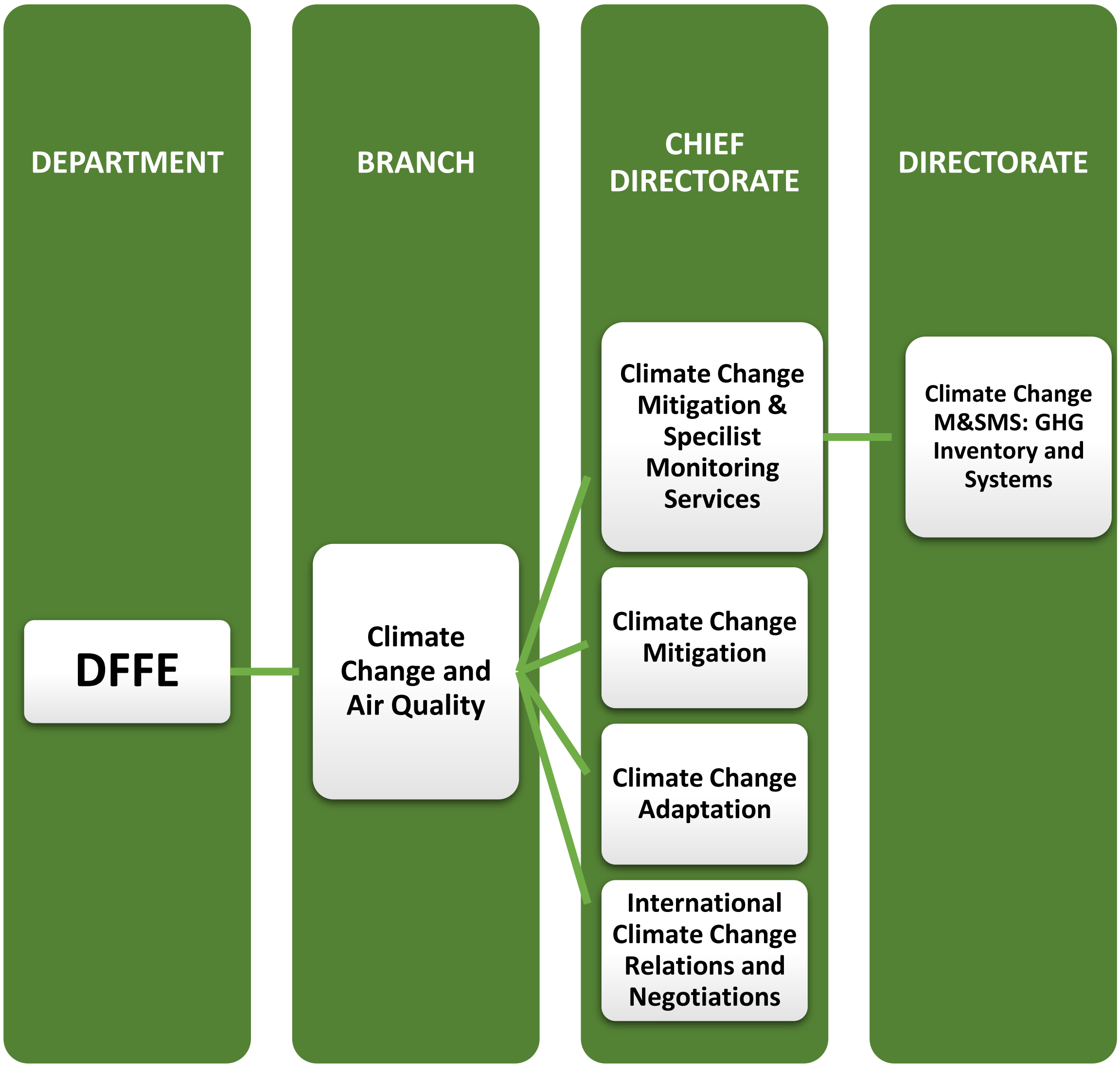


Figure 1.1: Organogram showing where the GHG Inventory compilation occurs within DFFE.

DFFE is currently responsible for managing all aspects of the National GHG Inventory development. The Director of the Climate Change Monitoring and Evaluation (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 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.
- Fostering and establishing links with related national projects, and other regional, international programmes as appropriate.

1.3.2 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 National Greenhouse Gas Emission Reporting Regulations (NGERs) (DEA, 2017a), 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 April 2017. The purpose of the GHG reporting regulation 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 Greenhouse Gas 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 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, namely 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.

The inventory compilation process (Figure 1.2) is co-ordinated through a central web-based inventory management system (National GHG Information Management System (NGHGIS)).

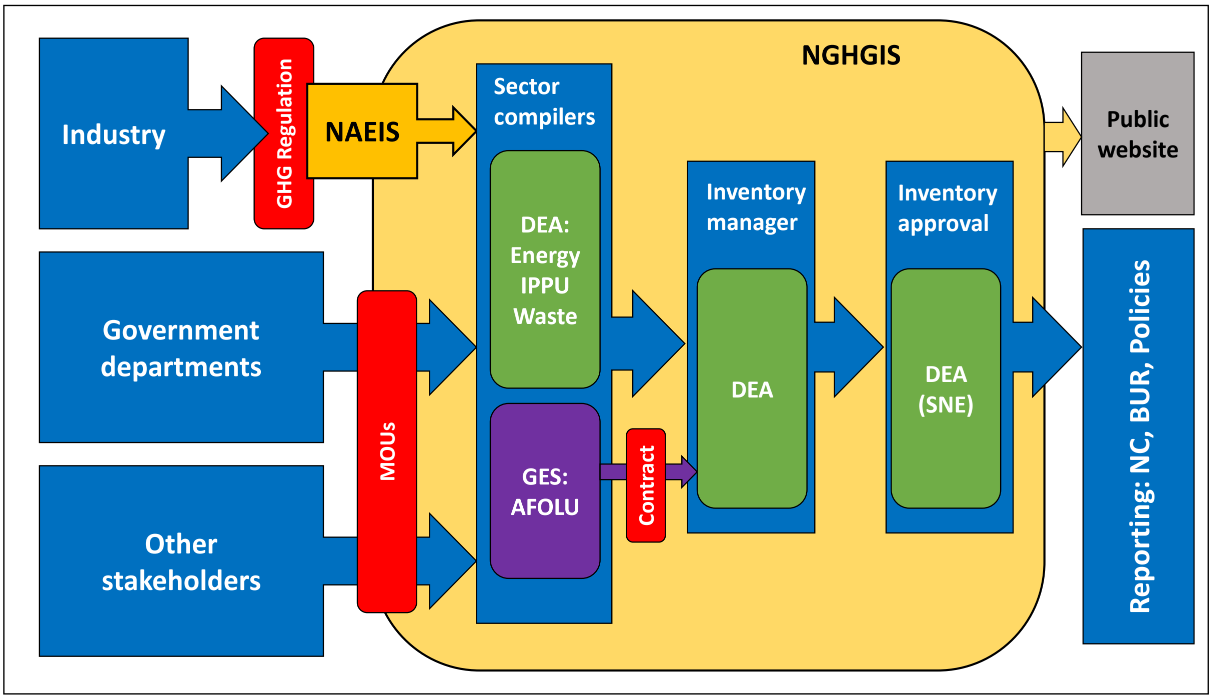


Figure 1.2: The inventory compilation process in South Africa.

1.4 Overview of inventory preparation and management

1.4.1 Inventory management

South Africa uses a hybrid (centralised/distributed) approach to manage the inventory programme. 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, Agriculture and Waste sector inventories, while the LULUCF sector is compiled (in collaboration with DFFE) by external consultants (Gondwana Environmental Solutions (GES)) who are appointed via a formal project-based contract with the UNDP as part of the Capacity Building Initiative for Transparency (CBIT) project of South Africa. DFFE assists with the QC of the LULUCF sector. DFFE were also responsible for combining and compiling the overall inventory and compiling the draft National Inventory Report.

1.4.2 Procedural arrangements

1.4.2.1 Inventory planning

A planning meeting was held in January 2022 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.

1.4.2.2 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.

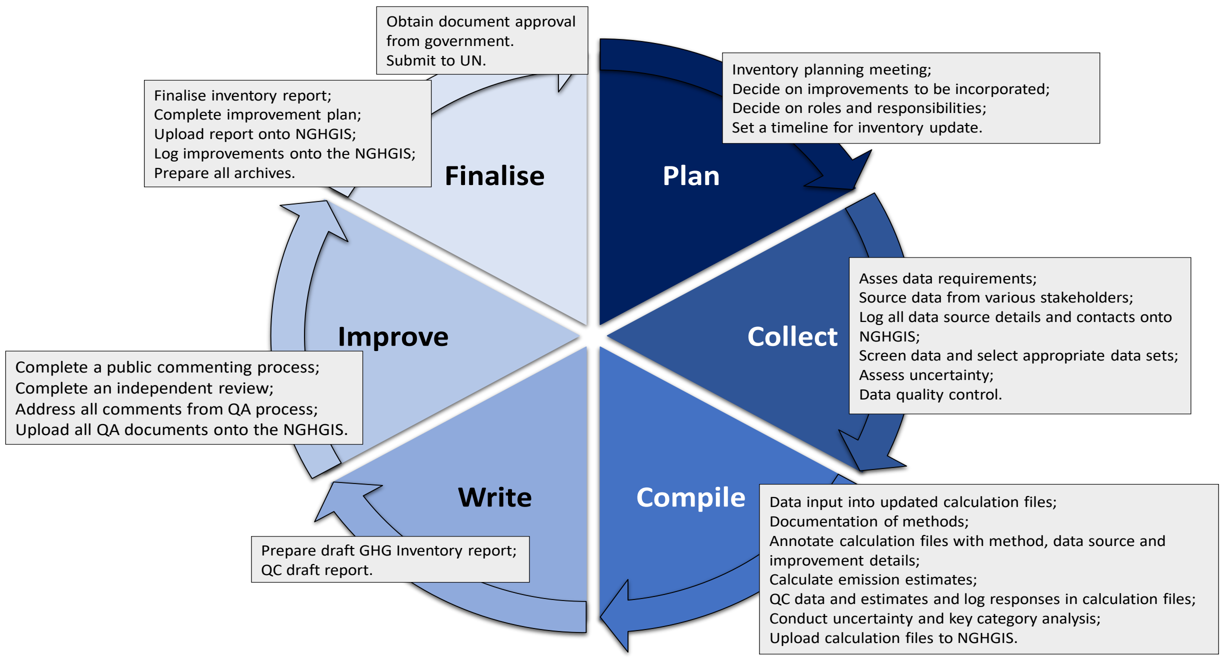


Figure 1.3: Overview of the phases of the GHG inventory compilation and improvement process undertaken for South Africa's 2020 GHG inventory.

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 crosscutting 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 2022 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.

1.4.3 Data collection, storage and archiving

1.4.3.1 Data collection

Data collection and documentation take place under the responsibility of the relevant experts. Three different processes are used to collect data for South Africa's inventory. The first is by obtaining data from government departments, institutes, companies, and organisations through an informal process, i.e. where data is obtained without any formal data collection agreements. The second is through the evaluation of publicly available data, official statistics, association statistics, studies, periodicals and third-party research projects. Most of the inventory data is collected using these two approaches, but for industry South Africa has started to move towards a more formalised data collection system. 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, 2017a). 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 (https://ghgreporting-public.environment.gov.za/GHGLanding/SAGERSHome.html). 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.

1.4.3.2 Data preparation and emission calculation

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

- Data entry
- Data preparation (model formation, disaggregation, aggregation)
- Calculation of emissions
- Preparation of report sections (texts) and
- 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, these materials are transmitted to the Single National Entity where it is reviewed by category-specific specialists at the Single National Entity. The results of this review are then provided to the sector lead experts to revise and finalise their contribution.

1.4.3.3 Report preparation

Report preparation includes the following steps:

- Aggregation of emissions data for the national trend tables and reporting formats, preparation of data tables for the NIR
- Compilation of submitted report texts to form a report draft (NIR), and editing of the complete NIR
- Internal review of the draft (national trend tables and NIR) by DFFE
- Public commenting process
- External review by 3rd party
- Finalization of NIR report
- Approval by DFFE Minister
- Submission to UNFCCC
- Archiving

1.4.3.4 Data storage and archiving

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

- Stakeholder list with full contact details and responsibilities
- List of input datasets which are linked to the stakeholder list
- QA/QC plan
- QA/QC checks
- QA/QC logs which will provide details of all QA/QC activities
- All method statements
- 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
- Calculation and supporting files
- Key references
- Key categories; and
- 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 section 1.6 below. The NGHGIS is used to archive inventory data.

1.5 Brief description of data sources and methods

1.5.1 Data sources

1.5.1.1 Energy sector

The main sources of data for the Energy sector are the energy balance data compiled by the Department of Mineral Resources and Energy (DMRE), data supplied by the main electricity provider, Eskom, and petroleum companies, i.e., PetroSA and Sasol. Annual reports from the 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 1.4 and data sources are provided in Table 1.3.

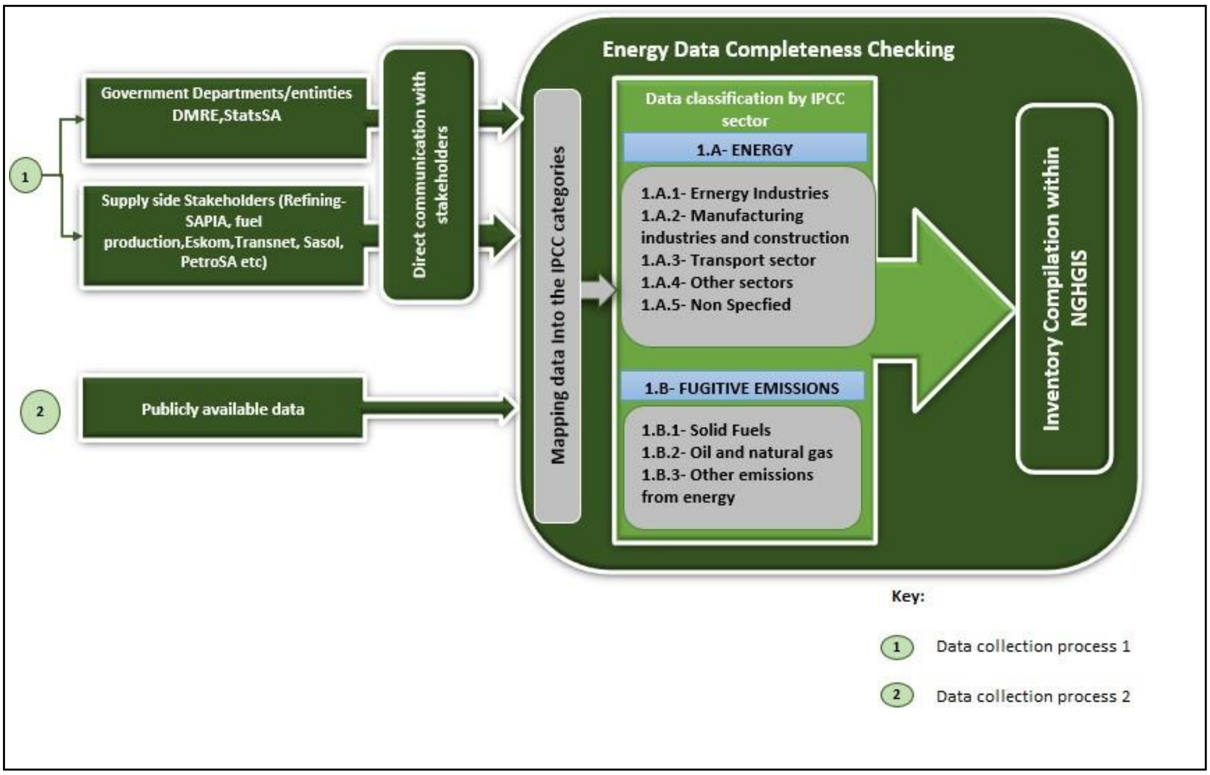


Figure 1.4: Data collection process for the 2022 Energy inventory.

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 andother energy industries	No activity data, only emission data - based onMass Balance and measurement	SAGERS, Food and Agriculture Organisation (FAO) 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 /fishfarms	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

1.5.1.2 IPPU sector

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 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	SAGERS
Lubricant use	Lubricant consumption	Extrapolated
Paraffin wax use	Paraffin wax consumption	Extrapolated
Refrigeration and air conditioning	Existing, new and retired refrigerators	HFC Survey, Stats SA
	Annual data on stationary air conditioning units	HFC Survey, DEA 2016;BSRIA
	Existing, new and retired refrigeration trucks	HFC study; South African Refrigerated Distribution Association (SARDA)
	Existing. New and retired vehicles	eNaTIS; National Association of Automobile Manufacturers of South Africa (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)

1.5.1.3 Agriculture sector

Data is obtained from various sources as indicated in Table 1.5. There are no formal data collection processes in place for all the agriculture data. Data is obtained from available government reports, statistical databases, and the literature. Cropland data is supplied by the Department of Agriculture, Land Reform and Rural development (DALRRD). Fertiliser and liming data are sourced from South African Revenue Service (SARS), DMRE and Fertilizer Association of South Africa (FertASA). Small amounts of crop statistics data are obtained from Statistics SA.

The main sources of livestock data for agriculture are the DALRRD and the Agricultural Research Council (ARC). Data from the ARC is completed on a project-by-project basis and is therefore often once-off data. The SAGERS has recently introduced a small component of data for agriculture, such as data from poultry farms. Reporting has only just started (in 2022), but the SAGERS will be a mechanism to collect some data for the agriculture sector in future.

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

Sub-category	Activity data	Data source	Data collection mechanism
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.
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

1.5.1.4 LULUCF sector

Data for the LULUCF sector sub-categories is obtained from various sources as indicated in Table 1.6. The DFFE employs consultants to process the satellite imagery to generate land cover datasets which are used to determine land cover change for the LULUCF 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. 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, such as carbon stock data and fuel wood removals. Data is obtained from available government reports, agricultural association reports, statistical databases and scientific literature. Plantation data is supplied by Forestry SA, and the croplanddata is supplied by DALRRD. Burnt area data is obtained from the MODIS burnt area product which is processed by Gondwana Environmental Solutions.

Plantation data is also being reported to DFFE through the SAGERS system (https://ghgreporting-public.environment.gov.za/GHGLanding/SAGERSHome.html) and so this data could be utilised in future inventories.

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

Sub-category	Activity data	Data source	Data collection mechanism
All land types (Forest land, Cropland, Grassland, wetland, Settlements, Other land)	Land cover and land use change maps	DFFE	Data and land maps are developed (usually by GTI) or funded through DFFE and are freely available on the EGIS website. Maps to be produced every 2 years.
	Soil maps	ISRIC	Available online (https://www.isric.org/)
	Carbon stock data	Scientific literature	Carbon stock data for the various vegetation classes is obtained for literature which is available online. Where data not available information is obtained from the carbon density maps.
	Carbon density maps	SAEON	Carbon density maps were produced through a project name the Terrestrial Carbon Sinks Assessment. This data is available online (https://catalogue.saeon.ac.za/).
	Burnt area data	MODIS	Available online
Forest land	Timber statistics	DALRRD	Statistical data is released annually and is freely available. DFFE is in the process of developing an MOU with DALRRD

	Plantation data	Forestry South Africa	Data obtained through direct request, no formal mechanism in place. Data is also freely available on their website.
	Household number and wood fuel use	Statistics SA	Available online
	Household fuel consumption data	Scientific literature	Available online
	Charcoal production	FAOStat	Available online
Harvest wood products	Production data	Forestry South Africa	Data obtained through direct request, no formal mechanism in place. Data is also freely available on their website.
	Import/export data	FAOStat	Available online

1.5.1.5 Waste sector

Waste data is collected from various data reports, statistics and global data sets (Table 1.7). As with the Agriculture and LULUCF sectors there is no formal data collection processes. The main data providers for the Waste sector are Statistics SA, DFFE, Department of Water and Sanitation (DWS) and UN. In time it may be possible to collect someof the Waste data through the SAGERS system.

Table 1.7: 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 biologicaltreatment type	SAWIC, DFFE (wastewater treatmentand 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	Population data	Statistics SA (2015);
		UN (2012)
	Split of population by income group	Statistics SA (2015)

and discharge	BOD generation rates per treatment type	IPCC 2006, DWS
	Per capita nitrogen generation rate	IPCC 2006

1.5.2 Methods

The methods used for the individual categories are outlined in the sector overview sections in each of the sector chapters. In addition, detailed descriptions are provided in the relevant category chapters.

A distinction is made between calculations made with country-specific ("CS") methods and calculations made, in the various categories, with IPCC calculation methods of varying degrees of detail ("Tiers"). Similarly for the emission factors. The manner in which a calculation is assigned to the various IPCC methods depends on the pertinent category's share (expressed as equivalent emissions) of total emissions and this determined via the key category analysis (see section 1.7).

1.6 Quality assurance, quality control and verification plans and procedures

1.6.1 Guiding principles

This report is guided by the inventory quality principles as defined in 2006 IPCC Guidelines (IPCC, 2006) (Table 1.8**Error! Reference source not found.**).

Table 1.8: Guiding principles applied during the preparation of the 2022 inventory.

Principle	Application of principle
Transparency	Sufficient and clear documentation is provided such that individuals or groups other than the inventory compilers can understand how the inventory was compiled and can assure themselves it meets the good practice requirements for national greenhouse gas emissions inventories.
Completeness	Estimates are reported for all relevant categories of sources and sinks, and gases. The entire geographic area of South Africa is included. Where elements are missing their absence is clearly documented together with a justification for exclusion.

Consistency	Estimates for different inventory years, gases and categories are made in such a way that differences in the results between years and categories reflect real differences in emissions. Inventory annual trends, as far as possible, are calculated using the same method and data sources in all years and aim to reflect the real annual fluctuations in emissions or removals and not be subject to changes resulting from methodological differences.
Comparability	The national greenhouse gas inventory is reported in a way that allows it to be compared with national greenhouse gas inventories for other countries. This comparability is reflected in the appropriate choice of key categories and in the use of the reporting guidance and tables and use of the classification and definition of categories of emissions and removals.
Accuracy	The national greenhouse gas inventory contains neither over- nor under-estimates so far as can be judged. All endeavours were made to remove bias from the inventory estimates.

1.6.2 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, 2019)). 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.

1.6.3 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 2022 inventory are provided in Table 1.9.

Table 1.9: Quality control checks carried out on South Africa's 2022 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
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

ID	Type of check	Description	Level
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
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

ID	Type of check	Description	Level
QC039	Documentation - Completeness	Check for completeness	Draft NIR
QC040	Documentation - Tables and figures	Check numbers in tables match spreadsheet; check for consistent table formatting; check the table and figure numbers are correct.	Draft NIR
QC041	Documentation - References	Check consistency of references.	Draft NIR
QC042	Documentation - General format	Check general NIR format - acronyms, spelling, all notes removed; size, style and indenting of bullets are consistent.	Draft NIR
QC043	Documentation - Updated	Check that each section is updated with current year information.	Draft NIR
QC044	Double counting - Sectors	Check there is no double counting between the sectors.	Draft NIR
QC045	National coverage	Check that activity data is representative of the national territory.	Calculation file
QC046	Review comments implemented	Check that review comments have been implemented.	Calculation file
QC047	Methodology documentation	Are the methods described in sufficient detail?	Sector report
QC048	Recalculation documentation	Are changes due to recalculations explained?	Sector report
QC049	Trend documentation	Are any significant changes in the trend explained?	Sector report
QC050	Documentation - QA/QC	Check the QA/QC procedure is adequately described.	Draft NIR
QC051	Complete uncertainty check	Check that the uncertainty analysis is complete.	Draft NIR
QC052	Consistency in methodology	Check that there is consistency in the methodology across the time series	Calculation file
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

ID	Type of check	Description	Level
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	Wastewater 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

1.6.4 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 has been useful even with the previous inventories. Everyone had a chance to understand other sectors and it also improved the cross linkages. This should continue in future inventories.

1.6.5 Review process

General public review (Figure 1.5). The expert and public reviews each present opportunity to uncover technical issues related to the application of methodologies, selection of activity data, or the development and choice of emission factors. The expert and public reviews of the draft document offer a broader range of researchers and practitioners in government, industry and academia, as well as the general public, the opportunity to contribute to the final document. The comments received during these processes are reviewed and, as appropriate, incorporated into the NIR or reflected in the inventory estimates.

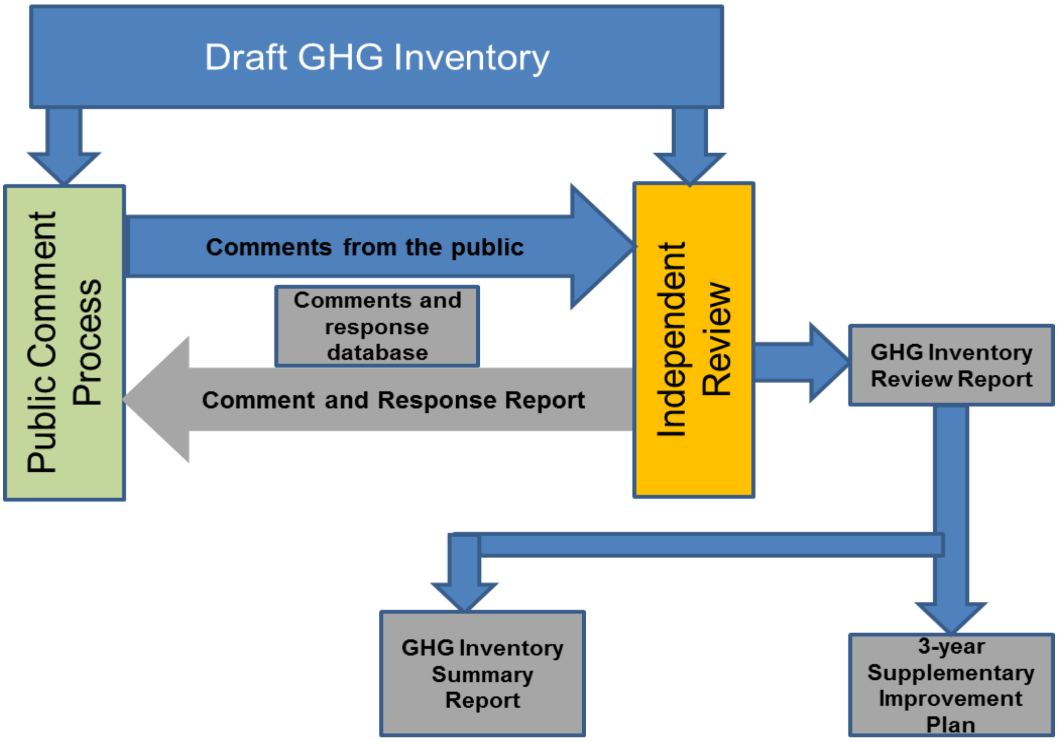


Figure 1.5: The quality assurance review process for the 2000 – 2022 inventory.

1.6.6 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 and international 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 chapters.

1.7 Key categories

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 % of the gross (excluding LULUCF) or net (including LULUCF) emissions and those that are within the top 95 % of the categories that contribute to the change between 2000 and 2022, 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 (2022), while the trend assessment utilised the base year 2000 and 2022.

For the 2000-2022 inventory the level of disaggregation for each sector was updated. However, as with the last two inventories the key categories were then ranked according to their combined contribution to the level and trend assessments. In the previous inventory there were 58 key categories, while in this inventory there are 53. Table ES 3 shows the top 30 key categories. Table 1.10 shows the 53 key categories identified for the 2000-2022 inventory.

Table 1.10: **Key categories for South Africa for 2022 (including LULUCF) and their ranking.**

Rank	IPCC code	IPCC Category	GHG#	Criteria
1	4.A.2.b	Grassland converted to forest land – all pools	CO_2	L,T
2	1.A.3.b	Road Transportation – Liquid Fuels	CO_2	L,T
3	4.A.1.a	Forest land remaining forest land – biomass	CO_2	L,T
4	1.A.1	Energy Industries – Solid Fuels	CO_2	L,T
5	3.D.1	Direct N_2O Emissions From Managed Soils	N_2O	L
6	4.C.1.a	Grassland remaining Grassland – biomass	CO_2	L,T
7	4.F.2.c	Grassland converted to other land – all pools	CO_2	L,T
8	1.A.5	Other – Solid Fuels	CO_2	L,T
9	2.C.2	Ferroalloys Production	C	L
10	1.B.3	Other emissions from energy production	CO_2	L,T
11	1.A.4	Other Sectors – Liquid Fuels	CO_2	L,T
12	3.A.1.a.ii	Non-dairy Cattle	CH_4	L,T
13	4.G	Harvested Wood Products	CO_2	T
14	5.D	Wastewater Treatment and Discharge – Industrial	CH_4	L

Rank	IPCC code	IPCC Category	GHG[#]	Criteria
15	1.A.3.a	Domestic Aviation	CO_2	T
16	1.A.1	Energy Industries – Gaseous Fuels	CO_2	T
17	1.A.5	Other – Liquid Fuels	CO_2	T
18	1.A.4	Other Sectors – Solid Fuels	CO_2	L,T
19	2.C.1	Iron and Steel Production	CO_2	L,T
20	3.A.1.a.i	Dairy Cattle	CH_4	L
21	4.A.1.b	Forest land remaining forest land – dead organic matter	CO_2	T
22	5.A	Solid Waste Disposal	CH_4	L,T
23	1.B.3	Other emissions from energy production	CH_4	L
24	2.B.2	Nitric Acid Production	N_2O	T
25	2.C.3	Aluminium Production	F-gases	T
26	1.A.2	Manufacturing Industries and Construction – Gaseous Fuels	CH_4	L,T
27	4.C.2.a	Forest land converted to Grassland – all pools	CO_2	L,T
28	1.B.2	Oil and Natural Gas	CO_2	T
29	4(V)	Biomass Burning	CH_4	L
30	4.B.2.b	Grassland converted to Cropland – all pools	CO_2	L
31	3.G	Liming	CO_2	L
32	4.C.2.c	Wetland converted to Grassland – all pools	CO_2	T
33	2.D.2	Paraffin was use	CO_2	T
34	1.B.1.a	Coal mining & handling	CH_4	L
35	3.A.4	Goats	CH_4	L
36	1.A.4	Other Sectors – Gaseous Fuels	CO_2	T
37	3.A.2	Sheep	CH_4	L,T
38	4.A.2.a	Cropland converted to forest land – all pools	CO_2	L,T
39	4.A.2.e	Other land converted to forest land – all pools	CO_2	L
40	4.B.2.a	Forest land converted to Cropland – all pools	CO_2	L
41	4.C.1.b	Grassland remaining Grassland – dead organic matter	CO_2	T
42	1.A.2	Manufacturing Industries and Construction – Solid Fuels	CO_2	L,T
43	2.F.1.a	Refrigeration and Air conditioning – stationary	CO_2	L,T
44	4.D.1	Wetlands Remaining Wetlands	CH_4	L,T
45	1.A.1	Energy Industries – Liquid Fuels	CO_2	L,T
46	4.D.2	Land Converted to Wetlands	CH_4	L,T
47	4.C.2.e	Other land converted to Grassland – all pools	CO_2	L,T
48	2.F.1.b	Refrigeration and Air conditioning	F-gases	L,T
49	2.A.1	Cement Production	C	L,T
50	5.D	Wastewater Treatment and Discharge – domestic	CH_4	L,T
51	1.A.2	Manufacturing Industries and Construction – Liquid Fuels	CO_2	L,T
52	4.C.2.b	Cropland converted to Grassland – all pools	CO_2	L,T
53	5.B	Biological Treatment of Solid Waste	CH_4	L,T

[#]C=Confidential

Forest land converted to grassland, *Direct N_2O emissions from managed soils* and *Ferroalloy production* are new to the top 10 key categories. In the previous inventory these categories were in 26th (as *Land converted to grassland*), 16th and 15th place, respectively.

Appendix A contains the full key category analysis results for the level assessments (2000 and 2022) and trend assessment, including and excluding LULUCF.

1.8 General uncertainty evaluation

1.8.1 Procedures for uncertainty determination

Uncertainty is inherent within any kind of estimation and arises from the limitations of the measuring instruments, sampling processes and model complexities and assumptions. Managing these uncertainties, and reducing them over time, is recognised by IPCC 2006 as an important element of inventory preparation and development. Chapter 3 of the 2006 IPCC Guidelines (IPCC, 2006) 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.

South Africa still lacks data in terms of country specific uncertainty for all sectors. Based on this the uncertainty in this inventory was determined using the simple propagation of error (Approach 1) method. A trend uncertainty between the base year (2000) and 2022 was determined, as well as a combined uncertainty of activity data and emission factor uncertainty. As more uncertainty data becomes available it will be incorporated but there is a general need to build capacity and develop projects to assess the uncertainty in each sector.

1.8.2 Uncertainty assessment results

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 LULUCF 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 total uncertainty for the inventory including LULUCF was determined to be between 12.1% and 12.5%, with a trend uncertainty of 8.9%[2]. This is an increase on the uncertainty in the last inventory (8.7%), however there were a few new categories in this inventory and a more detailed uncertainty assessment for Forest lands have been included. This led to an increase in uncertainty on the activity data (mostly due to the increased variability in the land change maps), but a reduction in the emission factor uncertainty. Excluding LULUCF reduces the overall uncertainty to 5.7%-6.4%, which is a reduction of the uncertainty from the last inventory.

The Energy sector uncertainty was reduced slightly (by 5% on the upper limit) compared to the previous inventory. The IPPU trend uncertainty increased by 32% compared to the last inventory. The IPPU sector did introduce some new categories in 2021 and 2022 and update some of the uncertainty estimates to be based on country specific data rather than defaults so these changes could contribute to the uncertainty change. The Agriculture sector uncertainty reduced for both the overall uncertainty and trend uncertainty. The uncertainty data did not really change but the emission estimates did, and there was also reallocation of some categories between Agriculture and LULUCF to align with the ETF CRT reporting. LULUCF uncertainty increased by about 30% compared to the previous inventory uncertainty analysis. Part of this change was due to the introduction of new land change maps, however additional changes were made due to a more in depth analysis of the uncertainty data rather then it being an actual change in uncertainty. The uncertainty data is one aspect of the inventory, which is being improved, so it is likely there will be further changes in the next inventory. Waste sector uncertainty was reduced, but this s likely due to the reduction in the emissions in this sector due to improvements.

1.9 General assessment of completeness

Table 1.11 provides information on the completeness of the inventory. It shows which activities are not estimated (NE), included elsewhere (IE) or that is not occurring (NO) within the South African jurisdiction.

Table 1.11: Activities in the 2022 inventory which are not estimated (NE), included elsewhere (IE) or not occurring (NO).

NE, IE or NO	IPCC Category	Activity	Comments

[2] *The full uncertainty assessment is provided in Appendix B.*

	1B1b	CO_2, CH_4 and N_2O from spontaneous combustion of coal seams	Researched to be considered in future
	1B1ai2	CH_4 emissions from abandoned mines	Research to be considered in future
	1C1	CO_2 transport	Insufficient data to include
	1C2	Injection and storage	Insufficient data to include
	2B7	CH_4 and N_2O emissions from Soda Ash Production	CO_2 included in this inventory. CH_4 and N_2O will not be included in future
	2C1	N_2O emissions from iron and steel production	Insufficient data to include
	2C2	N_2O emissions from ferroalloy production	Insufficient data to include
	2D2	CH_4 and N_2O emissions from paraffin wax use	Insufficient data to include
	2E	Electronics industry	Insufficient data to include
	2F5	PFCs and HFCs from solvents	Insufficient data to include
	2G1	PFCs from electrical equipment	Insufficient data to include
	2G2	PFCs from other product uses	Insufficient data to include
	2G3	N_2O from product uses	Insufficient data to include
	3B	CO_2 from organic soils	Due to priority this will only be included in the next inventory.
	3C4	N_2O from organic soils	Insufficient data to include
	4B	CH_4, N_2O emissions from biological treatment of waste	Insufficient data to include
	4C1	CO_2, CH_4 and N_2O from waste incineration	Insufficient data to include
	2	SF6 emissions in the IPPU sector	Insufficient data. Some information is included where possible
	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
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	Mobile unspecified	Included under 1A3b
	3B	Precursor emissions from controlled burning	Emissions from controlled burning are not separated from biomass burning and so are included under Biomass burning (3C1)

	3B	SOC changes for converted land	This data is included under the land remaining land category as Formulation A of the SOC equation was applied.
	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	
	3C7	Rice cultivation	

1.10 Recalculations

Each sector made improvements to their emission estimates and therefore recalculations were completed for the full time-series. The current inventory applied the AR5 GWPs so to see the actual impacts of the improvements alone the previous inventory data was converted to CO_2 equivalents by using the AR5 GWP. The data shows that the current inventory estimates (excl. LULUCF) are between 0.43% and 5.3% lower than the 2020 inventory estimates, while the estimates including LULUCF are between 0.23% and 4.94% lower than the 2020 estimates except for 2017 when emission were slightly higher (Figure 1.6).

The Energy sector improvements contribute the most to the reduction in the estimates in this inventory, with an average reduction of 14 294 Gg CO_2e since 2007 compared to the previous inventory. The LULUCF sector showed an average reduction of 16 929 Gg CO_2e between 2003 and 2014, after which it increases emissions by an average of 14 899 Gg CO_2e until 2018. This then changes to a reduction of 9 832 Gg CO_2e in 2020. The Agriculture sector shows an increase in emissions by an average of 5 234 Gg CO_2e across the time-series, while Waste emissions are reduced by an average of 7 082 Gg CO_2e over the same period.

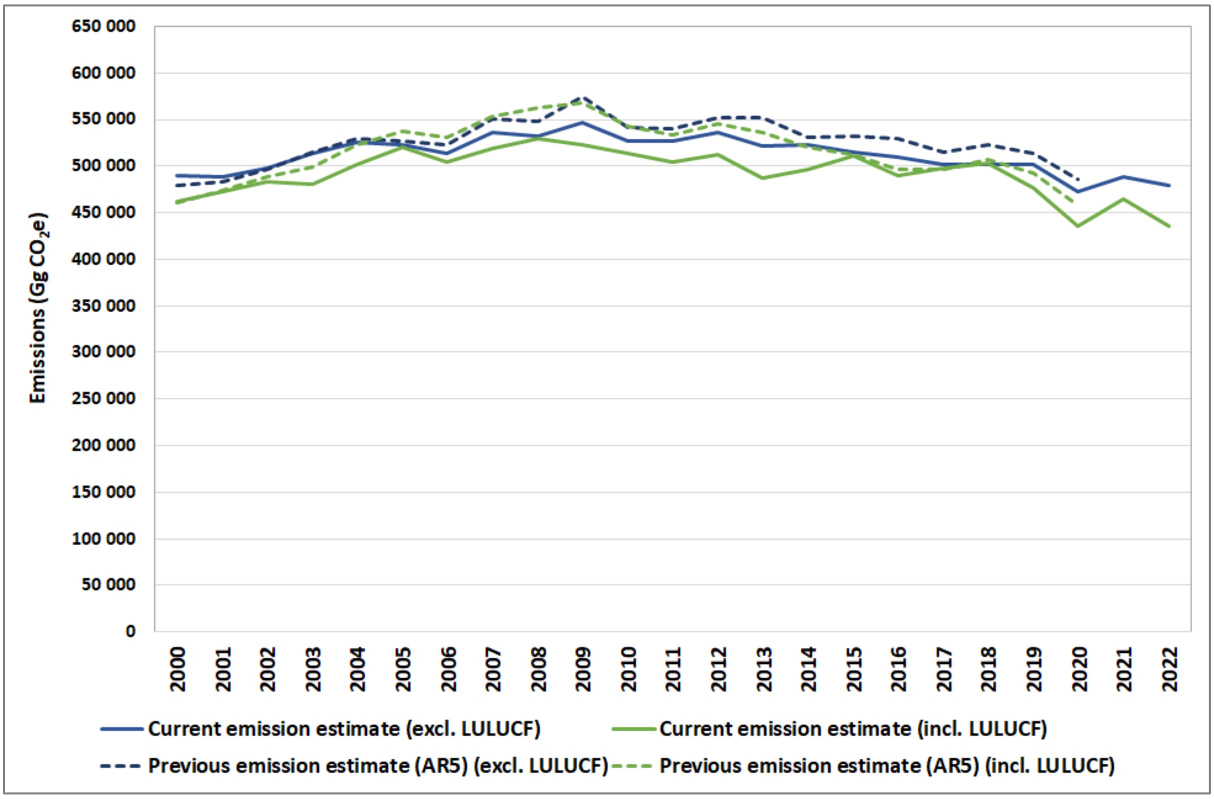


Figure 1.6: Impacts of recalculations on the overall emission estimates for South Africa.

1.11 Improvement plan

Table 1.12 shows planned improvements and the timelines for the completion of these improvements.

Table 1.12: List of planned improvements for South Africa's GHG inventory.

Sector	Improvement	Priority	Reason	Status	Completion timeframe	Barriers and constraints
Completed Tasks						
Energy	CO_2 and CH_4 fugitive emissions from oil and natural gas operations	Medium	Completeness	Completed	2022 inventory	Included in this inventory (2000-2022).
	Fugitive emissions from coke production to be reported separately from 2C process emissions	Low	Transparency	Completed	2022 inventory	Included in this inventory (2000-2022).
	Develop EFs, carbon content of fuels and NCVs of liquid fuels	High	Key category; Accuracy	Completed	2022 inventory	Included in this inventory (2000-2022).
Agriculture	Incorporate all background equations for the Tier 2 calculations of enteric fermentation	High	Key category; Accuracy; Transparency	Completed	2022 inventory	Included in this inventory (2000-2022).
LULUCF	Estimate the HWP contribution based on other approaches.	Medium	Key Category; Accuracy	Completed	2022 inventory	Included in this inventory (2000-2022).
	Incorporate updated National Terrestrial Carbon Sinks Assessment (NTCSA) data to improve estimates, particularly for soils	High	Key category; Accuracy	Resolved		The NTCSA data is not being updated regularly and is not incorporating the latest land cover maps. This data is therefore not being incorporated into the inventory due to issues of sustainability. The general carbon stock data per land type is being used for verification purposes.
	Include CO2 estimates for wetlands	Low	Accuracy; Completeness	Completed	2022 inventory	Included in this inventory (2000-2022).
	Included 2018 and 2020 SANLC maps	High	Key category; Accuracy; Completeness	Completed	2022 inventory	Included in this inventory (2000-2022), however there are numerous improvements that need to be made to the LULUCF data so a detailed LULUCF improvement plan has been developed and these ongoing improvements are listed below.

	Justify reason for use of Tier 1 methods for key categories and pools and include moving to higher tiers in the improvement plan.	Medium	Transparency	Completed	2022 inventory	Included in this inventory (2000-2022).
	Highlight the need for a National Forest Inventory	High	Key category; Accuracy	Completed	2022 inventory	Included in this inventory (2000-2022). The need for a national forest inventory was highlighted in the report, and is listed in the improvement plan below as an outstanding task.
	Include growth of biomass of the last 5 years in the maturity cycle in the cropland remaining cropland	Low	Accuracy	Completed	2022 inventory	Included in this inventory (2000-2022).
	Identify significant sub-categories and carbon pools	Medium	Key category; Accuracy	Completed	2022 inventory	Included the pools for each of the land classes and also included these in the KCA.
	Further explain the appropriateness of the country specific EF for CH4 for wetlands	Medium	Accuracy	Completed	2022 inventory	Included in this inventory (2000-2022). The country specific emission factor was assessed and it was found that it was a very site and condition specific factors, therefore the value was reverted back to the default emissions factor. Another country specific factor was found to be similar to the default factor in support of this change.
Tasks in progress						
Cross-cutting	Improve uncertainty data for all sectors by incorporating more country specific uncertainty values	Medium	Accuracy	In progress	Incorporated as data becomes available	Lack of uncertainty data constrains this activity. As data becomes available it will be incorporated. In this inventory a more detailed analysis of uncertainty for LULUCF sector was completed.
	Improve QA/QC process by addressing all issues in external review	High	Transparency	In progress	Future inventories	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 working through them. It is an ongoing process.

Energy	Improve the improvement plan by incorporating all review activities not addressed in current inventory	High	Transparency	In progress	Ongoing	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.
	Improve explanation of large changes in trends	High	Transparency	In progress	Ongoing	Partly resolved. Additional explanations have been provided, but there are still areas where this can be improved further. Ongoing process.
Agriculture	Incorporate all background data for the Tier 2 calculations of enteric fermentation	High	Key category; Accuracy; Transparency	In progress	2024 inventory	All the background equations have been included, but average data is still being used for the majority of the factors (instead of annual data) due to a lack of a sustainable data source. Data sources are being investigated and data will be included once it becomes available.
	There is a need for an alternate data source for Lime data	Medium	Key category; Accuracy	In progress	2024 inventory	Past inventory reviews have mentioned upgrading this information and investigating the alternate method of calculating potential lime use.
LULUCF	Complete a full uncertainty analysis for the Land sector, including area bias corrections	High	Key category; Accuracy	In progress	2024 inventory	A more detailed uncertainty analysis was included for biomass, DOM and SOC data in the LULUCF sector. Mapping uncertainties were improved, however these will be improved further during the land change improvement plan.

	Improvement of land change data through detailed assessment of maps and tracking of land parcels	High	Key category; Accuracy; Consistency	In progress	The land use improvement plan will be completed over the next 3 years so data will be incorporated as it becomes available (2024 and 2026 inventory).	This 2022 inventory incorporated a more detailed assessment of the land change data and identified the most important land change categories that need attention. The assessment also identified improvements that need to be done moving forward and the priority of these improvements. Removing changes due to seasonality is top priority and this will be improved as more land change maps are obtained. The 2022 SANLC map will already assist with making improvements. Tracking of land parcels over time is the second most important issue and training on Collect Earth to assist in this process is underway.
	Include deadwood in the DOM pool for all land categories	Low	Completeness	In progress	2024	Deadwood has been included for the forest land category. The other land categories with woody components are settlements and perennial crops, but data is very limited for these land categories. Deadwood in these categories is assumed to be very small, but an explanation of this will be included in the next inventory.
	Move to a higher tier level for DOM in forest lands	Medium	Key category; Accuracy	In progress	2024	This was considered in the 2022 inventory and more detailed disturbance matrix data was included to determine the amount of biomass entering the DOM pool, however there were still one or two pieces of data misisng which requires further investigation. This will be completed and included in the next inventory.
Waste	Data collection on quantities of waste disposed of into managed and unmanaged landfills		Key category; Accuracy	In progress	2024	Project is underway so data will be included in 2024 inventory.
Tasks outstanding						

Cross cutting	Investigate inconsistencies in lime activity data (for lime production in IPPU and lime application emission in Agriculture), explore alternative data sources or improve consistency.	Low	Consistency	Planned	5th BUR	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.
	Incorporate NOx, CO, NMVOC, and SOx emissions	High	Completeness	Proposed	5th BUR	Not resolved.
Energy	Further disaggregation of 1A2	Medium	Accuracy	Planned	Future inventories	Current inventory breaks down 1A2 into 1A2a, 1A2b and 1A2-ab. Further work is require to further disaggregate this sector and have emissions calculated per sub-sector.
	More activity data for estimating emissions associated with non-energy fuel use	Low	Accuracy	Planned	Future inventories	Research to be initiated in future.
	Inclusion of methodology documentation/summary/approval process for tier 3 methods	Low	Transparency	Planned	Future inventories	To be collated and included in future.
	CO_2, CH_4 and N_2O from spontaneous combustion of coal seams	Low	Completeness	Planned	Future inventories	Research to be initiated in future.
	CH_4 emissions from abandoned mines	Low	Completeness	Planned	Future inventories	Research to be initiated in future.
	Investigate pipeline transport	Low	Completeness	Proposed	Future inventories	Proposed but nothing planned.
	Investigate ground activities at airports and harbours	Low	Accuracy	Proposed	Future inventories	Proposed but nothing planned.
	Update of the VKT study, including segregation of on-road/off-road	Medium	Accuracy	Proposed	Future inventories	Proposed but nothing planned.
	Comparison of next VKT approach with fuel statistics	Low	Accuracy	Proposed	Future inventories	Proposed but nothing planned.
	Segregation of military energy use.	Low	Accuracy	Proposed	Future inventories	Proposed but nothing planned.

	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 heat and power (CHP) combustion systems	Medium	Completeness	Proposed	Future inventories	Proposed but nothing planned.
	Development of T3 methods for CTL-GTC and GTL	Low	Accuracy	Proposed	Future inventories	Resources and funding are required to complete this study so it will be incorporated into the GHGIP.
IPPU	Include emissions from electronics industry	Medium	Completeness	Planned		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		Lack of data is still a challenge.
Agriculture	Improve manure management data, including biogas digesters as a management system	Medium	Accuracy	Proposed	2024	Proposed project as there is a high variability in this dataset.
LULUCF	Incorporate organic soils study to include emissions from organic soils	Low	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.
	Undertake a National Forest Inventory and include SOC in the inventory	High	Key category; Accuracy	Proposed	Future inventories	This is an activity which would need to be completed by the Department of Forestry, therefore the date for completion is not known.
	Complete an assessment of crop types and areas and investigate discrepancies between crop statistics and NLC data	Medium	Consistency; Comparability	Planned	2024 inventory	This was partially investigated in this inventory; however a proper assessment will be included in the land use change improvement plan that will run over the next few years.
	Perform a more detailed assessment of HWP to include a wider range of products	Medium	Key category; Accuracy	Proposed		Proposed project that could be considered under the GHGIP. For future evaluation.

	Report activity data and parameters (e.g. half-life) used for HWP emission estimation for the whole time-series	Medium	Transparency	Planned	2024 inventory	This will be included in the 2024 inventory.
	Report on the frequency of the HWP activity data collection	Low	Transparency	Planned	2024 inventory	This will be included in the 2024 inventory.
	Assess if the emissions/removals in the overseas territories are significant	Low	Completeness	Planned	2024 inventory	Currently these emissions are assumed insignificant as the area of these territories is extremely small, but an assessment of possible emissions still needs to be explored.
	Collect data on other disturbances besides fire in forest lands	Low	Key category; Accuracy	Proposed	Future inventory	This would require a study so will be recommended as a project under the GHGIP.
	Develop a spatial map of fuel wood consumption based on literature to further improve fuel wood consumption	High	Key category; Accuracy	Proposed	Future inventory	This would require a study so will be recommended as a project under the GHGIP.
	Assess the significance of peatlands	Low	Completeness	Proposed	2026 inventory	Assessing the areas of peatlands would be the first step and this part could be done as part of the land use improvement plan.
Waste	Improve MCF and rate constants	Medium	Key category; Accuracy	Proposed		This would require a study so will be recommended as a project under the GHGIP.
	Include economic data for different population groups	Medium	Key category; Accuracy	In progress	2024 inventory	Will be included in the 2024 inventory
	Include information on population distribution in rural and urban areas as a function of income	Medium	Key category; Accuracy	In progress	2024 inventory	Insufficient data.
	Include HWP in solid waste	Medium	Key category; Completeness	Proposed	Future inventory	Once HWP data is improved (see above) it will be incorporated into solid waste.
	Obtain data on waste streams and the bucket system	Medium	Accuracy	In progress	2024 inventory	Insufficient data.
	CH_4, N_2O emissions from biological treatment of waste	Medium	Completeness	In progress	2024 inventory	Insufficient data.

	CO_2, CH_4 and N_2O from waste incineration	High	Completeness	In progress	2024 inventory	Insufficient data.

1.12 Approval and publishing process

The BUR and National Inventory Reports (NIRs) are endorsed by the Project Steering Committee (PSC), being chaired by the DFFE and comprising of various state departments before they are submitted to the Minister of the DFFE for approval. Once the reports are approved by Minister, they are submitted to the UNFCCC by the Chief Directorate for Climate Change International Relations and Reporting and undergo an international review process.

1.13 References

IPCC, 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories.* Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). ed. Japan: IGES.

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.

2.1.1 National trends

2.1.1.1 Overall emissions (excluding LULUCF)

Overall emissions (excl. LULUCF) include those from Energy, IPPU, Agriculture and Waste. It does not include the sources and removals from land use change and *Harvested wood products*, which together form the LULUCF sector.

2022

In 2022 the Energy sector was the largest contributor to South Africa's gross emissions (excl. LULUCF) in 2022, comprising 78% of total emissions (Figure 2). This was followed by the agriculture sector (11%), IPPU sector (6%) and the Waste sector (4 %).

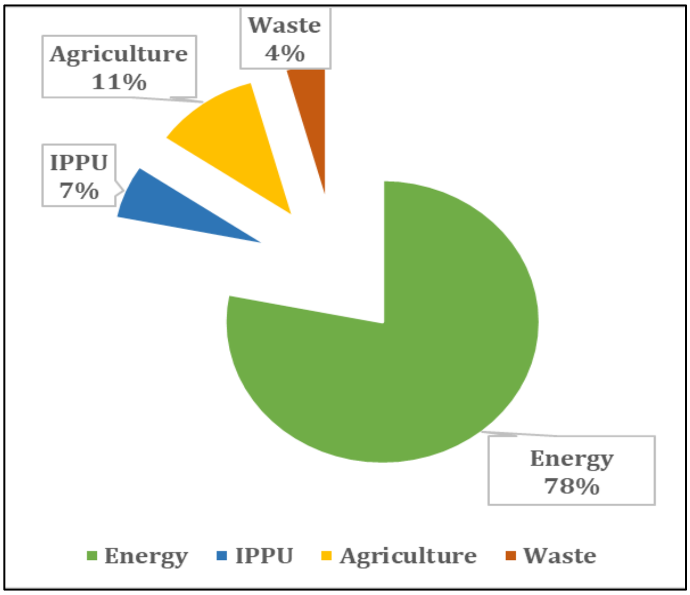


Figure 2.1: National GHG emissions (excluding LULUCF) for South Africa, 2022

2000 - 2022

South Africa's GHG emissions excl. LULUCF were 489 748 Gg CO_2e in 2000 and these decreased by 2.2% by 2022 (Table 2.1). Emissions (excl. LULUCF) in 2022 were estimated at 478 888 Gg CO_2e. The decrease in emissions compared to 2020 is attributed to the marginal decrease in emissions across all the sectors (Energy, IPPU, Agriculture and Waste).

There was an overall decrease in Energy emissions of 2.5%, this is attributed to the decrease in the *Residential sector*, *Aviation* as well *Petroleum refining*, there was also decrease in the IPPU sector in 2022. Despite the overall economic recovery after the COVID-19 pandemic, the IPPU sector's estimated emissions in 2022 were 6.7% lower than those in 2000. This decline is primarily attributed to a significant reduction in metals production (specifically Iron and Steel, and Aluminium) by 39.0%, driven by a decrease in global demand. The chemicals industry also experienced a notable decline of 31.4%.

The Table 2.2 provides annual emissions data for South Africa from 2000 to 2022, both excluding and including LULUCF, measured in gigagrams of carbon dioxide equivalent (Gg CO_2e). Notable points include a peak in emissions in 2004 at 524 903 Gg CO_2e, a dip in 2010 with a 3.71% decrease, and a significant decline in 2020 by -5.79% (Figure 2). The emissions increased in 2021 by 3.36% due to post covid economic recovery. The data reflects South Africa's ongoing journey to balance economic development with environmental sustainability.

2020 - 2022

Emissions (excl. LULUCF) in 2022 were estimated at 478 888 Gg CO_2e, this represents an increase of 1,4% compared to 2020 and was influenced by increased activities post the covid pandemic in the manufacturing sector.

Table 2.1: Changes in South Africa's emissions excluding and including LULUCF between 2000, 2020 and 2022.

	Emissions (Gg CO_2e)			Change between 2000 and 2022		Change between 2020 and 2022	
	2000	2020	2022	Gg CO_2e	%	Gg CO_2e	%
Emissions (excl. LULUCF)	489 747.5	472 437.8	478 887.5	-10,860.03	-2.2%	6,449.7	1.4%
Emissions (incl. LULUCF)	462 205.4	435 918.6	435 827.7	-26,377.69	-5.7%	-90.93	0.00%

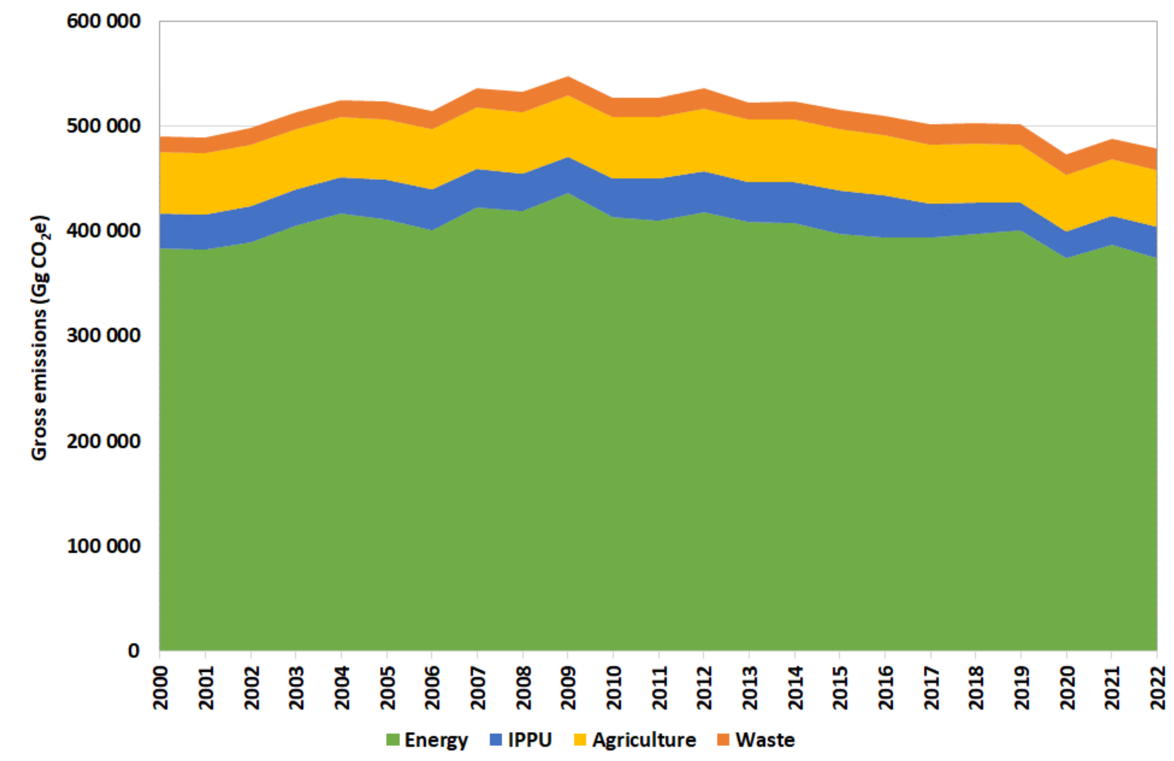


Figure 2.2: National GHG emissions (excluding LULUCF) for South Africa, 2000 – 2022

Table 2.2: Trends and annual change in emissions (excluding and including LULUCF), 2000 – 2022.

	Emissions (excl. LULUCF)		Emissions (incl. LULUCF)	
	Gg CO_2e	Annual change (%)	Gg CO_2e	Annual change (%)
2000	489 747.5		462 205.4	
2001	488 964.7	-0.16	472 002.4	2.12
2002	497 651.3	1.78	483 692.9	2.48
2003	513 190.2	3.12	481 053.7	-0.55
2004	524 902.7	2.28	501 254.4	4.20
2005	523 122.9	-0.34	519 760.2	3.69
2006	514 091.2	-1.73	504 500.4	-2.94
2007	535 672.5	4.20	518 559.4	2.79
2008	532 320.7	-0.63	529 003.6	2.01
2009	547 270.5	2.81	522 920.8	-1.15
2010	526 971.4	-3.71	512 987.3	-1.90

2011	527 161.3	0.04	504 638.0	-1.63
2012	536 003.0	1.68	512 196.6	1.50
2013	522 220.3	-2.57	487 134.0	-4.89
2014	522 899.6	0.13	496 835.8	1.99
2015	515 516.2	-1.41	511 428.6	2.94
2016	509 870.0	-1.10	489 254.4	-4.34
2017	501 987.5	-1.55	497 553.7	1.70
2018	502 130.2	0.03	502 893.9	1.07
2019	501 485.2	-0.13	476 686.4	-5.21
2020	472 437.8	-5.79	435 918.6	-8.55
2021	488 322.3	3.36	464 957.7	6.66
2022	478 887.5	-1.93	435 827.7	-6.27

2.1.1.2 Net emissions (including LULUCF)

Overall emissions (incl. LULUCF) include those from Energy, IPPU, Agriculture, Waste and the sources and removals from the LULUCF sector.

2022

The overall emissions (incl. LULUCF) were 435 828 Gg CO_2e in 2022. The LULUCF sector was a sink in 2022 with *Forest lands* being the largest contributor to the sink.

2000 – 2022

South Africa's GHG emissions (incl. LULUCF) were 462 205 Gg CO_2e in 2000 and these decreased by 5.5% by 2022 (Table 2.1). Emissions (incl. LULUCF) in 2022 were estimated at 435 828 Gg CO_2e. The emissions incl. LULUCF followed a similar trend to the emissions excl. LULUCF.

2020 – 2022

There was a negligible change in overall emissions (incl. LULUCF) since the last inventory submission (see Table 2.1).

2.1.2 Indicator trends

South Africa's carbon and energy intensity trends are determined from GHG emissions, GDP data (StatsSA 2023)[3], total primary energy supply data (DRME 2023) and population data (Stats SA 2022).

2.1.2.1 Total emission indicators

The carbon intensity of the population (i.e. total net emissions per capita) has decreased by 33% since 2000 (Figure 2.3). In 2020 the carbon intensity of the population decreased by 10%, which is the highest decrease since 2000. The carbon intensity continues to decrease beyond 2020 due to an increase in population without a proportional increase in energy emissions.

The carbon intensity of economy has decreased by 42% since 2000. In 2020 the carbon intensity of the economy decreased by 3%, however, the largest decrease was 8% in 2006.

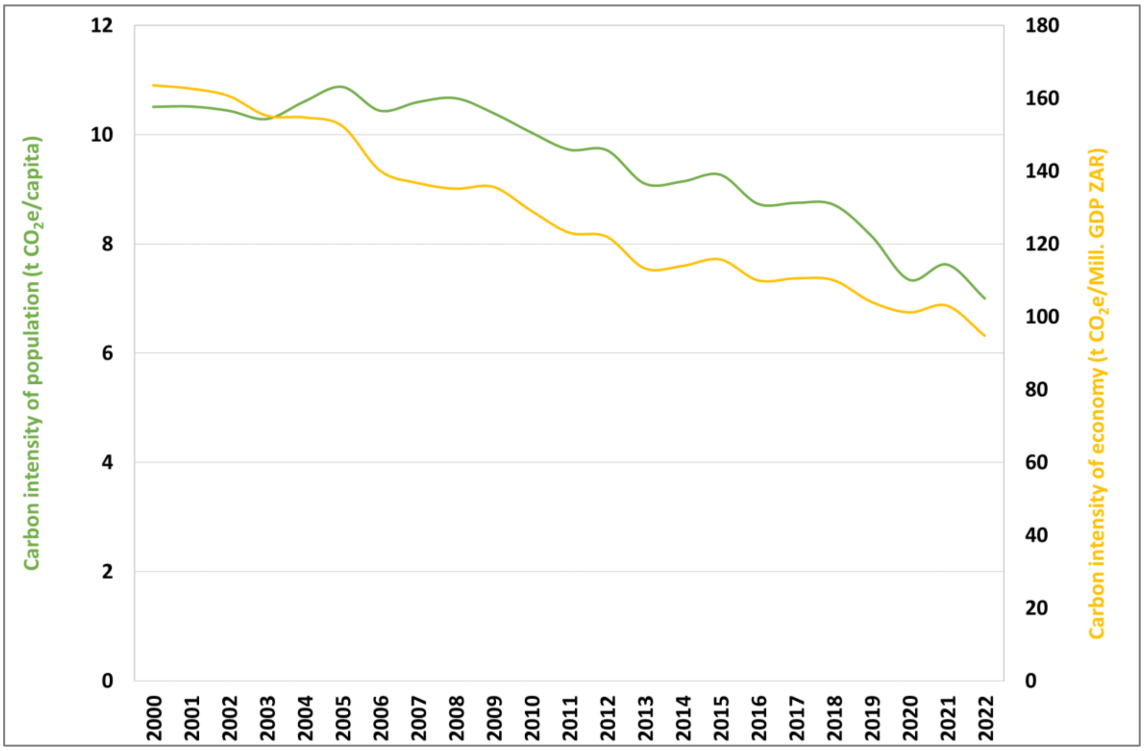


Figure 2.3: Trends in overall carbon intensity of the population and the economy of South Africa between 2000 and 2022.

2.1.2.2 Energy emission indicators

[3] *In previous inventories the GDP at constant 2010 prices was used. However, in this inventory the GDP at constant 2015 prices was used in line with the changes made by StatsSA in their publication.*

The energy carbon intensity of the population (energy emissions per capita, Figure 2.4) follows the same trend as the carbon intensity of the population and has decreased by 31% since 2000. This is expected since the energy sector contributes the most to the total emissions each year.

The carbon intensity of energy supply has decreased by 35% since 2000. However, the energy intensity of the population increased by 6% while the energy intensity of the economy decreased by 8% since 2000.

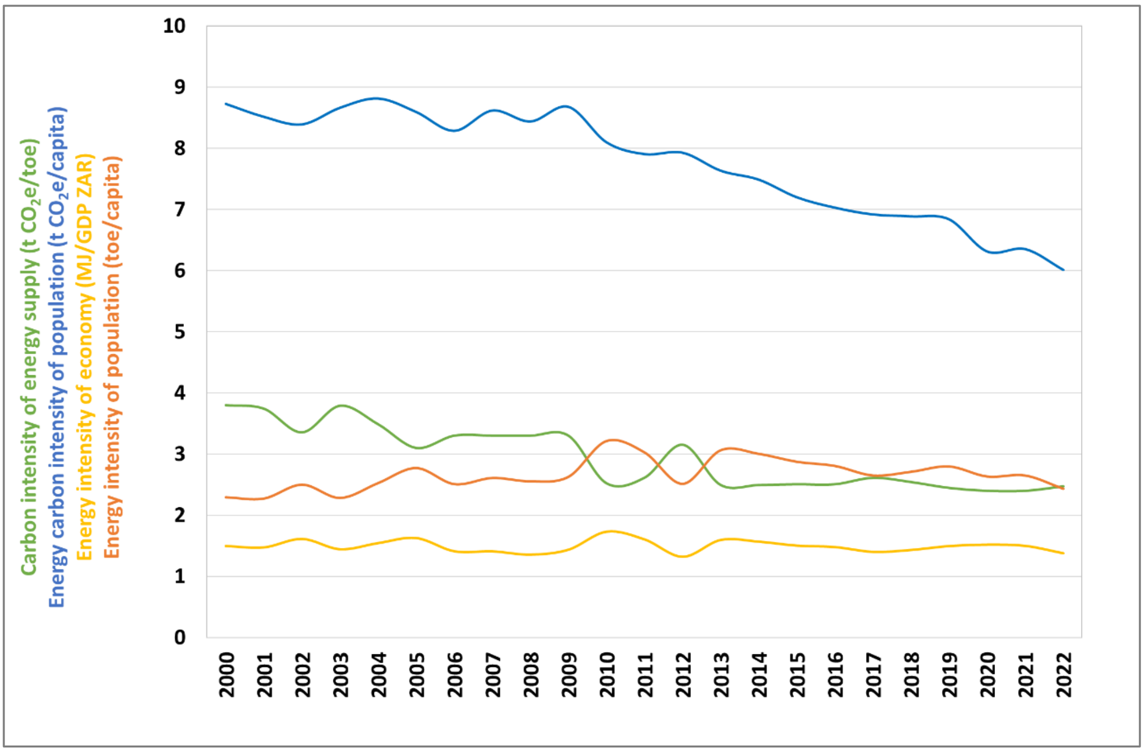
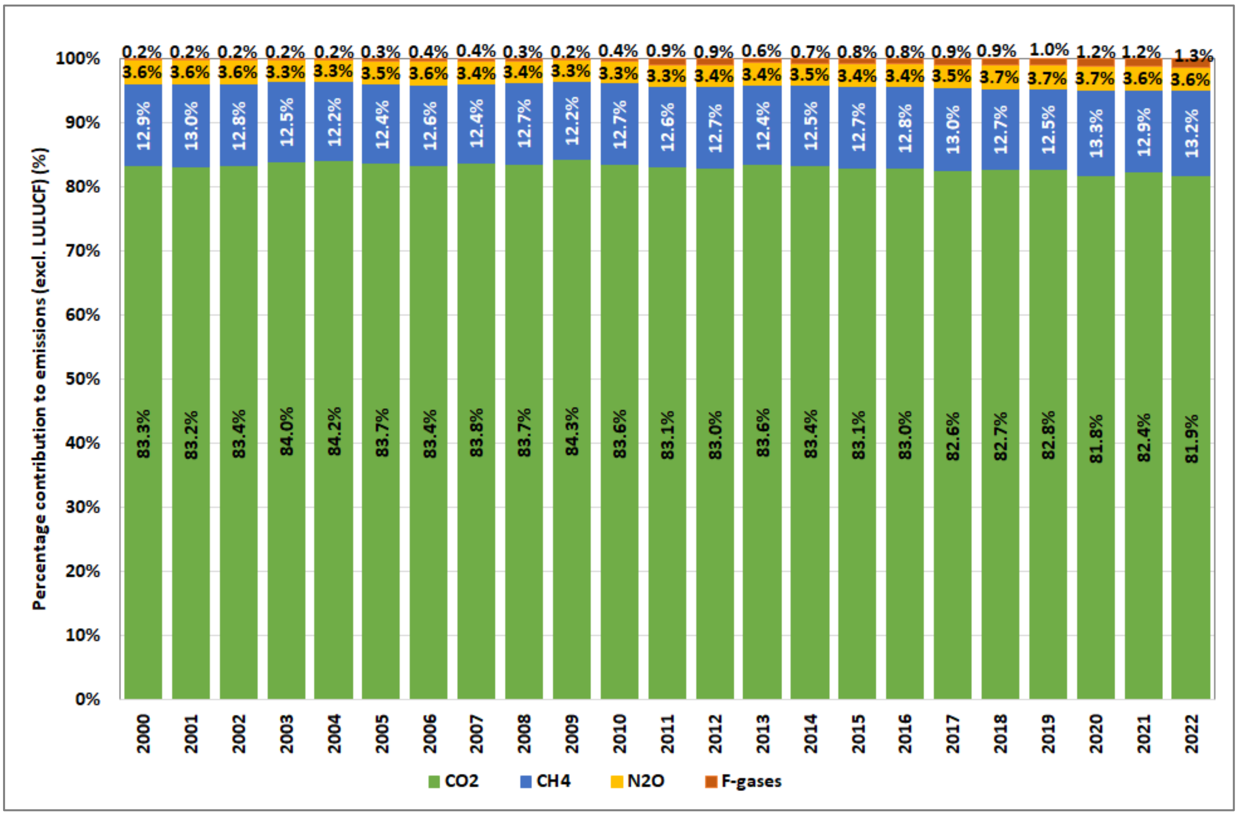


Figure 2.4: Trends in energy intensity indicators for South Africa between 2000 and 2022.

2.2 Description and interpretation of emission trends by greenhouse gas

Figure 2.5 represents the percentage contribution of each gas to South Africa's total emissions between 2000 and 2022, while Table 2.3 shows the emission amounts per gas.



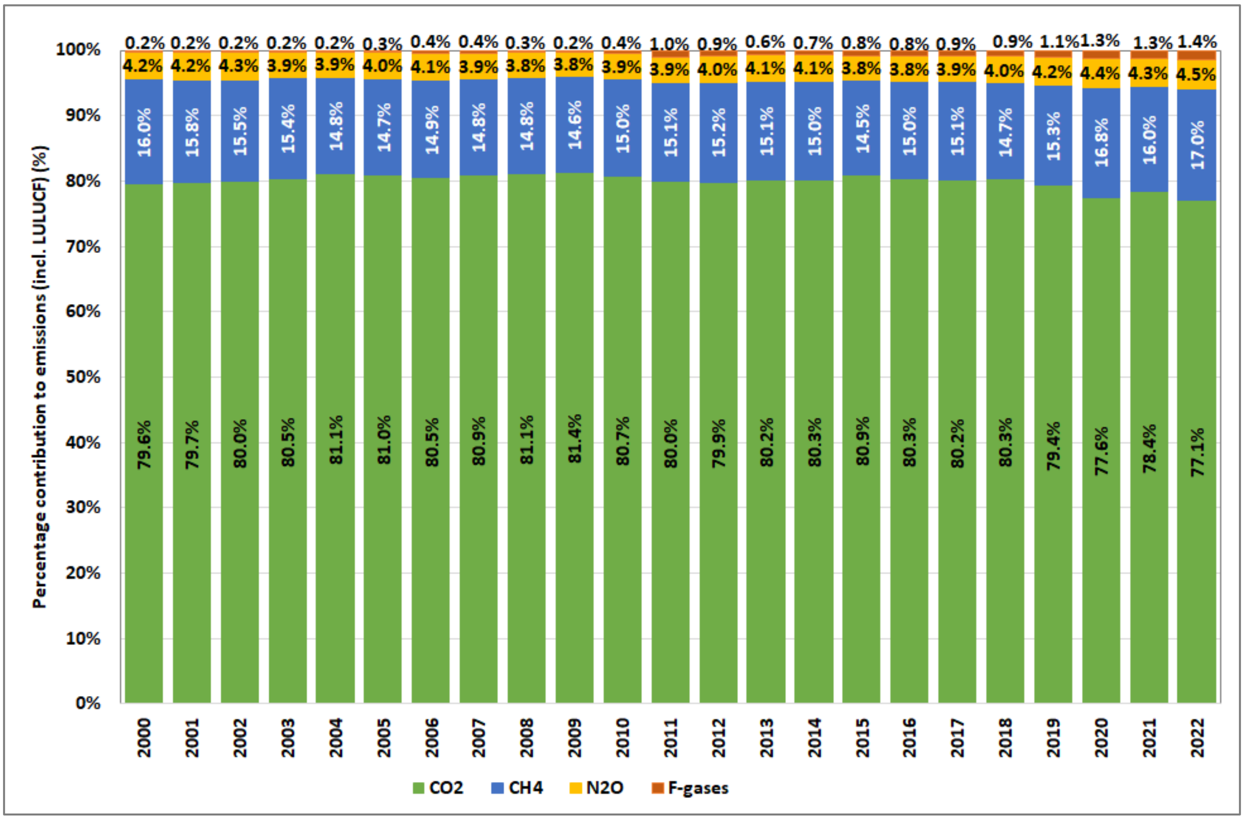


Figure 2.5: Percentage contributions from each of the gases to South Africa's emissions (excl. LULUCF (top) and incl. LULUCF (bottom)) between 2000 and 2022.

Table 2.3: Trend in CO_2, CH_4, N_2O and F-gases between 2000 and 2022.

	Emissions										
	CO_2 (excl. LULUCF)	CO_2 (incl. LULUCF)	CH_4 (excl. LULUCF)		CH_4 (incl. LULUCF)		N_2O (excl. LULUCF)		N_2O (incl. LULUCF)		F-gases
	Gg CO_2e		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	408 046.9	367 847.3	63 227.2	2 258.1	73 964.7	2 641.6	17 448.4	65.8	19 368.4	73.1	1 025.0
2001	406 610.1	376 331.1	63 654.4	2 273.4	74 738.5	2 669.2	17 649.5	66.6	19 882.2	75.0	1 050.6
2002	414 913.0	387 175.3	63 788.9	2 278.2	75 095.4	2 682.0	18 014.5	68.0	20 487.2	77.3	935.0
2003	431 054.0	387 095.3	64 013.6	2 286.2	74 121.2	2 647.2	17 188.7	64.9	18 903.2	71.3	933.9
2004	442 206.3	406 758.9	64 220.6	2 293.6	74 262.8	2 652.2	17 549.0	66.2	19 306.0	72.9	926.8
2005	438 097.3	421 153.9	65 117.4	2 325.6	76 176.0	2 720.6	18 157.6	68.5	20 679.7	78.0	1 750.5
2006	428 594.6	406 347.5	64 943.6	2 319.4	75 396.0	2 692.7	18 436.6	69.6	20 640.5	77.9	2 116.5
2007	448 922.5	419 464.3	66 544.5	2 376.6	76 837.0	2 744.2	18 111.6	68.3	20 164.2	76.1	2 093.9
2008	445 413.9	429 142.6	67 445.4	2 408.8	78 034.7	2 787.0	17 839.7	67.3	20 204.6	76.2	1 621.7
2009	461 484.1	425 532.5	66 808.1	2 386.0	76 487.7	2 731.7	17 866.6	67.4	19 788.8	74.7	1 111.7
2010	440 316.3	413 986.9	67 000.3	2 392.9	77 054.9	2 752.0	17 394.5	65.6	19 685.1	74.3	2 260.3
2011	438 186.5	403 922.4	66 593.4	2 378.3	76 209.1	2 721.8	17 513.1	66.1	19 638.2	74.1	4 868.3
2012	444 870.7	409 289.9	68 235.6	2 437.0	77 857.6	2 780.6	18 205.8	68.7	20 358.2	76.8	4 690.9
2013	436 580.2	390 699.9	64 672.7	2 309.7	73 674.3	2 631.2	17 986.4	67.9	19 778.8	74.6	2 981.0
2014	435 945.3	398 763.0	65 358.6	2 334.2	74 520.3	2 661.4	18 141.4	68.5	20 098.3	75.8	3 454.3
2015	428 318.4	413 934.3	65 597.2	2 342.8	74 365.9	2 655.9	17 683.2	66.7	19 211.1	72.5	3 917.4
2016	423 288.9	393 063.3	65 028.8	2 322.5	73 532.7	2 626.2	17 433.4	65.8	18 539.5	70.0	4 119.0
2017	414 660.4	398 814.6	65 370.1	2 334.6	75 084.9	2 681.6	17 546.5	66.2	19 243.6	72.6	4 410.6
2018	415 337.5	403 912.3	63 662.0	2 273.6	74 010.8	2 643.2	18 380.6	69.4	20 220.8	76.3	4 750.0
2019	415 177.7	378 412.3	62 888.1	2 246.0	73 153.9	2 612.6	18 322.7	69.1	20 023.5	75.6	5 096.8
2020	386 604.5	338 137.1	62 808.0	2 243.1	73 070.3	2 609.7	17 537.7	66.2	19 223.7	72.5	5 487.6
2021	402 172.8	364 510.8	62 876.8	2 245.6	74 579.5	2 663.6	17 437.0	65.8	20 031.7	75.6	5 835.7
2022	392 138.4	335 992.1	63 240.6	2 258.6	74 260.4	2 652.2	17 372.1	65.6	19 438.8	73.4	136.4

2.2.1 Carbon dioxide (CO_2)

CO_2 is the largest contributor to South Africa's emissions; followed by CH_4 and then N_2O (Figure 2.5). CO_2 emissions contributed 81.9% (excl. LULUCF) to South Africa's emissions in 2022. Majority of CO_2 emissions are from the Energy sector, contributing an average of 92.7% (excl. LULUCF)to the total CO_2 emissions between 2000 and 2022. The IPPU sector's contribution (excl. LULUCF) is an average of 6.8% of the total CO_2 emissions between 2000 and 2020, while the Agriculture sector contributed an average of 0.6%. The trend and contribution of each sector to CO_2 emissions can be seen in Figure 2.6.

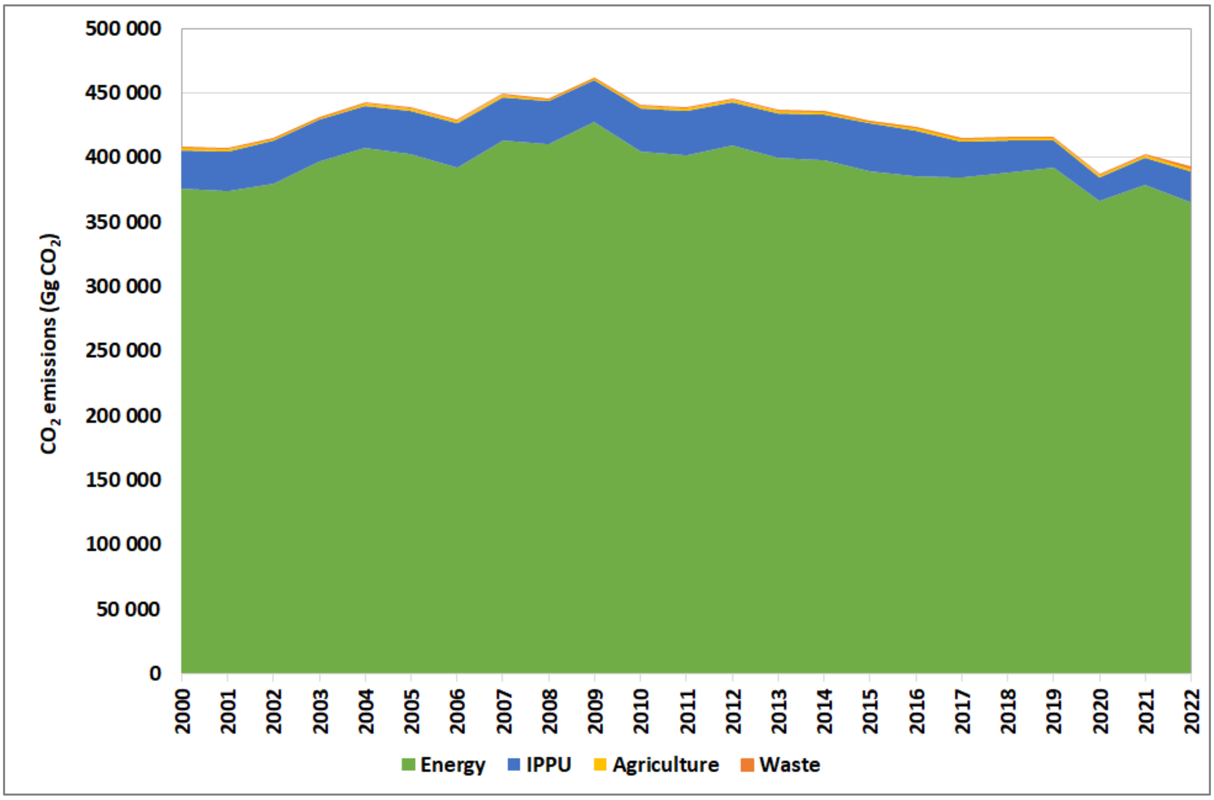


Figure 2.6: Trend and sectoral contribution to CO_2 emissions (excl. LULUCF), 2000 – 2022.

2.2.2 Methane (CH_4)

The trend and contribution of all the sectors to the total CH_4 emissions in South Africa are shown in Figure 2.7. CH_4 emissions (excl. LULUCF) only increased by 0.02% between 2000 and 2022. The *Enteric Fermentation* from Agriculture and *Solid Waste Disposal* from Waste were the major contributors to the total CH_4 emissions in 2022.

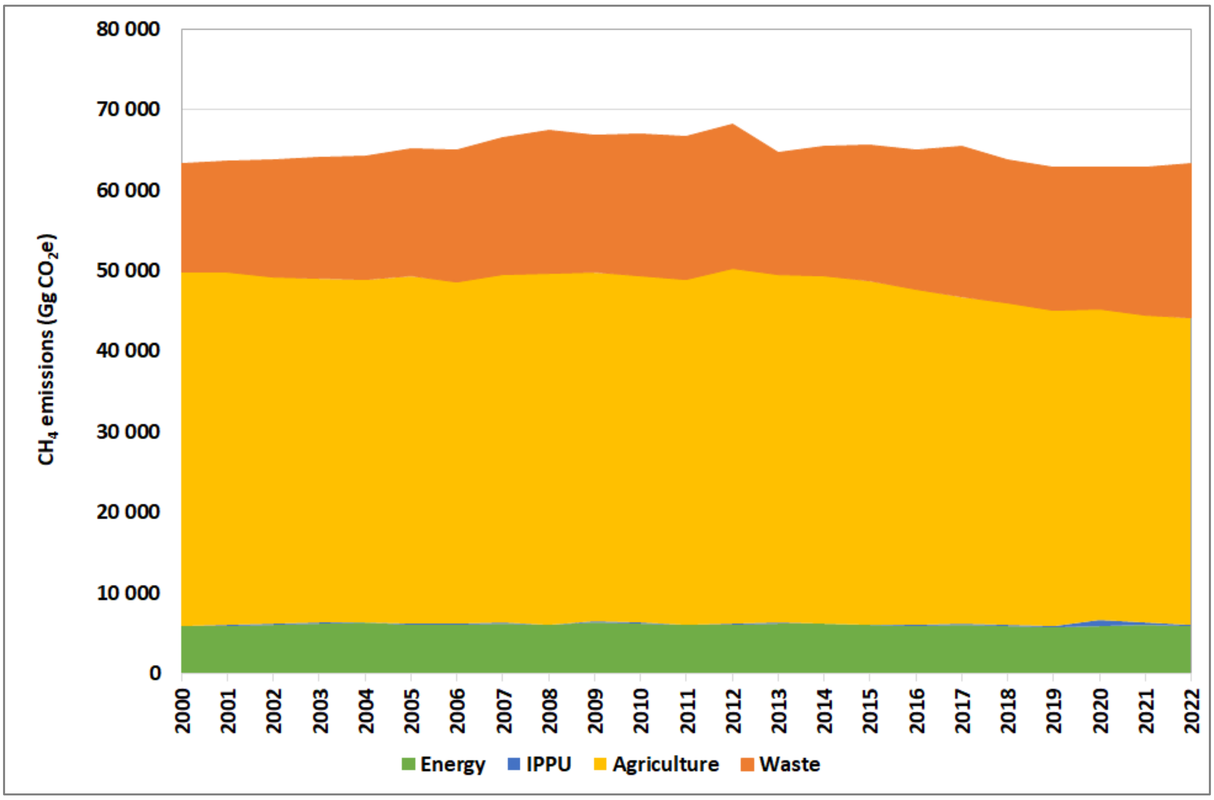


Figure 2.7: Trend and sectoral contribution to the CH_4 emissions, 2000 – 2022.

2.2.3 Nitrous oxide (N_2O)

The contribution of all the sectors to the N_2O emissions is shown in Figure 2.8. The main contributor to N_2O emissions is the Agriculture sector followed by Energy sector, contributing 74.4% and 14.4% (excl. LULUCF) respectively. N_2O emissions for 2022 from IPPU sector have decreased by 74.0% since 2000.

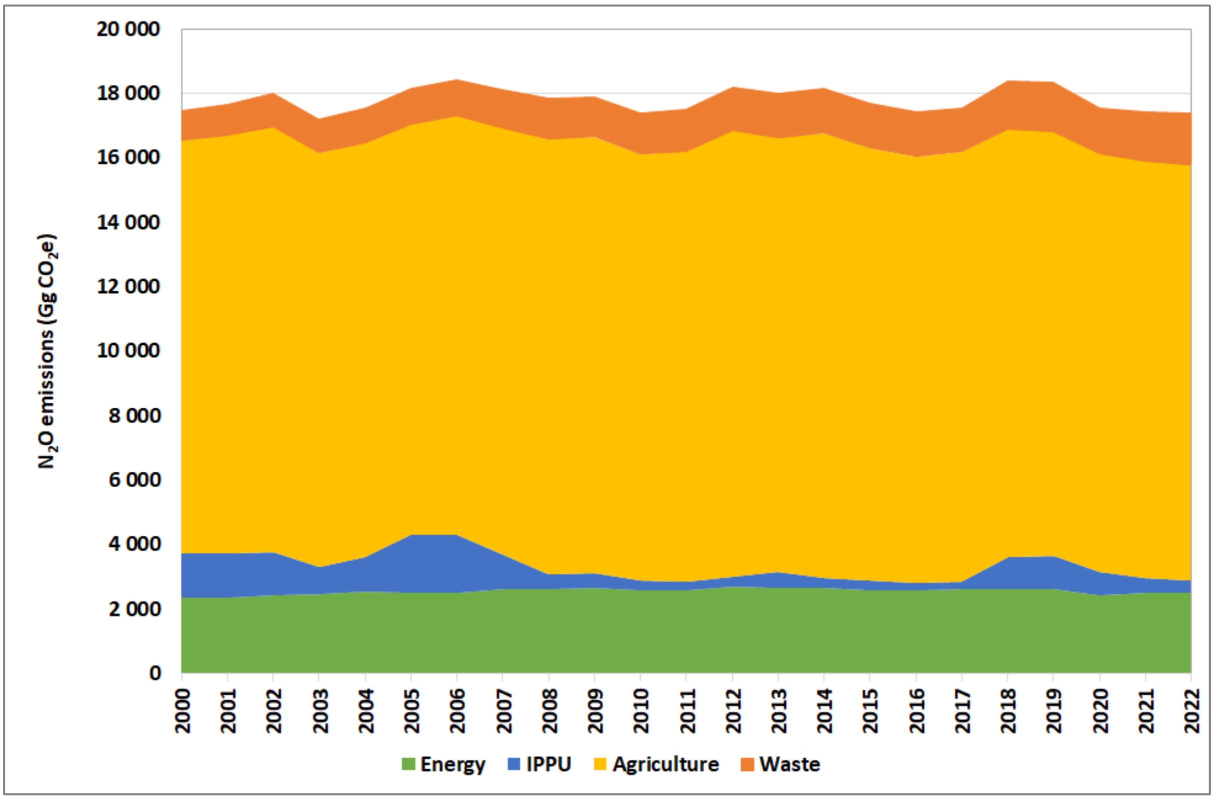


Figure 2.8: Trend and sectoral contribution to N_2O emissions in South Africa, 2000 – 2022.

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 2.9) and contributed 1.3% to overall emissions (excl. LULUCF) in 2022. 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.

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).

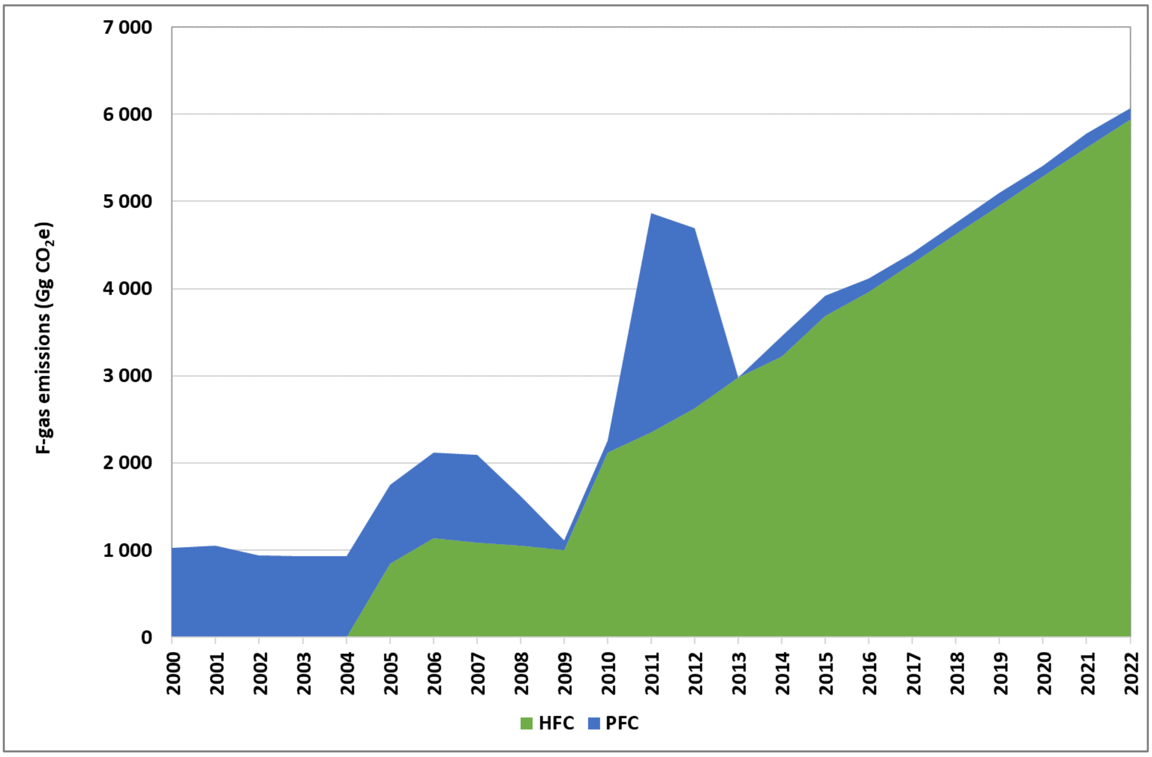


Figure 2.9: Trend in F-gas emissions in South Africa, 2000 – 2022.

2.3 Description and interpretation of emission trends by category

2.3.1 Energy

The Energy sector is the largest contributor to South Africa' emissions (excl. LULUCF), contributing 78% in 2022 and on average since 2000 (Figure 2.10). Since 2000, the Energy sector emissions have decreased by 2.5% with the biggest decrease (6.4%) being in 2020 due to COVID19 lockdown restrictions (Figure 2.11). In 2021 emissions increased by 3.5% and then dropped by 3.4% in 2022 to pandemic levels (2020). This decrease is due to a 6.5% decrease in emissions from the *Energy Industries* sub-sector, which on average accounts for 67% of the Energy sector emissions.

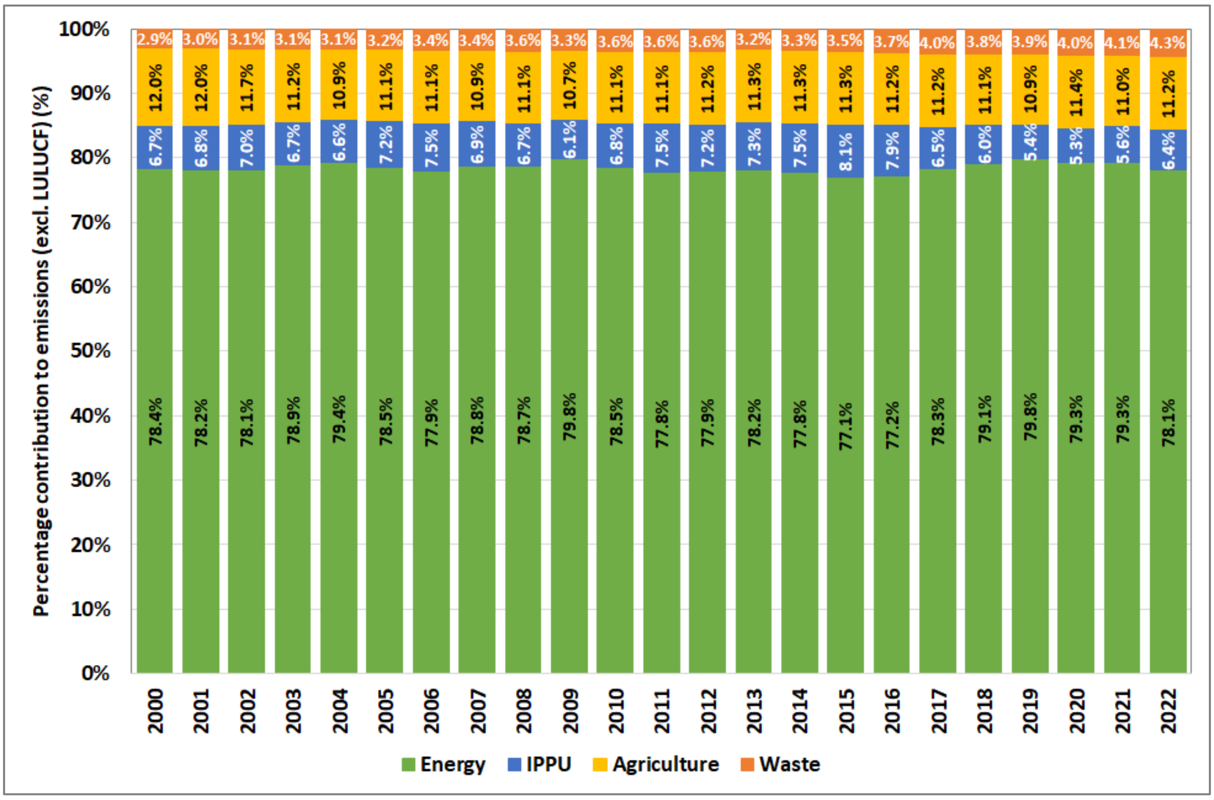


Figure 2.10: Percentage contributions from each of the sectors to South Africa's emissions (excluding LULUCF) between 2000 and 2022.

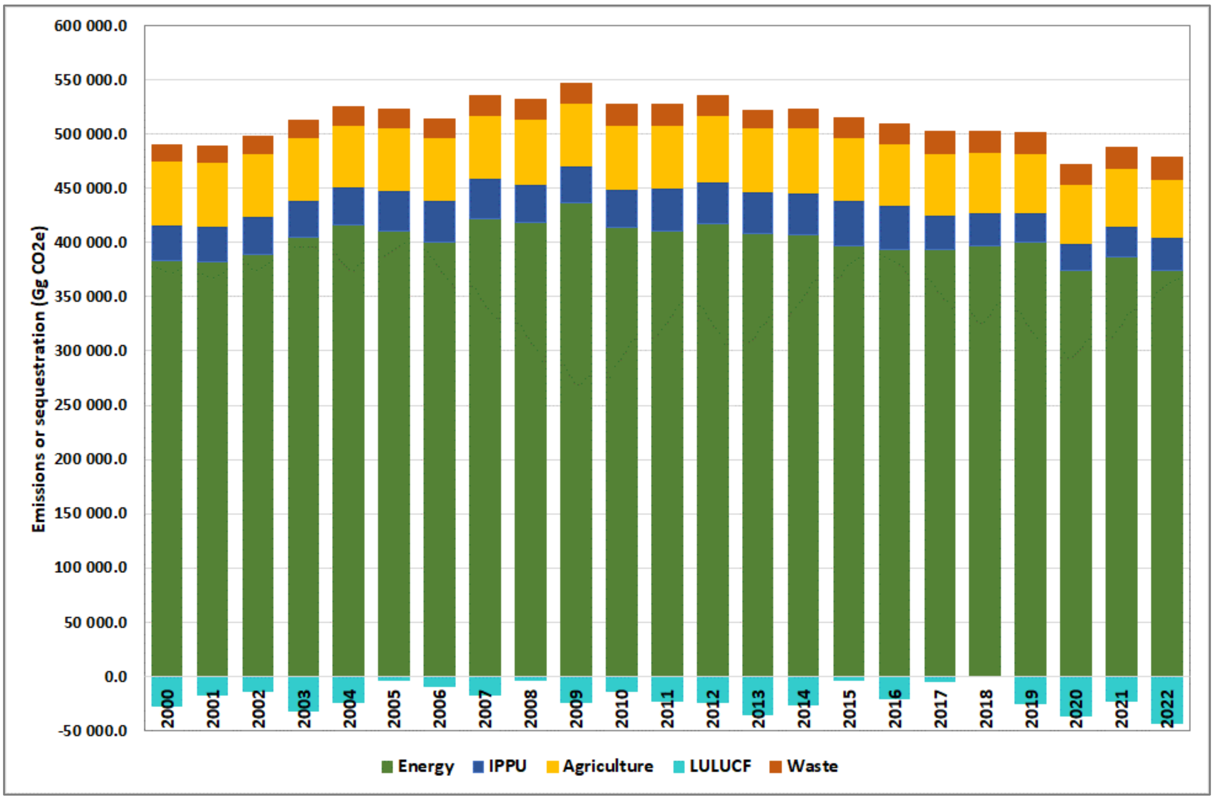


Figure 2.11: Emissions and sequestration trends per sector across the time-series, 2000-2022.

2.3.2 IPPU

In 2022 the IPPU sector produced 30 598 Gg CO_2e which is 6.4% of South Africa's emission (excl. LULUCF) (Figure 2.10).

The IPPU sector produces CO_2 emissions (78.4%), fluorinated gases (20.0%) and smaller amounts of CH_4 (0.4%) and N_2O (1.2%). Carbon dioxide and any other emissions from combustion of fuels in these industries are reported under the energy sector.

The largest source category is the *Metal industry* category. which contributes 51.2% to the total IPPU sector emissions. The *Mineral industry* and the *Product used as substitutes for ozone depleting substances* subsectors contribute 19.8% and 19.4%, respectively, to the IPPU sector emissions.

Even though the South African economy recovered after the COVID-19 pandemic, estimated emissions from the IPPU sector are 2 183 Gg CO_2e (-6.7%) lower than the emissions in 2000 (Table 2.4). The decline can be attributed to the decline in metals production (-39.0%), specifically Iron and Steel, and Aluminium. This can be ascribed to a decrease in global demand. The chemicals industry also declined (-31.4%). *Cement*

Production and *Non-Energy Product Use from Fuels and Solvents* increased emissions from 2000 by 2 081 Gg CO_2e. The local demand for cement increased dramatically from 2000.

2.3.3 Agriculture

The Agriculture sector contributed between 10% and 12% to the total emissions (excl. LULUCF) between 2000 and 2022 (Figure 2.10). The overall emissions have declined by 8.9% since 2000 (Table 2.4). The main driver of change in the Agriculture sector 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 22-year period.

The Agriculture sector produced 53 519 Gg CO_2e (excl. LULUCF) in 2022 (Table 2.4). Livestock contributed 76% to the Agriculture emissions in 2022, and the largest contributor to this category is CH_4 from *Enteric fermentation* (68%), while *Manure management* contributed (8%) to the total livestock emissions. Agricultural soils contributed 19 % to the total Agriculture emissions, while the least emissions were from *Liming* (3%), *Urea application* (1.1%) and *Field burning of agricultural residues* (0.1%).

Table 2.4: Trend in emissions and removals by sector for 2000 to 2022.

	Energy	IPPU	Agriculture	LULUCF	Waste
	Emissions (Gg CO_2e)				
2000	383 820.6	32 781.3	58 782.9	-27 542.1	14 362.7
2001	382 286.1	33 056.9	58 837.9	-16 962.3	14 783.7
2002	388 662.6	35 034.9	58 339.7	-13 958.4	15 614.1
2003	405 095.8	34 425.3	57 628.0	-32 136.5	16 041.1
2004	416 547.4	34 495.2	57 447.7	-23 648.3	16 412.4
2005	410 739.3	37 594.4	57 899.2	-3 362.8	16 890.0
2006	400 662.4	38 760.4	57 205.7	-9 590.8	17 462.7
2007	421 917.7	37 163.9	58 397.1	-17 113.1	18 193.7
2008	418 700.4	35 433.0	59 222.5	-3 317.1	18 964.8
2009	436 680.2	33 563.3	58 789.6	-24 349.8	18 237.4
2010	413 693.1	35 956.0	58 411.5	-13 984.1	18 910.7
2011	410 126.9	39 675.3	58 419.9	-22 523.3	18 939.2
2012	417 707.8	38 809.7	60 231.6	-23 806.4	19 254.0
2013	408 544.5	38 279.1	58 894.0	-35 086.3	16 502.7
2014	407 035.4	39 234.0	59 265.0	-26 063.7	17 365.2

2015	397 417.7	41 596.6	58 210.2	-4 087.6	18 291.8
2016	393 788.7	40 337.2	57 002.1	-20 615.6	18 742.0
2017	393 232.8	32 508.5	56 230.6	-4 433.8	20 015.7
2018	397 219.1	30 256.4	55 529.1	763.7	19 125.6
2019	400 292.8	27 289.3	54 590.5	-24 798.8	19 312.6
2020	374 748.2	24 857.6	53 830.0	-36 519.2	19 002.1
2021	387 309.9	27 547.4	53 523.2	-23 364.6	19 941.8
2022	374 072.4	30 598.0	53 518.7	-43 059.8	20 698.4
Change between 2000 and 2022 (Gg CO_2e)	-9 748.2	-2 183.3	-5 264.2	-15 517.7	6 335.7
Percentage change (%)	-2.5	-6.7	-9.0	56.3	44.1

2.3.4 LULUCF

The LULUCF sink was estimated at 43 060 Gg CO_2e in 2022. Forest lands were estimated to have a sink of 87 559 Gg CO_2e, with 62% of this being due to land being converted to *Forest lands*. The conversion of *Grasslands* to *Forest land* (mainly woodlands) accounted for 86.3% of the total land conversion sink. All other land categories were sources of emissions with *Other lands* contributing the most (42.5%) to this source, followed by *Grasslands* (26.6%). All the emissions for *Other lands* was from land being converted to bare ground and the largest conversion was low shrublands to bare ground.

The LULUCF sector showed an increase of 56.3% in its sink since 2000 (Table 2.4). The sink increased by 17.9% since 2020. The sink was reduced between 2015 and 2018 (Figure 2.11) and these changes were brought about by the change in land conversions introduced by the 2014-2018 change maps. During this period there was an increase in the emissions from *Grasslands* (due mainly to conversion between low shrubland and grasslands) and *Croplands*. The increased *Cropland* emissions were attributed to an increase in conversion of *Forest land* to *Cropland* and conversions between perennial and annual crops. These increased emissions led to a reduction in the sink during this period.

Grasslands were estimated to be a small sink between 2000 and 2014, but the trends show that from 2015 onwards the become a source of emissions. This is due to the conversions between low shrublands and grasslands, however this is one of the categories that can be impacted by seasonal variation. The land change improvement plan will investigate these changes further over the next few years in the aim of better understanding the changes and reducing the uncertainty.

The trends also show an increase in the *Forest land* sink. There is an increase in conversion of *Grassland* to *Forest land*, mainly grasslands to woodlands, which also supports the findings of a reduced *Grassland* sink. Thickets are an important sink in the *Forest land* category and the sink is seen to be fairly stable, however thickets are the land category that showed the most change in the land change maps due to reclassification, so the improvement plan will interrogate this further.

2.3.5 Waste

In South Africa the total Waste sector emissions for 2022 were 20 698 Gg CO_2e (Table 2.4). Most of these emissions are from *Wastewater treatment and discharge* contributing 9247 Gg CO_2e (44.1%) of the total Waste sector emissions. *Solid waste disposal* contributed a further 8 596 Gg CO_2e (41.5%) of waste emissions while *biological treatment of solid waste* contributed 2 530 Gg CO_2e (12.2%). Emissions from *Incineration and Open Burning of Waste* were estimated to be 325 Gg CO_2e (1.57%).

Solid waste disposal emissions have increased 47.6% since 2000. *Incineration and open burning of waste* emissions increased by 53.1% since 2000, while emissions from *Wastewater treatment and discharge* increased slightly across the time series. This overall increase in emissions is largely driven by increases of 35.6% in *Domestic wastewater treatment and discharge* emissions, whilst there was a 9.4% decline in *Industrial wastewater treatment and discharge* emissions.

2.4 Description and interpretation of emission trends for indirect GHG

The trend in emissions of CO, NOx and NMVOCs is shown in **Error! Reference source n ot found.**. These emissions were estimated for biomass burning only. There is annual variability because the emissions include wildfires as well as controlled fires.

Table 2.5: Trends in indirect GHG emissions between 2000 and 2022.

	NOx	CO	NMVOC
	(Gg)		
2000	98.3	1 994.2	187.2
2001	121.3	2 446.9	228.7
2002	136.8	2 775.0	259.8
2003	82.5	1 755.8	171.0
2004	87.9	1 833.6	176.0
2005	141.4	2 908.0	275.7

2006	119.9	2 473.1	235.1
2007	103.5	2 371.6	242.2
2008	127.9	2 799.2	277.2
2009	100.8	2 119.8	204.5
2010	127.9	2 613.1	246.2
2011	118.1	2 350.0	217.4
2012	118.0	2 450.2	233.3
2013	93.0	1 981.2	193.5
2014	105.5	2 251.8	219.8
2015	76.3	1 555.6	147.9
2016	44.8	945.2	91.9
2017	83.6	1 710.8	163.0
2018	90.3	1 915.6	187.4
2019	80.9	1 741.1	172.7
2020	80.3	1 666.3	161.6
2021	140.7	2 897.5	279.3
2022	105.1	2 184.7	211.3

2.5 References

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Gross Domestic Product (GDP). (2023). [online] South Africa: Statistics South Africa. Available at: https://www.statssa.gov.za/?page_id=1854&PPN=P0441&SCH=73562.

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Chapter 3: Energy (CRT sector 1)

3.1 Sector overview

South Africa's Energy sector inventory includes:

- Exploration and exploitation of primary energy sources;
- Conversion of primary energy source 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 Energy sector is South Africa's largest emitting sector. This sector is the largest source of CO_2 emissions (Figure 3.1) and the second largest source of N_2O emissions mainly as a result of *Fuel Combustion* activities.

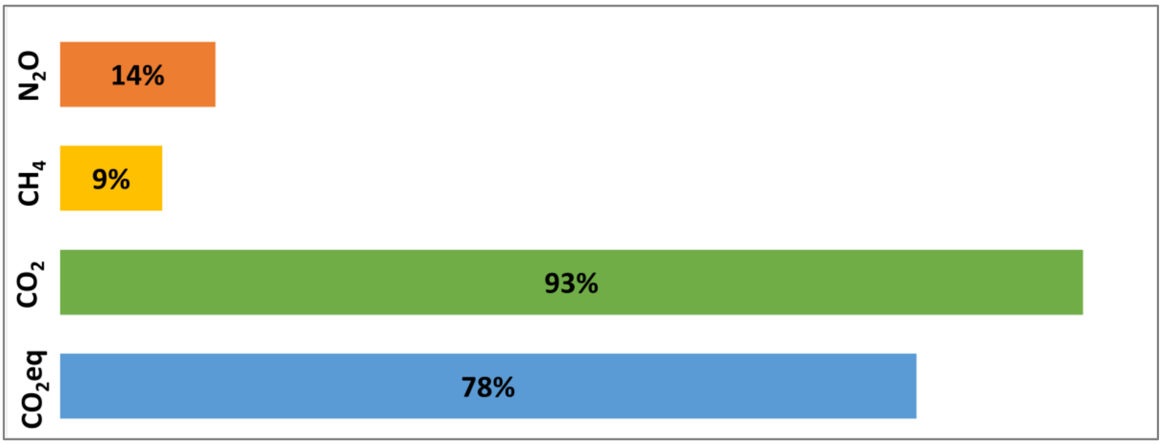

Figure 3.1: Energy sector contribution by gas (excl. LULUCF) for 2022.

The primary energy supply for South Africa is dominated by coal and crude oil as shown in Figure 3.2. The share of coal has increased by 5% since 2018 while the share of gas has decreased by 2% (DMRE 2023).

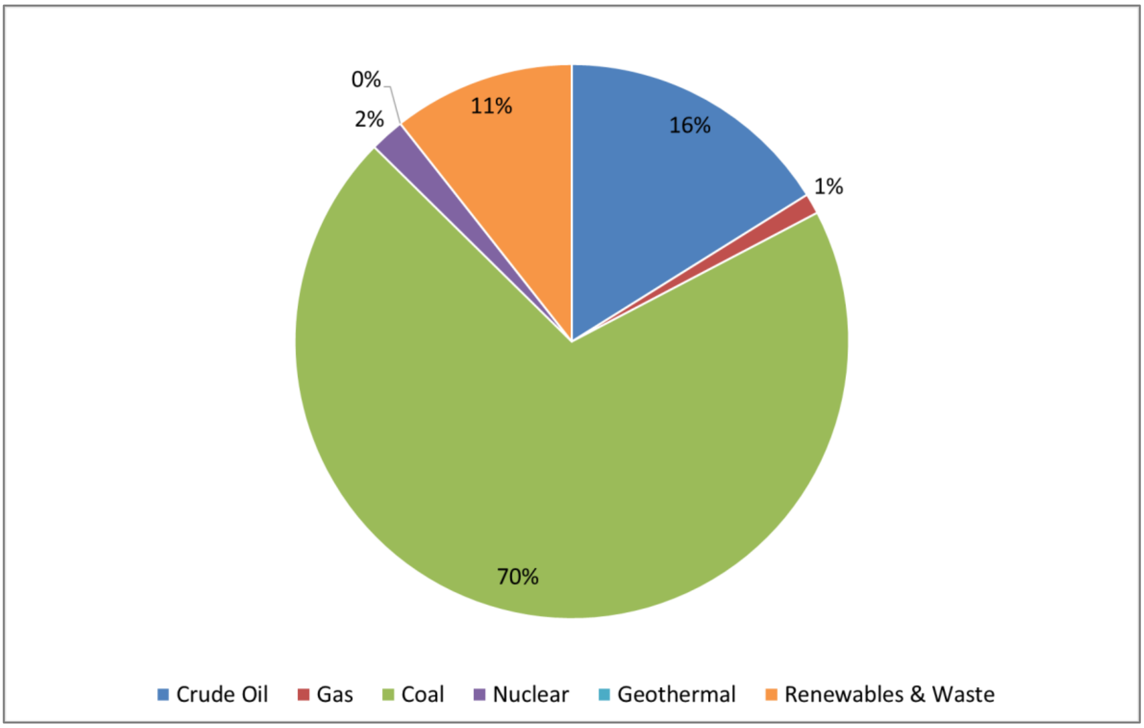

Figure 3.2: Total primary energy supply in South Africa, 2020[4]

3.1.1 Shares and trends in emissions

The total emissions from the Energy sector for 2022 are shown in Table 3.1. Emissions from *Fuel Combustion* activities accounted for 92% of the Energy sector emissions, with *Energy Industries* accounting for 65 % of emissions from *Fuel Combustion* activities.

Table 3.1: Summary of emissions from the Energy sector in 2022

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	**365 688**	**210**	**5 881**	**9**	**2 492**	**374 061**
1A Fuel combustion activities	341 776	36	1 011	9	2 487	345 274
1B Fugitive emissions from fuels	23 912	174	4 870	0	5	28 787
1C CO_2 transport and storage	NE	NE	NE	NE	NE	NE

The time series of energy emissions by sector is shown in Figure 3.3. *Fuel Combustion* activities have varied over the years, however, they have remained the largest

[4] *Values from the 2020 Energy Balance, DMRE 2023 Statutes & Practices | Department: Energy | REPUBLIC OF SOUTH AFRICA*

contributor to the Energy sector emissions. *Fugitive Emissions* have remained fairly constant since 2000.

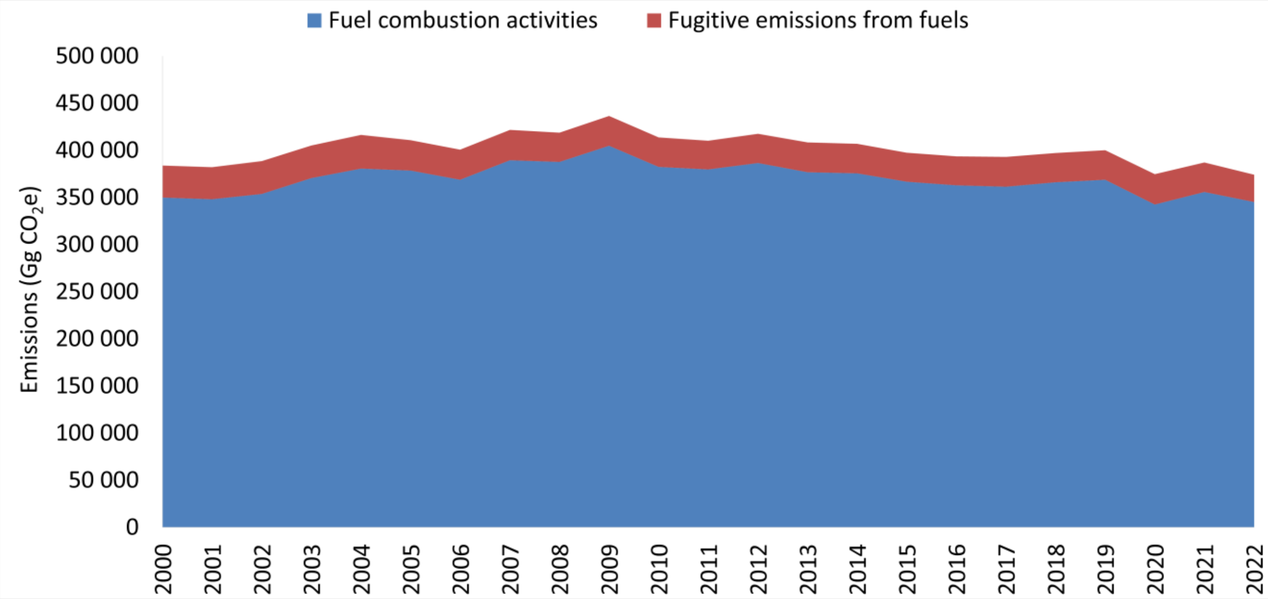

Figure 3.3: Energy emissions by sub-sector, 2000 – 2022

The changes in Energy sector emissions since 2000, at an aggregated level, are shown in Figure 3.4. The impact of stringent lockdown restrictions in 2020, due to the COVID-19 pandemic, is seen in the drop in emissions. Thereafter emissions increased in 2021 as less stringent measures were put in place in the first half of the year and all restrictions were then revoked for the remainder of the year.

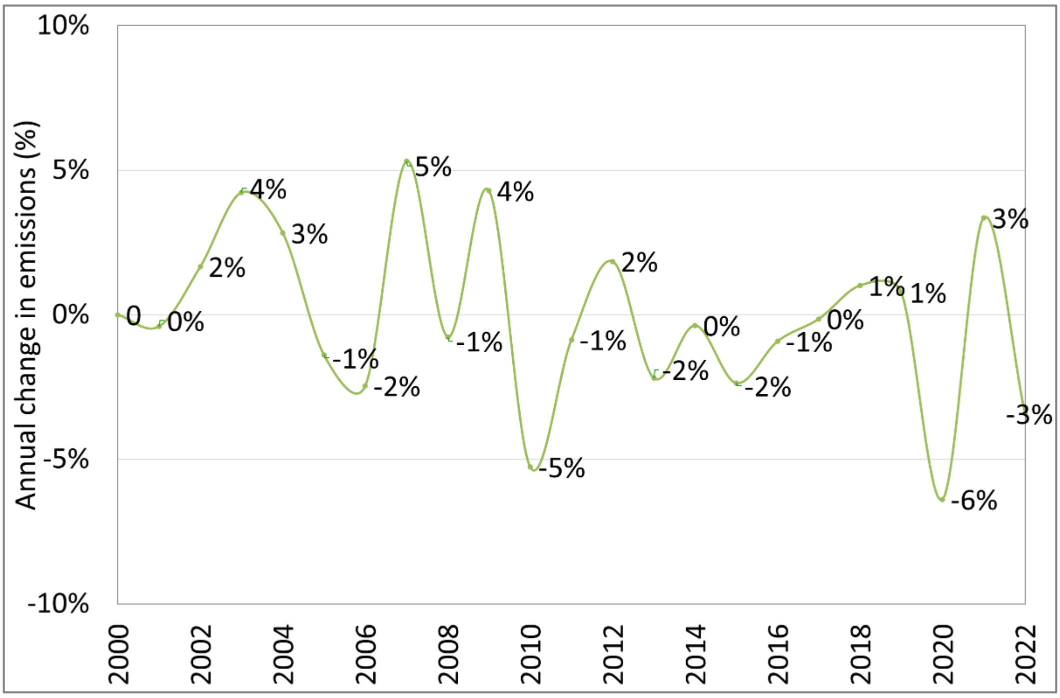

Figure 3.4: Trend in annual change in the total energy emissions in South Africa, 2000 – 2022.

Table 3.2 shows the disaggregated changes in emissions from 2000 and from 2022. The highest percentage increase in emissions since 2000 was experienced by the *Transport* and the *Manufacturing industries and construction* sub-sectors. This is due to a growing population and to growth in the manufacturing industry resulting in increased energy demand. Similarly, since 2020 the *Manufacturing industries and construction* sub-sector experienced the highest increase in emissions. This was because of increased demand in production following a temporary drop in 2020 caused by stringent lockdown restrictions.

The highest percentage decrease in emissions since 2000 was experienced by the *Other Sectors* sub-sector mainly due to a significant decrease in emissions from households due to increased electrification across the country since 2000 as well as an increase in residential solar installations.

Table 3.2: Summary of the change in emissions from the Energy sector between 2000 and 2022.

Greenhouse gas source and sink categories	Emissions ($Gg CO_2e$)			Difference ($Gg CO_2e$)		Change	
	2000	2020	2022	2000-2022	2020-2022	2000-2022	2020-2022
1. ENERGY	**383 821**	**374 748**	**374 072**	**-9 748**	**-676**	**-3%**	**0%**
1A Fuel combustion activities	**349 932**	**342 640**	**345 275**	**-4 657**	**2 634**	**-1%**	**1%**
1A1 Energy industries	*220 522*	*237 956*	*225 656*	*5 134*	*-12 300*	*2%*	*-5%*
1A1a Electricity and heat production	*185 947*	*206 059*	*196 977*	*11 031*	*-9 081*	*6%*	*-4%*
1A1b Petroleum refining	*4 012*	*3 289*	*1 080*	*-2 932*	*-2 209*	*-73%*	*-67%*
1A1c Manufacture of solid fuels	*30 563*	*28 609*	*27 599*	*-2 965*	*-1 010*	*-10%*	*-4%*
1A2 Manufacturing industries and construction	*21 132*	*19 958*	*26 647*	*5 515*	*6 688*	*26%*	*34%*
1A2a Iron & Steel	*1 604*	*1 170*	*1 630*	*26*	*460*	*2%*	*39%*
1A2b Non-ferrous Metals	*475*	*691*	*789*	*313*	*97*	*66%*	*14%*
1A2-ab 1A2 Remainder	*19 052*	*18 097*	*24 228*	*5 176*	*6 131*	*27%*	*34%*
1A3 Transport	*41 624*	*47 665*	*52 744*	*11 121*	*5 079*	*27%*	*11%*
1A3a Domestic aviation	*2 333*	*704*	*689*	*-1 644*	*-15*	*-70%*	*-2%*
1A3b Road transportation	*38 245*	*45 942*	*51 159*	*12 914*	*5 218*	*34%*	*11%*
1A3c Railways	*613*	*520*	*395*	*-217*	*-124*	*-35%*	*-24%*
1A3d Water-borne navigation (domestic)	*432*	*500*	*500*	*68*	*0*	*16%*	*0%*
1A3e Other transportation	*NE*	*NE*	*NE*	*NA*	*NA*		
1A4 Other sectors	*50 570*	*17 194*	*19 029*	*-31 541*	*1 835*	*-62%*	*11%*
1A4a Commercial/Institutional	*20 604*	*10 985*	*12 077*	*-8 528*	*1 092*	*-41%*	*10%*
1A4b Residential	*27 550*	*3 165*	*3 858*	*-23 692*	*693*	*-86%*	*22%*
1A4c Agriculture/Forestry/Fishing/Fish farms	*2 416*	*3 044*	*3 095*	*679*	*50*	*28%*	*2%*
1A5 Non-specified	*16 084*	*19 867*	*21 198*	*5 115*	*1 332*	*32%*	*7%*
1B Fugitive emissions from fuels	**33 889**	**32 108**	**28 798**	**-5 091**	**-3 310**	**-15%**	**-10%**
1B1 Solid fuels	*2 028*	*3 292*	*2 293*	*265*	*-999*	*13%*	*-30%*
1B2 Oil and natural gas	*765*	*434*	*94*	*-671*	*-340*	*-88%*	*-78%*
1B3 Other emissions from energy production	*28 147*	*25 645*	*23 477*	*-4 670*	*-2 168*	*-17%*	*-8%*
1C Carbon dioxide transport and storage	**NE**	**NE**	**NE**	***NA***	***NA***	***NA***	***NA***

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

3.1.1.1 Fuel combustion activities

The trends and subcategory contributions to emissions from *Fuel Combustion activities* since 2000 are shown in Figure 3.5. *Energy Industries* continues to be the largest source of emissions and this due to the high carbon intensity of South Africa's electricity production sector. The second largest source of emissions from *Fuel Combustion* activities is the *Transport* sector, which is largely dominated by emissions from road transportation.

All the *Fuel Combustion* activity subcategories experienced a drop in emissions in 2020 due to stringent COVID19 lockdown restrictions.

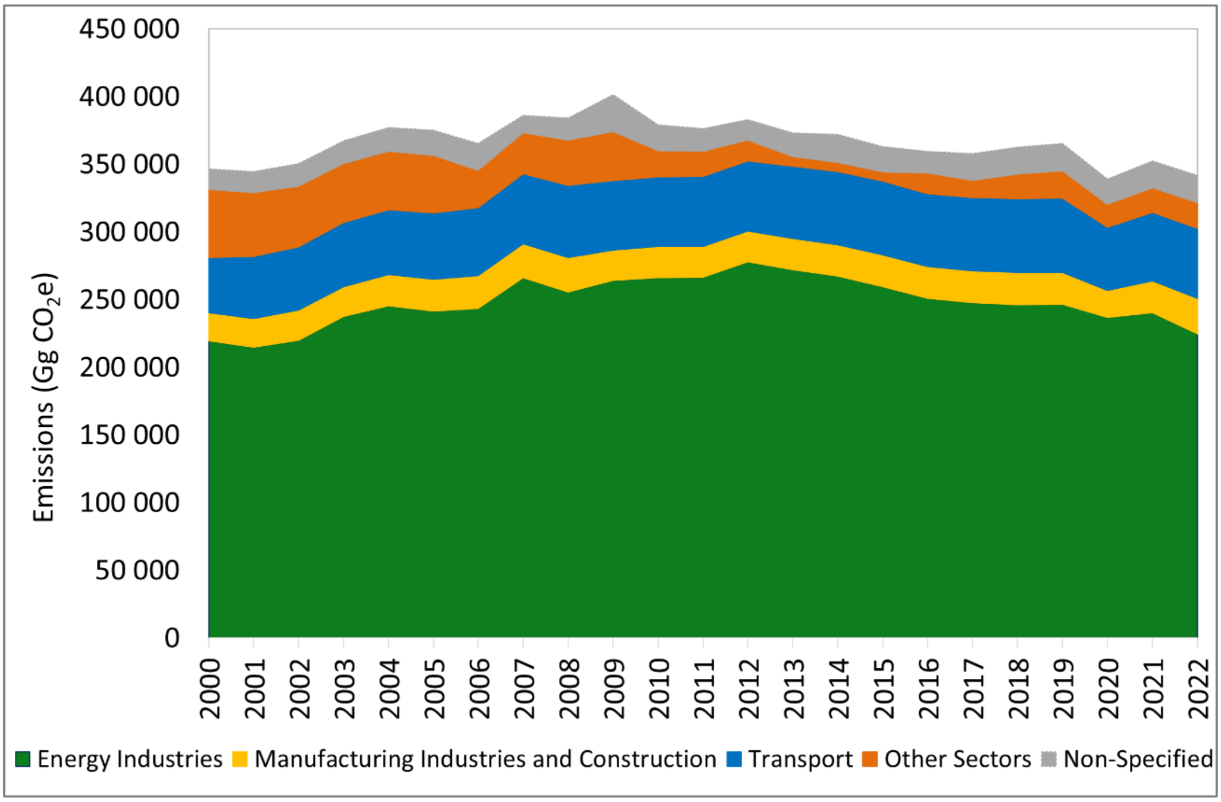

Figure 3.5: Trends and subcategory contributions to fuel combustion activity emissions in South Africa, 2000 – 2022.

Energy industries

Emissions from *Electricity and Heat Production* contribute the most to the *Energy Industries* sub-sector with *Petroleum Refining* contributing the least (Figure 3.6).

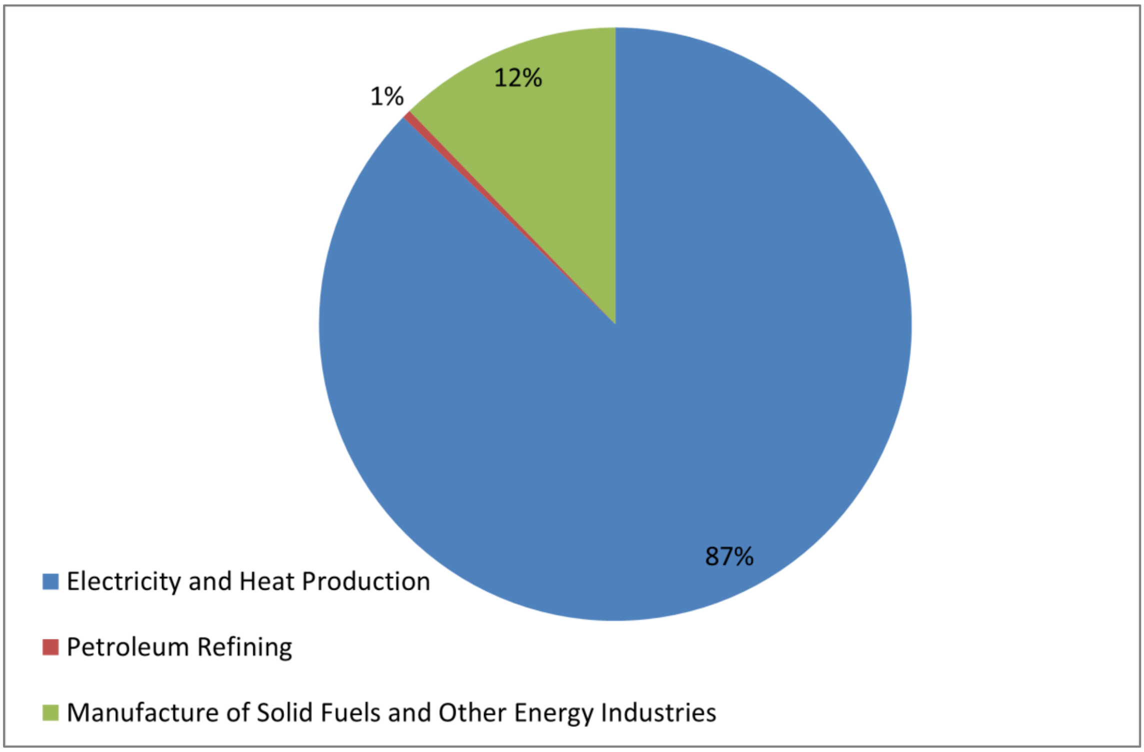

Figure 3.6: Contributions to *Energy Industries* emissions, 2022

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

Table 3.3 shows historical emissions from electricity produced by the main electricity producer in South Africa. Emissive electricity in South Africa is mainly produced from coal, diesel and fuel oil.

Table 3.3: Emission trends for the main electricity producer, 2000 - 2022

	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	174 627
2001	175 475	1.8	2.7	176 251
2002	181 307	1.9	2.8	182 109
2003	194 985	2.0	3.0	195 847
2004	204 690	2.1	3.2	205 595
2005	206 211	2.1	3.2	207 122
2006	207 465	2.2	3.2	208 382
2007	228 111	2.4	3.6	229 120
2008	218 518	2.3	3.4	219 484

	CO_2	CH_4	N_2O	Total
	Gg CO_2	Gg CH_4	Gg N_2O	Gg CO_2e
2009	224 545	2.4	3.5	225 537
2010	231 371	2.4	3.6	232 393
2011	233 159	2.5	3.6	234 188
2012	243 475	2.6	3.8	244 548
2013	237 434	2.6	3.7	238 479
2014	232 085	2.5	3.6	233 106
2015	223 979	2.5	3.4	224 963
2016	217 055	2.3	3.4	218 014
2017	214 602	2.3	3.3	215 550
2018	213 292	2.3	3.3	214 233
2019	210 819	2.3	3.3	211 747
2020	202 929	2.2	3.1	203 823
2021	207 292	2.3	3.2	208 204
2022	193 930	2.1	3.0	194 783

Emissions decreased in 2022 compared to the 2021 in line with the decreasing energy availability factor and electricity production, as seen Figure 3.7. Although electricity generation from fossil fuels has been decreasing Figure 3.8 shows a steady increase in electricity generated from renewable energy.

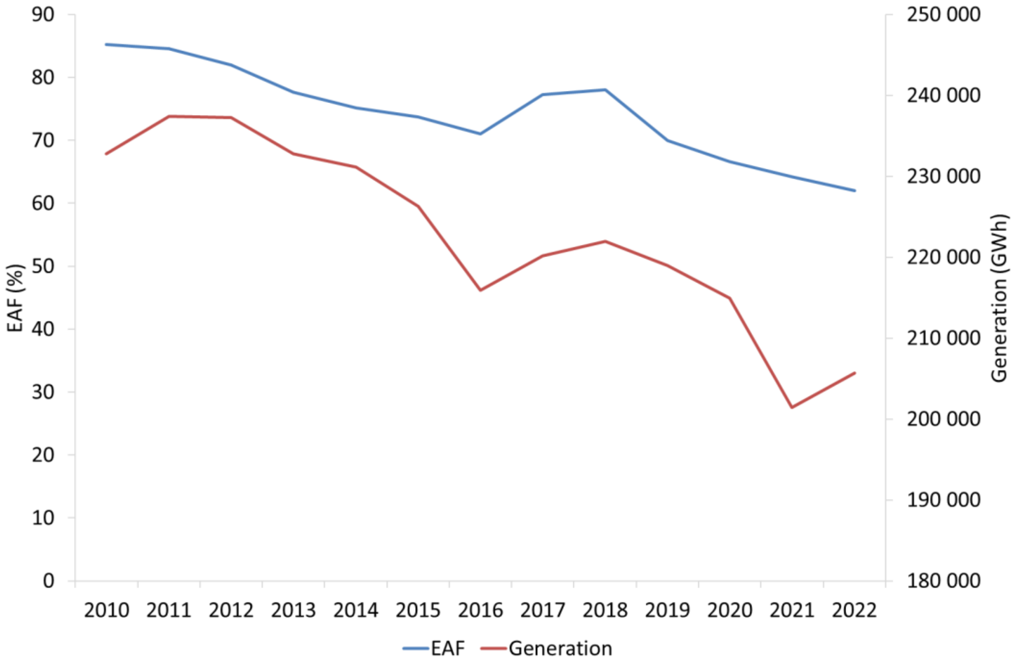

Figure 3.7: Historical energy availability factors and electricity generation information[5]

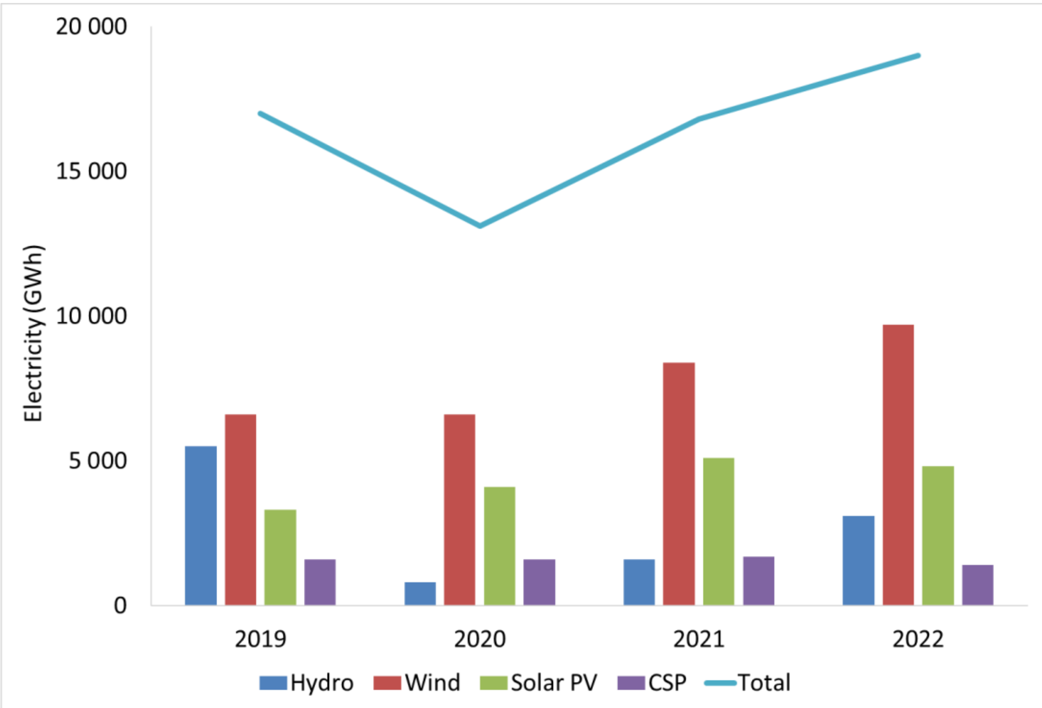

Figure 3.8: Annual electricity from renewable energy, 2019 - 2022[6]

[5] *Data from Eskom's Annual Integrated reports 2011 – 2022. Integrated results - Eskom*
[6] *Data from CSIR Statistics of utility-scale power generation in South Africa reports, 2020 - 2023*

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

Emissions from other electricity producers have varied since 2000, as shown in Table 3.4. However, since 2019 these emissions have been decreasing and this is likely due to the increasing infiltration of renewable energy in this sector.

Table 3.4: Trend in emissions from other electricity producers, 2000 – 2022.

	CO_2	CH_4	N_2O	Total
	Gg CO_2	Gg CH_4	Gg N_2O	Gg CO_2e
2000	11 271	0.12	0.17	11 320
2001	4 598	0.05	0.07	4 619
2002	4 983	0.05	0.08	5 005
2003	7 967	0.08	0.12	8 003
2004	6 248	0.07	0.10	6 276
2005	2 722	0.03	0.04	2 734
2006	3 849	0.04	0.06	3 866
2007	4 216	0.04	0.07	4 235
2008	3 502	0.04	0.05	3 518
2009	5 977	0.06	0.09	6 003
2010	1 977	0.02	0.03	1 985
2011	801	0.01	0.01	805
2012	1 076	0.01	0.02	1 080
2013	1 068	0.01	0.02	1 073
2014	1 096	0.01	0.02	1 100
2015	1 080	0.01	0.02	1 084
2016	186	0.00	0.00	187
2017	661	0.01	0.01	664
2018	661	0.01	0.01	664
2019	3 857	0.10	0.04	3 871
2020	2 227	0.04	0.03	2 236
2021	2 906	0.06	0.04	2 918
2022	2 186	0.05	0.03	2 195

Petroleum refining (1.A.1.b)

Figure 3.9 shows the historical emissions from *Petroleum Refining* and the *Manufacture of solid fuels and other energy industries*.

Emissions from *Petroleum Refining* have been decreasing since 2000 mainly due to a decrease in the amount of fuel oil and petroleum coke used. The amount of refinery gas used changed marginally between 2000 and 2019. Thereafter, a significant drop in refinery gas was reported.

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

Emissions from the *Manufacture of solid fuels and other energy* industries have not changed by more 6% annually since 2000 (see Figure 3.9).

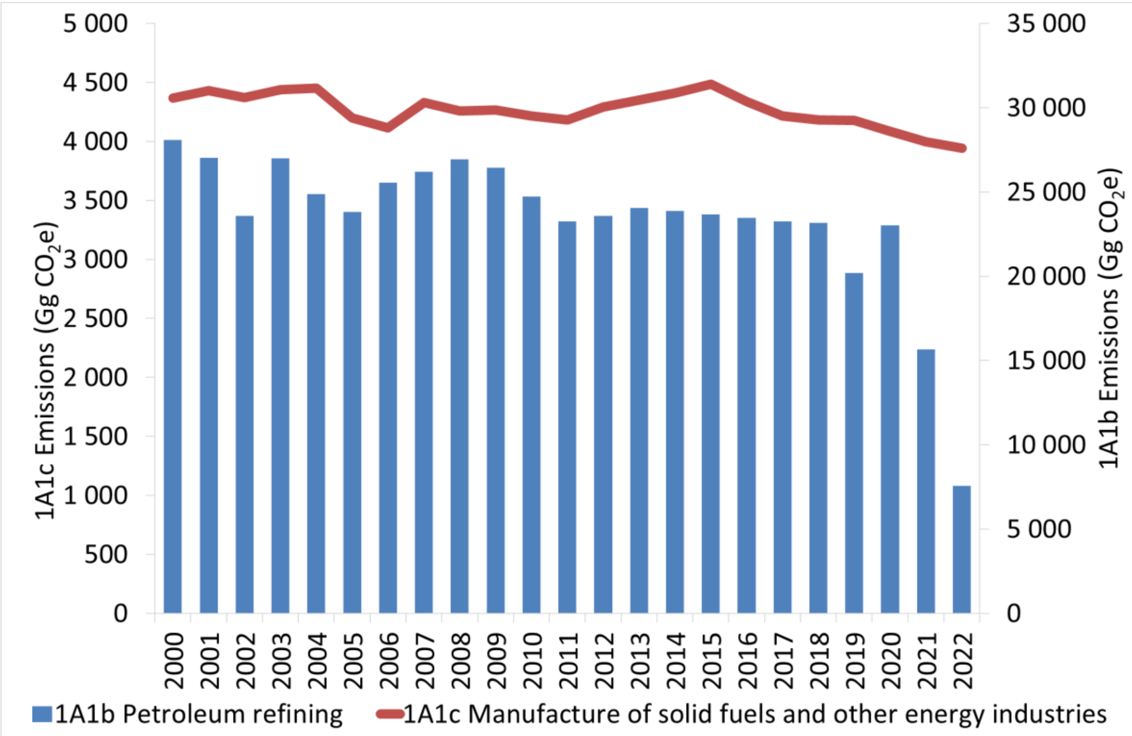

Figure 3.9: Historical emissions from *Petroleum Refining (1.A.1.b) and Manufacture of solid fuels and other energy industries (1.A.1c)*

Manufacturing industries and construction

Total emissions from fuel combustion activities in the *Manufacturing industries and construction* sectors are shown in Figure 3.10. Emissions from this sector include disaggregated estimates from the *Iron and Steel* and *Non-ferrous Metals* and aggregated emissions for the remainder of 1A2. Emissions from the remainder of 1A2 emissions are reported at an aggregated level because of insufficient data to disaggregate these emissions per manufacturing industry.

Emissions from *Iron & Steel* and *Non-Ferrous Metals* make up approximately 9% of the total 1A2 emissions.

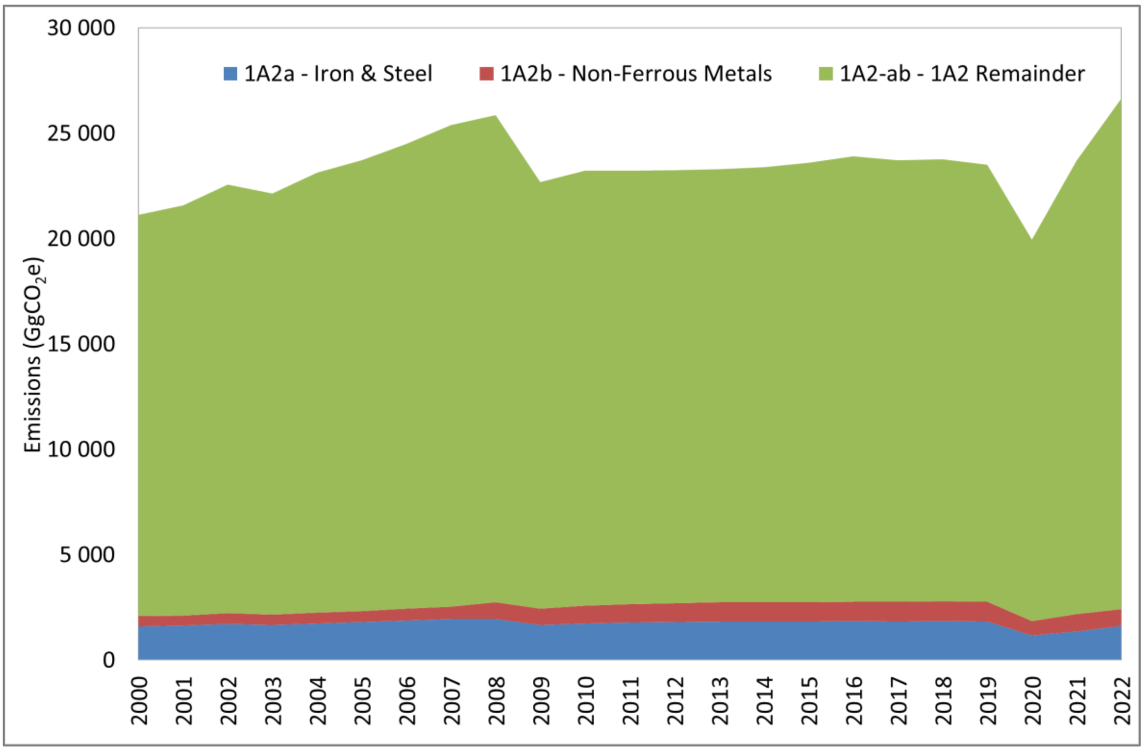

Figure 3.10: 1A2 Disaggregated emissions 2000 - 2022

Figure 3.11 shows the trends in fuel use in the *Manufacturing industries and construction* sector. Coal usage dominants the energy demand in industry in South Africa.

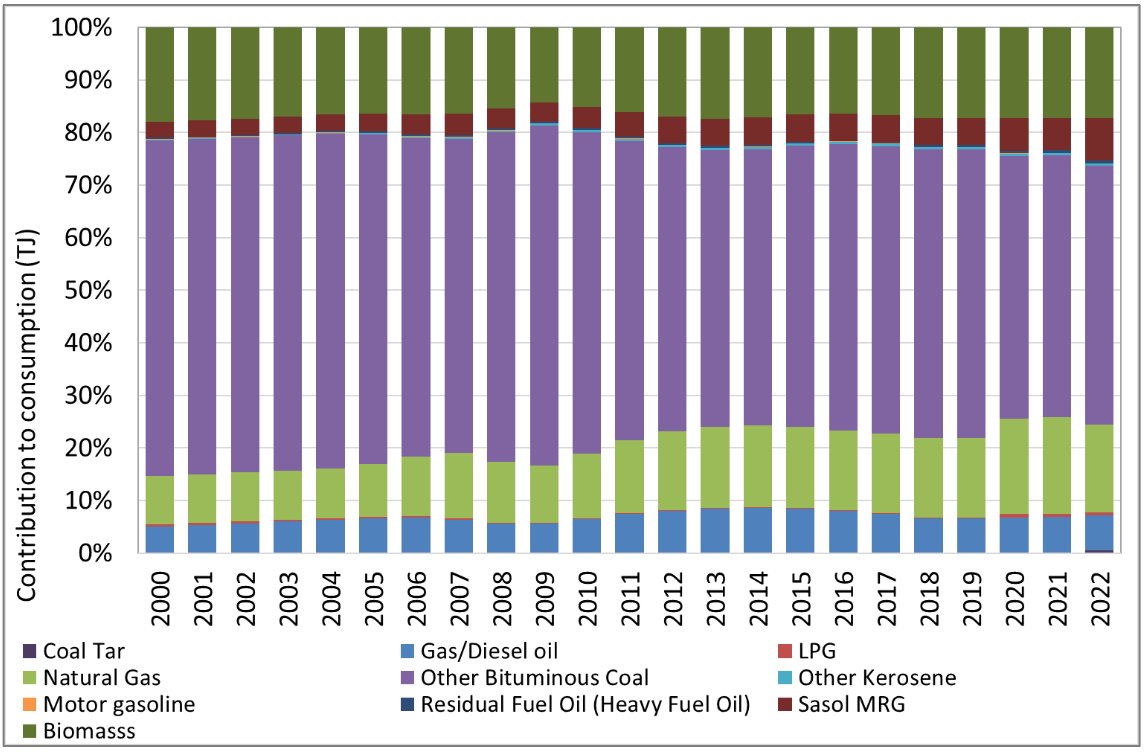

Figure 3.11: Manufacturing industries and construction – fuel consumption contributions

There was a significant increase (34%, see Table 3.2) in emissions between 2020 and 2022 and this is aligned with the significant increase (23%) in emissions from the IPPU sector during this period. However, the increase in emissions from 1A2 is more than that of the IPPU sector because in addition to the energy demand required for IPPU sectors, 1A2 also captures the energy demand in other industry sectors, such as the food industry, that are not reported under IPPU.

Transport

Historical emissions from different modes of transport are shown in Table 3.2. *Road transport* has always contributed the most to Transport sector emissions. Figure 3.12 shows the sub-sector contributions for 2022.

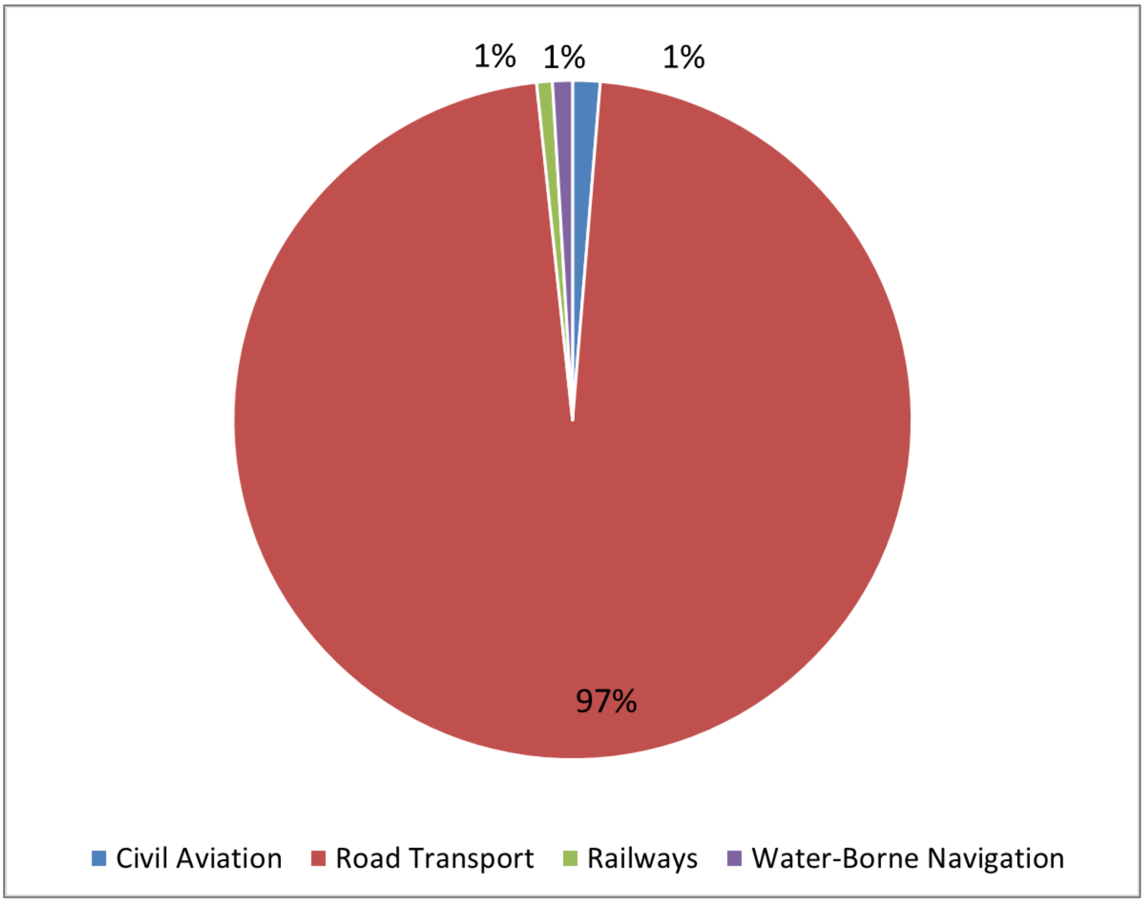

Figure 3.12: Transport sector emission contributions, 2022

Civil Aviation, Railway Transport & Waterborne navigation (1.A.3.a, 1.A.3.c & 1.A.3.d)

Emissions from civil aviation, railway transport and waterborne navigation cumulatively contribute 3 % of the *Transport* sector emissions in 2022. In South Africa these three modes of transportation typically use jet fuel, diesel and fuel oil.

Figure 3.13 shows the annual changes of volumes sold for these fuels since 2018. In 2020, jet fuel experienced the largest decrease sales which in turn resulted in a large drop in emissions from *Civil aviation*.

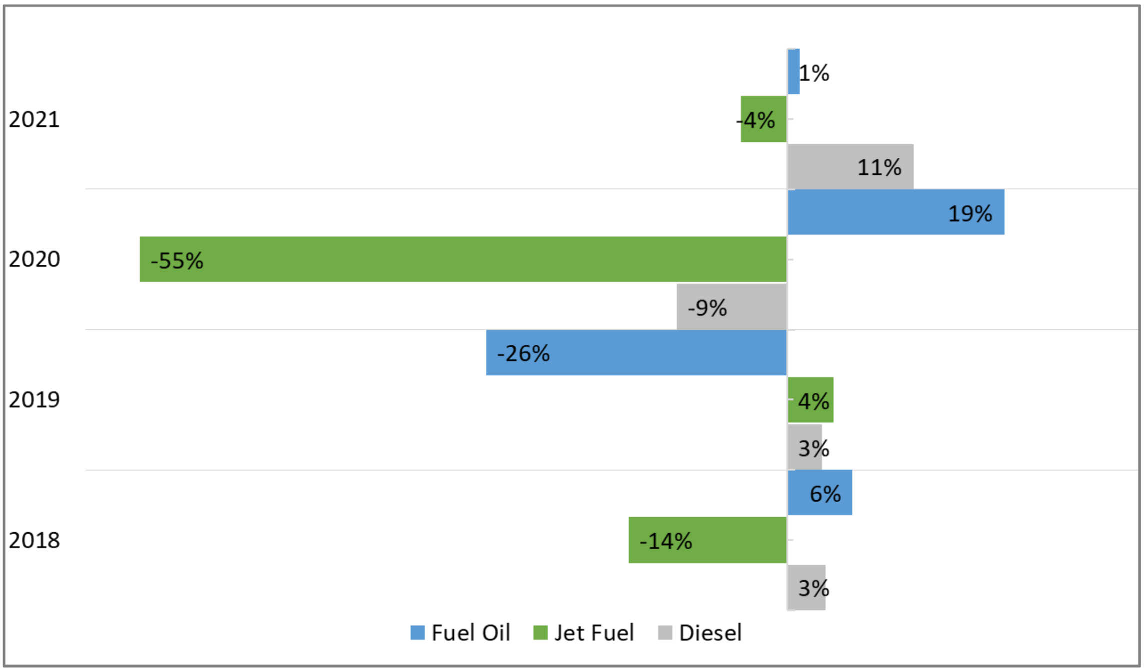

Figure 3.13: Annual volume changes for fuel oil, jet fuel and diesel sold since 2018[7]

Road Transport (1.A.3.b)

The share of diesel consumption for *Road transportation* has increased significantly since 2000, from 34% to 55%. This trend has resulted in a decrease in motor gasoline consumption from 66 % to 45 % (see Figure 3.14).

Figure 3.15 shows the historical price of both motor gasoline and diesel since 2018. Although the price for both fuels has been increasing, on average the diesel price has been 9% lower than the price of motor gasoline.

[7] *Data from SAPIA 2021 Annual Report, https://www.sapia.org.za/wp-content/uploads/2023/01/SAPIA_AR-2021_Final_LR.pdf*

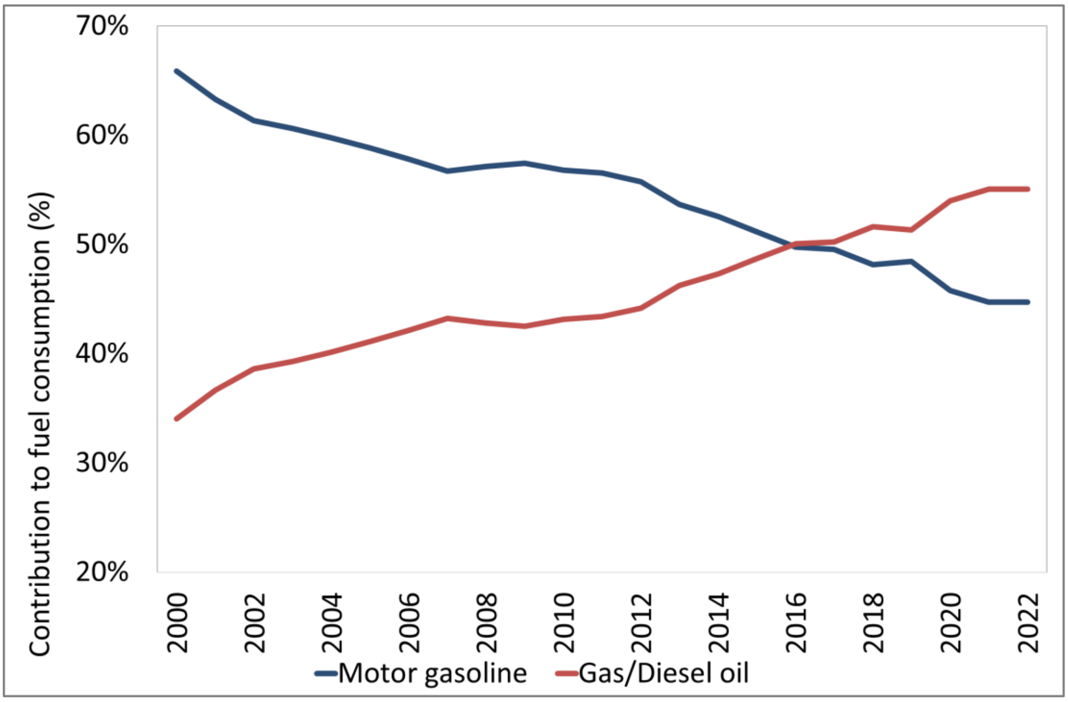

Figure 3.14: Historical share of diesel and motor gasoline consumption for road transportation

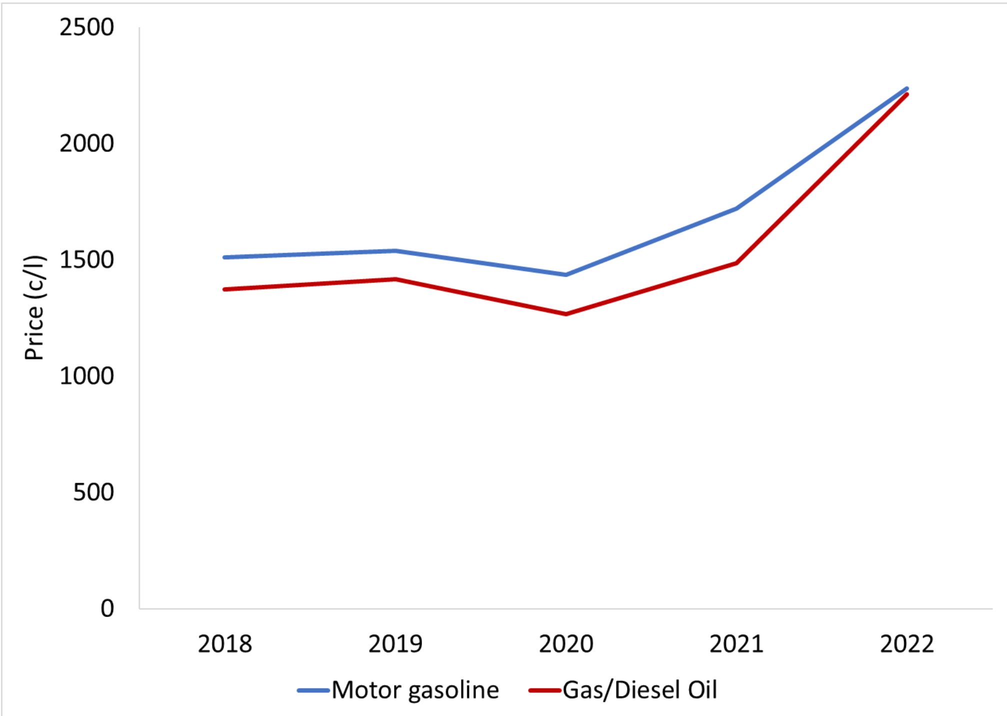

Figure 3.15: Historical fuel prices for motor gasoline and diesel[8]

[8] *Figure 3.15 shows the simple average price for the different variations of both motor gasoline and diesel found across the country. https://www.sapia.org.za/old-fuel-prices/*

Other sectors

Table 3.5 shows the disaggregated and total emissions from *Other* sectors. The *Commercial/institutional* and *Residential* sectors have both significantly contributed to emissions *Other* sectors.

Table 3.5: Trend in emissions from other sectors, 2000 – 2022.

	Commercial/ Institutional	Residential	Agriculture/ Forestry/ Fishing/ Fish farms	Total
	Gg CO_2e			
2000	20 604	27 550	2 416	50 570
2001	20 339	24 999	2 428	47 766
2002	20 163	22 658	2 456	45 277
2003	21 056	20 540	2 520	44 116
2004	22 537	18 415	2 574	43 526
2005	21 851	18 443	2 573	42 867
2006	9 054	16 312	2 597	27 964
2007	9 808	18 156	2 650	30 614
2008	11 301	19 778	2 691	33 769
2009	12 609	20 868	2 759	36 237
2010	7 978	8 365	2 945	19 287
2011	5 813	9 720	3 144	18 677
2012	3 666	8 777	3 074	15 517
2013	1 753	2 590	3 012	7 354
2014	1 783	2 433	2 999	7 215
2015	1 560	2 274	3 013	6 847
2016	10 487	2 164	3 060	15 711
2017	6 805	2 820	3 102	12 727
2018	13 362	2 178	3 143	18 682
2019	14 615	2 970	3 132	20 718
2020	10 985	3 165	3 044	17 194
2021	11 667	3 799	3 058	18 524
2022	12 077	3 858	3 095	19 029

Emissions from the *Commercial/Institutional* sector have significantly fluctuated and have overall decreased by 41 % since 2000. This decrease in emissions is aligned with the fuel consumption trends for the sector (see Figure 3.16). Although overall emissions have decreased over the years, there has been an increase in diesel, other kerosene and motor gasoline consumption likely in response to increased loadshedding.

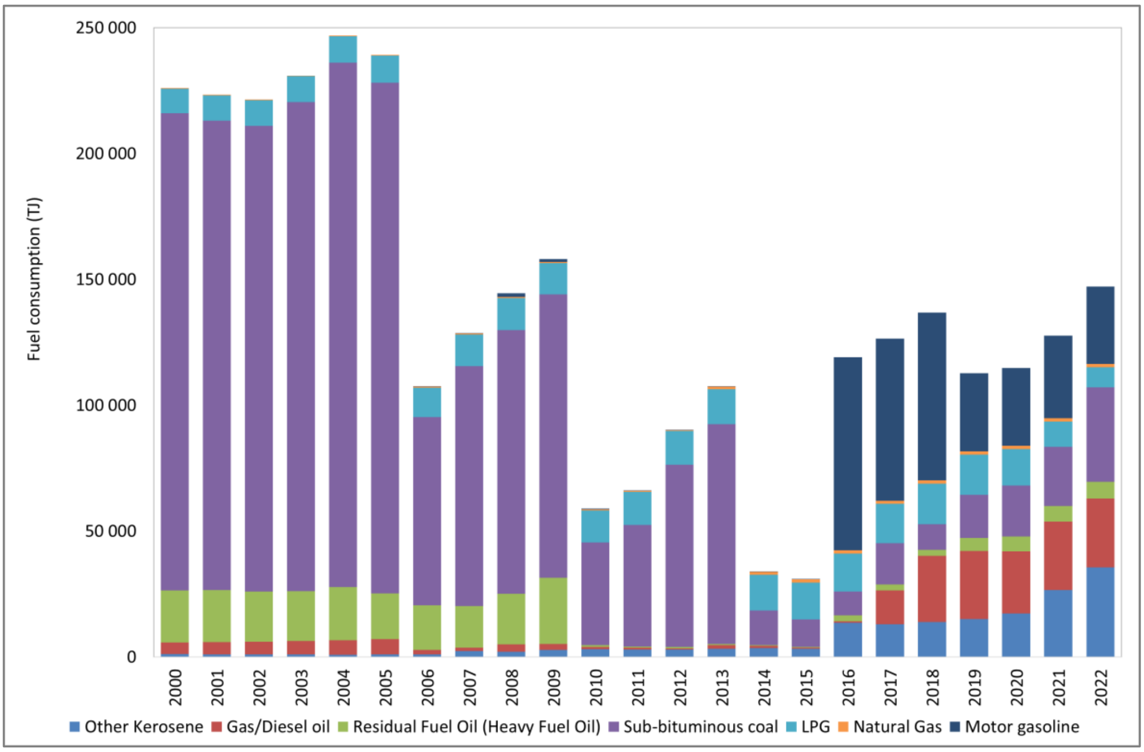

Figure 3.16: Fuel consumption trends for the Commercial/Institutional sector

Emissions from the *Residential* sector have significantly decreased steadily by 86% since 2000 and this is aligned with the energy supply trends in households seen in Figure 3.17. The number of households using electricity and other electricity (i.e. generators) has increased since 2002 and because of this the number of households using fuels for cooking have also decreased since 2002, with the exception of the use of gas which has been increasing since 2012.

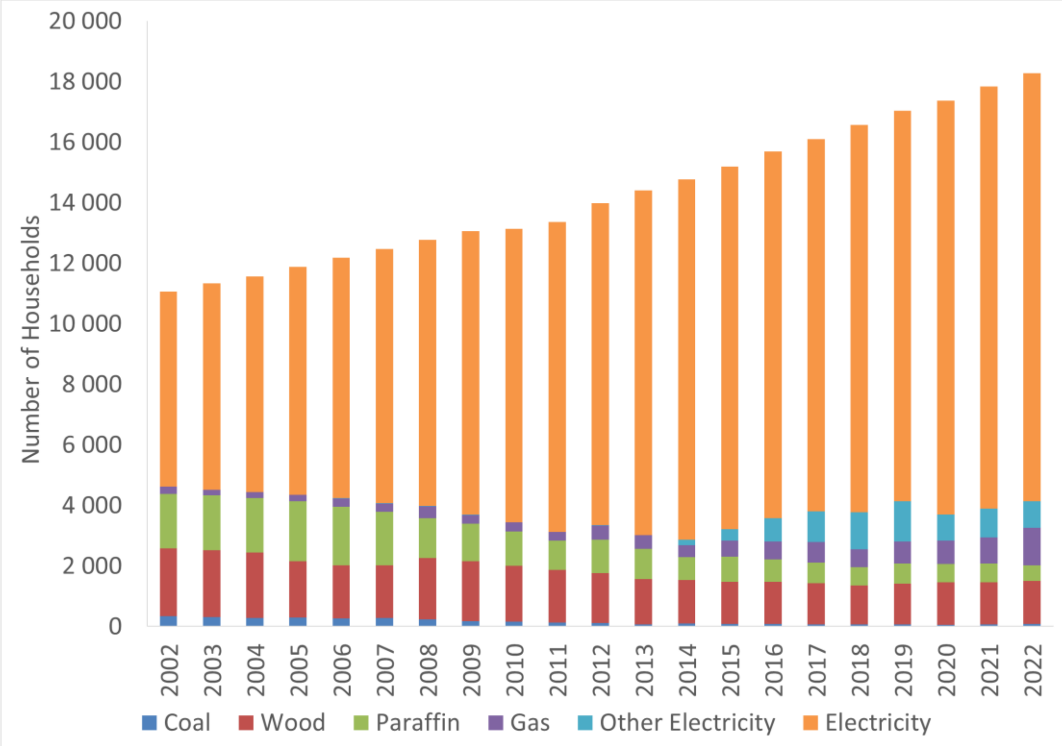

Figure 3.17: Trends in household energy supply for cooking[9]

Non-specified

The *Non-specified* category is used to report on other *Fuel Combustion* activities that do not fall under the other four sectors (*Energy industries*, *Manufacturing and construction, Transport* & *Othe*r). Emissions allocated to the category are shown in Table 3.2. In 2022, this category made up 6% of the emissions from *Fuel Combustion* activities.

3.1.1.2 Fugitive emissions from fuels

The *Fugitive emissions from fuels* sector in 2022 contributed 7.7% to total emissions from the *Energy* sector. The majority of these emissions are from the *Other emissions from energy production*. Table 3.6 shows total historical disaggregated emissions.

Table 3.6: Trend in fugitive emissions, 2000 – 2022.

	Solid Fuels	Oil and Natural Gas	Other Emissions	Total

[9] *Figure 3.17 shows the cooking energy supply trends of households since 2002. This data excludes the "Other" proportion (which contributes on average about 1% each year) from the StatsSA data. GHS 2020 P0318 (statssa.gov.za)*

			from Energy Production	
	Gg CO_2e			
2000	2 028	765	31 096	33 889
2001	2 077	766	31 325	34 167
2002	2 193	972	31 325	34 489
2003	2 647	1 483	30 190	34 320
2004	2 467	1 403	32 027	35 896
2005	2 633	1 180	28 217	32 030
2006	2 658	1 152	28 057	31 867
2007	2 701	1 150	28 523	32 374
2008	2 667	1 157	27 129	30 954
2009	3 063	1 266	27 426	31 755
2010	2 917	982	27 206	31 105
2011	2 685	805	26 817	30 307
2012	2 655	659	27 821	31 135
2013	2 794	686	28 227	31 707
2014	2 765	783	27 783	31 331
2015	2 609	728	27 343	30 680
2016	2 526	744	27 548	30 818
2017	2 662	625	28 446	31 733
2018	2 697	755	27 548	31 000
2019	2 408	666	28 362	31 436
2020	3 292	434	28 381	32 108
2021	3 208	154	27 973	31 335
2022	2 293	94	26 410	28 798

Solid fuels

Emissions from *Solid Fuels* have not varied significantly since 2000 and this is due to slight annual changes in coal production as shown in Figure 3.18.

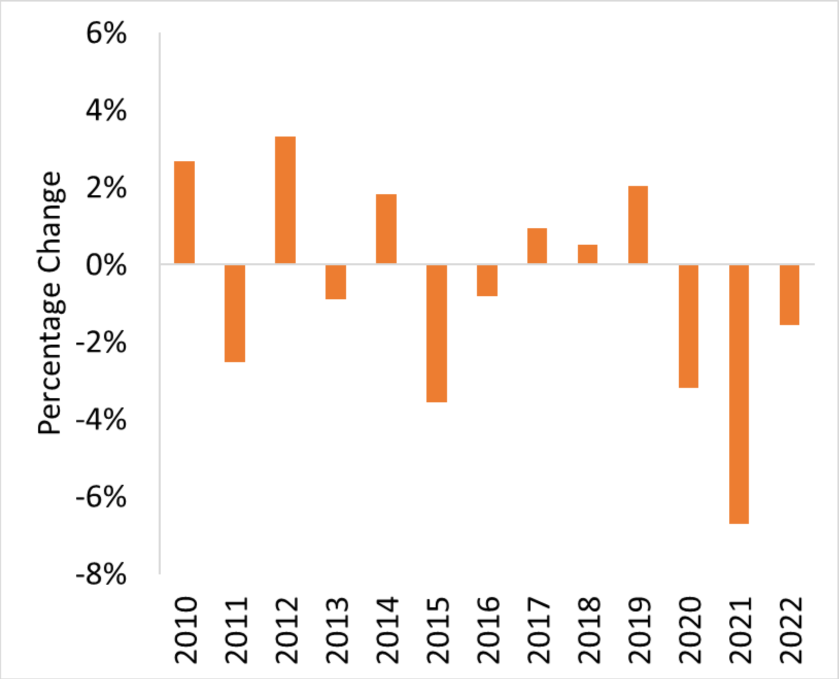

Figure 3.18: Annual change in Coal Production, 2010 - 2022[10]

Oil and natural gas

Emissions from the *Oil and natural gas* industry have contributed the least (< 5%) to the *Fugitive emissions from fuels* sector since 2000. Additionally, emissions from the *Oil and natural gas* industry have been decreasing steadily. Two refineries have shut down since 2020 and although the remaining refineries still operational they have not been processing any crude oil in the recent years.

Other emissions from energy production

Other emissions from energy production have, on average, accounted for 89% of *Fugitive emissions from fuels* sector since 2000.

3.1.2 Overview of methodology and completeness

Emissions for the *Energy* sector were estimated with a sectoral approach. Table 3.7 provides a summary of the methods and emission factors applied to each subsector.

[10] *Annual percentage change based on annual indexed coal production data from StatsSA. https://www.statssa.gov.za/publications/P2041/P2041May2023.pdf*

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 activitie**										
1A1	***Energy industries***										
	a. Main activity electricity and heat production	T2	CS	T1	DF	T1	DF	NE	NE	NE	NE
	b. Petroleum refining	T1, T2	DF, CS	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	CS	T1	DF	T1	DF	NE	NE	NE	NE
	b. Road transportation	T2	CS	T1	DF	T1	DF	NE	NE	NE	NE
	c. Railways	T2	CS	T1	DF	T1	DF	NE	NE	NE	NE
	d. Water-borne navigation	T2	CS	T1	DF	T1	DF	NE	NE	NE	NE
	e. Other transportation	NO		NO		NO		NO	NO	NO	NO
1A4	***Other sectors***										
	a. Commercial/ Institutional	T1, T2	DF, CS	T1	DF	T1	DF	NE	NE	NE	NE
	b. Residential	T1, T2	DF, CS	T1	DF	T1	DF	NE	NE	NE	NE
	c. Agriculture/ Forestry/ Fishing/ Fish farms	T1, T2	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		IE	IE	IE	IE
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						
	b. Uncontrolled combustion and burning coal dumps	NE		NE		NE		NE	NE	NE	NE
	c. Solid fuel transformation	T1	DF	T1	DF	T1	DF	NE	T1	NE	NE
1B2	***Oil and natural gas***										
	a. Oil	T3		T3		T3		NE	NE	NE	
	b. Natural gas	T3		T3		T3		NE	NE	NE	
1B3	***Other emissions from energy production***	T3		T3		NO		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									

3.1.3 Improvements and recalculations

Recalculations were performed for the Energy sector because of the following reasons:

- The use of country-specific emission factors for commonly used liquid and gas fuels. The emission factors result from a study that was completed in 2022. Emissions from the entire time-series were recalculated for the applicable *Fuel combustion* activities.

- Estimates from 1A2 were recalculated based on data from SAGERS and disaggregated to include emissions from 1A2a *Iron & Steel*, 1A2b *Non-ferrous Metals* and 1A2-ab the remainder of 1A2.
- Inclusion of emissions from charcoal and coke production under 1B1c for the entire time-series.
- Recalculation of 2019 and 2020 emissions estimates, where applicable[11], based on the updated activity data from the energy balance.

The improvements mentioned above resulted in the current inventory being 2.3% lower than the previous inventory estimates.

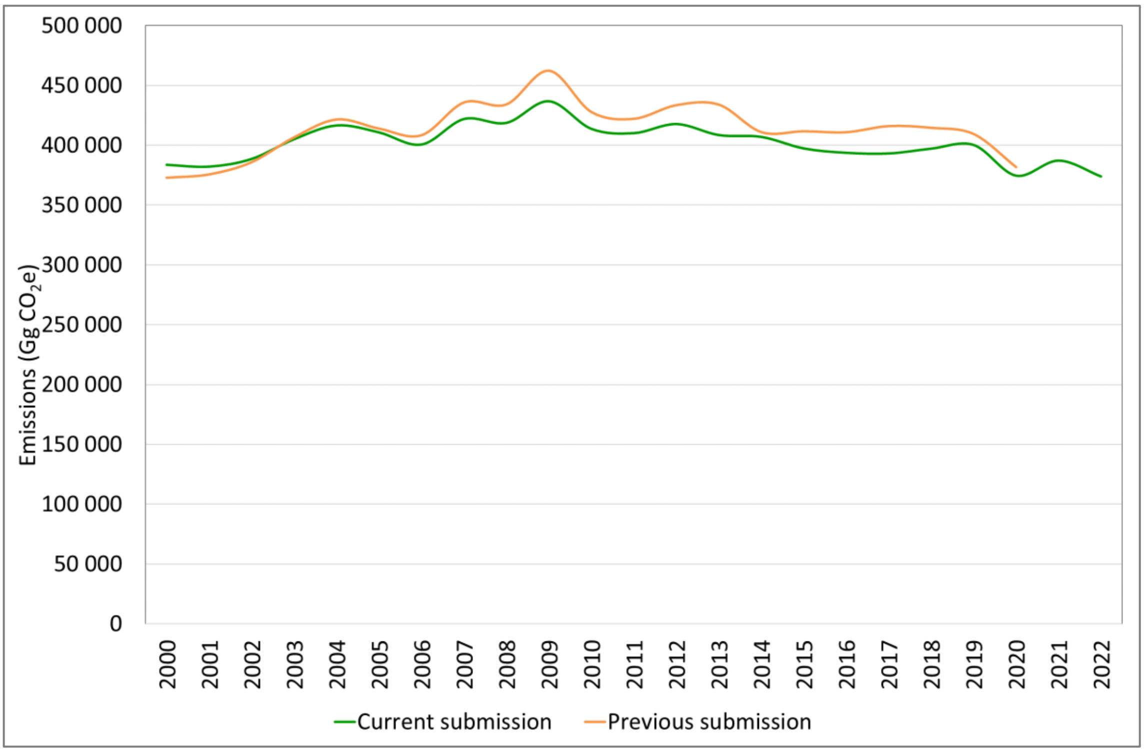

Figure 3.19: Recalculations for the Energy sector between 2000 and 2022.

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.

[11] *This only affects categories 1A4 and 1A5*

The following categories are new to the top 30 key categories indicated in Table ES 3:

- 1A3a – *Domestic aviation* - CO_2
- 1A1 – *Energy industries* – gaseous fuels CO_2
- 1B3 – *Other emissions from energy production* – CH_4
- 1A5 *Other – liquid fuels* – CO_2

These additions to the key category list are mainly due to the observed trend of the respective emissions, i.e. a significant decrease, since 2000.

Table 3.8: Key categories identified in the Energy sector.

IPCC code	IPCC Category	GHG#	Criteria
1.A.3.b	Road Transportation – Liquid Fuels	CO_2	L,T
1.A.1	Energy Industries – Solid Fuels	CO_2	L,T
1.A.5	Other – Solid Fuels	CO_2	L,T
1.B.3	Other emissions from energy production	CO_2	L,T
1.A.4	Other Sectors – Liquid Fuels	CO_2	L,T
1.A.3.a	Domestic Aviation	CO_2	T
1.A.1	Energy Industries – Gaseous Fuels	CO_2	T
1.A.5	Other – Liquid Fuels	CO_2	T
1.A.4	Other Sectors – Solid Fuels	CO_2	L,T
1.B.3	Other emissions from energy production	CH_4	L
1.A.2	Manufacturing Industries and Construction – Gaseous Fuels	CH_4	L,T
1.B.2	Oil and Natural Gas	CO_2	T
1.B.1.a	Coal mining & handling	CH_4	L
1.A.4	Other Sectors – Gaseous Fuels	CO_2	T
1.A.2	Manufacturing Industries and Construction – Solid Fuels	CO_2	L,T
1.A.1	Energy Industries – Liquid Fuels	CO_2	L,T
1.A.2	Manufacturing Industries and Construction – Liquid Fuels	CO_2	L,T

3.1.5 QA/QC process and verification

Generic QA/QC measures were conducted for the *Energy* sector calculation file, as indicated in Table 3.9.

Table 3.9: QA/QC measures for the Energy sector inventory

QA/QC principle	Check
Accuracy	Activity data source
Accuracy	Correct units
Accuracy	Unit carry through
Accuracy	Method validity
Accuracy	Calculations check
Accuracy	Uncertainties
Accuracy	Double counting
Accuracy	Correct GWP
Accuracy	Notation keys
Accuracy	Calorific values
Accuracy	Oxidation factors
Accuracy	Carbon content
Accuracy, Completeness, Consistency, Transparency	Trend check
Accuracy, Transparency	Emission factor applicability
Accuracy, Transparency, Consistency, Completeness	Recalculations
Completeness, Comparability	Sub-category completeness
Consistency	Time series consistency
Transparency	Documentation
Transparency, Completeness, Consistency, Accuracy	Colour coding
Accuracy, Comparability	Cross check data
Accuracy	Spot checks
Transparency, Consistency	Data source referencing
Transparency	Links to source data
Transparency	Raw primary data
Accuracy	QA review

3.1.6 Planned improvements

Improvements planned for the Energy sector are as follows:

- Moving to country-specific CO_2 factors for key solid fuels. A study was initiated in 2023 to determine the country-specific carbon contents, NCVs and emission factors for commonly used solid fuels.
- Improving activity data for fuel wood consumption in different sub-sectors.
- Including emissions from abandoned mines and spontaneous combustion.
- Disaggregating the uncertainty assessment to align with the disaggregation used for key category analysis.

3.2 Fuel combustion (1.A)

3.2.1 Comparison between sectoral and reference approach

The emissions reported for *Fuel combustion* activities are estimated using the Sectoral Approach. The Reference Approach was also used estimate emissions and the comparison of the two approaches is shown in Figure 3.20. The comparison is done until 2020 in accordance with the latest energy balance data from the DMRE.

The Reference Approach resulted in higher estimates than the Sectoral Approach, as was the case with previous inventories. On average the Sectoral Approach has resulted in estimates that are 19% lower since 2000.

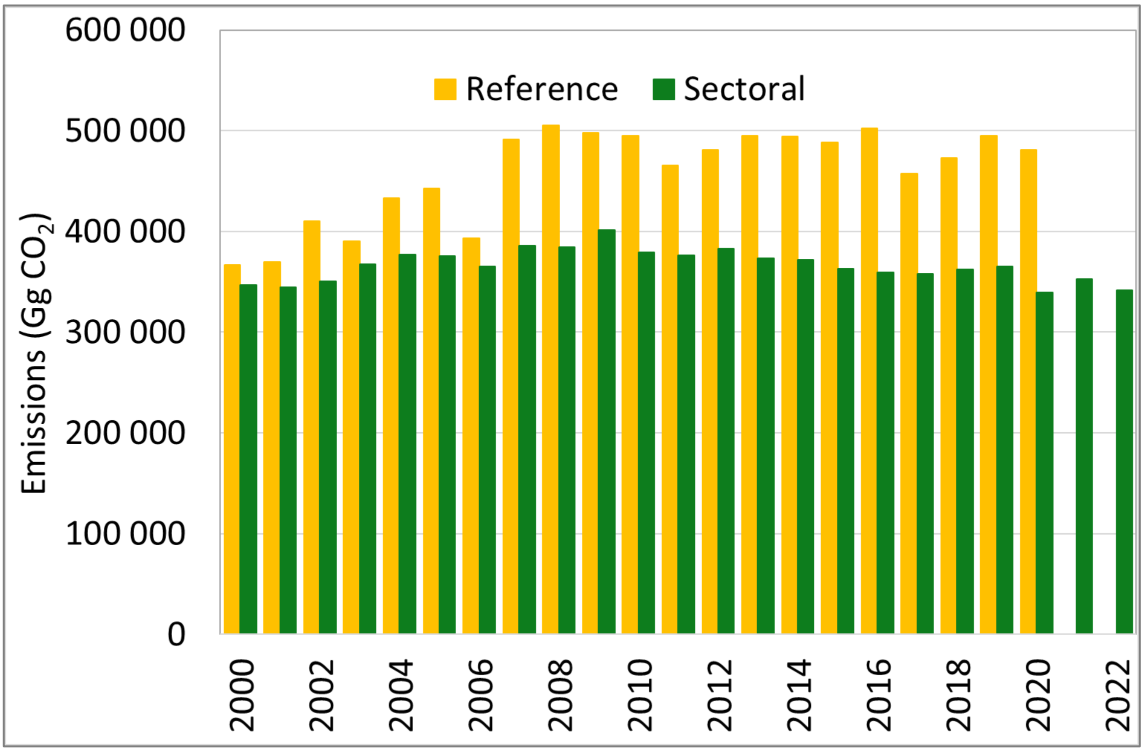

Figure 3.20: Comparisons between the reference and sectoral approach of determining the CO_2 emissions for the energy sector for South Africa.

Appendix D shows the comparison between the Reference and Sectoral Approach for solid, fuel and gaseous fuels consumption between 2000 and 2020. The Sectoral Approach, on average, shows consumption that is 30% lower for solid fuels, 6% higher for liquid fuels and 20% lower for gaseous fuels. The difference in consumption and estimates for both approaches is due to:

- 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.
- 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.
- 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.

3.2.2 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.

3.2.3 Common Data used for Fuel Combustion Activities

This section outlines the net calorific values, densities (Table 3.10) and emission factors (Table 3.11) used to estimate emissions from fuels used in under the various Fuel Combustion subcategories.

Table 3.10: Net calorific values for solid, liquid and gaseous fuels[12]

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	0.765
	Diesel	35.5	MJ/l	0.826
	Heavy Fuel Oil	43	MJ/kg	0.994
	Fuel Oil 180	42	MJ/kg	0.99
	Petrol	32.5	MJ/l	0.741
	Avgas (100LL)	33.9	MJ/l	0.714
	Jet Fuel (Jet-A1)	37.5	MJ/l	0.79
Gaseous fuels	LPG	46.29	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	

Table 3.11: IPCC default and country-specific emission factors for fuel combustion[13]

Fuel		CO_2		CH_4	N_2O
		DF (Tier 1)	CS (Tier 2)	DF (Tier 1)	DF (Tier 1)
Liquid	Motor gasoline	69 300	72 430	3	0.6
	Aviation gasoline	70 000	65 752	3	0.6
	Jet gasoline	70 000	65 752	3	0.6
	Jet kerosene	71 500	73 463	3	0.6
	Other kerosene	71 900	64 640	3	0.6
	Gas/Diesel oil	74 100	74 638	3	0.6
	Residual fuel oil	77 400	73 090	3	0.6
	Liquified petroleum gases	63 100	64 852	1	0.1
	Bitumen	80 700	NA	3	0.6
	Petroleum coke	97 500	NA	3	0.6
Solid	Anthracite	98 300	NA	1	1.5
	Coking coal	94 600	NA	1	1.5
	Other bituminous coal	94 600	NA	1	1.5
	Sub-bituminous coal	96 100	96 250	1	1.5
	Coke oven coke and lignite coke	107 000	NA	1	1.5
	Gas coke	107 000	NA	1	0.1

[12] *Values are from the South African Petroleum Industry Association (SAPIA) and from the study Development of country-specific CO_2 emissions factors for key liquid and gaseous fuels in South Africa https://energyjournal.africa/article/view/13592*

[13] *Country-specific emission factors for liquid and gaseous fuels are from the study Development of country-specific CO_2 emissions factors for key liquid and gaseous fuels in South Africa https://energyjournal.africa/article/view/13592*

Fuel		CO_2		CH_4	N_2O
		DF (Tier 1)	CS (Tier 2)	DF (Tier 1)	DF (Tier 1)
	Gas works gas	44 400	NA	1	0.1
	Coke oven gas	44 400	NA	1	0.1
	Blast furnace gas	260 000	NA	1	0.1
	Oxygen steel furnace gas	182 000	NA	1	0.1
	Wood/wood waste	112 000	NA	30	4
	Other primary solid biomass	100 000	NA	30	4
	Charcoal	112 000	NA	30	4
Gases	Natural gas	56 100	55 709	1	0.1

South Africa's country-specific CO_2 emission factors were higher than the IPCC default emission factors for motor gasoline (5%), jet kerosene (3%), diesel (1%), LPG (3%) and sub-bituminous coal (0.2%). On the other hand, the country-specific CO_2 emission factors were lower than the default emission factors for aviation gasoline (6%), jet gasoline (6%), other kerosene (10%) and residual fuel oil (6%).

The country-specific CO_2 emission factors in Table 3.11 were developed from studies that included collecting fuel samples from across the country and during different seasons, where applicable.[14] Hence, even though these emission factors may differ from the IPCC default emissions factors, they more accurately represent the fuels used in the country.

3.2.4 Energy industries (1.A.1)

3.2.4.1 Category description

The *Energy Industries* sub-category includes fuel combustion activities from the following industries:

- 1A1a *Electricity and heat production* – In South Africa's inventory this is further disaggregated into main electricity producer and other electricity producers and hence includes all emissive electricity production plants that feed into the national grid. Emissions from auto-producers are accounted for under the respective main industry for which the fuel combustion occurs.
- 1A1b *Petroleum refining* – this includes all fuel combustion emissions from crude oil refining. Emissions from this activity have been decreasing due to limited oil reserves and the closure of major refineries in the recent years.

[14] *LPG is the only exception due to limitations on analysis. More details on this can be found in the journal article for the study. https://energyjournal.africa/article/view/13592*

- 1A1c *Manufacture of solid fuels and other energy industries* – this includes fuel combustion emissions associated with the production of secondary and tertiary fuels.

3.2.4.2 Methodological issues

Table 3.7 indicates the type of methods and emission factors used for all categories under the Energy sector, including at sub-category level.

The activities shown in Table 3.12 were indicated as key categories in the 2000-2020 inventory. Emissions from 1A1a *Electricity and Heat Production* (solid) and 1A1c *Manufacture of solid fuels and other energy industries* (liquid) were estimated using higher tier methods for the 2000-2020 inventory. Hence, no change in methodology was required for these sub-categories for the 2000-2022 inventory.

However, to ensure that good practise was followed, changes in methodology were required for emissions from 1A1a *Electricity and Heat Production* (liquid) and 1A1b *Petroleum Refining* (gas). These changes are indicated in Table 3.12. The only deviation is the estimation of emissions from refinery gas under 1A1b *Petroleum Refining*, which still uses Tier 1 and the IPCC default emission factor. This deviation is due to a lack of country specific emission factors.

Table 3.12: Methodological details - *Energy Industries*

2000-2020 Key category	2000-2020 inventory		2000-2022 inventory		Notes
	Method	Emission Factor	Method	Emission Factor	
1A1a Electricity and heat production (solid, CO_2)	T2	CS	T2	CS	NA
1A1a Electricity and heat production (liquid, CO_2)	T1	DF	T2	CS	Emissions from all liquid fuels estimated using CS parameters.
1A1b Petroleum refining (gas, CO_2)	T1	DF	T1, T2	DF, CS	Natural gas: T2, CS MRG: T2, CS Refinery gas: T1, DF
1A1c Manufacture of solid fuels and other energy industries (liquid, CO_2)	T3	NA	T3	NA	NA

Activity data

Table 3.13 shows the type and sources of activity data used to estimate emissions from 1A1 *Energy industries*. Majority of the activity data for the *Energy industries* sub-category is now retrieved from the SAGERS with the assistance of the NGERs. Table 3.14 shows the trend in fuel consumption for 1A1a and 1A1b.

Table 3.13: Activity data used for 1A1 *Energy Industries*

Sub-category	Activity Data	Source
1A1a *Electricity & heat production*	Fuel consumption for both main and other electricity producers	Electricity producers SAGERS
	NCVs & densities	SAGERS Kornelius *et al 2023*
1A1b *Petroluem refining*	Fuel consumption	Refineries SAGERS
	NCVs & densities	Kornelius *et al 2023*
1A1c *Manufacture of solid fuels & other energy industries*	NA – Emissions sourced from	Producers SAGERS

Table 3.14: Trend in fuel consumption for the various categories in the energy industry sector, 2000 – 2022.

	Public electricity producer	Other electricity producer	Petroleum refining
	Fuel consumption (TJ)		
2000	1 806 317	117 430	59 638
2001	1 823 119	47 910	57 599
2002	1 883 709	51 923	50 680
2003	2 025 822	83 014	57 487
2004	2 126 649	65 100	53 292
2005	2 142 682	28 363	51 610
2006	2 155 477	40 100	55 121
2007	2 369 988	43 928	56 073
2008	2 271 791	36 489	57 870
2009	2 335 101	62 276	56 523
2010	2 406 936	20 594	52 520
2011	2 426 965	8 346	50 235
2012	2 537 365	11 206	51 049
2013	2 477 632	11 129	51 890
2014	2 423 731	11 414	51 504
2015	2 343 934	11 250	51 118

	Public electricity producer	Other electricity producer	Petroleum refining
	Fuel consumption (TJ)		
2016	2 259 087	1 943	50 731
2017	2 233 426	6 887	50 345
2018	2 221 443	6 887	50 147
2019	2 199 965	46 215	49 952
2020	2 116 465	25 074	52 844
2021	2 165 560	32 941	35 140
2022	2 028 038	25 307	17 065

Emission factors

The emission factors used are shown in Table 3.11. Where a country-specific emission factor is available, it was used to estimate emissions from that fuel.

3.2.4.3 Uncertainty

The uncertainties for activity data and the emission factors used to estimate emission from *Energy Industries* is shown in Table 3.15.

Table 3.15: Uncertainty for the *Energy Industries* category.

Gas	Sectors	Activity data uncertainty		Emission factor uncertainty	
		%	Source	%	Source
CO_2	1A1a Electricity generation – liquid	5	IPCC 2006	7	IPCC 2006
	1A1a Electricity generation – solid	5	IPCC 2006	7	IPCC 2006
	1A1b Petroleum refining – liquid	5	IPCC 2006	7	IPCC 2006
	1A1b Petroleum refining – gaseous	5	IPCC 2006	7	IPCC 2006
	1A1c Manufacture of solid fuels – liquid	5	IPCC 2006	7	IPCC 2006
CH_4	1A1a Electricity generation – liquid	5	IPCC 2006	75	IPCC 2006
	1A1a Electricity generation – solid	5	IPCC 2006	75	IPCC 2006
	1A1b Petroleum refining – liquid	5	IPCC 2006	75	IPCC 2006
	1A1b Petroleum refining – gaseous	5	IPCC 2006	75	IPCC 2006
	1A1c Manufacture of solid fuels – liquid	5	IPCC 2006	75	IPCC 2006
N_2O	1A1a Electricity generation – liquid	5	IPCC 2006	75	IPCC 2006
	1A1a Electricity generation – solid	5	IPCC 2006	75	IPCC 2006
	1A1b Petroleum refining – liquid	5	IPCC 2006	75	IPCC 2006
	1A1b Petroleum refining – gaseous	5	IPCC 2006	75	IPCC 2006
	1A1c Manufacture of solid fuels – liquid	5	IPCC 2006	75	IPCC 2006

3.2.4.4 Time-series consistency

1A1a Electricity and heat production

The time-series for 1A1a *Electricity and heat production* is incomplete with regards to fuel consumption data for diesel from other electricity producers prior to 2019. In the last two years diesel has not contributed more than 0.6% to the total fuel consumption for other electricity producers.

Additionally, the time-series is not consistent because from 2019 onwards data from the SAGERS is used as it is regarded to be more accurate.

1A1b Petroleum refining

The time-series for 1A1b *Petroleum refining* is incomplete with regards to fuel consumption data for diesel, natural gas, MRG and LPG prior to 2019. In the last two years these fuels have not contributed more than 8% to the total fuel consumption for the sub-category.

Additionally, the time-series is not consistent because from 2019 onwards data from the SAGERS is used as it is regarded to be more accurate.

1A1c Manufacture of solid fuels and other energy industries

The time-series for 1A1c *Manufacture of solid fuels and other energy industries* is complete and consistent from 2000-2022.

3.2.4.5 Category specific QA/QC and verification

The QA/QC measures indicated in Table 3.9 were used for this category.

3.2.4.6 Category specific improvements and recalculations

Recalculations were performed for the *Energy industries* sector because of the following improvement:

- The use of country-specific emission factors for commonly used liquid and gas fuels. The emission factors result from a study that was completed in 2022. Emissions from the entire time-series were recalculated for the applicable *Fuel combustion* activities.

3.2.4.7 Category specific planned improvements

Improvements planned specifically for the *Energy Industries* sector are as follows:

- Completing the time-series for:
  - diesel consumption from other electricity producers prior to 2019 for 1A1a Electricity and Heat Production.
  - diesel, natural gas, MRG and LPG consumption prior to 2019 for 1A1b Petroleum *refining*.

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

3.2.5.1 Category description

The *Manufacturing industries and construction* sub-category includes fuel combustion activities from the industries shown in Table 3.16. In previous inventories emissions from this sub-category were reported at an aggregated level due to lack of information to disaggregate the fuel use. Table 3.16 also shows the new disaggregation used for reporting the 2000 – 2022 inventory.

Table 3.16: Disaggregation of Manufacturing industries and construction category for reporting

Reporting group	Activities included
1A2a	1A2a Iron & Steel
1A2b	1A2b Non-ferrous Metals
1A2-ab	1A2c Chemicals 1A2d Pulp, Paper & Print 1A2e Food Processing, Beverages & Tobacco 1A2f Non-metallic Minerals 1A2g Transport Equipment 1A2h Machinery 1A2i Mining & Quarrying 1A2j Wood & Wood Products 1A2k Construction 1A2l Textile & Leather 1A2m Brick Manufacturing 1A2n Manufacture of ceramic products

3.2.5.2 Methodological issues

Table 3.7 indicates the type of methods and emission factors used for all categories under the Energy sector, including at sub-category level.

The activities shown in Table 3.17 were indicated as key categories in the 2000-2020 inventory. To ensure that good practise was followed, changes in methodology were required for emissions from all fuel types used in the *Manufacturing industries and construction* sector. However, the move to higher reporting tier was only possible for the liquid and gaseous fuels indicated in Table 3.11 with country-specific emission factors. Hence, there was a deviation with emissions estimated from other bituminous coal, biomass and coal tar due to lack of country-specific emission factors.

Table 3.17: Methodological details for the *Manufacturing industries and construction* category.

2000-2020 Key category	2000-2020 inventory		2000-2022 inventory		Notes
	Method	Emission Factor	Method	Emission Factor	
1A2 Manufacturing industries & construction (solid, CO_2)	T1	DF	T1	DF	NA
1A2 Manufacturing industries & construction (liquid, CO_2)	T1	DF	T1, T2	DF, CS	Coal Tar: T1, DF All others: T2, CS
1A2 Manufacturing industries & construction (gas, CO_2)	T1	DF	T2	CS	NA

Activity data

Fuel consumption data for the *Manufacturing industries and construction* sector is taken from SAGERS from 2020 to 2022 and calculated from 2000-2019 based on SAGERS data and the Fuel Consumption Study. Table 3.18 shows the fuel consumption trend for this sector.

Table 3.18: Fuel consumption (TJ) in the manufacturing industries and construction category, 2000 – 2022.[15]

	Diesel	LPG	NG	Coal	OK	Petrol	HFO	MRG	Bio	Total
	(TJ)									
2000	14 742	1 399	26 710	186 895	432	284	687	8 903	52 513	292 565
2001	15 897	1 377	27 397	190 082	340	310	714	9 132	52 631	297 879
2002	17 572	1 367	29 020	197 860	269	346	752	9 673	53 940	310 797
2003	18 173	1 234	28 118	193 902	227	356	729	9 373	51 561	303 674
2004	19 914	1 147	29 720	201 606	301	378	741	9 907	52 401	316 112
2005	21 522	1 011	32 792	204 047	524	384	747	10 931	53 482	325 440
2006	23 107	827	38 731	206 229	903	390	795	12 910	56 529	340 421
2007	22 618	617	44 093	211 501	1 217	377	869	14 698	58 169	354 159
2008	19 948	435	41 040	221 143	1 192	328	935	13 680	54 440	353 142
2009	17 084	288	33 500	196 613	1 004	249	877	11 167	43 401	304 183
2010	20 740	299	39 014	194 689	1 194	267	982	13 005	47 957	318 147
2011	24 319	336	45 460	186 577	1 326	288	1 051	15 153	52 853	327 362
2012	27 028	363	50 089	180 869	1 362	300	1 036	16 696	56 997	334 740
2013	28 701	376	52 315	178 419	1 417	309	979	17 438	59 023	338 980
2014	29 242	379	52 841	178 613	1 454	306	913	17 614	58 325	339 687
2015	28 617	373	52 494	181 544	1 457	293	867	17 498	56 290	339 432
2016	27 476	366	52 045	186 114	1 453	277	934	17 348	55 934	341 948
2017	25 438	354	51 412	186 102	1 425	258	1 098	17 137	56 829	340 054
2018	22 822	348	51 999	188 114	1 418	244	1 199	17 333	59 290	342 768
2019	22 568	344	51 420	186 020	1 403	241	1 185	17 140	58 630	338 952
2020	19 641	2 106	53 916	147 643	1 242	218	1 580	18 106	51 154	295 731
2021	23 691	2 059	64 986	174 905	1 471	259	1 827	21 217	60 802	351 509
2022	26 500	2 310	66 140	194 761	1 649	290	2 379	31 539	68 484	395 918

Emission factors

The emission factors used are shown in Table 3.11. Where a country-specific emission factor is available, it was used to estimate emissions from that fuel.

3.2.5.3 Uncertainty

The uncertainties for activity data and the emission factors used to estimate emission from *Energy Industries* is shown in Table 3.19.

[15] LPG – Liquified petroleum gases, NG – natural gas, Coal – other bituminous coal, OK – other kerosene, HFO – residual fuel oil, MRG – Sasol methane rich gas, Bio - biomass

Table 3.19: Uncertainty for the *Manufacturing industries and construction* category.

Gas	Sectors	Activity data uncertainty		Emission factor uncertainty	
		%	Source	%	Source
CO_2	1A2 Manufacturing industries and construction – liquid	10	IPCC 2006	7	IPCC 2006
	1A2 Manufacturing industries and construction – solid	10	IPCC 2006	7	IPCC 2006
	1A2 Manufacturing industries and construction – gaseous	10	IPCC 2006	7	IPCC 2006
CH_4	1A2 Manufacturing industries and construction – liquid	10	IPCC 2006	75	IPCC 2006
	1A2 Manufacturing industries and construction – solid	10	IPCC 2006	75	IPCC 2006
	1A2 Manufacturing industries and construction – gaseous	10	IPCC 2006	75	IPCC 2006
N_2O	1A2 Manufacturing industries and construction – liquid	10	IPCC 2006	75	IPCC 2006
	1A2 Manufacturing industries and construction – solid	10	IPCC 2006	75	IPCC 2006
	1A2 Manufacturing industries and construction – gaseous	10	IPCC 2006	75	IPCC 2006

3.2.5.4 Time-series consistency

The time-series for 1A2 *Manufacturing industries and construction* is complete.

3.2.5.5 Category specific QA/QC and verification

The QA/QC measures indicated in Table 3.9 were used for this category.

3.2.5.6 Category-specific recalculations

Recalculations were performed for the *Manufacturing industries and construction* sector because of the following improvements:

- The use of country-specific emission factors for commonly used liquid and gas fuels. The emission factors result from a study that was completed in 2022. Emissions from the entire time-series were recalculated for the applicable *Fuel combustion* activities.
- 1A2a and 1A2b was calculated separately and hence this led to a recalculation of the entire time-series to accommodate this improvement.

3.2.5.7 Category-specific planned improvements

Improvements planned specifically for the *Manufacturing industries and construction* sector are as follows:

- Disaggregating the remainder of the 1A2.

3.2.6 Transport (1.A.3)

3.2.6.1 Category description

The *Transport* sub-category includes fuel combustion activities from the following types of transportation:

- 1A3a *Civil aviation* – domestic aviation with international aviation indicated as a memo item.
- 1A3b *Road transportation* – this includes the use of agricultural vehicles on paved roads.
- 1A3c *Railways* – this includes both freight and passenger travel.
- 1A3d *Waterborne navigation* – this includes navigation bunkers as memo line items and includes fishing vessels.

3.2.6.2 Methodological issues

Table 3.7 indicates the type of methods and emission factors used for all categories under the *Energy* sector, including at sub-category level.

The activities shown in Table 3.20 were indicated as key categories in the 2000-2020 inventory. To ensure that good practise was followed, changes in methodology were required for emissions from all fuels used in the *Transport* sector. The country-specific CO_2 emission factors indicated Table 3.11 were used to move to Tier 2 report for the *Transport* sector.

Table 3.20: Methodological details for the *Transport* category.

2000-2020 Key category	2000-2020 inventory		2000-2022 inventory	
	Method	Emission Factor	Method	Emission Factor
1A3b Road transport (liquid, CO_2)	T1	DF	T2	CS
1A3d Waterborne navigation (liquid, CO_2)	T1	DF	T2	CS

Activity data

Table 3.21 shows the type and sources of activity data used to estimate emissions from 1A3 *Transport*.

Table 3.21: Activity data used for 1A3 *Transport*

Sub-category	Activity Data	Source
1A3a ***Civil aviation***	Fuel consumption	Fuel consumption study
1A3b ***Road Transport***	VKT for Fuel consumption estimation	Fuel consumption study
1A3c ***Railways***	Fuel consumption	SAPIA & SAGERS
1A3d ***Water-borne navigation***	Fuel consumption	Fuel consumption study

Figure 3.21 shows the fuel consumption contribution per sub-category to the total Transport sector fuel consumption from 2000-2022. The majority of the fuel consumption is as a result of road transportation.

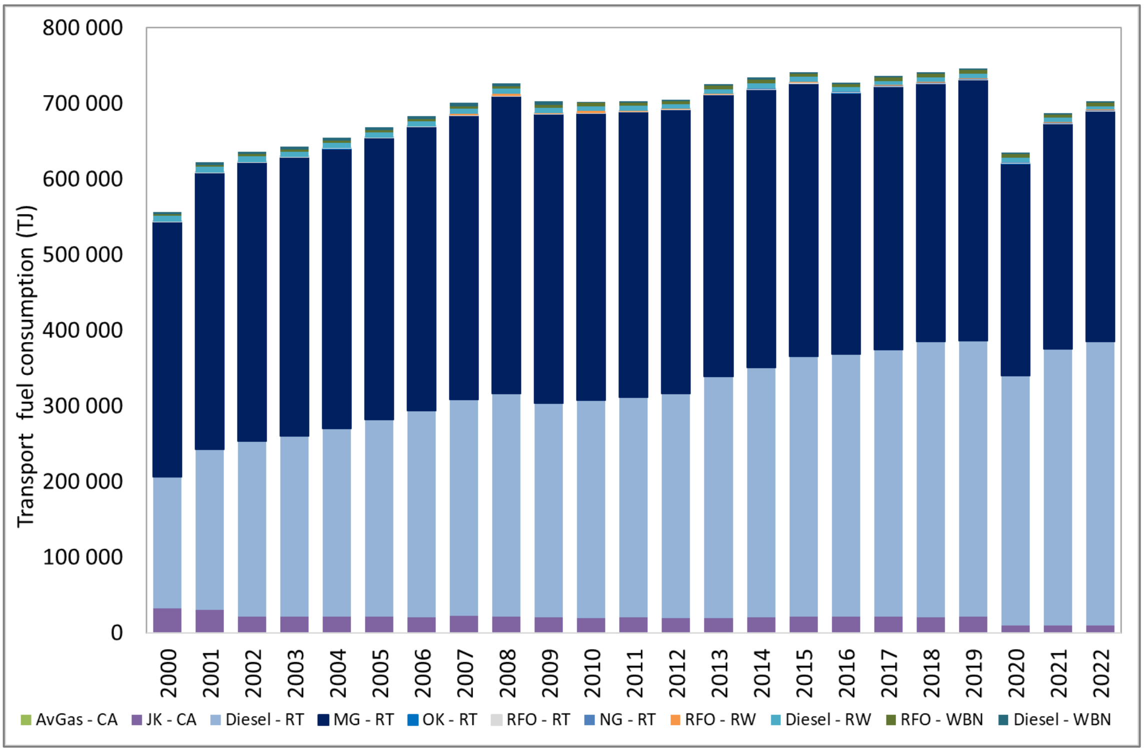

Figure 3.21: Fuel consumption for the *transport* sector (1A3), 2000 – 2022.[16]

Emission factors

[16] *AvGas – aviation gasoline, JK – jet kerosene, MG – motor gasoline, OK – other kerosene, RFO – residual fuel oil, NG – natural gas, CA – civil aviation, RT – road transportation, RW- railways , WBN – waterborne navigation. Fuel consumption for international aviation and international bunkers are not included.*

The emission factors used are shown in Table 3.11. Where a country-specific emission factor is available, it was used to estimate emissions from that fuel.

3.2.6.3 Uncertainty

The uncertainties for activity data and the emission factors used to estimate emission from the *Transport* sector is shown in Table 3.22.

Table 3.22: Uncertainty for South Africa's transport emission estimates.

Gas	Sectors	Activity data uncertainty		Emission factor uncertainty	
		%	Source	%	Source
CO_2	1A3a Civil aviation – liquid	5	IPCC 2006	1.5	IPCC 2006
	1A3b Road liquid	5	IPCC 2006	2	IPCC 2006
	1A3c Railways liquid	5	IPCC 2006	2	IPCC 2006
	1A3d Waterborne navigation – liquid	5	IPCC 2006	3	IPCC 2006
CH_4	1A3a Civil aviation – liquid	5	IPCC 2006	50	IPCC 2006
	1A3b Road liquid	5	IPCC 2006	9	IPCC 2006
	1A3c Railways – liquid	5	IPCC 2006	9	IPCC 2006
	1A3d Waterborne navigation – liquid	5	IPCC 2006	50	IPCC 2006
N_2O	1A3a Civil aviation – liquid	5	IPCC 2006	50	IPCC 2006
	1A3b Road liquid	5	IPCC 2006	72	IPCC 2006
	1A3c Railways - liquid	5	IPCC 2006	72	IPCC 2006
	1A3d Waterborne navigation – liquid	5	IPCC 2006	50	IPCC 2006

3.2.6.4 Time-series consistency

The time-series for all four sub-categories are complete and consistent.

3.2.6.5 Category specific QA/QC and verification

The QA/QC measures indicated in Table 3.9 were used for this category.

3.2.6.6 Category-specific improvements and recalculations

Recalculations were performed for the *Transport* sector because of the following improvement:

- The use of country-specific emission factors for commonly used liquid and gas fuels. The emission factors result from a study that was completed in 2022.

Emissions from the entire time-series were recalculated for the applicable *Fuel combustion* activities.

3.2.6.7 Category-specific planned improvements

Improvements planned specifically for the *Transport* sector is as follows:

- Updating the VKT and fuel consumption studies.

3.2.7 Other sectors (1.A.4)

3.2.7.1 Category description

The *Other sectors* sub-category includes fuel combustion activities from the following industries:

- 1A4a *Commercial/Institutional* – includes all fuel combustion in commercial and institutional buildings.
- 1A4b *Residential* – includes all fuel combustion from households.
- 1A4c *Agriculture/Forestry/Fishing/Fish Farms* – this includes fuel combustion from agriculture, forestry, fishing and fish farms.

3.2.7.2 Methodological issues

Table 3.7 indicates the type of methods and emission factors used for all categories under the *Energy* sector, including at sub-category level.

The activities shown in Table 3.23 were indicated as key categories in the 2000-2020 inventory. To ensure that good practise was followed, changes in methodology were required for the sub-sector key categories. Changes were implemented for the 2000-2022 inventory for liquid fuels used in the 1A4b *residential* and 1A4c *agriculture/forestry/fishing/fish farms* sectors. The deviation is with the estimation of emissions from solid fuels used in the 1A4a *commercial/institutional* and 1A4b *residential* sectors. This deviation is due to a lack of country specific emission factors for solid fuels.

Table 3.23: Methodological details for the *Other sectors* category.

2000-2020 Key category	2000-2020 inventory		2000-2022 inventory	
	Method	Emission Factor	Method	Emission Factor
1A4a Commercial/Institutional (solid, CO_2)	T1	DF	T1	DF
1A4b Residential (solid, CO_2)	T1	DF	T1	DF
1A4b Residential (liquid, CO_2)	T1	DF	T2	CS
1A4c Agriculture/Forestry/Fishing/Fish Farms (liquid, CO_2)	T1	DF	T2	CS

Activity data

Table 3.24 shows the type and sources of activity data used to estimate emissions from 1A4 *Other Sectors*.

Table 3.24: Activity data used for 1A4 *Other Sectors*

Sub-category	Activity Data	Source
1A4a *Commercial/Institutional*	Fuel consumption	Energy balance
1A4b *Residential*	VKT for Fuel consumption estimation	Energy balance & Fuel consumption study
1Ac *Agriculture/Forestry/Fishing/Fish farms*	Fuel consumption	Fuel consumption study

Figure 3.22 and Figure 3.23 show the fuel consumption trends for the 1A4 *Other sectors* sub-categories, since 2000.

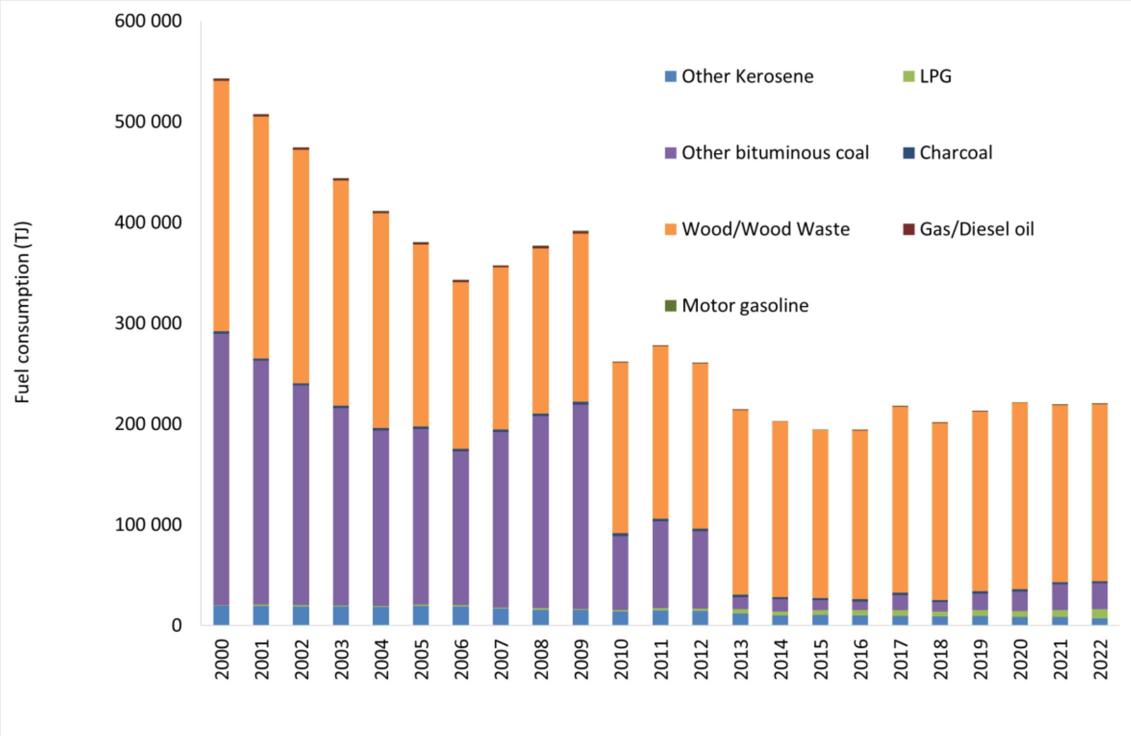

Figure 3.22: Fuel consumption for the 1A4b *residential* category, 2000-2022

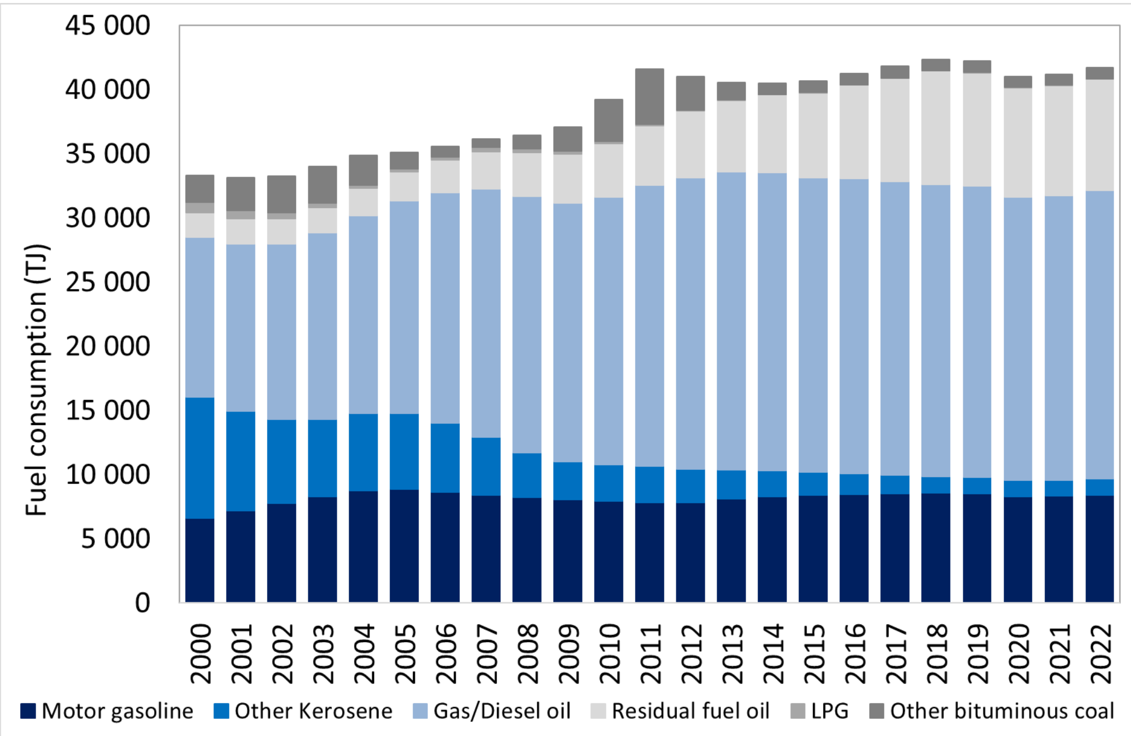

Figure 3.23: Fuel consumption for the 1A4c agriculture/forestry/fishing/fish farms category, 2000-2022

Emission factors

The emission factors used are shown in Table 3.11. Where a country-specific emission factor is available, it was used to estimate emissions from that fuel.

3.2.7.3 Uncertainty

The uncertainties for activity data and the emission factors used to estimate emission from *Other sectors* is shown in Table 3.25.

Table 3.25: 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	10	IPCC 2006	7	IPCC 2006
	1A4 Other sectors – solid	10	IPCC 2006	7	IPCC 2006
	1A4 Other sectors – gaseous	10	IPCC 2006	7	IPCC 2006
CH_4	1A4 Other sectors – liquid	10	IPCC 2006	75	IPCC 2006
	1A4 Other sectors – solid	10	IPCC 2006	75	IPCC 2006
	1A4 Other sectors – gaseous	10	IPCC 2006	75	IPCC 2006
N_2O	1A4 Other sectors – liquid	10	IPCC 2006	75	IPCC 2006
	1A4 Other sectors – solid	10	IPCC 2006	75	IPCC 2006
	1A4 Other sectors – gaseous	10	IPCC 2006	75	IPCC 2006

3.2.7.4 Time-series consistency

The time-series for 1A4 *Other sectors* is complete.

3.2.7.5 Category specific QA/QC and verification

The QA/QC measures indicated in Table 3.9 were used for this category.

3.2.7.6 Category-specific recalculations

Recalculations were performed for *Other sectors* because of the following improvement:

- The use of country-specific emission factors for commonly used liquid and gas fuels. The emission factors result from a study that was completed in 2022. Emissions from the entire time-series were recalculated for the applicable *Fuel combustion* activities.

3.2.7.7 Category-specific planned improvements

There are no category specific improvements planned for *Other sectors,* other than the use of country-specific emission factors for solid fuels.

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

3.2.8.1 Category description

The *Non-specified sectors* sub-category includes fuel combustion activities from the following industries:

- 1A5a *Stationary* – includes all fuel combustion not allocated in the other Fuel Combustion activities.
- 1A5b *Mobile*– no emissions are estimated for this sub-category.

3.2.8.2 Methodological issues

Table 3.7 indicates the type of methods and emission factors used for all categories under the *Energy* sector, including at sub-category level. The only key category identified for the *Non-specified sectors* in the 2000-2020 inventory was 1A5a stationary (solid, CO_2).

In the 2000-2020 inventory emissions from this key category were estimated using Tier 1 and default emission factors. This is the same in this inventory and hence this deviates from good practice. This deviation is due to a lack of country specific emission factors for solid fuels.

Activity data

Fuel consumption data for the *Non-specified sectors* is taken from the energy balance. Figure 3.24 shows the fuel consumption trends for 1A5 *Non-specified sectors* since 2000.

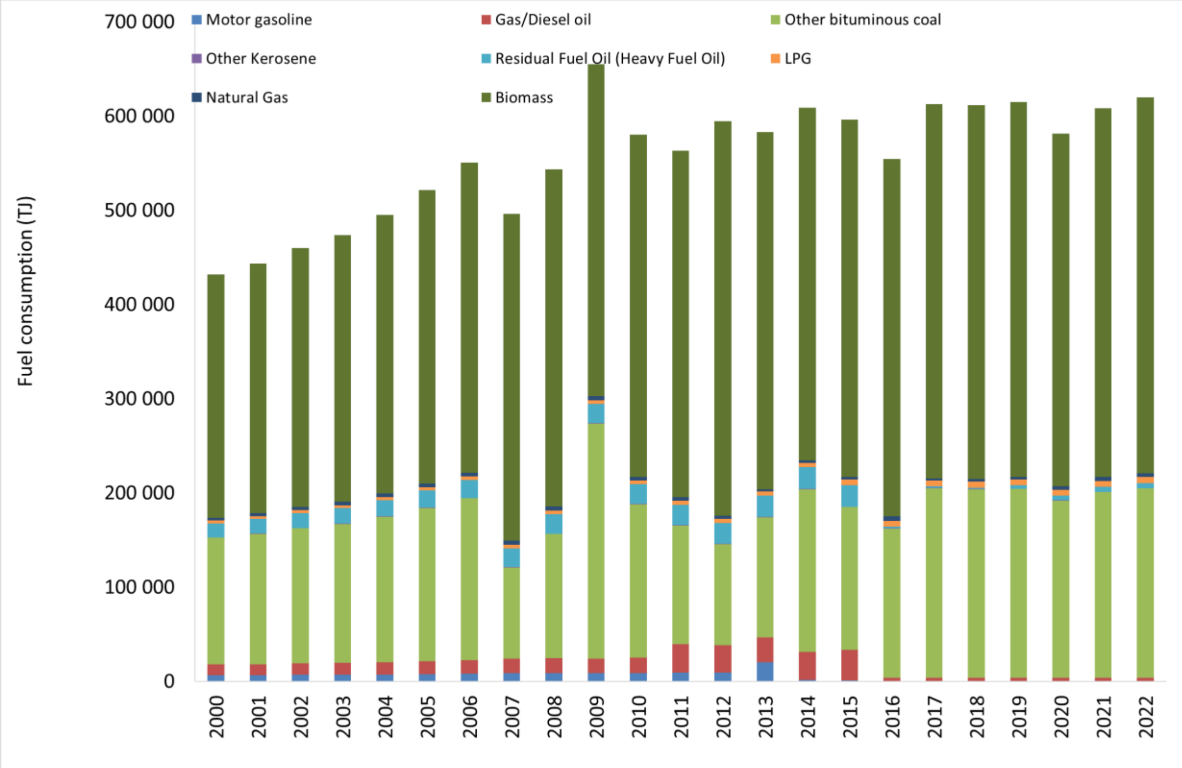

Figure 3.24: Fuel consumption for 1A5 *Non-specified sectors*, 2000-2022

Emission factors

The emission factors used are shown in Table 3.11. Where a country-specific emission factor is available, it was used to estimate emissions from that fuel.

3.2.8.3 Uncertainty

The uncertainties for activity data and the emission factors used to estimate emission from *Non-specified sectors* is shown in Table 3.26.

Table 3.26: Uncertainty for South Africa's *Non-specified sectors* emission estimates.

Gas	Sectors	Activity data uncertainty		Emission factor uncertainty	
		%	Source	%	Source
CO_2	1A5 Other sectors – liquid	5	IPCC 2006	7	IPCC 2006
	1A5 Other sectors – solid	5	IPCC 2006	7	IPCC 2006
	1A5 Other sectors – gaseous	5	IPCC 2006	7	IPCC 2006
CH_4	1A5 Other sectors – liquid	5	IPCC 2006	75	IPCC 2006
	1A5 Other sectors – solid	5	IPCC 2006	75	IPCC 2006

Gas	Sectors	Activity data uncertainty		Emission factor uncertainty	
		%	Source	%	Source
	1A5 Other sectors – gaseous	5	IPCC 2006	75	IPCC 2006
N_2O	1A5 Other sectors – liquid	5	IPCC 2006	75	IPCC 2006
	1A5 Other sectors – solid	5	IPCC 2006	75	IPCC 2006
	1A5 Other sectors – gaseous	5	IPCC 2006	75	IPCC 2006

3.2.8.4 Time-series consistency

The time-series is complete this category.

3.2.8.5 Category specific QA/QC and verification

The QA/QC measures indicated in Table 3.9 were used for this category.

3.2.8.6 Category-specific recalculations

Recalculations were performed for *Non-specified sectors* because of the following improvement:

- The use of country-specific emission factors for commonly used liquid and gas fuels. The emission factors result from a study that was completed in 2022. Emissions from the entire time-series were recalculated for the applicable *Fuel combustion* activities

3.2.8.7 Category-specific planned improvements

There are no category specific improvements planned for *Non-specified sectors,* other than the use of country-specific emission factors for solid fuels.

3.3 Fugitive emissions from fuels (1.B)

3.3.1 Solid fuels (1.B.1)

3.3.1.1 Category description

The *Solid Fuels* sub-category includes fugitive emissions from the following activities:

- 1B1a *Coal mining and handling* – this includes fugitive emissions from the extraction, processing, storage and transport of coal from surface and underground mines.
- 1B1c *Solid fuel transformation* – this includes all fugitive emissions associated with the manufacture of charcoal and coke.

This sub-category does not include emissions from abandoned mines or uncontrolled combustion and burning coal dumps.

3.3.1.2 Methodological issues

Table 3.7 indicates the type of methods and emission factors used for all categories under the *Energy* sector, including at sub-category level. The only key category identified for the 1B1 *Solid fuels* sector in the 2000-2020 inventory was 1B1a Coal mining and handling (CH_4).

In the 2000-2020 inventory emissions from this key category were estimated using Tier 2 and country-specific emission factors. Hence, no change in the methodology was required for the 2000-2022 to ensure good practise was implemented.

Activity data

Table 3.27 shows the type and sources of activity data used to estimate emissions from 1B1 *Solid fuels*.

Table 3.27: Activity data used for 1B1 *Solid Fuels*

Sub-category	Activity Data	Source
1B1a ***Undergound and surface mines***	Amount of coal produced from both underground and surface mines	SAMI Minerals Council SA
1B1c ***Solid fuel transformation - charcoal***	Amount of charcoal produced	FAO
1B1c ***Solid fuel transformation - coke***	Amount of coke produced Amount of iron produced locally	SAGERS Minerals Council SA

Table 3.28 shows the production figures for coal (from surface and underground mines) and charcoal since 2000.

Table 3.28: Amount of coal and charcoal produced, 2000 – 2022.[17,18]

[17] *Coal production data calculated based on information published in the SAMI Annual reports and Minerals Council SA Facts & Figures reports.*
[18] *Charcoal data from the FAO*

	Surface	Underground	Charcoal	Coke
	Amount produced (tonnes)			
2000	174 918 853	106 308 704	41 000	2 451 940
2001	179 330 802	108 990 110	41 000	2 547 566
2002	189 951 547	115 444 975	41 000	2 646 801
2003	191 768 929	116 549 508	200 600	2 891 467
2004	193 506 539	117 605 558	127 300	2 975 656
2005	193 348 574	117 509 553	188 900	2 874 759
2006	195 639 060	118 901 619	188 900	2 881 078
2007	199 587 383	121 301 252	188 900	2 970 030
2008	196 569 036	119 466 821	188 900	2 694 892
2009	175 784 200	141 515 800	188 900	2 003 359
2010	184 150 000	133 350 000	188 900	2 528 025
2011	195 727 800	120 472 200	188 900	2 356 492
2012	211 200 000	118 800 000	188 900	2 009 041
2013	204 681 600	126 518 400	188 900	2 225 078
2014	213 399 640	124 900 360	188 900	2 291 173
2015	207 716 400	116 283 600	188 900	1 798 356
2016	207 415 000	111 685 000	188 900	1 474 697
2017	212 733 600	116 066 400	209 783	1 718 018
2018	227 288 282	105 101 718	295 500	1 681 607
2019	234 234 200	99 765 800	223 195	1 813 063
2020	217 240 013	103 472 569	231 779	1 433 006
2021	200 219 454	95 365 587	220 334	1 597 100
2022	197 015 943	93 839 738	220 334	1 504 969

Emission factors

1B1a coal mining and handling

Country-specific emission factors are available for CO_2 and CH_4 for surface and underground mining in South Africa (Table 3.29).

Table 3.29: Country-specific emission factors for coal mining and handling.

Mining method	Activity	GHG	Emission factor (m^3 $tonne^{-1}$)	
			South African EF	IPCC default
Underground mining	Coal mining	CH_4	0.77	18
	Post-mining (handling and transport)		0.18	2.5
	Coal mining		0	1.2

Mining method	Activity	GHG	Emission factor (m^3 $tonne^{-1}$)	
			South African EF	IPCC default
Surface mining	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

1B1c solid fuel transformation

Emissions from charcoal and coke production were estimated using Tier 1 and the IPCC default emission factors shown in Table 3.30, with the exception of CO_2 emissions from coke production that are based on measurements.

Table 3.30: Tier 1 emission factors for charcoal and coke production

Activity	GHG	Emission factors (kg/tonne)	Source
Charcoal production	CO_2	1 570	IPCC 2019 Refinement
	CH_4	40.3	IPCC 2019 Refinement
	N_2O	0.08	IPCC 2019 Refinement
	CO	220	IPCC 2019 Refinement
Coke production	CH_4	0.049	IPCC 2019 Refinement

3.3.1.3 Uncertainty

The uncertainties for activity data and the emission factors used to estimate emission from *Solid Fuels* is shown in Table 3.31.

Table 3.31: Uncertainty for 1B1 *Solid fuels* sector

Gas	Sub-category	Activity data uncertainty		Emission factor uncertainty	
		%	Source	%	Source
CO_2	1B1ai1 Mining	10	IPCC 2006	63	IPCC 2006
	1B1ai2 Post-mining seam gas emissions	10	IPCC 2006	50	IPCC 2006
	1B1ci Charcoal production	10	IPCC 2006	60	IPCC 2006
CH_4	1B1ai1 Mining	10	IPCC 2006	63	IPCC 2006
	1B1ai2 Post-mining seam gas emissions	10	IPCC 2006	50	IPCC 2006
	1B1ci Charcoal production	10	IPCC 2006	121	IPCC 2006

Gas	Sub-category	Activity data uncertainty		Emission factor uncertainty	
		%	Source	%	Source
	1B1cii Coke production	10	IPCC 2006	90	IPCC 2006
N_2O	1B1ci Charcoal production	10	IPCC 2006	163	IPCC 2006
CO	1B1ci Charcoal production	10	IPCC 2006	53	IPCC 2006

3.3.1.4 Time-series consistency

The time-series is complete for coal, charcoal and coke production.

3.3.1.5 Category specific QA/QC and verification

The QA/QC measures indicated in Table 3.9 were used for this category.

3.3.1.6 Category-specific recalculations

No category specific recalculations were conducted for coal mining. The improvement for this sector was the inclusion of emissions from charcoal and coke production.

3.3.1.7 Category-specific planned improvements

Improvements planned for the *1B1 Solid fuels* sector are as follows:

- Including emissions from abandoned mines and spontaneous combustion.

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

3.3.2.1 Category description

The *Oil and natural gas* sub-category includes fugitive emissions from the following activities:

- 1B2a *Oil* – this includes fugitive emissions from venting, flaring and all other sources associated with the exploration, production, transmission, upgrading and refining of crude oil and the distribution of crude oil products.
- 1B2b *Natural gas* – this includes fugitive emissions from venting, flaring and all other sources associated with the exploration, production, processing, transmission, storage, upgrading and the distribution of natural gas.

3.3.2.2 Methodological issues

No 1B2 activities were indicated as key categories in the 2000-2020 inventory. Additionally, emissions from this category are based on direct measurements.

Activity data

Emissions from this category are based on direct measurements from the relevant refineries. Hence, no activity data or emission factors were used to estimate emissions.

Emission factors

Emissions from this category are based on direct measurements. Hence, no activity data or emission factors were used to estimate emissions.

3.3.2.3 Uncertainty

The uncertainty of the emission estimates (Table 3.32) is based on the assumption of a normal distribution of the emission estimates.

Table 3.32: Uncertainty for 1B2 *Oil and natural gas* sector.

Gas	Sub-category	Emissions uncertainty	
		%	Source
CO_2	1B2 Oil & natural gas	65	SAGERS
CH_4		0.005	SAGERS
N_2O		0.02	SAGERS

3.3.2.4 Time-series consistency

The time-series is complete for 1B2a *Oil*, however the time-series is not consistent as emissions estimates are sourced from SAGERS from 2019 onwards.

For 1B2b *Natural gas* the time-series is not complete as emissions only from 2019 onwards from SAGERS are included in the inventory.

3.3.2.5 Category specific QA/QC and verification

The QA/QC measures indicated in Table 3.9 were used for this category.

3.3.2.6 Category-specific recalculations

No category specific recalculations were conducted for the 1B2 *Oil and natural gas* sector. The improvement for this sector was the inclusion of emissions from natural gas activities from 2019.

3.3.2.7 Category-specific planned improvements

An improvements planned for the *Oil and natural gas* sector is ensuring time-series completeness for fugitive emissions from natural gas

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

3.3.3.1 Category description

The *Other emissions from energy production* sub-category includes fugitive emissions from the following activities:

- 1B3 *Coal mining and handling* – this includes other fugitive emissions from energy production not included in 1B2 *Oil and natural gas*.

3.3.3.2 Methodological issues

Carbon dioxide from *Other emissions from energy production* was indicated as a key category in the 2000-2020 inventory. Emissions from this sector were already based on direct measurements, hence, no methodological changes were required for the 2000-2022 inventory to ensure alignment with good practise.

Activity data

Emissions from this category are based on direct measurements from the relevant producers. Hence, no activity data or emission factors were used to estimate emissions.

Emission factors

Emissions from this category are based on direct measurements from the relevant producers. Hence, no activity data or emission factors were used to estimate emissions.

3.3.3.3 Uncertainty

The uncertainty of the emission estimates (Table 3.33) is based on the assumption of a normal distribution of the emission estimates.

Table 3.33: Uncertainty for 1B3 *Other emissions from energy production* sector.

Gas	Sub-category	Emissions uncertainty	
		%	Source
CO_2	1B3 *Other emissions from energy production*	0.001	SAGERS
CH_4		0.001	SAGERS

3.3.3.4 Time-series consistency

The times-series of emissions from 1B3 *Other emissions from energy production* is complete and consistent.

3.3.3.5 Category specific QA/QC and verification

The QA/QC measures indicated in Table 3.9 were used for this category.

3.3.3.6 Category-specific recalculations

No category specific recalculations were conducted for the 1B3 *Other emissions from energy production* sector.

3.3.3.7 Category-specific planned improvements

There are no category-specific improvements planned for the 1B3 *Other emissions from energy production* sector.

3.4 References

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Chapter 4: Industrial Processes and Product Use (IPPU) (CRT sector 2)

4.1 Sector overview

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, PFCs and SF_6. Emissions from the following industrial processes are included in South Africa's IPPU sector:

- Cement Production
- Hydrogen Production
- Lime Production
- Other Chemicals
- Glass Production
- Production of steel from iron and scrap steel
- Other Product Uses of Carbonates
- Ferroalloys Production
- Ammonia Production
- Aluminium Production
- Nitric Acid Production
- Lead Production
- Carbide Production
- Zinc Production
- Titanium Dioxide Production
- Vanadium Production
- Soda Ash Production
- Lubricant Use
- Petrochemical and carbon black production
    - 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. SF_6 is also included in IPPU due to the use of electrical equipment.

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 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.

As a result of the recession, GHG emissions during that period decreased across almost all categories in the IPPU sector. Since then, 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. During 2021 and 2022 economic growth recovered to pre-covid figures.

During 2022 South Africa moved away from Tier 1 reporting towards Tier 2 and Tier 3 calculations. In certain sectors, this made quite a difference. The Metal Industry was affected most, but the accuracy has improved. The 2023 Verification programme also enhanced accuracy of Tier 3 reporting. Due to these changes, comparison with historical figures is compromised in the short term.

The largest source of emissions in the IPPU sector in South Africa is the production of ferroalloys, iron and steel followed by cement production.

4.1.1 Shares and trends in emissions

In 2022 the IPPU sector produced 30 598 Gg CO_2e which is 6.4% of South Africa's emission (excl. LULUCF).

The IPPU sector produces CO_2 emissions (78.4%), fluorinated gases (20.0%) and smaller amounts of CH_4 (0.4%) and N_2O (1.2%) (Table 4.1). Carbon dioxide and any other emissions from combustion of fuels in these industries are reported under the Energy sector.

The largest source category is the *Metal industry* category. which contributes 51.2% to the total IPPU sector emissions. The *Mineral industry* and the *Product used as substitutes for ozone depleting substances* subsectors contribute 19.8% and 19.4%, respectively, to the IPPU sector emissions (Table 4.**1**).

Iron and steel production and *Ferroalloys production* are the biggest CO_2 contributors to the *Metal industry* subsector, producing 6 307 Gg CO_2 (40.3%) and 8 081 Gg CO_2 (51.6%) respectively to the total metal industry Greenhouse Gas emissions.

Ammonia production produce 114 Gg CO_2e of CH_4, while *chemical industries* are estimated to produce 364 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 2022 for South Africa.

GHG source categories	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	Total
	Gg CO_2e						
2.IPPU	**23 976**	**121**	**364**	**5 945**	**126**	**66**	**30 598**
2.A Mineral industry	6 055	NA	NA	NA	NA	NA	6 055
2.B Chemical industry	1 268	121	364	NA	NA	NA	1 753
2.C Metal industry	15 529	NE	NA	NA	126	NA	15 655
2.D Non-energy products from fuels and solvents	1 125	NA	NA	NA	NA	NA	1 125
2.E Electronic industry	NE	NE	NE	NE	NE	NA	NE
2.F Product uses as substitute ODS	NA	NA	NA	5 945	NE	NA	5 945
2.G Other product manufacture and use	NE	NE	NE	NE	NE	66	66
2.H Other	NE	NE	NE	NE	NE	66	NE

Numbers may not sum exactly due to rounding off.

Even though the South African economy recovered after the COVID-19 pandemic, estimated emissions from the IPPU sector are 2 183 Gg CO_2e (-6.7%) lower than the emissions in 2000 (Table 4.2). The decline can be attributed to the decline in metals production (-39.0%), specifically *Iron and Steel production* and *Aluminium production*. This can be ascribed to a decrease in global demand. The decline in the chemicals industry also made a huge difference (-31.4%). *Cement production* and *Non-energy product use from fuels and solvents* increased emissions from 2000 by 2 081 Gg CO_2e. The local demand for cement increased dramatically from 2000.

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. From 2010 emissions increased due to an increase in the *metal industry* and *products used as substitutes for ozone depleting substances* subsectors. The economy was also beginning to recover from the global recession.

Emissions decreased from 2016 as demand for South African chemical and metals dropped. COVID-19 also had a major local and international impact between 2020 and 2021.

Table 4.2: Summary of the change in emissions from the IPPU sector between 2000 and 2022.

GHG source categories	Emissions ($Gg\ CO_2e$)			Difference ($Gg\ CO_2e$)		Change (%)	
	2000	2020	2022	2000-2022	2020-2022	2000-2022	2020-2022
2.IPPU	**32 781**	**24 858**	**30 598**	**-2 183**	**5 740**	**-6,7**	**23,1**
2.A Mineral industry	**4 371**	**4 774**	**6 055**	**1 684**	**1 281**	**38,5**	**26,8**
2A1 Cement Production	3 871	3 796	5 023	1 152	1 227	29,8	32,3
2A2 Lime Production	426	715	694	268	-21	62,8	-3,0
2A3 Glass Production	74	154	191	117	37	157,5	23,9
2A4 Other Process Uses of Carbonates	NE	109	147		38		34,7
2.B Chemical industry	**2 557**	**2 247**	**1 753**	**-804**	**-494**	**-31,4**	**-22,0**
2B1 Ammonia Production	C	C	C				
2B2 Nitric Acid Production	C	C	C				
2B5 Carbide Production	C	C	C				
2B6 Titanium Production	C	C	C				
2B7 Soda Ash Production	NE	C	C				
2B8f Petrochemical and Black Carbon Production	C	C	C				
2B8g Hydrogen Production	NE	C	C				
2B10 Other	NE	C	C				
2.C Metal industry	**25 658**	**12 391**	**15 655**	**-10 003**	**3 263**	**-39,0**	**26,3**
2C1 Iron and Steel Production	15 334	3 854	6 307	-9 027	2 453	-58,9	63,6
2C2 Ferroalloy Production	8 084	7 233	8 081	-3	848	0,0	11,7
2C3 Aluminium Production	2 116	1 261	1 259	-857	-2	-40,5	-0,1

2C5 Lead Production	15	7	7	-8	1	-52,4	9,0
2C6 Zinc Production	108	37	0	-108	-37	-100,0	-100,0
2.D Non-energy products from fuels and solvents	**196**	**84**	**1 125**	**929**	**1 041**	**474,1**	**1 245,5**
2D1 Lubricant Use	189	82	516	327	434	173,6	527,5
2D2 Paraffin Wax Use	7	1	609	602	608	8 091,2	43 042,8
2.E Electronic industry	NE	NE	NE				
2.F Product uses as substitute ODS	NE	**5 284**	**5 945**	**5 945**	**661**		**12,5**
2F1 Refrigeration and Air Conditioning	NE	5 187	5 837		650		12,5
2F2 Foam Blowing Agents	NE	2	2		0		0,0
2F3 Fire Protection	NE	76	88		11		15,0
2F4 Aerosols	NE	18	18		0		0,0
2.G Other product manufacture and use	NE	**78**	**66**	**66**	**-12**		**-15,5**
2.H Other	NE	NE	NE				

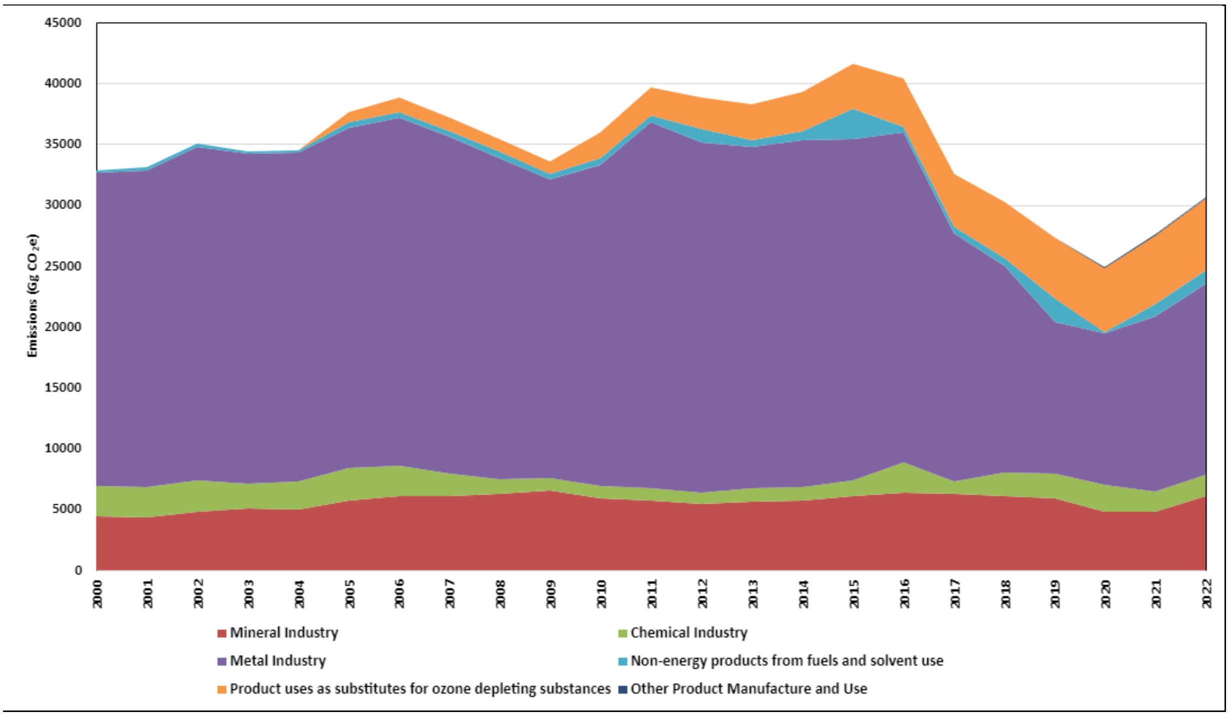

Figure 4.1: Trend in South Africa's IPPU sector emissions, 2000 – 2022.

4.1.1.1 Mineral industry

In 2022 the *mineral industries* produced 6 055 Gg CO_2, which is 19.8% of the IPPU sector emissions. *Cement production* accounted for 83.0% of emissions from the *Mineral industry*. All the emissions in this category were CO_2 emissions.

The emissions were 38.5% (1 684 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* because of economic growth during this period. In 2009 the South African economy went into recession and the GDP decreased by 1.8% in that year.

Cement demand in the residential market and construction industry in 2009/2010 decreased due to higher interest rates, increased inflation, and the introduction of the National Credit Act (DMR, 2010). *Other process uses of carbonates* was included in the category from the 2018 inventory. Emissions declined between 2019 and 2020 mainly due to the COVID-19 pandemic and the stringent lockdown regulations within South Africa during 2020. The market did recover after this.

Cement production is the largest contributor to the emissions from this category (Figure 4.2).

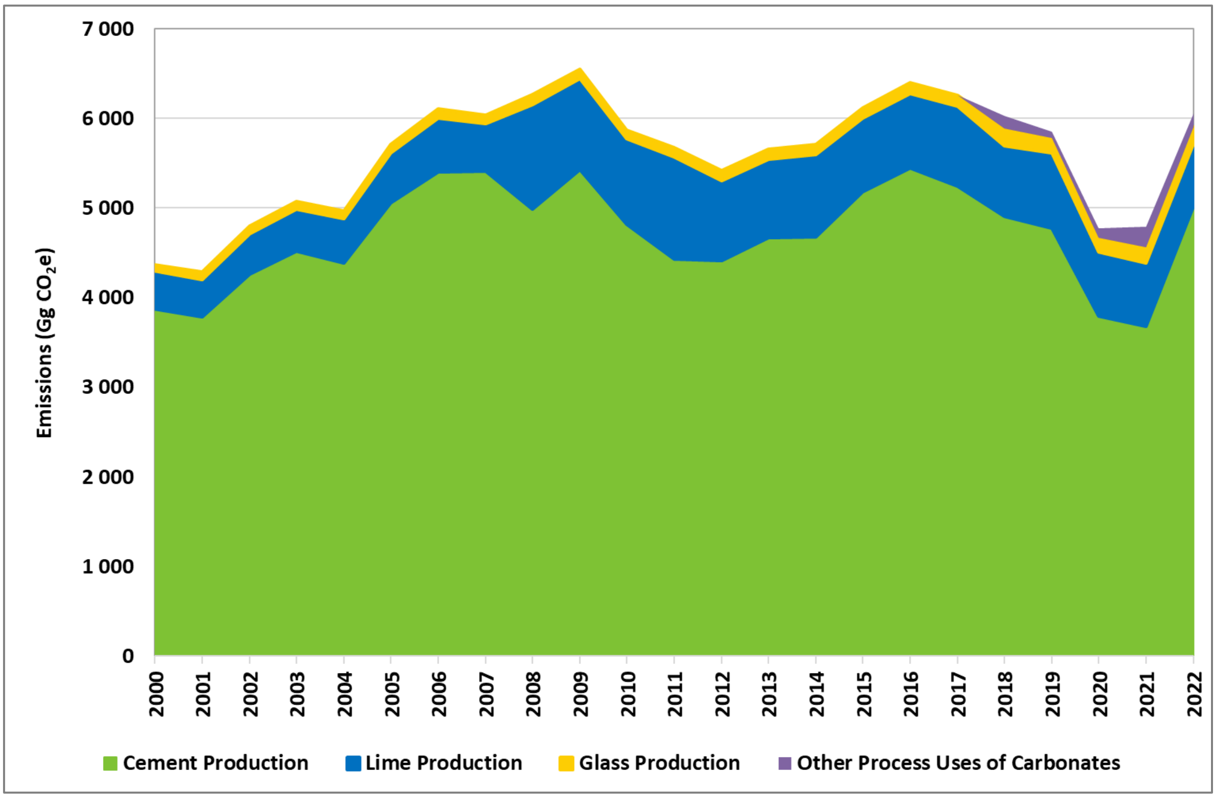

Figure 4.2: Category contribution and trend for the mineral subsector, 2000 – 2022.

Cement production

Cement production was estimated to produce 16.4% of the IPPU sector emissions. Emissions were 29.8% above the 2000 level but fluctuate with economic conditions.

Lime production

Lime production was estimated to produce 2.3% of the IPPU sector emissions. Emissions were 29.8% above the 2000 level. 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. Emissions for 2018 and 2019 were extrapolated for quicklime due to a lack of activity data received. The 2019 inventory included the addition of dolomitic lime to the calculation, as previously this type of lime was not reported.

Glass production

Glass production was estimated to produce 0.6% of the IPPU sector emissions. Emissions were 62.8% above the 2000 level. Emissions increased steady until 2018 from when it stabilised.

Other Process Uses of Carbonates (OPUC)

Emissions from the *Other Process Uses of Carbonates* (*OPUC)* were only reported from the 2018 inventory due to a lack in activity data and emissions. *OPUC* emissions were estimated to produce 0.5% of the IPPU sector emissions. Emissions do fluctuate with normal industrial adjustment to economic circumstances.

4.1.1.2 Chemical industry

The *Chemical industries* were estimated to produce 1 753 Gg CO_2e in 2022, which is 5.7% of the IPPU sector emissions. The largest contributions are from *Titanium dioxide production*, *Nitric acid production and Ammonia production*.

Emissions from the *Chemical industries* decreased by 804 Gg CO_2e (31.4%) since 2000 (2 774 Gg CO_2e). Emissions from this subsector fluctuated considerably over the 20-year period (Figure 4.1) due to the nature of the business. 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*. *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 15 655 Gg CO_2e in 2022, which is 51.2% of the IPPU sector emissions. The largest contribution to the *Metal industries* comes from *Ferroalloy production* (8 081 Gg CO_2e or 51.6%), followed by *Iron and steel production* (6 307 Gg CO_2e or 40.3%).

Emissions from the *Metal industry* decreased by 10 003 Gg CO_2e (39.0%) 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, mainly due to *Ferrometals production*. A sharp decline in production and related emissions from 2016 can be attributed to increased input cost, energy supply challenges and low-cost international alternatives in the *Iron and steel* and *Ferrometals* sectors. *Zinc production* was minimal for 2022. Various entities used the COVID-19 period to stop production in favour of major maintenance after which production increased again.

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 South African electricity grid. PFCs emissions afterwards stabilised to a point where it is currently (2022) contributing 10.0%.

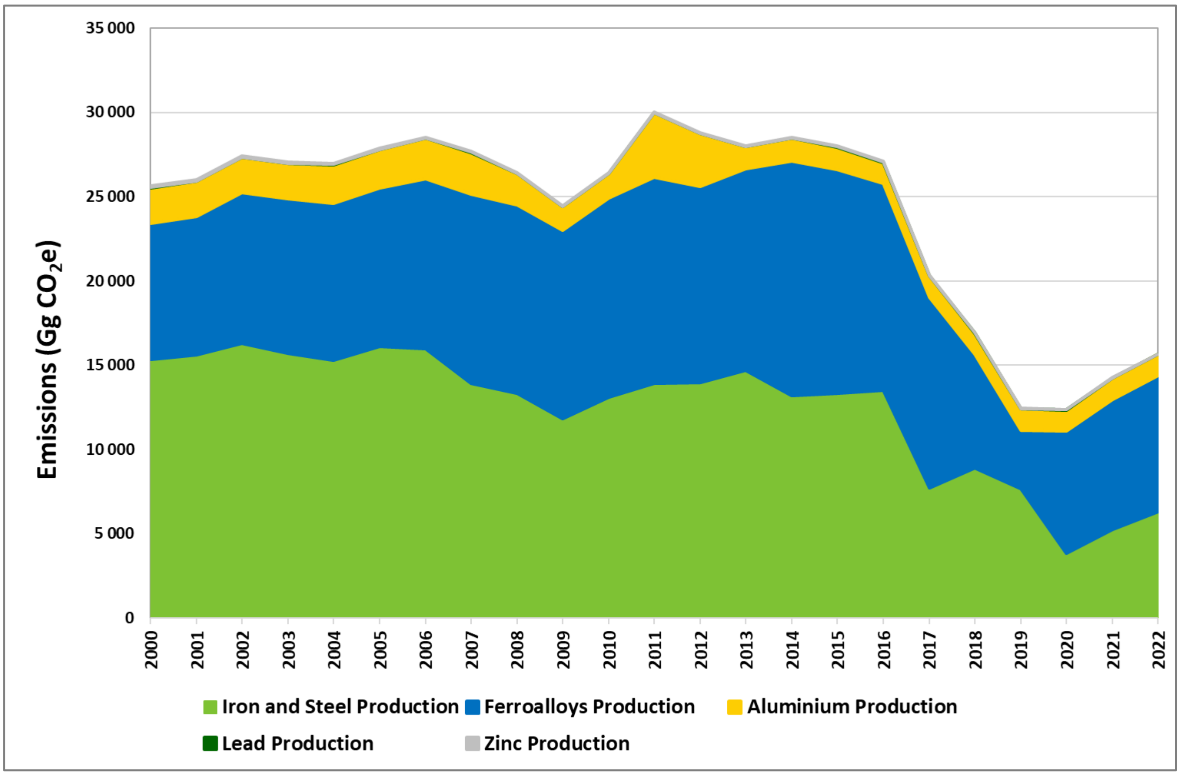

Figure 4.3: Trend and category contribution to emissions from the metal industries, 2000 – 2022.

4.1.1.4 Non-energy products from fuels and solvents

The *Non-energy products from fuels and solvent use* were estimated to produce 1 125 Gg CO_2e in 2022, which is 3.7% of the IPPU sector emissions.

Emissions from the *Non-energy products from fuels and solvent use* category were 474% 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. 2020 saw a steep decrease in the use of lubricants and paraffin wax, which is most probably ascribed to COVID-19. No information for 2021 and 2022 is available and extrapolation was done.

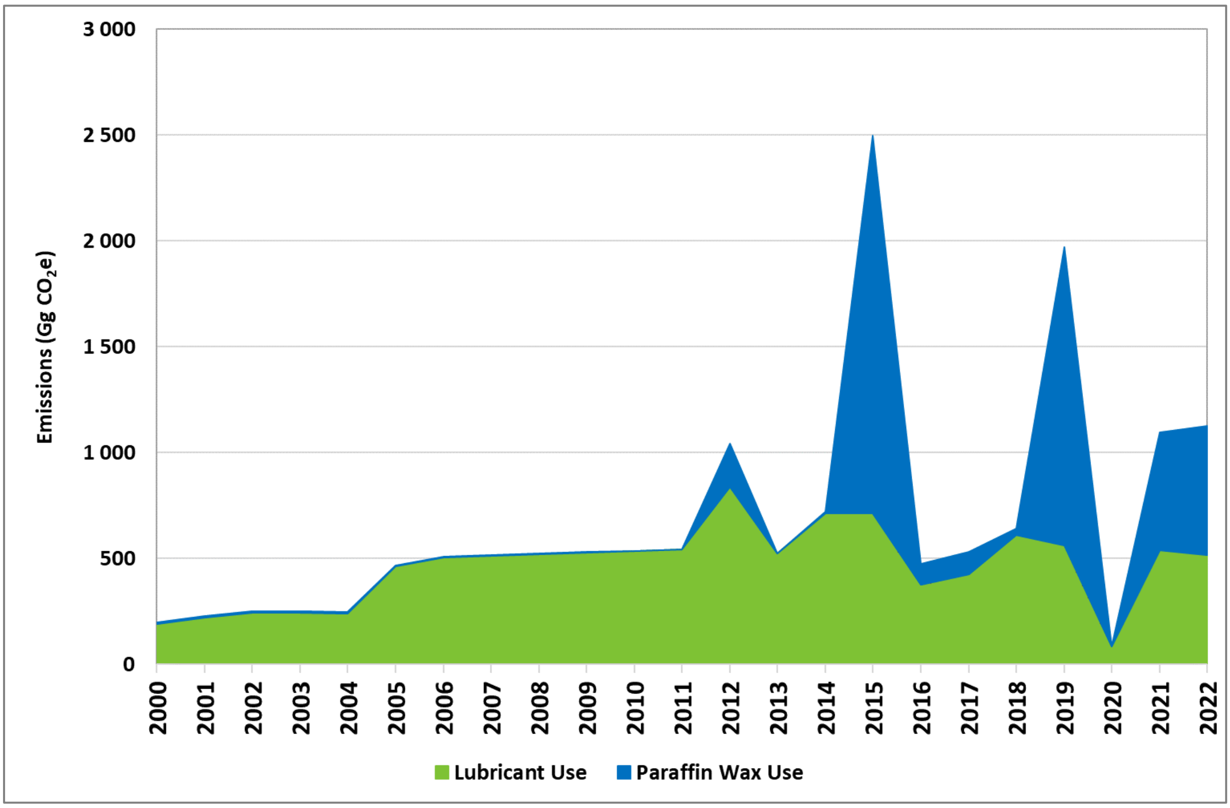

Figure 4.4: Trend and category contribution in the emissions from non-energy products from fuels and solvents. 2000 – 2022.

4.1.1.5 Products used as substitutes ODS

The *Products used as substitutes for ODSs* category was estimated to produce 5 945 Gg CO_2e in 2022, which is 19.4% of the IPPU sector emissions. The largest contribution comes from *Refrigeration and air conditioning* (5 837 Gg CO_2e or 98.2%).

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. Recalculations were not done for the years prior to 2011 due to a lack of data. *Refrigeration and air conditioning* as well as *Fire protection* has been extrapolated since 2016. Emissions from foam blowing agents and aerosols have not changed since 2015.

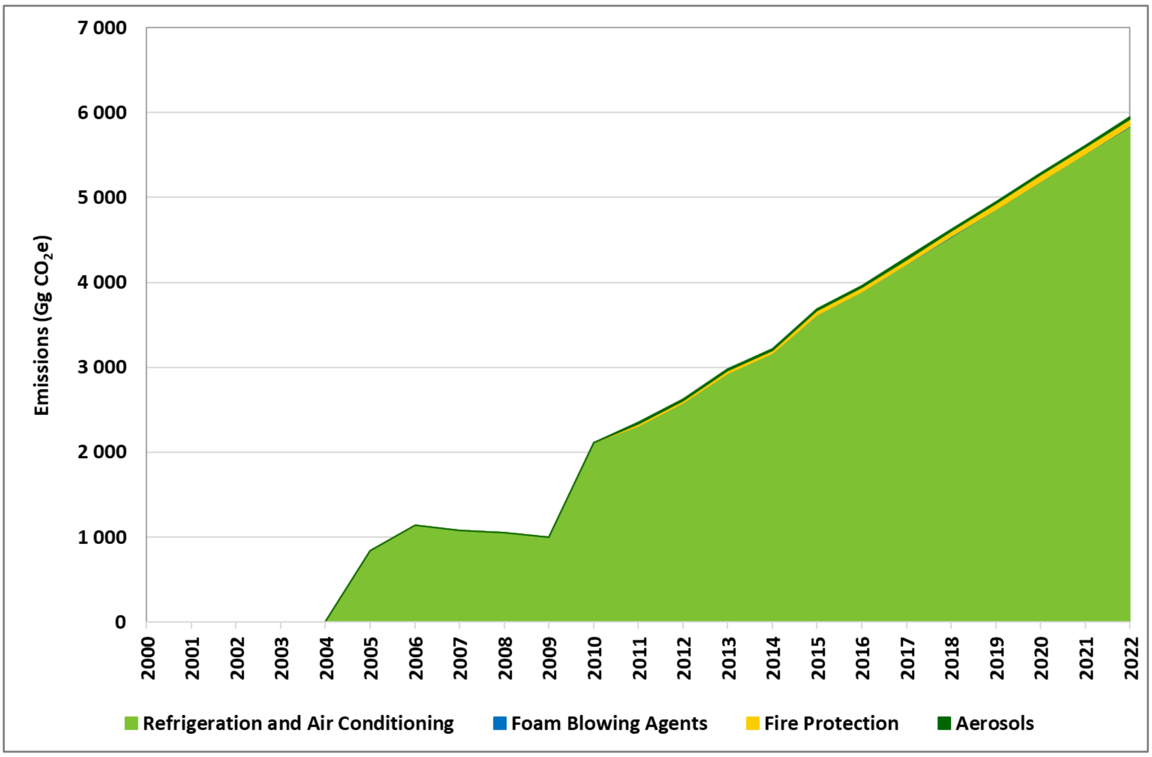

Figure 4.5: Trend and category contribution to the product uses as substitutes for ODS emissions, 2000 – 2022.

4.1.2 Overview of methodology and completeness

Table 4.**1** 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*	T2	CS	NE										NE	NE	NE	NE
2	*Lime production*	T3	CS	NE										NE	NE	NE	NE
3	*Glass production*	T3	CS	NE										NE	NE	NE	NE
4	*Other process uses of carbonates*	T3	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*	T3	CS	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*	T3	CS	NE		NE								NE	NE	NE	NE
2	*Ferroalloy production*	T3	CS	T3	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

Through the introduction of the NGER in 2017 (DEA, 2017a), 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 up to 2020. During 2020 a major change was the introduction of Tier 2 and Tier 3 calculation methods as far as possible. This did lead to improved accuracy of the inventory. An external verification process was launched for key emission contributors which increased the level of accuracy. The accuracy improvement has not been quantified.

No categories were added from 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
2C1	Iron and Steel Production	CO_2	L, T
2C2	Ferroalloys Production	CO_2	L, T
2C2	Ferroalloys Production	CH_4	L
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

Planned improvements and recommendations are given in Table 4.5. These will be prioritised as required and are dependent on resources.

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. • Ensure that facility intensity data is available (even though not publicly). • Expand reporting to have sector and technology specific intensities.
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.
2D	• Investigate the availability of more accurate data
2F	• Investigate the availability of more accurate data

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)*. *Other mineral products processes (2A5)* are not included due to a lack of data.

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. COVID-19 effected the local market in the sense that lower strength cement was more in demand verses high strength cement during the 2020 period.

4.2.1.2 Methodological issues

From 2022, most cement producers used a Tier 2 methodology. Previously 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. Clinker production for the years 2018 and 2019 were provided by the cement industries (Table 4.) 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. The clinker fraction for the years 2018 and 2019 were not provided by all cement industries, however the clinker produced was provided (Table 4.). The clinker fraction was available from the 2020 reporting period through the GHG reporting programme.

Table 4.6: Production data for the mineral industries, 2000 – 2022.

	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
2021		7 081 758	782 545	156 361	27 202	1 718 883	392 129	69 140	149 781
2022		9 545 453	707 912	204 874	36 175	1 798 427	255 071	75 765	187 763

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 2021 ranged between 69% - 76%. From 2022 a Tier 2 calculation was done by production plants. The implied emission factor of 0.526 is very close that of the IPCC.

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. From 2022, these uncertainties will be much less due to the Tier 2 and Tier 3 reporting protocols but will only be updated once enough data is available to determine these.

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). From 2022 Tier 2 and Tier 3 methods are used. Uncertainty should be much less, but is not quantified yet.

Time-series consistency

The time-series for this sub-category is not consistent. A Tier 1 method has been used from 2000 to 2021 to estimate emissions from this category. Tier 2 and Tier 3 methodologies have been used for 2022. 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

External verification of 2022 emissions were requested for most of the cement producers.

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. Direct reporting and verification by data providers have limited these uncertainties.

4.2.1.5 Category specific recalculations

Recalculations were not performed for this category.

4.2.1.6 Category specific planned improvements

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 pg 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.

For 2022 a Tier 2 methodology is used for the calculation of emissions.

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.). It was assumed that all quicklime is high calcium lime. From 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.

From 2022, a Tier 3 methodology was used with implied emission factors of 0.78 and 0.58 tonnes CO_2 per ton lime for quicklime and hydrated lime respectively.

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%.

For 2022 a Tier 2 methodology is used, but even though uncertainty would be much less, it has not been calculated.

Emission factor uncertainty

According to the IPCC 2006 Guidelines, the uncertainty on L*ime 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 2021. 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. From 2022 a Tier 3 methodology is used.

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, from 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

The inclusion of Tier 3 emission estimates and external verification of emissions data is planned for 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 most 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 2022 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. External verification is done on the 2022 data.

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. External verification is however done on the 2022 data.

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

External verification of emissions were done for the 2022 data from individual companies.

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 are also 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). Within South Africa it has been shown that carbonates are very low in raw materials.

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 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. Most industrial operators have however switched to a Tier 3 methodology.

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 resulted 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. More data providers are also switching to Tier 3 methodologies over time.

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. Currently there are no processes registered in South Africa.

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. 2022 data was verified externally.

Activity data

Consumption data is not provided within this report due to confidentiality. It is however reported via the SAGERS system.

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 emissions.

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

The 2022 data was verified externally.

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. It is however reported via SAGERS.

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

The 2022 data were verified externally.

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. From 2022 emissions are reported based on Tier 3 methodologies.

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 historically. Since 2022 Tier 3 methodologies are used.

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. From 2022 Tier 3 methodologies are used with indicated uncertainty of ±2%.

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. From 2022 a Tier 3 method is used.

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. Tier 3 calculations are done for this sector.

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 from 2020 onwards.

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. It is however reported via SAGERS.

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 4.7). 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 4.7: 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 from 2020 onwards.

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 from 2020 onwards.

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. Tier 3 calculations are used for reporting in this sectors.

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*. Due to the moving towards Tier 3 calculations and estimation methodologies, CH_4 emissions are not estimated for all entities and uncertainties might be higher than stated.

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. COVID-19 had a negative effect on iron and steel production, but the market recovered to a large extend afterwards. The negative market effect was however used to shut down certain plants or areas for major maintenance.

4.4.1.2 Methodological issues

Historically a Tier 1 approach was applied to calculation emissions from *Iron and steel production*. A Tier 1 and 3 approach was applied for the different process types in 2020 and Tier 3 was used from 2022. 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.

Energy-related emissions from *Iron and steel production* have been accounted for under the Energy Sector.

Activity data

Activity data was provided by the *Iron and steel production* plants (Table 4.8) via the SAGERS Portal, through the GHG Reporting Programme.

Table 4.8: Production data for the iron and steel industry, 2000 – 2022.

	Basic oxygen furnace	Electric arc	Pig iron	Direct reduced iron	Sinter	Other
	Production (tonne)					
2000	4 674 511	4 549 828	4 674 511	1 552 553		705 872
2001	4 849 655	4 716 954	4 849 655	1 220 890		706 225

2002	5 051 936	4 888 870	5 051 936	1 340 976		706 578
2003	5 083 168	5 353 456	4 474 699	1 542 008		706 931
2004	4 949 693	5 508 488	4 224 487	1 632 767		733 761
2005	5 255 831	5 089 818	4 441 904	1 781 108		735 378
2006	5 173 676	5 413 204	4 435 551	1 753 585		739 818
2007	4 521 461	5 473 908	3 642 520	1 735 914		705 428
2008	4 504 275	4 581 523	3 746 786	1 177 925		460 746
2009	3 953 709	4 359 556	3 184 566	1 339 720		429 916
2010	4 366 727	4 235 993	3 695 327	1 120 452		584 452
2011	3 991 686	3 554 803	4 603 558	1 414 164		570 129
2012	3 904 276	3 904 276	4 599 015	1 493 420		677 891
2013	4 271 948	3 292 870	4 927 550	1 295 000		590 356
2014	3 622 909	2 789 291	4 401 734	1 611 530		585 728
2015	3 907 513	2 490 587	4 463 759	1 124 971		581 399
2016	3 498 862	3 039 702	4 650 922	1 806 067		577 332
2017	4 242 431	1 153 047	101 115	660 605	3 631 445	107 153
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	
2021	2 898 267	1 789 950	220 417	297 316	2 712 917	
2022		3 801 800		149 784		

Emission factors

Historically IPCC default emission factors were applied for the calculation of emissions from *Iron and steel production*. From 2022 all reporting was done using a Tier 3 approach based on mass balance.

4.4.1.3 Uncertainties and time-series consistency

Activity data uncertainty

As historically 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). From 2022 a Tier 3 approach is used, and uncertainty is estimated as ±5%.

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 historically to estimate emissions an uncertainty range of ±5% and ±25% was used for the EF. From 2022 a Tier 3 approach is used, and uncertainty is estimated as ±5%.

Time-series consistency

Data was not consistent throughout the time series as the data was provided by different sources for the 2019 inventory. From 2020 the 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 NGER there has been disaggregation between direct reduced iron and sinter processes. Due to the effects of COVID-19, steel production values also differ with regards to production methodology for the past few years.

4.4.1.4 Category specific QA/QC and verification

External verification of 2022 data was done.

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 (.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). COVID-19 had a negative effect on ferroalloys production, but the market recovered to a large extend afterwards. The negative market effect was however used to shut down certain plants or areas for major maintenance.

4.4.2.2 Methodological issues

Historically a Tier 1 and 3 approach was applied across the different ferroalloy production plants for different types of ferroalloys. From 2022 only a Tier 3 approach is applied.

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, from 2018 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 4.9. 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. This inconsistency was overcome form 2018 as the SAGERS requires the split to be made.

Table 4.9: Production data for the ferroalloy industry, 2000 – 2022.

	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	106 397	100 858	96 614		31 285			38 627
2020	2 971 325	1 178 851	55 395		47 925		5 414	108 060	66 370
2021	3 772 366	897 259	56 579		63 105			150 553	231 789
2022	3 828 284	821 314	76 986		43 766	1 139	1 137	133 889	133 889

Emission factors

Historically Tier 1 emission factors where used. Over the past 3 years it moved more towards a Tier 3 approach to the point that 2022 is purely Tier 3. Due to certain assumptions for the Tier 3 approach, there is still higher uncertainty with CH_4 emissions and Tier 1 is used in some instances.

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) (IPCC, 2006, 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 for CH_4 the uncertainty range was assumed to be between ±5% and ±25% for and CH_4. CO_2 uncertainty is assumed to be ±5%.

Time-series consistency

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

4.4.2.4 Category specific QA/QC and verification

The 2022 data was verified externally by the respective companies.

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

Aluminium production 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.

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 from 2018.

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 Centre-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.

4.4.3.4 Category specific QA/QC and verification

The 2022 data has been externally verified.

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 4.10, however from 2018 activity data was supplied by the lead production plants through the GHG Reporting Programme, via the SAGERS.

Table 4.10: Production data for the lead and zinc industries, 2000 – 2022.

	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
2021	35 948	22 874
2023	35 819	3

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 DFFE was 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 currently no planned improvement projects.

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 to produce zinc:

- Electro-thermic distillation: this is a metallurgical process that combines roasted concentrate and secondary zinc products into sinter that is combusted to remove zinc. Halides, cadmium, and other impurities. The reduction results in the release of non-energy CO_2 emissions.
- The pyrometallurgical process: this involves the utilization of an Imperial Smelting Furnace. Which allows for the simultaneous treatment of zinc and zinc concentrates. The process results in the simultaneous production of lead and zinc and the release of non-energy CO_2 emissions.
- 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 the period 2018 to 2021 and an extrapolation was applied. The 2022 data was sourced from industry.

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 consistently since 2017 and an extrapolation was undertaken to obtain data values where necessary.

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 currently no planned improvement projects.

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.

4.5.1.2 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 DoE (Table 4.11). 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 4.11: Lubricant and paraffin wax consumption, 2000 – 2022.

	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	5 603	96
2021	36 769	37 944
2022	35 161	41 529

Emission factors

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

4.5.1.3 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 5.10). 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 to 2022 and an extrapolation was undertaken to obtain data values.

4.5.1.4 Category specific QA/QC and verification

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

4.5.1.5 Category specific recalculations

No recalculations were performed for this category.

4.5.1.6 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 4.11). An extrapolation was applied to the activity data from 2020, 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 from 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, due to the lack of data.

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 4.12 summarises the approach used for each sub-application in the RAC sector.

Table 4.12: 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 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.

Activity data from 2016 onwards was extrapolated due to inconsistent data availability.

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. Activity data from 2016 onwards was extrapolated due to inconsistent data availability.

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.

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). Activity data was assumed to be stable from 2016.

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 4.13.

Table 4.13: Emission factors and defaults applied in the foam blowing agents emission estimates.

Sub-category	Value	Units	Source
Product life	34	Years	

First year loss	14	%	(UNEP, 2005; IPCC. 2006)
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. Due to a lack of consistency in data availability, activity data was assumed to be the same from 2016.

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

No improvements are planned currently.

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. Activity data from 2016 onwards was extrapolated due to inconsistent data availability.

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 r the emissions of agent during recovery, recycling or disposal at the time of removal from service. 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. Activity data from 2016 onwards was extrapolated due to inconsistent data availability.

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:

- 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. Due to a lack of consistency in data availability, activity data was assumed to be the same from 2016.

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. Due to a lack of consistency in data availability, activity data was assumed to be the same from 2016.

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

No improvements are currently planned.

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 (CRT sector 3)

5.1 Sector overview

This chapter includes GHG emissions and removals from Agriculture sector. Based on the IPCC 2006 Guidelines, the main categories included in the emission estimates for the agriculture sector are shown in Table 5.1.

Table 5.1: Main IPCC categories included in the Agriculture sector emission estimates.

IPCC Category	Category name	Included
3A	Enteric fermentation	√
3B	Manure management	√
3C	Rice cultivation	NO
3D1	Direct N_2O emissions from managed soils	√
3D2	Indirect N_2O from managed soils	√
3E	Prescribed burning of savannahs	IE
3F	Field burning of agricultural residues	√
3G	Liming	√
3H	Urea application	√
3I	Other carbon containing fertilisers	NE

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.

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 Transport (category 1A4c *Agriculture/forestry/fisheries*) in the Energy sector subsector (see Section 3.2.7).

5.1.1 Overview of shares and trends in emissions

In 2022 the Agriculture sector produced 53 519 Gg CO_2e which is 11% of South Africa's total emissions. The largest source category in 2022 is Enteric fermentation category which contributed 36 352 Gg CO_2e, 68% to the total agricultural sector emissions as shown in Figure 5.1 below. Overall decreasing trend, the total emissions were 9% lower in 2022 compared to 2000 levels, this is due to decrease in livestock population numbers.

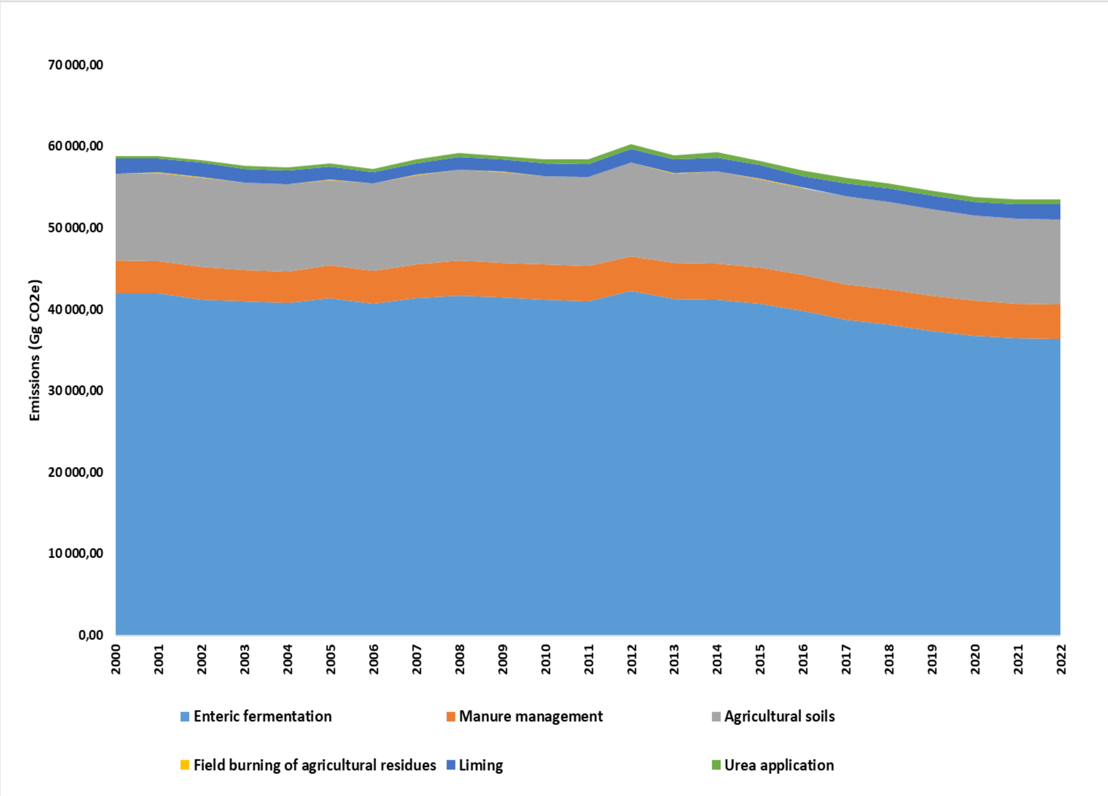

Figure 5.1: Trend in emissions from Agriculture sector, 2000 – 2022

5.1.1.1 Enteric fermentation

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 (Table 5.2; Figure 5). This trend follows the same pattern as cattle population, the largest contributors to emissions from the livestock population data (Figure 5). 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 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 (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 2022 the *Enteric fermentation* category contributed 36 352 Gg CO_2e (Table 5.2). Other cattle and sheep were the largest contributors to the *Enteric fermentation* category). Emissions from horses showed a slight increase between 2000 and 2022, while emissions from all other livestock declined during this time.

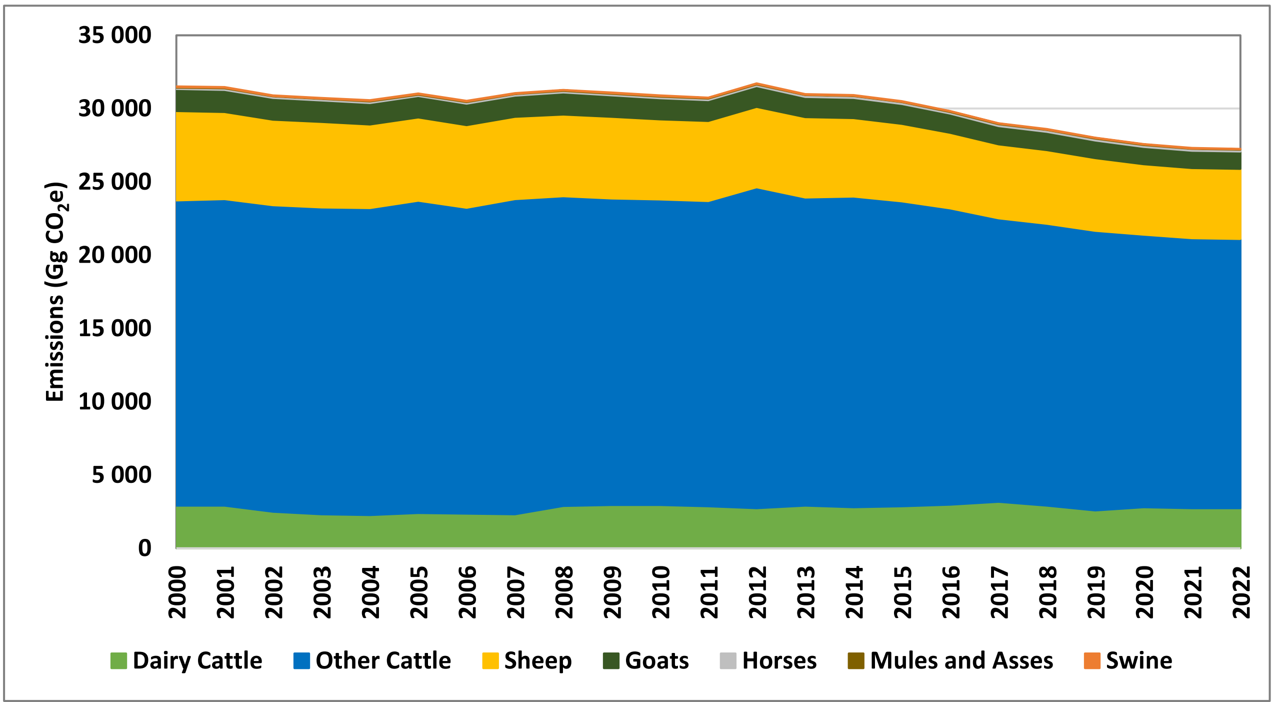

Figure 5.2: *Enteric fermentation* emission trends, 2000 – 2022.

Table 5.2: *Enteric fermentation* emission trends between 2000 and 2022.

	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021	2022
	Gg CO_2e										
Dairy cattle	3 884.1	3 217.1	3 923.3	3 805.6	3 962.6	4 237.2	3 884.1	3 452.5	3 727.2	3 648.7	3 639.7
Other cattle	27 776.4	28 385.9	27 823.1	27 740.6	26 948.0	25 776.9	25 633.8	25 436.0	24 814.0	24 559.9	24 499.2
Buffalo	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Sheep	8 121.1	7 579.3	7 281.5	7 075.9	6 891.6	6 726.3	6 702.6	6 608.8	6 394.7	6 374.9	6 377.5
Goats	1 990.8	1 950.5	1 921.3	1 801.0	1 731.4	1 680.2	1 658.5	1 612.6	1 586.6	1 580.3	1 578.6
Camels	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Horses	136.1	136.1	151.2	159.2	161.0	162.8	164.4	165.2	164.0	165.4	168.0
Mules & asses	45.9	45.9	46.6	47.4	46.7	45.9	45.8	46.2	46.2	46.1	45.8
Swine	53.0	53.1	51.3	49.0	48.7	47.7	46.8	44.7	43.7	43.2	43.2
Other	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Total	42 007.4	41 368.0	41 198.3	40 678.7	39 789.8	38 677.0	38 136.0	37 366.1	36 776.3	36 418.6	36 352.1

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

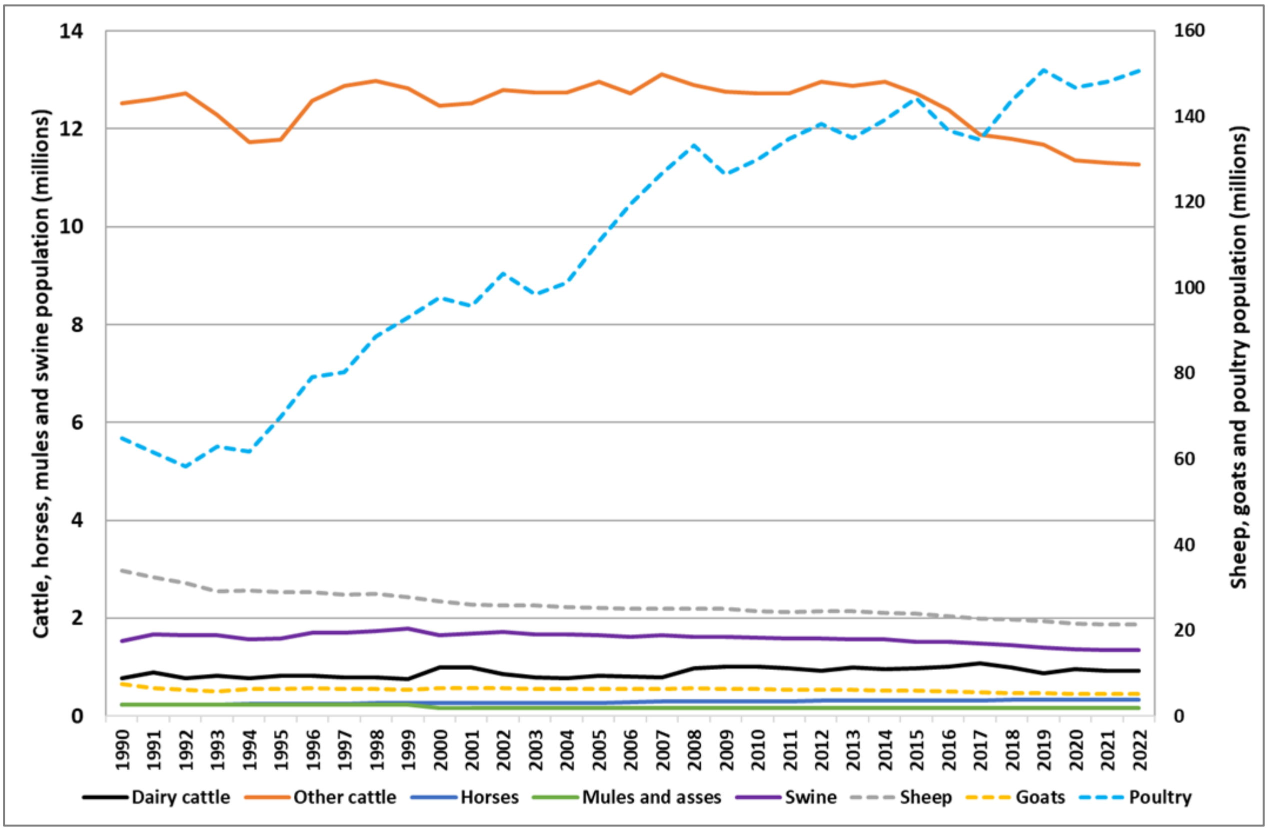

Figure 5.3: Livestock population trends, 2000 – 2022 (Data source: DALRRD, 2022).

Table 5.4 illustrates the fluctuations in enteric fermentation emissions from 2000 to 2022, along with the proportional contributions of different livestock categories to the overall emissions. The total enteric fermentation emissions showed an increase from 9.2% to 10% over the period from 2000 to 2022. Among the livestock categories, non-dairy cattle made the most substantial contribution, accounting for 67% of the total enteric fermentation emissions, followed by sheep, which contributed 18% to the overall enteric fermentation emissions.

Table 5.3: Change in *Enteric fermentation* emissions (2000 – 2022) and relative contribution of the various livestock categories to the total emissions.

	Emissions ($Gg\ CO_2e$)		Change (2000-2022)		Share of enteric fermentation (%)	
	2000	2022	Diff	%	2000	2022
Dairy cattle	3 884.1	3 639.7	-244.3	-6.3	9.2	10.0
Non-dairy cattle	27 776.4	24 499.2	-3 277.2	-11.8	66.1	67.4
Buffalo	NO	NO	NO	NO	NO	NO
Sheep	8 121.1	6 377.5	-1 743.5	-21.5	19.3	17.5
Goats	1 990.8	1 578.6	-412.2	-20.7	4.7	4.3
Camels	NO	NO	NO	NO	NO	NO
Horses	136.1	168.0	31.9	23.4	0.3	0.5
Mules and asses	45.9	45.8	-0.1	-0.3	0.1	0.1
Swine	53.0	43.2	-9.8	-18.5	0.1	0.1
Other	NO	NO				
Total	42 007.4	36 352.1	-5 655.3	-13.5	**100**	**100**

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

5.1.1.2 Manure management

Emissions from *Manure management* increased by 8.0% between 2000 and 2022 (Table 5.3). CH_4 emissions declined, while N_2O emissions increased. N_2O contributed 56% of the total emissions from manure management, while methane emissions contributed 44% in the year 2022. From 2000 to 2022, CH_4 emissions showed a 5% increase, whereas N_2O showed a 5% decrease over the same period.

Table 5.3: Trends and changes in manure management emissions (2000 to 2022).

	Emissions ($Gg\ CO_2e$)	Change (2000 – 2022)	Share of manure management

	2000	2022	Diff	%	2000	2022
					%	%
Methane	1 812.4	1 741.9	-70.4	-3.9	49.4	44.0
Nitrous oxide	1 853.8	2 217.4	363.6	19.6	50.6	56.0
Total manure management	**3 666.2**	**3 959.4**	293.2	8.0	100	100

Most of South Africa's livestock (cattle, sheep, goats, horses, mules and asses) are kept on pasture, range and paddock, therefore the *Manure management* category emissions were relatively small in 2022. Methane from *Manure management* declined in 2019 and started to increase again in 2020 and started decreasing in 2021 and 2022 (Figure 5), while the N_2O emissions have been increasing from 2000 to 2015, after which the emissions started to level off (Figure 5). The N_2O emissions have remained constant since the 2017 inventory and started decreasing in 2018 to 2022 inventory. This is because, even though, poultry numbers are increasing, the decline in cattle numbers has been counteracting this increase. Managed manure from *Non-dairy cattle* and *Dairy cattle* contributed the most to the CH_4 emissions (39% and 32% respectively); while the largest contributors to the N_2O emissions were *Non-dairy cattle cattle* (42%) and *Poultry* (39%).

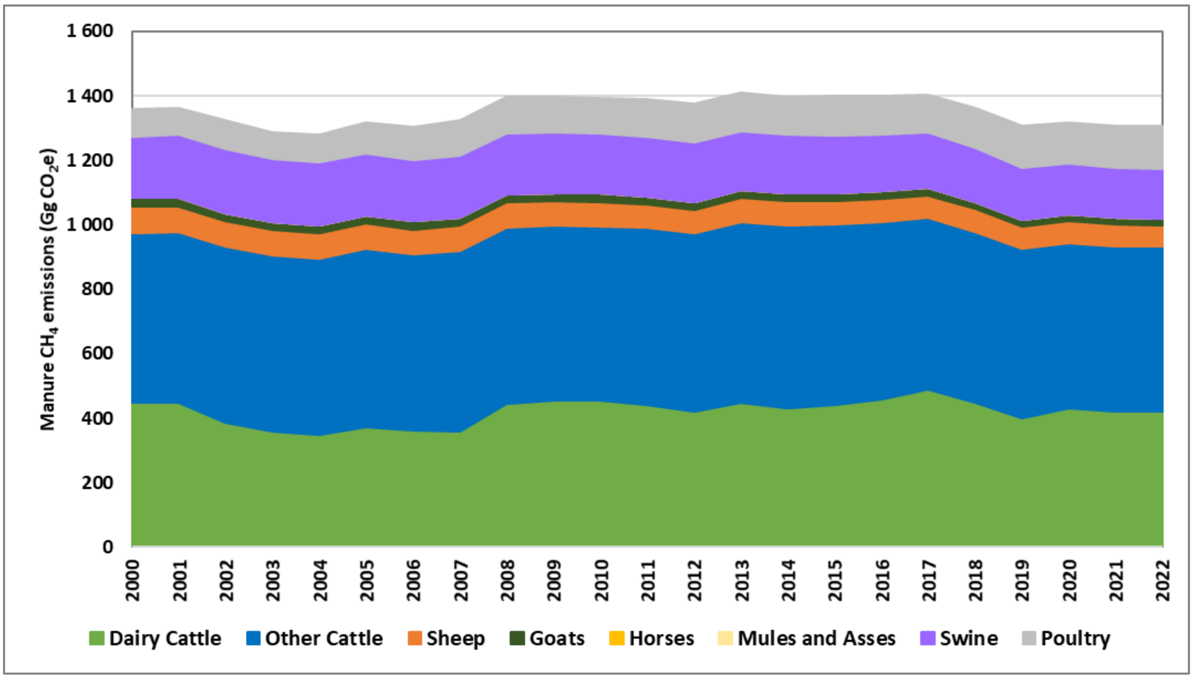

Figure 5.4: Trend in manure management CH_4 emissions from livestock, 2000 – 2022.

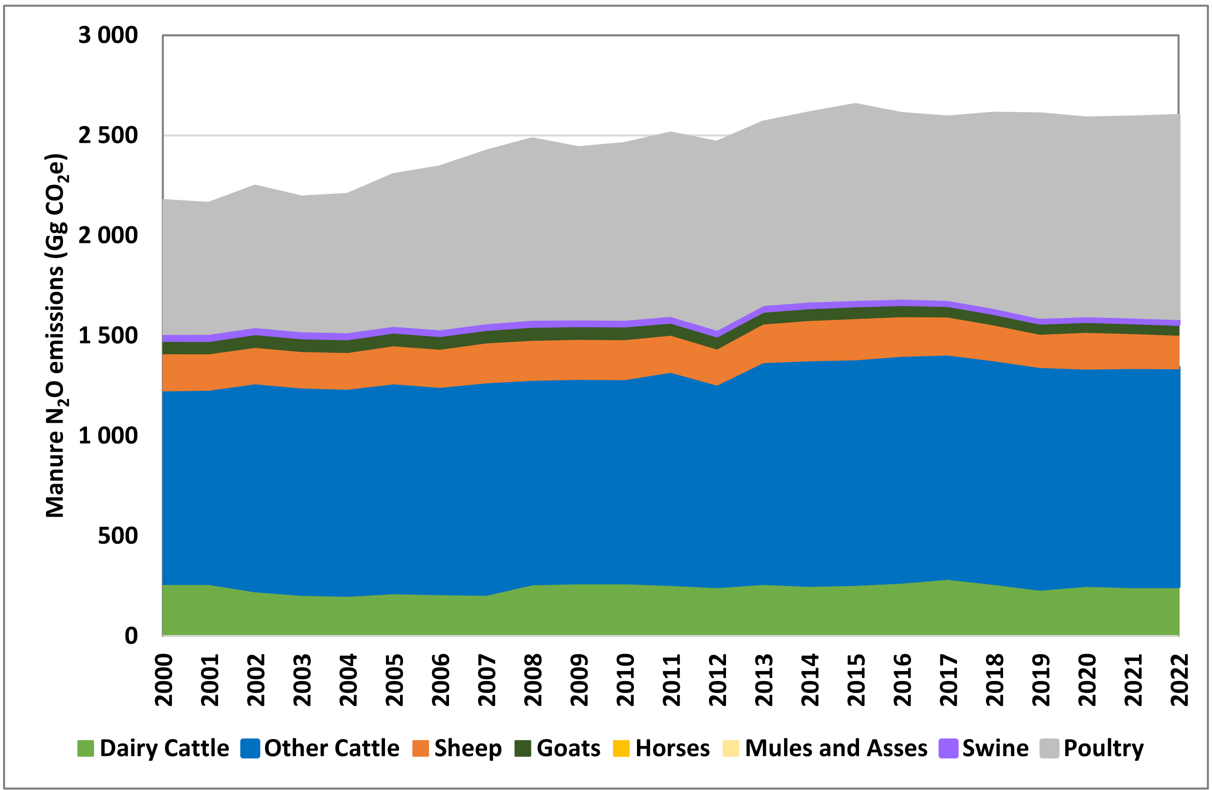

Figure 5.5: Trend in manure management N_2O emissions from livestock, 2000 – 2022.

Table 5.7 illustrates the indirect N_2O emissions resulting from manure management across different livestock types. This encompasses N_2O emissions arising from both volatilization and leaching/runoff. In 2022, indirect N_2O emissions from manure management amounted to 354.9 Gg CO_2e in total. There has been a slight shift since the year 2000.

Table 5.7: Indirect N_2O emissions from manure management (3B5)

	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021	2022
	Gg CO_2e										
Emissions due to volatilization											
N2O from dairy cattle manure	53.7	44.5	54.3	52.7	54.8	58.6	53.7	47.8	51.6	50.5	50.4
N2O from other cattle manure	129.8	140.3	136.2	152.4	153.7	152.4	151.9	151.7	148.2	149.3	149.1
N2O from sheep manure	24.3	24.8	26.2	26.9	25.9	24.8	23.3	21.7	23.9	22.6	21.9

	2000	2005	2010	2015	2016	2017	2018	2019	2020	2021	2022
	Gg CO_2e										
N2O from goat manure	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6
N2O from horse manure	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
N2O from mule and ass manure	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
N2O from swine manure	24.4	24.4	23.6	22.5	22.4	21.9	21.5	20.6	20.1	19.9	19.9
N2O from poultry manure	34.5	39.0	45.9	50.9	48.4	47.5	50.8	53.6	52.2	52.5	53.5
Emissions due to leaching/runoff											
N2O from dairy cattle manure	2.9	2.4	2.9	2.8	3.0	3.2	2.9	2.6	2.8	2.7	2.7
N2O from other cattle manure	10.8	11.7	11.4	12.6	12.7	12.5	12.5	12.4	12.1	12.2	12.2
N2O from sheep manure	2.1	2.1	2.2	2.3	2.2	2.1	2.0	1.9	2.1	1.9	1.9
N2O from goat manure	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
N2O from horse manure	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
N2O from mule and ass manure	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
N2O from swine manure	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3
N2O from poultry manure	8.2	9.2	10.8	12.0	11.4	11.2	12.0	12.6	12.3	12.4	12.6
Total	316.3	325.7	342.6	366.5	365.2	364.8	361.5	355.7	355.7	354.8	354.9

5.1.1.3 Agricultural soils

Emissions from *Agricultural soils* are summarised in Table 5.4. *Direct N_2O from managed soils and liming* contribute the most toward this category. The contribution from field burning of agricultural residue, direct 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 field burning of agricultural residue appears to be the main contributor to these decrease. In the year 2022, *direct N_2O from managed soils* contributed the most toward this category (73%), while *Liming* is the second largest contributor (14%).

Table 5.4: Changes in emissions related to agricultural soils between 2000 and 2022.

Category	Emissions ($Gg\ CO_2e$)		Change (2000 – 2022)	
	2000	2022	Diff	%
3D1 Direct N_2O from managed soils	9 574.6	9 382.9	-191.7	-2.0
3D2 Indirect N_2O from managed soils	1 056.5	995.2	-61.3	-5.8
3F Field burning of agricultural residue	69.1	58.5	-10.5	-15.2
3G Liming	1 820.0	1 860.7	40.7	2.2
3H Urea application	297.3	584.7	287.3	96.6

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

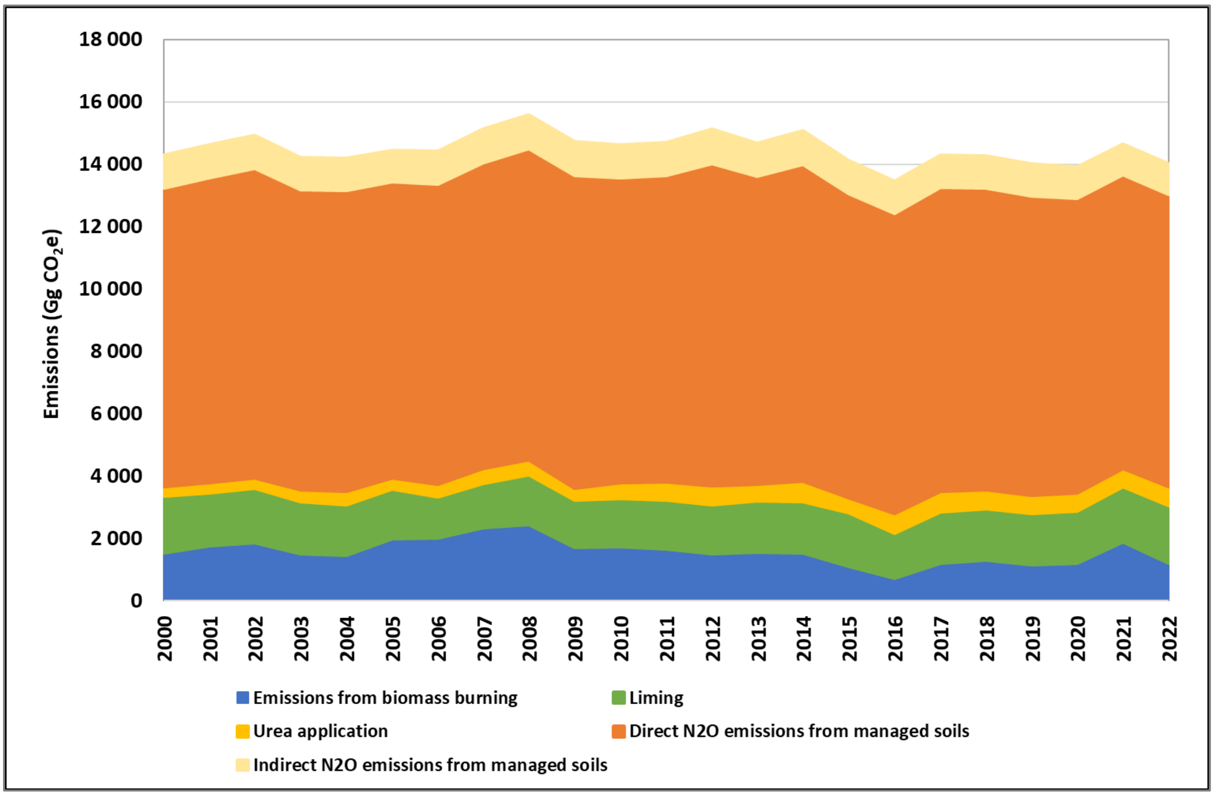

Figure 5.6: Trends in emissions related to agricultural soils, 2000 – 2022.

5.1.2 Overview of methodology and completeness

The IPCC 2006 methodology (IPCC, 2006) is applied in this sector, with a few updated methodologies being taken from the IPCC 2019 Refinement of the 2006 Guidelines (IPCC, 2019). 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 5.5Table 5. 9 shows the methods and types of EF used in the Agriculture inventory.

Table 5.5: Summary of methods and emission factors for the Agriculture sector and an assessment of the completeness of the Agriculture sector emissions.

	GHG Source and sink category	CO_2		CH_4		N_2O		NO_x	CO	NMVOC	NH_3
		Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor				
3A LIVESTOCK	***3.A Enteric fermentation***										
	3.A.1- Cattle										
	3.A.1.a - Dairy cows	NA	NA	T2	CS	NA	NA	NA	NA	NA	NA
	3.A.1.b - Other cattle	NA	NA	T2	CS	NA	NA	NA	NA	NA	NA
	3.A.2 - Sheep	NA	NA	T2	CS	NA	NA	NA	NA	NA	NA
	3.A.3 - Swine	NA	NA	T2	CS	NA	NA	NA	NA	NA	NA
	3.A.4 - Other										
	3.A.4.a - Buffalo	NA	NA	NO	NO	NA	NA	NA	NA	NA	NA
	3.A.4.b - Camels	NA	NA	NO	NO	NA	NA	NA	NA	NA	NA
	3.A.4.d - Goats	NA	NA	T2	CS	NA	NA	NA	NA	NA	NA
	3.A.4.e - Horses	NA	NA	T1	DF	NA	NA	NA	NA	NA	NA
	3.A.4.f – Mules and Asses	NA	NA	T1	DF	NA	NA	NA	NA	NA	NA
	3.B Manure management										
	3.B.1- Cattle										
	3.B.1.a - Dairy cows	NA	NA	T2	CS	T2	DF	NE	NA	NA	NE
	3.B.1.b - Other cattle	NA	NA	T2	CS	T2	DF	NE	NA	NA	NE
	3.B.2 - Sheep	NA	NA	T2	CS	NO	NO	NE	NA	NA	NE
	3.B.3 - Swine	NA	NA	T2	CS	T2	DF	NE	NA	NA	NE
	3.B.4 - Other										
	3.B.4.a - Buffalo	NA	NA	NO	NO	NO	NO	NE	NA	NA	NE
	3.B.4.b - Camels	NA	NA	NO	NO	NO	NO	NE	NA	NA	NE
	3.B.4.d - Goats	NA	NA	T2	CS	NO	NO	NE	NA	NA	NE
	3.B.4.e - Horses	NA	NA	T2	CS	NO	NO	NE	NA	NA	NE
	3.B.4.f – Mules and Asses	NA	NA	T2	CS	NO	NO	NE	NA	NA	NE
	3.B.4.g - Poultry	NA	NA	T2	CS	T2	DF	NE	NA	NA	NE
	3.B.5-Indirect N_2O emissions										

GHG Source and sink category	CO_2		CH_4		N_2O		NO_x	CO	NMVOC	NH_3
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor				
3.C – Rice cultivation	NO		NO		NO					
3.D –Agricultural soils										
3.D.1 – Direct N_2O Emissions from managed soils										
Synthetic fertilizers	NA		NA		T1	DF		NA	NA	
Animal waste added to soils	NA		NA		T1	DF		NA	NA	
Other organic fertilizers	NA		NA		T1	DF		NA	NA	
Urine and dung deposited by grazing livestock	NA		NA		T1	DF		NA	NA	
Crop residues	NA		NA		T1	DF		NA	NA	
3.D.2 – Indirect N_2O Emissions from managed soils										
Atmospheric deposition	NA		NA		T1	DF				
Nitrogen leaching and runoff	NA		NA		T1	DF				
3.E – Prescribed burning of savannas										
Prescribed burning of savannas	NE		NE		NE					
3.F – Field burning of Agricultural residues										
Field burning of Agricultural residues	T2	DF, CS	T2	DF, CS	T2	DF, CS				
3.G - Liming										
Liming	T1	DF	NA		NA		NA	NA	NA	NA
3. H - Urea application										
Urea application	T1	DF	NA		NA		NA	NA	NA	NA
3.I – Other carbon containing fertilisers										

GHG Source and sink category	CO_2		CH_4		N_2O		NO_x	CO	NMVOC	NH_3
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor				
Other carbon containing fertilisers	NE		NE		NE					
3.J - Other										
Other	NE		NE		NE					

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

Agriculture and LULUCF were split into separate chapters. All the other land category (*Forest land, Grassland, Wetland and Settlement*) non-CO_2 biomass burning emissions were removed from agriculture sector and incorporated into the LULUCF sector. The agricultural burning emissions, which in this inventory were assumed to be emissions from pre-harvest burning of sugarcane, were incorporated into category 3F (*Field burning of agricultural residues*).

The Agriculture sector is under continual improvement which leads to recalculations. Figure 5.7 shows the changes in Agriculture emission estimates due to recalculations since 2022 submission. The recalculations for the Agriculture sector led to an increase of 20% increase in the estimates over the times series. The recalculations resulted in a 20% increase in the 2022 estimates for agriculture, primarily attributed to significant improvements.

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) in emissions compared to the previous inventory. The calculation of lime application emissions per crop type was based on crop area data and application rates. This involved utilizing crop area estimates in combined with application rates sourced from Tongwane et al. (2016). However, this approach resulted in an estimate exceeding 3 million tons of lime in 2008, in contrast to the 1.5 million tons reported by the Fertiliser Association of South Africa.

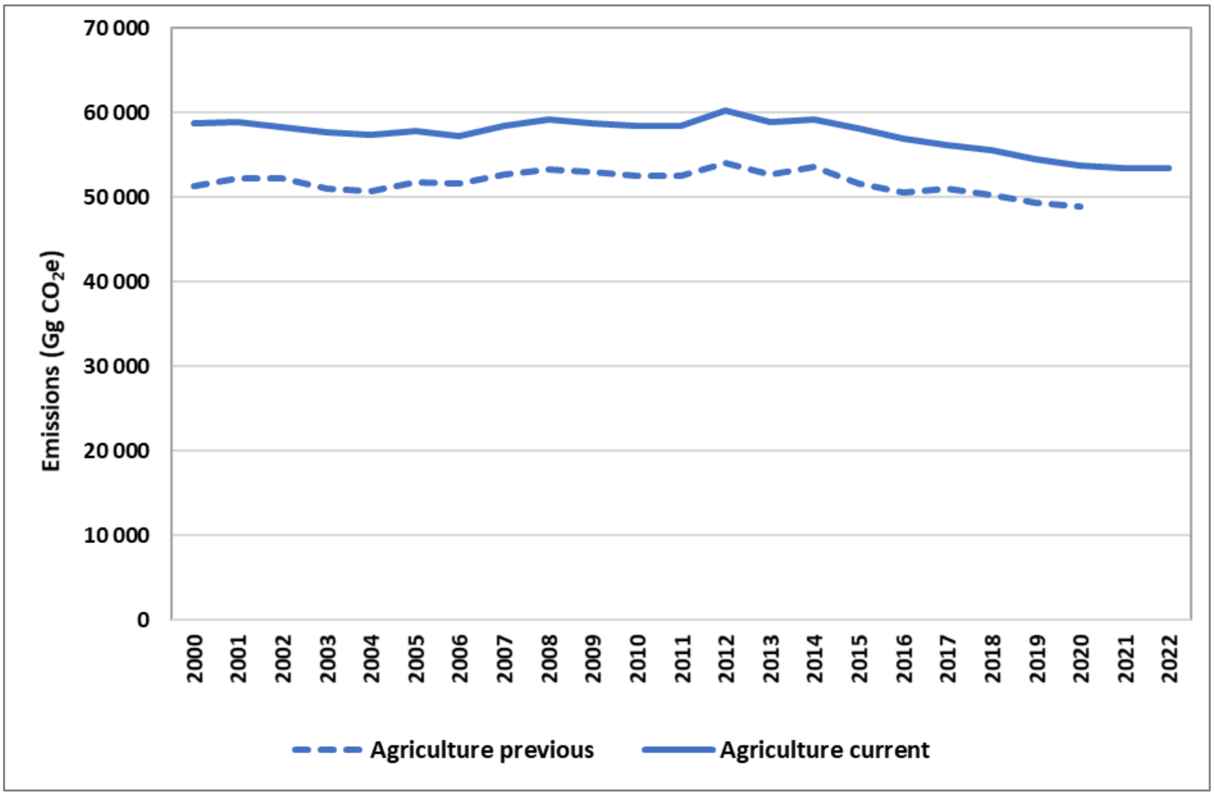

Figure 5.7: Change in Agriculture emission estimates due to recalculations since 2022 submission.

5.1.4 Key categories in the Agriculture sector

The key categories for the Agriculture sector as determined by the level (L) and trend (T) assessment are shown in Table 5.6.

Table 5.6: Key categories in the Agriculture sector in 2022.

CRT code	Category	GHG	Criteria
3.A.1.a.ii	Non-dairy Cattle - CH_4	CH_4	L, T
3.A.1.a.i	Dairy Cattle - CH_4	CH_4	L
3.A.2	Sheep - CH_4	CH_4	L, T
3.A.4	Goats - CH_4	CH_4	T
3D1	Direct N_2O Emissions From Managed Soils - N_2O	N_2O	L
3.G	Liming - CO_2	CO_2	L

#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.

g) There is a need for alternate data source for lime data

5.2 Livestock and manure characterisation

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 5.7. The main data source is the Abstracts of Agricultural Statistics (DALRRD, 2022a) which is a sustainable data source released every year. The livestock population data is collected 4 times in a year (every 3 months). For the year 2022, the 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 (2022b). The same data for number of animals of the various animal groups is used in all the different calculations of emissions.

Table 5.7: Livestock population data sources.

Livestock category		Data source
Cattle	Total cattle	DALRRD (2022b)
	Commercial dairy cows (>2yrs)	DALRRD (2022a)
	Commercial dairy heifers (1-2 yrs)	DALRRD (2022a)
	Feedlot cattle	Feedlot SA (2022)
	Commercial other cattle total	DALRRD (2022a)
	Subsistence cattle	Calculated (see text)
Sheep	Total sheep	DALRRD (2022b)
	Commercial sheep total	DALRRD (2022a)
	Feedlot sheep	Calculated from DALRRD (2022a) slaughter data (see text)
	Subsistence sheep	Calculated (see text)
Goats	Total goats	DALRRD (2022b)
	Commercial goats total	DALRRD (2022a)
	Subsistence goats	Calculated (see text)
Horses, mules and asses		FAOSTAT (2022)
Swine	Total swine	DALRRD (2022b)
	Commercial swine	Calculated (see text)
	Subsistence swine	Calculated (see text)
Poultry	Commercial broilers	Extrapolated based on the data from Leading edge Poultry Software CC (2022)
	Commercial broiler parents	Extrapolated based on the data from Leadingedge Poultry Software CC (2022)
	Commercial layers	Extrapolated based on the data from Leadingedge Poultry Software CC (2022)
	Commercial pullets	Extrapolated based on the data from Leadingedge Poultry Software CC (2022)
	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, 2022a), 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 (2022b). 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 (2022a) 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, 2022a). 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, 2022a).

The subsistence sheep population is estimated by subtracting the total commercial sheep (DALLRD, 2022a) from the total sheep (DALRRD, 2022b).

Subsistence goats

The subsistence goat population is estimated by subtracting the total commercial goats (DALLRD, 2022a) from the total goats (DALRRD, 2022b).

Commercial and subsistence swine

The total swine population provided by DALRRD (2022b) is almost the same as that provided in the Abstracts of Agricultural Statistics (DALRRD, 2022a), suggesting that there are no subsistence swine. Du Toit et al (2013c) noted that there was a large discrepancy between DALRRD (2022a) 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 (2022b) 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 was extrapolated based on the data from Leadingedge Poultry Software CC (2022), 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. 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.

Leading Poultry Software CC (2021) reports that in 2015, subsistence populations accounted for 4-5% of commercial poultry populations. The percentage (4%) is assumed to be constant between 2000 and 20015. In 2022, the projected number of subsistence poultry is 4-5% of commercial poultry, therefore, 5% was applied in 2022 and linear extrapolation was used to estimate the percentage of poultry subsistence poultry in other years.

5.2.1.2 Population characterisation and herd composition

The previous inventory included more detailed characterization of livestock. This is based on a study conducted in 2010 (Du Toit et al., 2013a, b, c) which provided country-specific emission factors for all livestock types. 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 5.8) 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 5.8) 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 5.8: Livestock characterization and herd composition data sources and assumptions.

<table>
<tr><th>Main category</th><th>Production category</th><th>Subcategory</th><th>Herd composition data and assumptions</th></tr>
<tr><td>Dairy cattle</td><td>• High production (Holstein)
• Medium production (Jersey)</td><td>• Mature female cows
• Heifers (12-18 months)
• Heifers (6-12 months)
• Heifers (3-6 months)</td><td>Herd composition based on DALRRD (2021a) data; 57% Holstein and 43% Jersey; even distribution of heifer categories</td></tr>
<tr><td rowspan="3">Other cattle</td><td>• Commercial (Afrikaner; Angus; Beefmaster; Bonsmara; Boran; Brahams; Brangus; Braunvich; Charolais; Drakensburger; Hereford; Hugenoot; Limousin; Bradford; Santa Gertrudis; Simbra; Simmentaler; Susses; Wagyu; Tuli)</td><td>• Mature cows
• Bulls
• Young bulls
• Heifers (12-18 months)
• Heifers (6-12 months)
• Heifers (3-6 months)
• Ox
• Young ox
• Calves</td><td>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</td></tr>
<tr><td>• Subsistence</td><td>• Mature cows
• Bulls
• Heifers (12-18 months)
• Heifers (6-12 months)
• Heifers (3-6 months)
• Ox
• Young ox
• Calves</td><td>Subsistence herd composition based on ARC Report (2021) data; even distribution of heifer categories</td></tr>
<tr><td>• Feedlot</td><td></td><td>All calves</td></tr>
<tr><td rowspan="2">Sheep</td><td>• Commercial wool (Merino)
• Commercial meat (Dorper)
• Commercial dual-purpose (Mutton Merino, Dohne merino)</td><td>• Mature ewe
• Replacement ewe
• Mature ram
• Young ram
• Female lamb
• Male lamb</td><td>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)</td></tr>
<tr><td>• Subsistence</td><td>• Mature ewe
• Replacement ewe
• Mature ram
• Young ram
• Female lamb
• Male lamb</td><td>Subsistence sheep herd composition based on ARC Report (2021) data; even distribution of mature and replacement ewes; even distribution of mature and young rams;</td></tr>
</table>

			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

Livestock data were compared with FAO data and other studies. For all livestock except poultry, the national statistics data (DALRRD, 2022a) used in this inventory correspond to those in the FAO database. There were small differences in the early years (1990 – 2002), but the data were then adjusted accordingly. Regarding poultry data, the data applied in this inventory are on average 33% lower than the FAO data. However, it should be noted that the majority of FAO poultry data are estimates and do 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 (2022a) data. The commercial and subsistence other cattle numbers provided by Du Toit et al. (2013a) are 22% and 4% higher than the DALRRD (2022a) 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 (2022a). 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 (2022a). 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 shows that there is still a gap 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 ARC Report (2021) and there were various sources for this data as indicated in Table 5.9. 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 5.10 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 since there is no data and it is not significant. 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 5.10) 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 5.10, 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 5.10 is low for swine but is high for poultry, therefore the uncertainty is adjusted to ±10% and ±25% for swine and poultry, respectively.

Table 5.9: 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) ; [4,6]Expert opinion, [5]Du Toit et al. (2013c);

Table 5.10: 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

5.3 Enteric Fermentation (3.A)

5.3.1 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:

- Divide livestock population into animal subgroups based on sex, age, and production level.
- Estimate the emission factors for each subgroup in terms of kilograms of CH4 per animal per year.
- Multiply the subgroup emission factors by the subgroup populations to estimate subgroup emissions and sum across the subgroups to estimate total emission.

Enteric fermentation emissions decreased by 20.7% in the period 2000-2020 and decreased by 4.6% between 2017-2020. Enteric fermentation contributed 36 352 Gg CO_2e in 2022, which is 67.9% of the agriculture sector emissions. 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.

5.3.2 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:

$$CH_4\ emissions = EF * Population$$

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 5.11)

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 5.11: 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).

5.3.2.1 Activity data

The activity data for enteric fermentation is livestock population and this is described in detail in section 5.2.1.

5.3.2.2 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 5.12) for the livestock categories with population data. The weighting is based on the herd and breed composition assumptions provided in Table 5.13.

Table 5.12: Enteric fermentation emission factors 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 (3.A.1)

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 5.13).

Sheep (3.A.2) and goats (3.A.4.d)

Emission factors for sheep and goats are calculated using a Tier 2 methodology (Table 5.14). 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.Swine (3.A.3)

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.

Table 5.13: Equations for the calculation of emissions factors for cattle using the Tier 2 approach.

IPCC Equation	IPCC 2006 equations	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: Lactating dairy cows = 0.386, Non-lactating cattle = 0.322, Bulls = 0.37] *Weight* = live weight of animal (kg)
10.4	$NE_a = C_a \times NEm$	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	$NE_g = 22.02 \times (\frac{BW}{C \times MW})^{0.75} \times (WG)^{1.097}$	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	$NE_l = Milk \times (1.47 + 0.40 \times Fat)$	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	$NE_{work} = 0.10 \times NE_m \times Hours$	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 5.14: 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	$\mathrm{NE_m} = \mathrm{Cf}_i \times (weight)^{0.75}$	NE_m = net energy for maintenance (MJ day^{-1}) Cf_i = maintenance coefficient (MJ day^{-1} kg^{-1}) [IPCC 2019 Refinement, Table 10.4: 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	$\mathrm{NE_a} = \mathrm{C}_a \times (weight)$	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	$\mathrm{NE_g} = \frac{WG_{lamb/kid} \times (a + 0.5b(BW_i + BW_f))}{365}$	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	$\mathrm{NE_l} = \left[\frac{5 \times WG_{wean}}{365}\right] \times EV_{milk}$	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

5.3.3 Uncertainty

5.3.3.1 Activity data uncertainty

Activity data time-series is complete from 1990 to 2022, 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.

5.3.3.2 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 5.15). 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 5.15: Enteric fermentation emission factor uncertainties.

Animal categories	Animal subcategories	Emission Factor uncertainty	Reference
3.A.1.a - 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)
3.A.1.b - 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)
3.A.1.b - 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	
3.B.2 - 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)
3.A.4.d - 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)
3.A.4.e - Horses		± 40	IPCC 2006
3.A.4.f - Mules & asses		± 40	IPCC 2006
3.A.3 - Swine		± 20	IPCC 2006

5.3.4 Time-series consistency

The time-series for enteric fermentation is consistent.

5.3.5 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.

5.3.6 Category-specific recalculations

The weighting is applied to the emission factors and not to the population data as was done in the previous inventory and the recalculations were done.

5.3.7 Category-specific planned improvements

In this inventory all the background calculations 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.

5.4 Manure Management (3.B)

5.4.1 CH_4 emissions from manure management (3.B)

5.4.1.1 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.

According to IPCC the method for estimating CH_4 emissions from manure management requires the following steps:

- Divide livestock population into animal subgroups based on sex, age, and production level.
- 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.

Manure management contributes 4 284.52 Gg CO_2e in 2022, which is 8.1% of the Agriculture sector emissions. Methane emissions contribute 40.7% to these emissions.

5.4.1.2 Methodological issues

Activity data

Activity for manure CH_4 emissions is livestock population data which is described in section 5.2.1.

Emission factors

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). Thefraction 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).

5.4.1.3 Uncertainty

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

The data on uncertainty for CH_4 emission factors from livestock manure is presented in Table 5.17. 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. 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.

Table 5.16: Uncertainty data for livestock manure CH_4 emission factors.

Animal categories	Animal subcategories	Emission Factor uncertainty	Reference
3.B.1.a - 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)
3.B.1.b - 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)
3.B.1.b - 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	
3.B.2 - 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)
3.B.4.d - 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)
3.B.4.e - Horses		± 30	IPCC 2006
Mules & asses		± 30	IPCC 2006

3.B.3 - Swine		± 20	IPCC 2006
3.B.4.g - Poultry		± 20	IPCC 2006

5.4.1.4 Time-series consistency

The time-series is consistent throughout the period 2000 – 2022.

5.4.1.5 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.

5.4.1.6 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) in emissions compared to the previous inventory.

5.4.1.7 Category-specific planned improvements

There are no planned improvements for this category in the next year.

5.4.2 Direct and indirect N_2O emissions from manure management (3.B)

5.4.2.1 Category description

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 direct N_2O emissions from manure management requires the following steps:

- Divide livestock population into animal subgroups based on sex, age, and production level.
- 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 livestockcategory 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 systemand sum over all manure management systems.

Manure management contributes 4 284.52 Gg CO_2e in 2022, which is 8.1% of the Agriculture sector emissions. N_2O emissions contributed 59.3% of the total Manure management emissions in 2022.

5.4.2.2 Methodological issues

Direct manure N_2O emissions are calculated following the IPCC equation 10.25 (IPCC, 2006, volume 4, chapter 10).

Activity data

Direct N_2O emissions require information on livestock population (section 5.2.1), manuremanagement (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}, andtypical animal mass. ARC (2021) provides a typical animal mass of 595 kg for horses and250 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 5.17). 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 5.17: Nitrogen excretion rate for different livestock categories

Livestock category	Subcategories	Nitrogen excretion rate (kg N/animal/year)
3.A.1.a - 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
3.A.1.b - 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
3.A.1.b - 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
3.A.2 - 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
3.A.2 - 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
3.A.4.d - 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

Emission factors for all livestock are obtained from IPCC 2019 Refinement (Table 10.21).

5.4.2.3 Uncertainty

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 IPCC default N_2O manure emission factors is -50% to +100%.

5.4.2.4 Time-series consistency

The time-series is consistent throughout the period 2000 – 2022.

5.4.2.5 Category specific QA/QC and verification

Category specific QA/QC and verification is provided in section 5.2.1.3.

5.4.2.6 Category-specific recalculations

There are no specific recalculations for this category.

5.4.2.7 Category-specific planned improvements

There are no planned improvements for this category in the next year.

5.5 Rice cultivation (3.C)

Rice cultivation is not included. The explanation is provided in section 5.1.

5.6 Agricultural soils (3.D)

5.6.1 Direct N_2O emissions from managed soils (3.D.1)

5.6.1.1 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, andis, 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 9 382.9 Gg CO_2e in 2022. The emission contribution of the various types of N inputs is shown in Table 5.18. 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 5.18: 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)**	1 732,1	643,4	6 179,9	426,9
	% Agriculture	2,9	1,1	10,5	0,7

2017	**Emissions ($Gg CO_2e$)**	1 844,4	770,6	5 618,3	894,4
	% Agriculture	3,3	1,4	10,0	1,6
2022	**Emissions ($Gg CO_2e$)**	1 713,6	775,6	5 295,9	977,7
	% Agriculture	3,2	1,4	9,8	1,8
Change	**2000 – 2020 (%)**	-1,1	20,5	-14,3	129,0
	2017 – 2020 (%)	-7,1	0,6	-5,7	9,3

5.6.1.2 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 (F_N) (3.D.1.a)

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 (F_{ON}) (3.D.1.b)

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 (F_{PRP}) (3.D.1.c)

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 (F_{CR}) (3.D.1.d)

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.

Mineralisation/immobilisation associated with loss/gain of soil organic matter (F_{SOM}) (3.D.1.e)

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:

- Livestock population data (section 5.2.1)
- N excretion data (section 5.2.4.2)
- Manure management system usage data (Table 5. 30)
- Amount of managed manure nitrogen that is lost in each manure management system ($Frac_{LossMS}$). IPCC 2006 default values were used here (Table 10.23, Chapter 10, Volume 4, IPCC 2006).
- Amount of nitrogen from bedding. There were no data available for this, so the values provided by IPCC (IPCC, 2006; pg. 10.66) are utilized and
- The fraction of managed manure used for feed, fuel, or construction. Again, there were insufficient data and thus F_{AM} was not adjusted for these fractions (IPCC 2006 Guidelines, p. 11.13).

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, 2022) 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).

5.6.1.3 Uncertainty

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).

5.6.1.4 Time-series consistency

The time-series for direct N_2O emissions is complete and consistent.

5.6.1.5 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.

5.6.1.6 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.

5.6.1.7 Category-specific planned improvements

There are no category specific improvements planned.

5.6.2 Indirect nitrous oxide emissions from managed soils (3.D.2)

5.6.2.1 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 995.2 Gg CO_2e to the total emissions in 2022.

5.6.2.2 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).

5.6.2.3 Uncertainty

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).

5.6.2.4 Time-series consistency

The time-series is consistent throughout the inventory time period.

5.6.2.5 Category specific QA/QC and verification

There were no category specific quality control checks.

5.6.2.6 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.

5.6.2.7 Category-specific planned improvements

There are no planned improvements for this category.

5.7 Field burning of agricultural residues (3.F)

5.7.1 Category description

Agricultural burning is the intentional use of fire for residue management in agricultural fields. Agricultural burning helps farmers remove crop residues left in the field after harvesting grains. This section reports emissions of non-CO_2 gases (CH_4, CO, N_2O and NOx) from cropland while other categories are discussed in the LULUCF section.

In this inventory this category includes biomass burning of sugarcane residues only since the burning of other crop residues is not significant in South Africa. Sugarcane is the only crop which utilises pre-harvest burning to expose the cane stalks removing the outer leaves, driving away insects, snakes and other wild animals making easy not only manual, but also mechanical harvesting additionally, after harvesting, sugarcane residues are burned releasing to the atmosphere GHGs. 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, NOx, NH_3, NMVOC and CO are also produced, and these are precursors for the formation of GHG in the atmosphere (IPCC, 2006).

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. All non-CO_2 emissions, on the other hand, are included in this category.

Field burning of agricultural residues produced 58.54 Gg CO_2 in 2022 which is 0.1% of the agriculture sector emissions.

5.7.2 Methodological issues

The Tier 1 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)

5.7.2.1 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.

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 alevel 3 gridded 500 m product, and the quality of the information is described in Giglio etal. (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 wasconducted 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)

Fuel density of 7 t/ha was used for cropland and it was sourced from DAFF (2010), and the combustion factor of 1 was used and sourced from DAFF (2010). The IPCC value of fuel combustion (t/ha) of 4-10 was used for cropland (IPCC, 2006).

5.7.2.2 Emission factors

IPCC 2006 default emission factors (IPCC, 2006, vol 4, chapter 2, Table 2.5, page 2.47) are applied.

5.7.3 Uncertainty

5.7.3.1 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, cropland was assigned ± 8% uncertainties.

Based on uncertainties in IPCC (IPCC, 2006; Table2.4) and van Leeuwen et al. (2014) fuel consumption uncertainty was determined to be 20% for croplands.

5.7.3.2 Emission factor uncertainty

IPCC default uncertainties for emission factors are provided in the guidelines (IPCC, 2006; Table 2.5).

5.7.4 Time-series consistency

Time series is consistent as same data sources are used throughout.

5.7.5 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.

5.7.6 Category-specific recalculations

There are no specific recalculations for this category.

5.7.7 Category-specific planned improvements

There are no specific planned improvements for this category.

5.8 Liming (3.G)

5.8.1 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. Lime is commonly applied to agricultural lands where nitrogenous fertilisers are continuously used and where precipitation exceeds evapotranspiration.

Liming produced 1 860.71 Gg CO_2 in 2022 which is 3% of the agriculture sector emissions. These emissions have more than doubled since 2000, however, there was a 23% reduction in emissions since 2017.

5.8.2 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). Tier 2 approach is not available for this category.

5.8.2.1 Activity data

Emissions from lime application was estimated per crop type using crop area data and application rates. The calculation was derived from crop areas and application rates, employing estimates from Tongwane et al. (2016). However, this resulted in a figure exceeding 3 million tons of lime in 2008, contrasting with the 1.5 million tons reported by the Fertiliser Association of South Africa.

5.8.2.2 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*.

5.8.3 Uncertainty

5.8.3.1 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%.

5.8.3.2 Emission factor uncertainty

The dolomite and limestone default emission factors have an uncertainty of -50% (IPCC 2006 Guidelines, p. 11.27).

5.8.4 Time-series consistency

A splicing technique was used to combine data sets to ensure a consistent time-series.

5.8.5 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 incorporated and there is a need for an alternate data source should be sought in future.

5.8.6 Category-specific recalculations

The methodology was changed, the calculation of lime application emissions per crop type was based on crop area data and application rates. This involved utilizing crop area estimates in combined with application rates sourced from Tongwane et al. (2016).

5.8.7 Category-specific planned improvements

There is a need for alternate data source for lime data.

5.9 Urea application (3.H)

5.9.1 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 584.6 Gg CO_2 in 2022 (1.1% of the agriculture sector emissions) and this is almost double what was emitted in 2000. Emissions declined by 14.0% since 2017.

5.9.2 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).

5.9.2.1 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 13/07/2022).

5.9.2.2 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.

5.9.3 Uncertainty

5.9.3.1 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.

5.9.3.2 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).

5.9.4 Time-series consistency

The time-series is consistent.

5.9.5 Category specific QA/QC and verification

Urea data is checked against the FAOStat dataset and found to be very similar.

5.9.6 Category-specific recalculations

No recalculations are performed for this category.

5.9.7 Category-specific planned improvements

No improvements are planned for this category in the next year.

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Chapter 6: Land use, Forestry and Land Use Change (LULUCF) (CRT sector 4)

6.1 Sector overview

In the previous inventory the LULUCF sector was referred to as the FOLU sector (Forestry and Other Land Use) and it formed part of the AFOLU (Agriculture, Forestry and Other Land Use) sector. In this inventory the Agriculture and LULUCF sectors have been separated to bring the inventory into alignments with the Common Reporting Table (CRT) reporting requirements under the Enhanced Transparency Framework (ETF). In the LULUCF sector South Africa reports on the emissions (positive) and removals (negative) of CO_2 from the following carbon pools:

- Above-ground biomass:
    - Includes all living biomass above the soil including stem, stump, branches, bark, seeds, and foliage.
    - Included for all land categories.
- Below-ground biomass:
    - Includes all biomass of live roots.
    - Included for all land categories.
- Litter:
    - Included all non-living biomass, lying dead, in various states of decomposition above the mineral or organic soil.
    - Included for all land categories.
- Dead wood:
    - Includes all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil.
    - Only included for the Forest land category.
- Mineral soils:
    - Includes organic carbon in mineral soils to a depth of 30cm.
    - Included for all land categories.
- Harvested wood products (4.G.).

Organic soils were assumed to be negligible (Moeletsi et al., 2015) with further details being provided in section 6.1.3.4.

The carbon pools are reported for the following land-use categories:

- *Forest land* (4.A.)
- *Cropland* (4.B.)
- *Grassland* (4.C.)
- *Wetlands* (4.D.)
- *Settlements* (4.E.)
- *Other land* (4.F.)

As well as the relevant land-use changes between these categories. A distinction is made between areas which, during the reporting period:

- undergo no land-use changes, and thus remain, in unchanged form, in the land-use category they are in ("land remaining" categories 4.A.1 – 4.F.1)
- undergo land-use changes:
    - From the time of conversion onward, these areas are reported in the category to which they were converted. Within those land-use categories, the converted areas are then reported in conversion categories ("land conversion" categories 4.A.2 – 4.F.2) for a total of 20 years. After 20 years in a conversion category, the areas are reported under the relevant remaining categories.

Wetlands also include the emissions of CH_4 and N_2O and non-CO_2 gases emitted from biomass burning are included for *Forest land*, *Grassland*, *Wetlands*, and *Settlements*. In *Croplands* the burning is due to pre-harvest burning of sugarcane and this is included under Agriculture in category 3.F. Other lands are assumed not to burn due to the absence of biomass. Emissions from humus mineralisation in mineral soils as a result of land use change and/or land management are reported in the Agriculture sector under category 3.D.1.

The reporting of non-CO_2 emissions from biomass burning was incorporated into the Agriculture component of the AFOLU sector in the previous inventory (under the *Aggregated and non-CO_2 emissions* category (3.C)), however due to the adjusted reporting requirements these non-CO_2 emissions are now included within each land use category under the LULUCF sector.

6.1.1 Shares and trends in emissions

The LULUCF sector was a sink in 2022 (Table 6.1) with *Forest lands* being the largest contributor to the sink. All other land categories were a source of emissions in 2022, with *Other lands* being the largest.

Table 6.1: Summary of emissions from the LULUCF sector in 2022.

Greenhouse gas source and sink categories	CO_2	CH_4		N_2O		Total
	Gg CO_2	Gg	Gg CO_2e	Gg	Gg CO_2eq	Gg CO_2e
4. LULUCF	**-56 146.3**		**11 019.8**		**2 066.7**	**-43 059.8**
4.A. Forest land	-90 082.4	57.7	1 614.3	3.4	**909.3**	-87 558.8
4.B. Cropland	3 508.9	IE	IE	IE	IE	3 508.9
4.C. Grassland	10 576.8	25.2	705.87	2.3	610.65	11 893.4
4.D. Wetlands	748.0	310.6	8 697.0	2.1	544.4	9 989.3
4.E. Settlements	258.5	0.1	2.7	0.01	2.4	263.6
4.F. Other land	19 025.4	NA	NA	NA	NA	19 025.4
4.G. Harvested wood products	-181.4	NA	NA	NA	NA	-181.4

Figure 6.1 provides an overview of the LULUCF emission trends for South Africa over the time-series 2000-2022. The time-series reflects the trends in land-use changes. The land-use changes have been determined based on South African National Land Cover (SANLC) data sets for the reference years 1990, 2014, 2018 and 2020. Between the reference years, the land-use changes have been linearly interpolated, hence the larger changes after each refence year and the constant average land-use changes between reference periods. A map is being developed for 2022 but was not finalised before the preparation of this inventory and so the data was not included in this inventory. Data for the period 2020-2022 was extrapolated based on the change area provided between 2018 and 2020.

Forest lands were the largest contributor to the sink across the time-series. The dominant *Forest land* sinks were thickets and woodlands. The increasing *Forest land* sink between 2014 and 2022 is due to an increasing woodland sink because of an increase in the conversion of grassland to woodland. The increasing woodland sink was reduced slightly between 2017 and 2022 by the decreasing thicket sink caused by a reduction in the thicket area. The overall variation in the *Forest land* category follows a similar pattern to the burnt area data. For example, the years 2005 and 2021 were high burn years which meant an increase in emissions and an increase in disturbance losses in *Forest lands* therefore a reduced sink in 2005 and 2021.

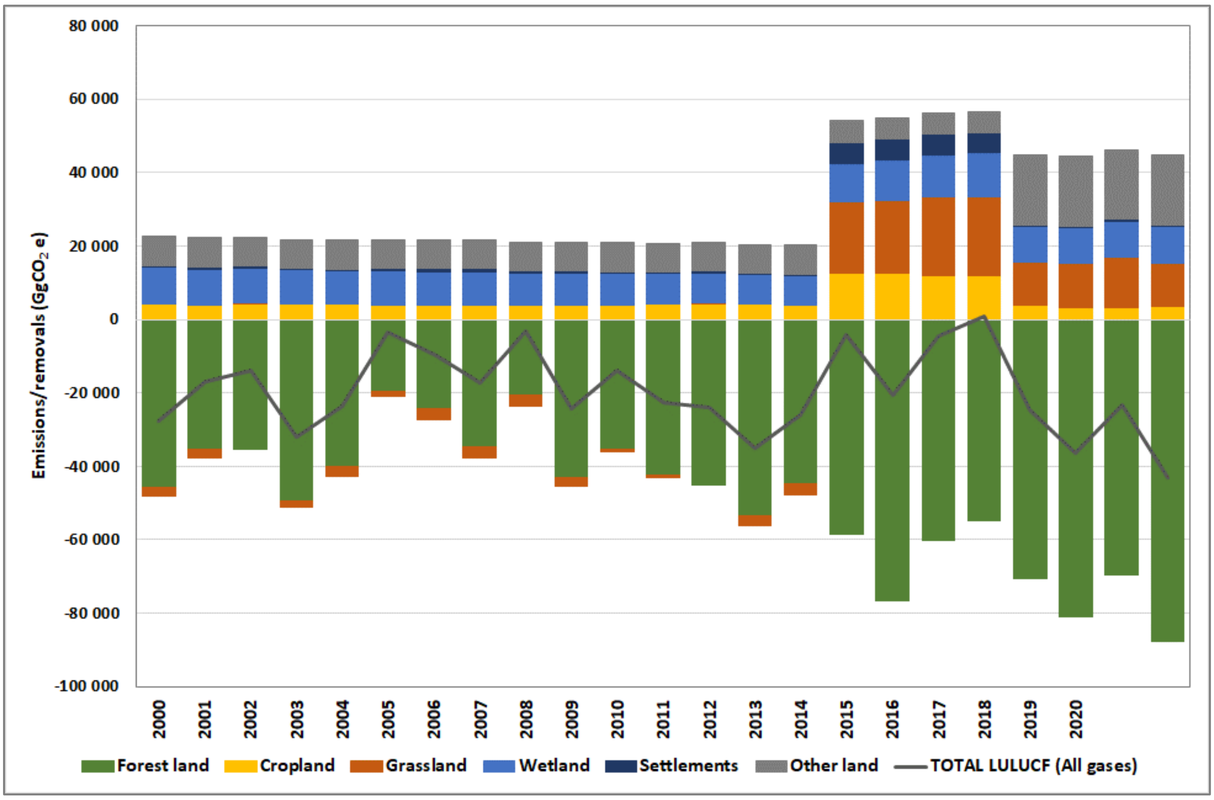

Figure 6.1: Time series for GHG emissions and removals by land type in the LULUCF sector in South Africa, 2000 - 2022.

Croplands showed an increase in emissions between 2015 and 2018 due to the conversion of perennial crops to annual crops and the conversion of woodlands to subsistence crops. These emissions were reduced between 2019 and 2022 as these conversions were reduced and there was some conversion of annual crops to perennial crops.

The change in *Grasslands* is what was causing the reduced sink between 2017 and 2022. Between 2015 and 2018 there is an increase in the conversion of low shrublands to grasslands, while between 2019 and 2022 there is an increase in the conversion of woodland to grassland leading to an increased source.

Converted lands were the largest contributors to all land categories except *Wetlands* (Table 6.2) where non-CO_2 emissions from wetlands play a role. Overall, the LULUCF sector increased its sink by 56.3% since 2000 and by 17.9% since 2020. *Grasslands* changed from a small sink in 2000 to a large source in 2020 and 2022. Changes were large between 2000 and 2020 (Table 6.2) with part of the reason being that the data for these years came from two different land change maps, however change is small between 2020 and 2022 as would be expected from a shorter change period and where the comparison is between two maps produced in exactly the same way.

Biomass is the dominant carbon pool (**Error! Reference source not found.**). Soils r emain a small sink throughout the time-series, while The DOM pool increases its sink strength between 2019 and 2022.

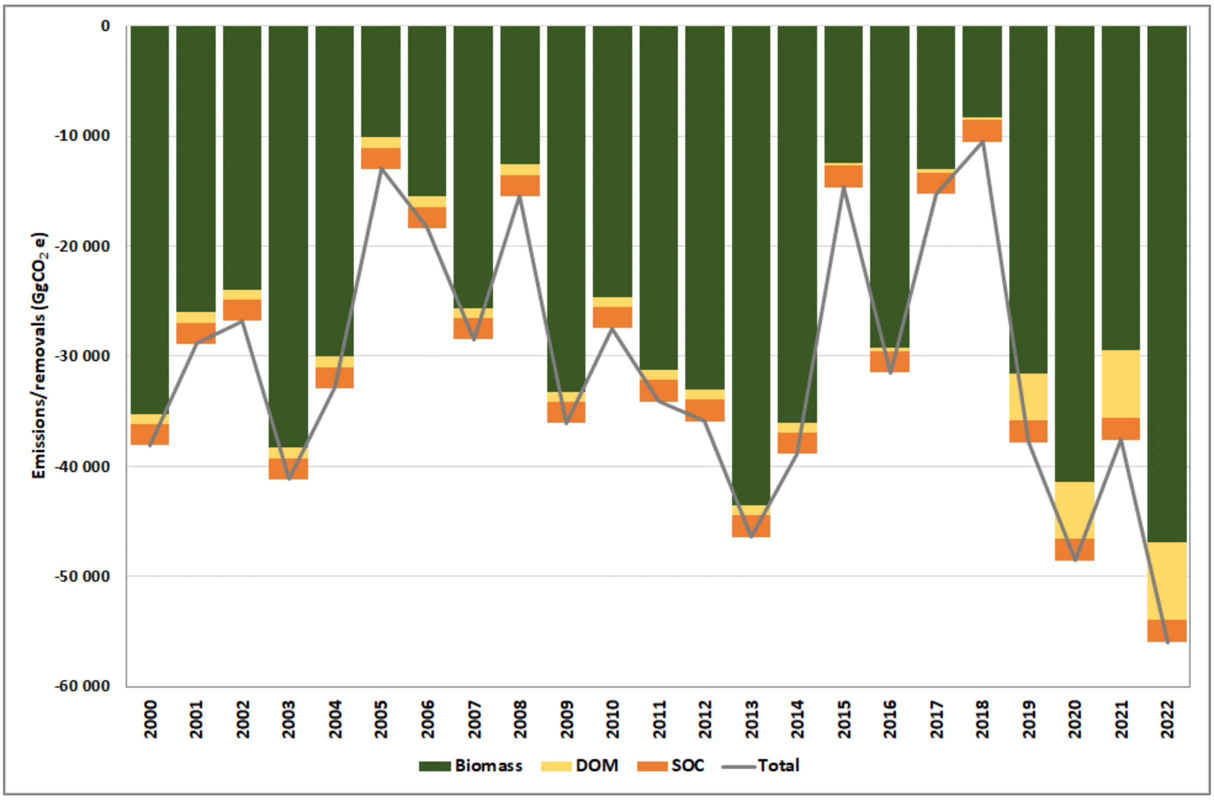

Figure 6.2: Time-series of GHG emission and removals by carbon pool for the LULUCF sector in South Africa, 2000-2022.

Table 6.2: Summary of the change in emissions from the LULUCF sector over the time-series 2000-2022 and since the last inventory in 2020.

GHG source and sink categories	Emissions ($Gg\ CO_2eq$)			Difference ($Gg\ CO_2eq$)		Change (%)	
	2000	2020	2022	2000-2022	2020-2022	2000-2022	2020-2022
4. LULUCF	**-27 840.2**	**-36 519.2**	**-43 059.8**	**-15 875.4**	**-6 540.6**	**56.3**	**17.9**
4.A. Forest land	**-45 816.6**	**-81 062.2**	**-87 558.8**	**-41 742.2**	**-6 496.6**	**91.1**	**8.0**
4.A.1. Forest land remaining forest land	*-16 662.6*	*-34 344.8*	*-32 696.7*	*-16 034.1*	*1 648.1*	*96.2*	*-4.8*
4.A.2. Land converted to forest land	*-29 154.0*	*-46 717.4*	*-54 862.1*	*-25 708.1*	*-8 144.7*	*88.2*	*17.4*
4.B. Cropland	**4 365.1**	**3 353.3**	**3 508.9**	**-856.3**	**155.6**	**-19.6**	**4.6**
4.B.1. Cropland remaining cropland	*234.6*	*151.6*	*79.5*	*-155.1*	*-72.1*	*-66.1*	*-47.6*
4.B.2. Land converted to cropland	*4 130.5*	*3 201.7*	*3 429.4*	*-701.2*	*227.7*	*-17.0*	*7.1*
4.C. Grassland	**-2 205.6**	**12 026.9**	**11 893.4**	**14 098.9**	**-133.5**	**-639.2**	**-1.1**
4.C.1. Grassland remaining grassland	*-611.5*	*13 538.6*	*13 728.0*	*14 339.5*	*189.3*	*-2 344.9*	*1.4*
4.C.2. Land converted to grassland	*-1 594.0*	*-1 511.7*	*-1 834.6*	*-240.6*	*-322.9*	*15.1*	*21.4*
4.D. Wetlands	**9 848.8**	**9 774.4**	**9 989.3**	**140.5**	**214.9**	**1.4**	**2.2**
4.D.1. Wetlands remaining wetlands	*7 476.6*	*4 889.4*	*5 088.5*	*-2 388.1*	*199.1*	*-31.9*	*4.1*
4.D.2. Land converted to wetlands	*2 372.2*	*4 885.0*	*4 900.8*	*2 528.6*	*15.7*	*106.6*	*0.3*
4.E. Settlements	**559.8**	**302.9**	**263.6**	**-296.2**	**-39.3**	**-52.9**	**-13.0**
4.E.1. Settlements remaining settlements	*-261.2*	*-421.6*	*-442.6*	*-181.4*	*-21.0*	*69.4*	*5.0*
4.E.2. Land converted to settlements	*820.9*	*724.5*	*706.1*	*-114.9*	*-18.3*	*-14.0*	*-2.5*
4.F. Other land	**7 812.5**	**19 025.7**	**19 025.4**	**11 212.8**	**-0.3**	**143.5**	**0.0**
4.F.1. Other land remaining other land	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
4.F.2. Land converted to other land	*7 812.5*	*19 025.7*	*19 025.4*	*11 212.8*	*-0.3*	*143.5*	*0.0*
4.G. Harvested wood products	**-2 106.2**	**59.9**	**-181.4**	**1 924.8**	**-241.4**	**-91.4**	**-402.8**

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

6.1.2 Impacts of natural disturbance

The inventory includes both wildfires (natural disturbance) and controlled fires as there was insufficient data to separate the two. Fires were included in the inventory through disturbance losses (which removes biomass and litter and leads to emissions) and through the non-CO_2 emissions from fires (which also contribute towards emissions). Fires are an important component of South Africa's natural ecosystems and cannot always be controlled. Removing all fire disturbance impacts leads to an enhanced sink with reduced annual variability (Figure 6.3). Not all fires are natural as a small percentage will be controlled fires. Collecting data to enable the fire data to be split into controlled and wildfires is important for understanding how or where fire emissions can be reduced and for establishing a baseline for natural disturbance contributions.

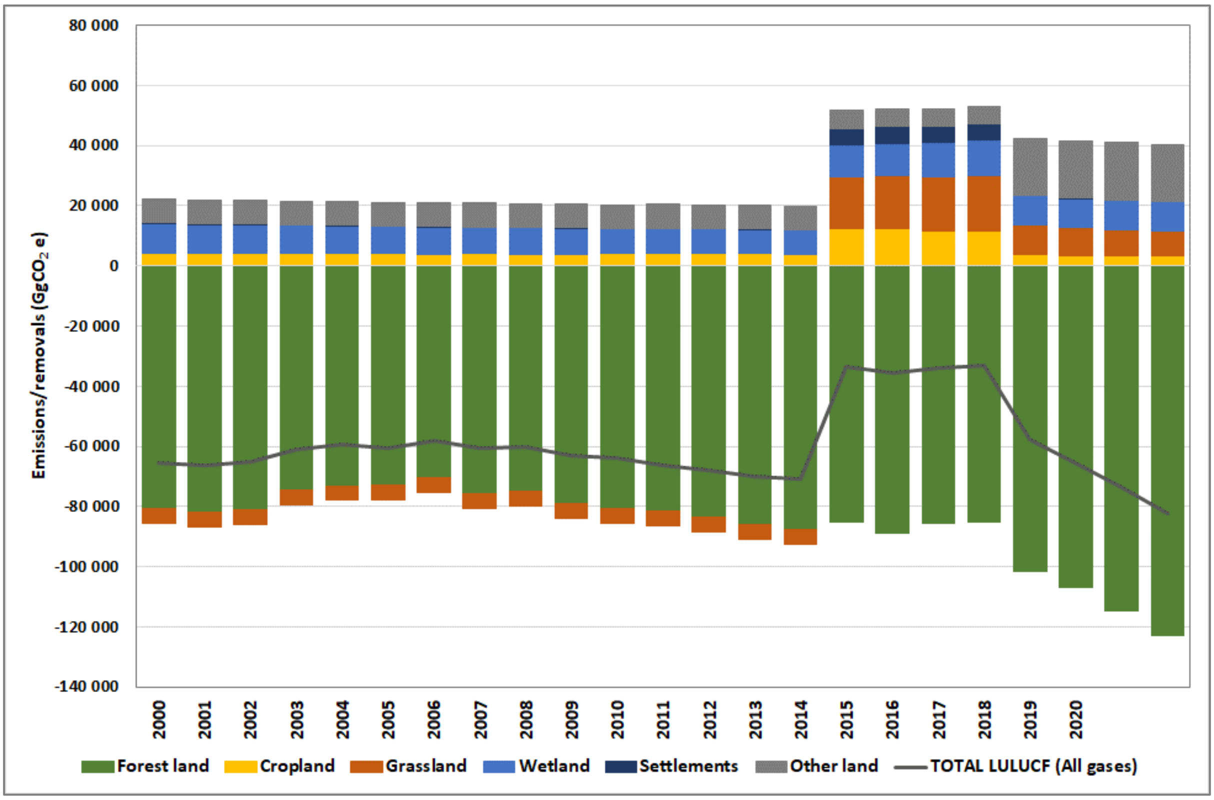

Figure 6.3: Time-series of GHG emission and removals by land type for the LULUCF sector when fire impacts are excluded.

6.1.3 Overview of methodology and completeness

The following basic elements and process was required to prepare the LULUCF inventory:

1. Land cover/use maps: SANLC maps, containing 73 land classes, were obtained for 1990, 2014, 2018 and 2020. The relevant land uses, and the specific areas assigned to them, were explicitly determined for these years, while the areas applying to the periods between those years were obtained by linearly interpolating the calculated areas.
2. Land change matrix: The 73 classes from the SANLC maps were aggregated into 20 classes for land change determination. The classes were Indigenous forests, Thicket/Dense bush, Woodlands/Open bush, Forest plantations, Vineyards, Orchards, Annual pivot crops, Annual non-pivot crops, Subsistence crops, Grasslands, Low shrublands, Eroded land, Wetlands, Waterbodies, Residential areas, Commercial areas, Industrial areas, Small-holdings, Mines, and Bare ground. The annual land change areas were determined from the change matrix for 1990-2014, 2014-2018 and 2018-2020 for the above-mentioned land categories to assist in the calculation of "land remaining" and "land converted" categories.
3. 20-year default transition period: The land-use-matrix calculation is referenced to the year 1970, to make it possible to determine land-use-change areas for years prior to the actual reporting period. Identified conversion areas were assigned to the relevant land-use-change category, in the year in which the land-use change took place, and they remained in that category for a maximum of 20 years. At the end of the 20-year period, the areas were assigned to the remaining category within the final use category. The "land remaining" was calculated from the land area converted to that land category and the area coveted to another land category. The "land converted" was calculated from the annual converted area accumulated over the period in which it remains in the "land converted" up to the default 20-year conversion period. Consequently, as of the second reporting year, the areas in the remaining categories are smaller, and those in the conversion categories larger, than the corresponding areas in an annual land-use matrix. Since land parcels were not tracked the amount of change allocated to "land remaining" and "converted land" was determined through a process of overlaying the "land remaining" areas for 1990-2014, 2014-2018 and 2018-202 to determine by what fraction the "land remaining" area was reduced. This provided the area that was converted to other lands and the rest of the conversions were assumed to occur on already converted land (i.e. removed from the "converted land" category).
4. Annual increase in carbon stocks due to biomass growth: Estimated the annual increase in biomass carbon stocks for each land class by applying the 2006 IPCC Guidelines equations 2.9 and 2.10.
5. Annual decrease in biomass carbon stocks due to losses: Losses due to harvest, fuelwood collection, disturbances and conversion losses were estimated using

2006 IPCC Guidelines equations 2.11 to 2.14. The disturbance losses were only for fires except for Forest plantations where other disturbance losses (such as insects, wind) were also included.

6. Annual change in carbon stocks in biomass in land remaining categories: Outputs from points 4 and 5 above were incorporated into the IPCC Gain-loss equation (2006 IPCC Guideline equation 2.7) to determine the annual change in biomass carbon stocks.
7. Biomass change due to land conversions: Estimated annual change in biomass carbon stocks due to land changes by apply the 2006 IPCC Guidelines equation 2.15 and 2.16 (Tier 2).
8. Annual change in carbon stocks in deadwood and litter (DOM): For "land remaining" the DOM was assumed not to change (Tier 1 assumption) so a value of zero was applied. The "converted land" categories the annual change in stocks in DOM were estimated using 2006 IPCC Guideline equation 2.23.
9. Soil organic carbon reference values: Soils were classified into the 6 IPCC soil classes and this map was intersected with the ISRIC soils dataset to obtain a SOCRef value for each soil type.
10. Land conversions by soil type: The land conversion maps were clipped by soil type and a land change matrix for each conversion period for each soil type were developed.
11. Soil carbon stock change factors: The IPCC stock change factors were applied for *Forest land, Grassland, Wetlands and Settlements*, while detailed data on cropland management provided estimates of the stock change factors for croplands.
12. Annual change in carbon stocks in mineral soils: This was estimated by applying the 2006 IPCC Guideline equation 2.25 (Approach B).
13. Calculation of CO_2 emissions on the basis of the carbon-stocks values for the NIR, via multiplication of carbon-stock changes by the factor -44/12.
14. Non-CO_2 emission estimates: CH_4 and N_2O emissions from each land class was determined from burnt area data (MODIS Collection 6), fuel loads, combustion factors and emission factors using 2006 IPCC equation 2.27. Equation 5.1. of the IPCC Wetland Supplement (IPCC, 2014; Chapter 5) was used to estimate non-CO_2 emission estimates from *Wetlands*.
15. Calculation of N_2O emissions from nitrogen values, via multiplication of the nitrogen-stock changes by the factor -44/28; the N_2O values are converted into CO_2 equivalents using the factor 265 (GWP 100 pursuant to IPCC AR5 (IPCC, 2014b)).
16. The CH_4 emissions are converted into CO_2 equivalents using the factor 28 (GWP 100 pursuant to IPCC AR5).
17. The data from the 20 classes were aggregated (as discussed in section 6.3) into the 6 IPCC categories for reporting purposes.

A summary of the tier level of the methods and types of emission factors incorporated into the inventory are provided in Table 6.3.

Table 6.3: Summary of methods and emission factors for the LULUCF sector and an assessment of the completeness of the sector.

GHG Source and sink category	CO_2		CH_4		N_2O		NO_x	CO	NMVOC	NH_3
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor				
4A Forest land										
4.A.1. Forest land remaining forest land	Biomass: T2 Litter: T2 Soil: T2	Biomass: CS Litter: CS Soil: CS	T1	DF	T1	DF	T1/DF	T1/DF	T1/DF	NE
4.A.2. Land converted to forest land	Biomass: T2 Litter: T2 Soil: T2	Biomass: CS Litter: CS Soil: CS	IE	DF	IE	DF	T1/DF	T1/DF	T1/DF	NE
4B Cropland										
4.B.1. Cropland remaining cropland	Biomass: T1 (annuals), T2 (perennials) Litter: T1/T2 Soil: T2	Biomass: DF/CS Litter: DF/CS Soil: CS	IE		IE		IE	IE	IE	NE
4.B.2. Land converted to cropland	Biomass: T2 Litter: T2 Soil: T2	Biomass: CS Litter: CS Soil: CS	IE		IE		IE	IE	IE	NE
4C Grassland										
4.C.1. Grassland remaining grassland	Biomass: T1 (grasslands), T2 (low shrubland) Litter: T1/T2 Soil: T2	Biomass: DF/CS Litter: DF/CS Soil: CS	T1	DF	T1	DF	T1/DF	T1/DF	T1/DF	NE

GHG Source and sink category	CO_2		CH_4		N_2O		NO_x	CO	NMVOC	NH_3
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor				
4.C.2. Land converted to grassland	Biomass: T2	Biomass: CS	T1	DF	T1	DF	T1/DF	T1/DF	T1/DF	NE
	Litter: T2	Litter: CS								
	Soil: T2	Soil: CS								
4D Wetland										
4.D.1. Wetland remaining wetland	Biomass: T1/T2 Litter: T1/T2 Soils: T2	Biomass: DF/CS Litter: DF/CS Soil: CS	T1	DF/CS	T1	DF/CS	T1/DF	T1/DF	T1/DF	NE
4.D.2. Land converted to wetland	Biomass: T2 Litter: T2 Soil: T2	Biomass: CS Litter: CS Soil: CS	T1	DF	T1	DF	T1/DF	T1/DF	T1/DF	NE
4E Settlements										
4.E.1. Settlements remaining settlements	Biomass: T2	Biomass: CS	T1	DF	T1	DF	T1/DF	T1/DF	T1/DF	NE
	Litter: T2	Litter: CS								
	Soil: T2	Soil: CS								
4.E.2. Land converted to settlements	Biomass: T2	Biomass: CS	T1	DF	T1	DF	T1/DF	T1/DF	T1/DF	NE
	DOM: T2	Litter: CS								
	Soil: T2	Soil: CS								
4F Other land										
4.F.1. Other land remaining other land	Biomass: NA		NA		NA		NA	NA	NA	NA
	Litter: NA									
	Soil: T2	Soil: CS								
4.F.2. Land converted to other land	Biomass: T2	Biomass: CS	NA		NA		NA	NA	NA	NA

GHG Source and sink category	CO_2		CH_4		N_2O		NO_x	CO	NMVOC	NH_3
	Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor				
	Litter: T2	Litter: CS								
	Soil: T2	Soil: CS								
4G Harvested wood products										
Harvested wood products	T2	DF	NA		NA		NA	NA	NA	NA

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.

6.1.3.1 Carbon emissions from biomass

South Africa uses a combination of Tier 1, and Tier 2 methods for estimating emissions for the LULUCF sector. 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 the Gain-loss method was applied.

For the "land remaining" category in *Forest land, Cropland, Grasslands* and *Settlements* the 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 equation 2.10 (Tier 1 approach) but with country specific data. For plantations the Tier 2 approach of this equation was applied. For pure grasslands the assumption of equivalence was applied (Tier 1) but incorporated in the *Grassland* category is the low shrubland class which has a small shrub element which was accounted for. For *Wetlands* and *Other lands* the Tier 1 assumption of equivalence was applied. The above-ground biomass and biomass gains for all woody or perennial land categories were sources from the scientific literature. Literature was also relied on for root to shoot ratios so that below-ground biomass could be determined. Data on MAI for estimating growth in forest plantations were obtained from collected forestry data.

The annual decrease in carbon stocks due to disturbance losses were estimated from IPCC equations 2.11 to 2.14 (IPCC, 2006). Fire disturbance losses (from both Wildfires and controlled fires) were incorporated for *Forest land, Grassland, Wetlands*, and *Settlements*. In *Croplands* the burning losses were only for pre-harvest burning of sugarcane, and *Other lands* were assumed not to burn due to the lack of biomass on these lands. The burnt area estimation is discussed under section 6.1.3.6.

Harvest losses were included for forest plantations and perennial crops, while the woodland/open bush category included fuelwood collection losses. Forest plantations were the only category where other losses (such as losses due to insects and wind) were included due to a lack of data in other land categories.

The 2006 IPCC Guideline equations 2.15 and 20.16 were utilised for estimating emissions from biomass changes on converted land. A Tier 2 approach was applied as country specific biomass stocks were applied and natural land classes were not assumed to be cleared but rather transition slowly from initial to final biomass levels. Land was only assumed to be cleared for forest plantations, croplands and settlements, so carbon stocks immediately after conversion were set to zero. For land transitions to land categories with woody components the carbon growth values were used and carbon was gained over the 20 default transition period. Woody losses were assumed to be immediate an accounted for in the year of conversion. Growth in converted lands was estimated using the growth rates for the various land categories.

6.1.3.2 Carbon emissions from litter and deadwood

The dead organic matter pool includes litter and deadwood for Forest lands and only litter for other land categories. It is assumed that there are no DOM changes in "land remaining" categories (Tier 1), and it is assumed that in "converted land" categories all litter pool carbon losses occur entirely in the year of transition (Tier 1). The 2006 IPCC Guidelines equation 2.23 was used to estimate changes in litter in converted land. Litter and deadwood (DOM) estimates for the various land categories were determined from literature or from intersecting the SANLC data with the National Terrestrial Carbon Sinks Atlas (NTCSA) carbon density maps (DEFF, 2020) and are provided in the relevant land category sections below.

6.1.3.3 Carbon emissions from mineral soils

Soil categorisation

South Africa's detailed soils map was reclassified into the 7 soil classes provided by IPCC 2006 Guidelines (DEA, 2015) (Figure 6.4). 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 6.4 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.

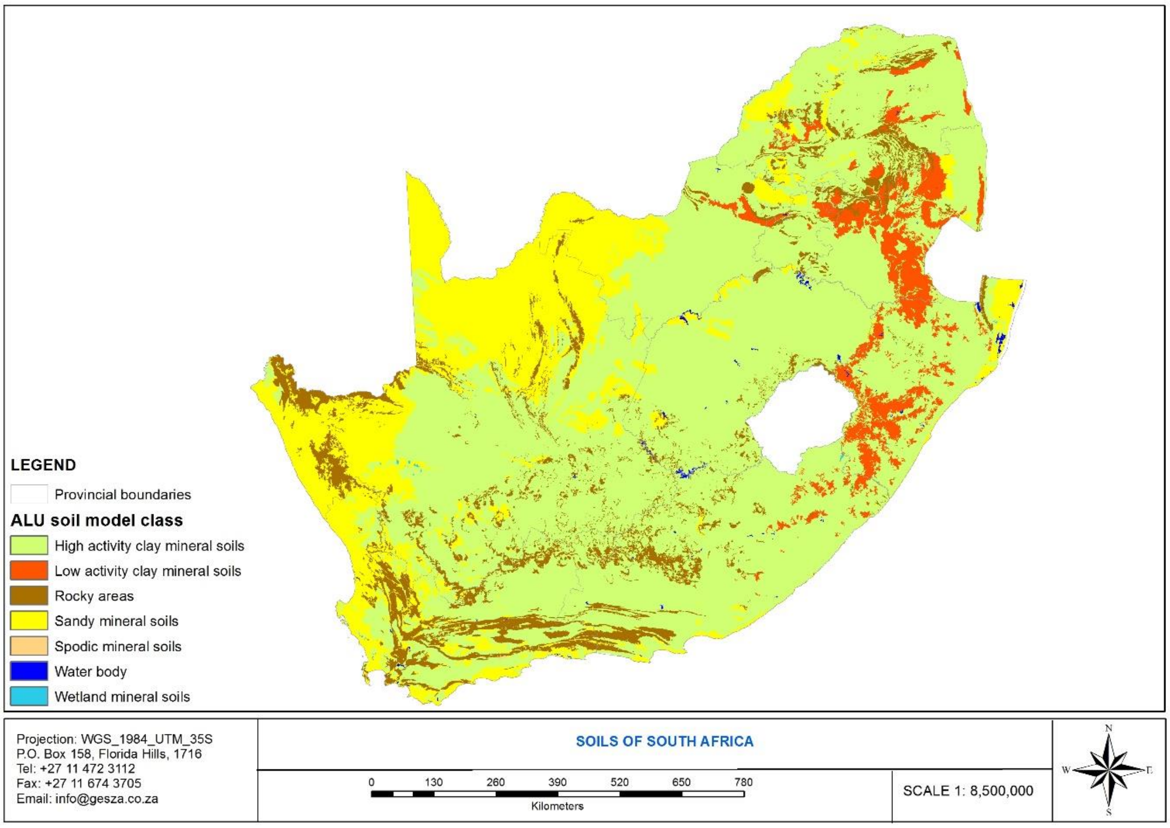

Figure 6.4: South African soils classified into the IPCC classes (DEA, 2015).

Table 6.4: Soil types and their description (Source: DEA, 2015)

	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,	Land types where champagne soil forms comprise more than 40%.

	so their distribution is limited to small zones in KwaZulu-Natal.	
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, such as KwaZulu-Natal and Mpumalanga.	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%, 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.

SOC reference values

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 stand-alone 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 6.5. Comparisons were 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 6.5: Soil carbon reference data per soil type as obtained from ISRIC database.

	SOCRef value (t C/ha)	IPCC 2006 default[19]	IPCC 2019 Refinement
Sandy mineral soils	20.85	19	10 ±5%
Wetland soils	40.53	88	74 ±17%
Spodic soils	71.65	115[20]	143 ±30%
Rocky soils	47.03	NA	NA
Low activity clay	65.54	24	19 ±16%
High activity clay	35.21	38	24 ±5%

Soil carbon stock change factors

Country specific stock change factors were applied where possible. For *Forest lands* and *Wetlands* a stock change factor of 1 (IPCC default) was applied, while country specific factors (described in the relevant land category sections) were incorporated for *Croplands*, *Grasslands* and *Settlements*.

Table 6.6: 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

[19] *Defaults are for warm, temperate climates*
[20] *This is the default value for cold, temperate climates as there is no value for warm, temperate environments.*

Annual crops	Combined sock change factor varies annually (between 0.68 and 0.74) based on crop types, crop areas, management and inputs			Moeletsi et al. (2015)
Subsistence crops	0.58			NTCSA (DFFE 2020)
Settlements and mines	1	1	1	IPCC 2006

SOC emission estimation

The soil map in Figure 6.4 was intersected with the land change maps to obtain a land change matrix per soil type. This information, along with the SOC reference values and stock change data, were incorporated into the 2006 IPCC Guideline equation 2.25 (Formulation B) to determine the annual SOC change for each land category.

Verification

Soils estimates were verified by comparing the outputs to the Tier 1 approach (Formulation A of 2006 IPCC Guideline equation 2.25) for the data between 1990 and 2020. The total estimated CO_2 sequestration per year using the Tier 2 approach was 2 101 Gg CO_2 while applying the Tier 1 approach gave a value of 2 186 Gg CO_2 which are very similar (Table 6.7).

Table 6.7: Comparison of total CO_2 (Gg CO_2 per year) from soils between the Tier 1 and Tier 2 approaches

Soil type	Tier 1 (Formulation A)	Tier 2 (Formulation B)
Sandy soils	27.1	24.1
Wetland soils	10.8	10.9
Spodic soils	0.2	0.2
Rocky soils	-31.2	-27.0
Low activity clay soils	63.0	61.8
High activity clay soils	-2 252.8	-2 167.9

6.1.3.4 Organic soils

As mentioned above, organic soils were assumed to be negligible, however a more recent study by Schulze and Schutte (2018) indicates there is a small area of organic soils. This study 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 (DEFF, 2021a) indicates that wetlands cover approximately 19 000ha of which most are assumed to contain high organic soils. This will be included in the improvement plan but the priority, due to its small area and impact to overall emissions, is low and will therefore only be incorporated at a later stage (see details in improvement plan).

6.1.3.5 Nitrous oxide and methane emissions from wetlands

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.

6.1.3.6 Biomass burning

The CO_2 emissions from biomass burning are included as biomass disturbance losses (as discussed in section 6.1.3.1). South Africa reports emissions of non-CO_2 gases (CH_4, CO, N_2O, and NO_x) from *Forest land, Grasslands, Wetlands* and *Settlements*. *Other lands* are assumed not to burn as there is no biomass. For *Croplands* only the pre-harvest burning of sugarcane is accounted for and this is not included here bur rather under agriculture as burning of crop residues.

There is insufficient data to separate controlled fires from wildfires, so all emissions are for total fires. 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*.

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 here.

Burnt area data

The MODIS Collection 5 Burnt Area data is available for the years 2001 to 2017 as this is the data that was used in inventories prior to the 2020 inventory. In 2020 the MODIS Collection 6 Burnt Area data was utilised, which is an upgrade from the Collection 5. 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 very little difference in the two data sets for the years since 2010 (<1%), but there was a 15% difference for the 2001 dataset. Data was incomplete for 2000 so this data set was extrapolated.

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). Monthly data was combined to obtain annual burnt area maps for each year. Each year's dataset was clipped (extract by mask) to the actual South African boundary The burnt area maps were intersected with the SANLC data to obtain burnt area per land class. Land cover maps are not available for every year, so the 2014 map was intersected with the burnt areas for 2000 to 2014, the 2018 intersected with the years 2015-2019 and 2020 with the rest of the years.

To estimate the burnt area per land conversion category, the fraction of the land class that was burnt was assumed to occur evenly across all conversions, so the fraction was applied to each land conversion area.

Emission estimation calculation

The Tier 2 methodology was applied, with the emissions from biomass burning being calculated using the 2006 IPCC Guideline equation 2.27. This equation combines the burnt area with the mass of fuel available (see specific land category sections for details) and the 2006 IPCC default emission factors (IPCC, 2006, vol 4, chapter 2, Table 2.5, page 2.47). Indirect emissions of CO, NOx and VOCs were also estimated and reported as indirect emissions in Gg of gas. The CO and NOx emissions factors were the default factors provided by IPCC (IPCC, 2006, vol 4, chapter 2, Table 2.5, page 2.47), while the VOC emission factors were sourced from Andreae (2019).

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.

6.1.3.7 Climate

Long term climate maps were developed for South Africa (DEA, 2015) which categorize the climate into the classes provided by 2006 IPCC Guidelines. Although 4 climate types (Figure 6.5) 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. 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. Including the addition climate zones is on the improvement list but it has a low priority.

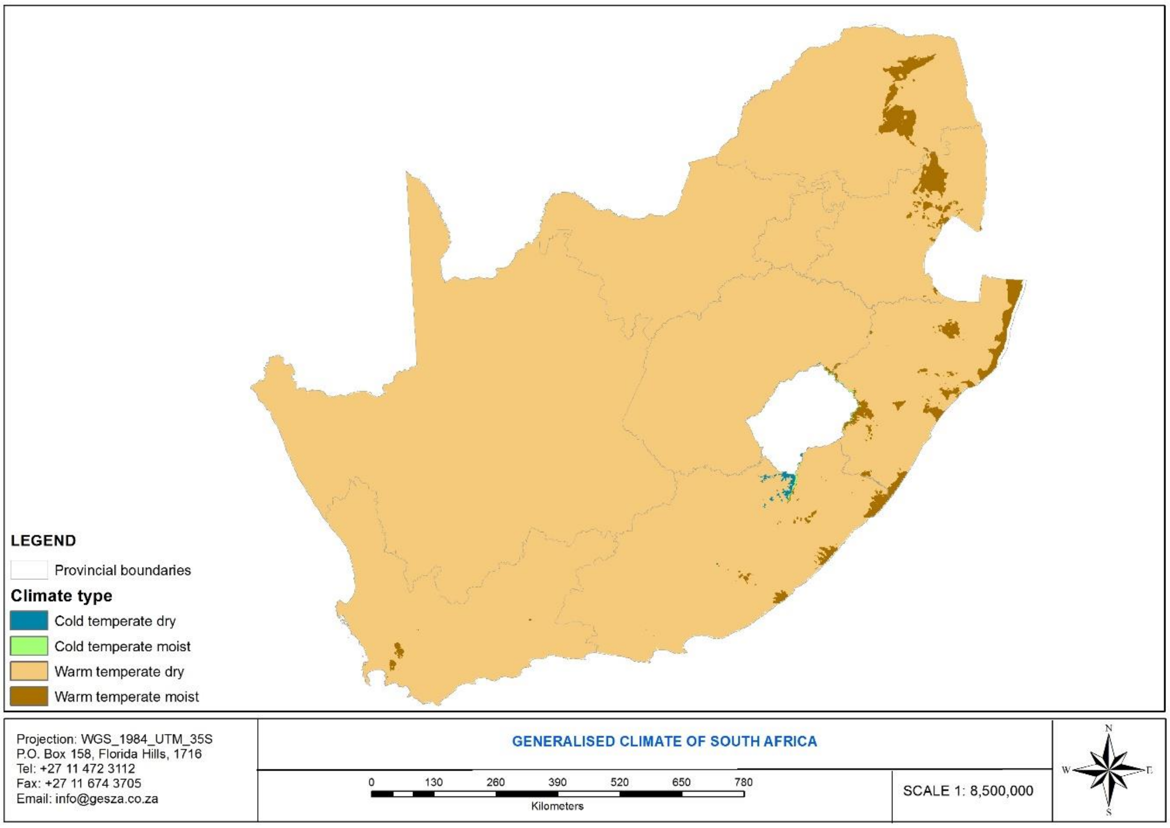

Figure 6.5: South Africa's long term climate map classified into the IPCC climate classes (Source: DEA, 2015).

6.1.4 Improvements and recalculations

The main inventory improvements that were carried out and which led to recalculations were:

- Inclusion of the three separate land change maps:
    - 1990-2014
    - 2014-2018
    - 2018-2020
- Updated corrections and assumptions for the 2014-2018 change to correct for the change in land classification due to improved resolution of the maps
- Removal of "unlikely" conversions from all land change matrix

- Removal of potential seasonal variation for the conversion between *Forest lands* and *Grasslands*
- Inclusion of corrections for conversions from converted lands
- Inclusion of country specific BCEF factors for plantations
- Inclusion of disturbance matrix for plantations
- Updated the household fuelwood consumption factor
- Updated carbon stock data for the various land categories
- Inclusion of an assumption that the only cropland area that burned was sugarcane and that 90% of the sugarcane was burnt during pre-harvest and these emissions move to category 3.F
- Inclusion of the growth of biomass of the last 5 years of the maturity cycle in the cropland remaining cropland category
- Implementation of a corrected CH_4 emission factor for wetlands
- Incorporation of non-CO_2 emissions from biomass burning into LULUCF to align with ETF reporting requirements
- Change from SAR to AR5 GWPs

The specific details of these improvements are discussed in the relevant category or sub-category sections within this report.

The recalculations showed the same trend between 1990 and 2014 as the previous data except that the sink was enhanced in this inventory (Figure 6.6). After 2014, with the introduction of the new land change maps, the LULUCF sector sink was reduced compared to the previous inventory. The sink then returned to previous levels in 2014 by 2019. In the previous inventory the 2020 estimated sink was -27 321 Gg CO_2, and in this inventory the LULUCF sink was estimated at -36 891 Gg CO_2 in 2020.

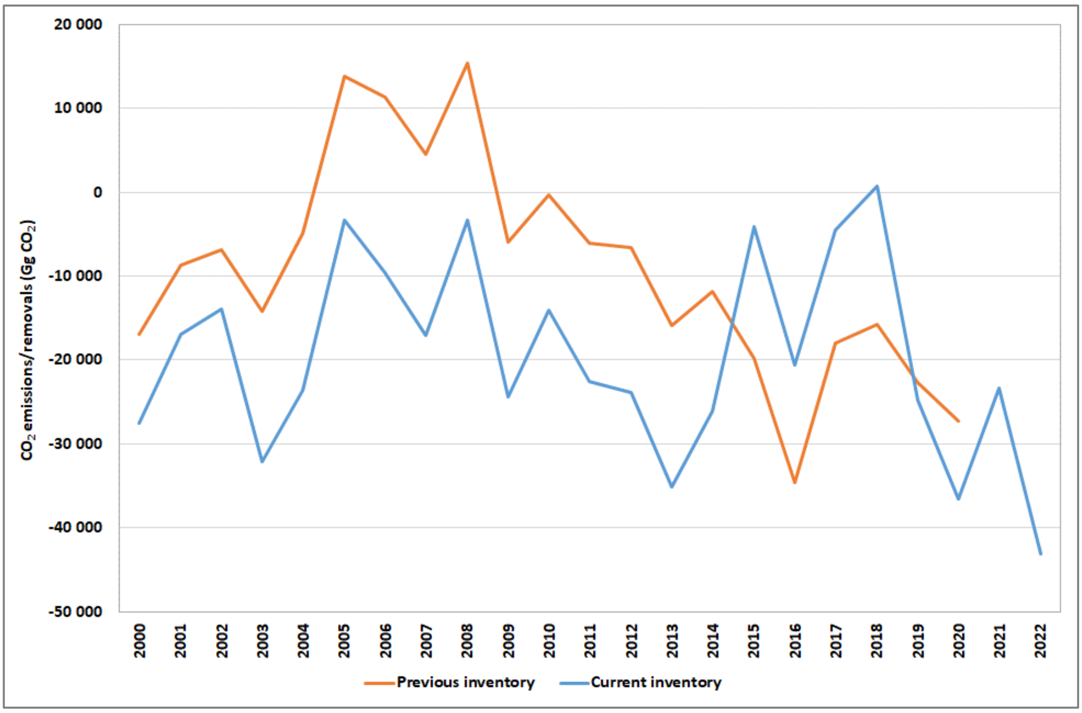

Figure 6.6: Change in LULUCF emission estimates due to recalculations since 2020 submission.

6.1.5 Key categories in the LULUCF sector

The key categories in the LULUCF sector and their ranking are shown in Table 6.8.

Table 6.8: Key categories in the LULUCF sector in 2022.

Rank	IPCC code	IPCC Category	GHG#	Criteria
2	4.C.2.a	Forest land converted to Grassland – all pools	CO_2	L,T
4	4.A.2.b	Grassland converted to forest land – all pools	CO_2	L,T
11	4.F.2.c	Grassland converted to other land – all pools	CO_2	L,T
12	4.C.1.a	Grassland remaining Grassland – biomass	CO_2	L,T
17	4.G	Harvested Wood Products	CO_2	T
21	4.B.2.b	Grassland converted to Cropland – all pools	CO_2	T
24	4.A.1.a	Forest land remaining forest land – biomass	CO_2	L,T
29	4.C.2.b	Cropland converted to Grassland – all pools	CO_2	L
30	4.E.2.a	Forest land converted to settlements – all pools	CO_2	T

#L = Level Assessment; T = Trend Assessment

6.1.6 QA/QC process and verification

The QA/QC processes applied are detailed in each of the category sections below.

6.1.7 Planned improvements

The major uncertainty in the LULUCF sector is related to the land conversion areas. Currently there are various corrections that are being applied to distinguish seasonal change from actual change and to estimate which fraction of land conversion are occurring on "land remaining". An additional land change map for the period 2020-2022 will be available in the next year and along with this will be the basic 8 class maps for each year between 2018 and 2022. These additional data sets could assist in reducing uncertainty on these land conversion corrections and areas. A detailed plan is being setup to improve the land change data in a systematic manner and to incorporate all corrections spatially to insure more consistency in the overlays. The aim is to obtain a better understanding of actual change. This will involve more detailed analysis of the land change data will take time to complete, so the improvement plan for this component will run over the next 3 years. The initial phases of the improvement plan will be focussed on Forest land and Grasslands as these are the key categories, after which the other categories will be addressed. As part of this improvement plan the difference between the SANLC cropland area and the reported agricultural area in the Agricultural Abstracts will be investigated. As part of this improvement plan the difference between the SANLC cropland area and the reported agricultural area in the Agricultural Abstracts will be investigated. Incorporated into the plan will be the use of Collect Earth to verify land use change and assist in tracking these changes.

These planned land change mapping improvements will also lead to an improved soil overlay, thereby allowing for an improvement in the SOC data. The overall improvement would mean a reducing in the uncertainty on the SOC data.

The other proposed improvement is a more detailed analysis of the HWP. This was proposed in the last inventory, however the incorporation of the additional land change maps and the more detailed analysis of the land change took preference because this data influenced the key categories. The HWP analysis will need to be done as a project and funds will need to be sought to complete this improvement.

The incorporation of organic soils still remains on the improvement list, but the priority is lower than that of the improvements to the land change analysis.

6.2 Land category classifications and definitions

The land-cover legend and associated information content within the SANLC 2018 (DEA, 2019) and 2020 (DFFE, 2021) dataset was based primarily on the new gazetted land-cover classification standard (SANS 19144-2)[21], but with modifications to ensure, as far as possible, comparability and compatibility with the legend and information content associated with the previous 1990 and 2013-14 South African National Land-Cover (SANLC) datasets (DEA, 2015a). The SANLC maps have 73 land classes (definitions are included in each of the relevant sections below) which were aggregated firstly into 20 classes for land change assessment, and then further aggregated into the 6 IPCC classes for reporting. The relationship between the IPCC classes, the change classes and the various SANLC datasets are shown in Table 6.9.

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., 2020; 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.

Table 6.9: Relationship between the IPCC categories, land change categories and the SANLC datasets in the 2022 inventory.

SANLC 1990 and 2013/14 Class		Change class		IPCC category	SANLC 2018 and 2020 Class	
4	Indigenous forest	1	Indigenous forest	Forest land	1	Contiguous forest
5	Thicket/ dense bush	2	Thicket/dense bush	Forest land	2 24	Contiguous low forest & thicket Mangrove wetlands
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

[21] *South African Land Cover Classes and Definitions (SDI Act No. 54 of 2003).*

8 9	Shrublands fynbos Low shrubland	5	Shrubland	Grassland	8 9 10 11	Low shrubland (other, fynbos, succulent karoo, nama karoo) Fallow lands (low shrub)
7	Grassland	6	Grassland	Grassland	12 13 44	Sparsely wooded grassland Natural grassland Fallow land (grass)
1 2 37 38	Water seasonal/permanent Mine water seasonal/permanent	7	Waterbodies	Wetland	14 15 16 17 18 19 20 21	Rivers Estuaries and lagoons Ocean and coastal Lakes Pans Artificial dams Artificial sewage ponds Artificial flooded mine pits
3	Wetlands	8	Wetlands	Wetlands	22 23 73	Herbaceous 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,	Various types of urban classes (informal, residential,	16	Built-up residential	Settlements	47–56, 61-64	Various types of residential (formal,

57- 72	sport, township, village, built-up)					informal, village, recreational, urban)
53 54 55 56 42	Various urban small holdings	17	Built-up smallholdings	Settlements	57 58 59 60	Various smallholdings
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

6.2.1 Forest land

The National Forest Act (Act 84 of 1998) (NFA) 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 still remain applicable even to degraded woodlands.

Taking guidance from the Marrakesh Accord (2011) and adjusting the specific thresholds so as 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."

The *Forest land* category therefore includes indigenous forests, plantation/woodlots, thicket/dense bush and woodland/open bush as defined in Table 6.10. Note that Mangroves are included under *Forest land* but they are currently aggregated with thickets for the change analysis.

Table 6.10: Definitions of the land classes, as given in the SANLC 2018, that are included in the Forest land category (Source: DEA, 2019).

SANLC class number	Aggregated change class	Class name	Class definition
1	Indigenous forest	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	Thicket/Dense bush	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	Woodland	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	Woodland	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	Plantation	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	Plantation	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	Plantation	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.
24	Thicket/Dense bush	Mangrove Wetlands	Naturally occurring mangrove community wetlands.
42	Woodland	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	Woodland	Fallow Land & Old Fields (Bush)	Long-term, non-active, previously cultivated lands that are *now* overgrown with bush dominated woody vegetation.

6.2.2 Cropland

Croplands include annual commercial croplands (pivot and non-pivot), permanent perennial orchards, permanent perennial vines, and semi-commercial or subsistence croplands. The SANLC classes that are included under croplands, along with their definitions, are provided in Table 6.11.

Table 6.11: Definitions of the land classes, as given in the SANLC 2018, that are included in the Cropland category (Source: DEA, 2019).

SANLC class number	Aggregated change class	Class name	Class definition
32	Perennial orchards	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	Perennial vines	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	Annual pivot irrigated	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	Perennial orchards	Commercial Permanent (Pineapples)	Active or recently active cultivated lands used for the production of agricultural crops, in this case specifically associated with pineapples.
36	Annual non-pivot crops	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	Annual non-pivot crops	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	Annual pivot irrigated	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	Annual non-pivot crops	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	Annual non-pivot crops	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	Cultivated subsistence crops	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.

6.2.3 Grassland

Grassland includes grasslands, low shrublands and degraded land. It also includes range and pasture lands that were not considered cropland. The category covers all grasslands from wild lands to recreational areas as well as agricultural and silvi-pastural systems, consistent with national definitions. Definitions of land areas included in *Grasslands* are given in Table 6.12.

Table 6.12: Definitions of the land classes, as given in the SANLC 2018, that are included in the Grassland category (Source: DEA, 2019).

SANLC class number	Aggregated change class	Class name	Class definition
8	Low shrubland	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	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	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	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	Grassland	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	Grassland	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.
27	Eroded land	Eroded Lands	Permanent or semi-permanent, non-vegetated erosion surfaces, typically represented by gullies, dongas, and/or sheet erosion areas.
44	Grassland	Fallow Land & Old Fields (Grass)	Long-term, non-active, previously cultivated lands that are now overgrown with grass dominated woody vegetation.

6.2.4 Wetlands

Wetlands include all wetlands and waterbodies as defined in the SANLC 2018 (Table 6.13). Mangroves are classified in the *Forest land* category so do not fall under *Wetlands*.

Table 6.13: Definitions of the land classes, as given in the SANLC 2018, that are included in the Wetland category (Source: DEA, 2019).

SANLC class number	Aggregated change class	Class name	Class definition
14	Waterbodies	Natural Rivers	Naturally occurring waterbodies associated with perennial and non-perennial rivers and associated tributaries.
15	Waterbodies	Natural Estuaries & Lagoons	Naturally occurring coastal region water bodies that are located at river mouths or are replenished by coastal tidal flows.
16	Waterbodies	Natural Ocean	Naturally occurring saltwater coastal and ocean waterbodies.
17	Waterbodies	Natural Lakes	Naturally occurring, large inland waterbodies containing freshwater.
18	Waterbodies	Natural Pans (flooded)	Naturally occurring inland waterbodies within pans, where the water extent is both spatially and temporally sufficient to be image-detectable.
19	Waterbodies	Artificial Dams	Man-constructed artificial inland waterbodies, ranging from small farm dams to large reservoirs, and if image-detectable, large irrigation canals.
20	Waterbodies	Artificial Sewage Ponds	Man-constructed artificial inland waterbodies, specifically associated with water and effluent treatment activities.
21	Waterbodies	Artificial Flooded Mine Pits	Man-generated artificial inland waterbodies, specifically associated with flooded mine pits, tailings ponds, or other surface-based mining activities.
22	Wetlands	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	Wetlands	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.
73	Wetlands	Fallow Land & Old Fields (wetlands)	Long-term, non-active, previously cultivated lands that are currently classified as wetland vegetation.

6.2.5 Settlements

The *Settlement* category covers 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. Definitions as given in the SANLC 2018 are provided in Table 6.14.

Table 6.14: Definitions of the land classes, as given in the SANLC 2018, that are included in the Settlement category (Source: DEA, 2019).

SANLC class number	Aggregated change class	Class name	Class definition
47	Built-up residential	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	Built-up residential	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	Built-up residential	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	Built-up residential	Residential Formal (Bare)	Built-up areas primarily containing formally planned and constructed residential structures and associated utilities. The surface is predominantly non-vegetated.
51	Built-up residential	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	Built-up residential	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	Built-up residential	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	Built-up residential	Residential Informal (Bare)	Built-up areas primarily containing informal, often unplanned residential structures and associated utilities. The surface is predominantly non-vegetated.
55	Built-up residential	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	Built-up residential	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	Built-up smallholdings	Smallholdings (Tree)	Agricultural holdings typically located in peri-urban environments, where the dominant vegetation is tree-based.
58	Built-up smallholdings	Smallholdings (Bush)	Agricultural holdings typically located in peri-urban environments, where the dominant vegetation is bush-based.
59	Built-up smallholdings	Smallholdings (low veg / grass)	Agricultural holdings typically located in peri-urban environments, where the dominant vegetation is low shrub or grass based.
60	Built-up smallholdings	Smallholdings (Bare)	Agricultural holdings typically located in peri-urban environments, where the dominant cover is non-vegetation is bush-based.

61	Built-up residential	Urban Recreational Fields (Tree)	Non-built-up, vegetated urban areas primarily associated with formally planned and established parks, sports fields, and golf courses.
62	Built-up residential	Urban Recreational Fields (Bush)	Non-built-up, vegetated urban areas primarily associated with formally planned and established parks, sports fields, and golf courses.
63	Built-up residential	Urban Recreational Fields (Grass)	Non-built-up, vegetated urban areas primarily associated with formally planned and established parks, sports fields, and golf courses.
64	Built-up residential	Urban Recreational Fields (Bare)	Non-built-up, open urban areas primarily associated with formally planned and established parks, sports fields, and golf courses.
65	Built-up commercial	Commercial	Built-up areas primarily containing formally planned and constructed commercial structures and associated utilities. Includes shops, offices, schools, hospitals, and administration structures.
66	Built-up industrial	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	Built-up commercial	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	Mines: Surface Infrastructure	Built-up structures associated with the administration and/or industrial processing and extraction of mined resources.
69	Mines	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	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	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	Mines	Land-fills	Primarily non-vegetated, active or non-active land-fill sites used for the large scale disposal of urban waste.

6.2.6 Other land

The definitions of the land classes included in *Other lands* are provided in Table 6.15.

Table 6.15: Definitions of the land classes, as given in the SANLC 2018, that are included in the Other land category (Source: DEA, 2019).

SANLC class number	Aggregated change class	Class name	Class definition
25	Barren land	Natural Rock Surfaces	Naturally occurring areas of non-vegetated, exposed rock and consolidated substrate.
26	Barren land	Dry Pans	Naturally occurring areas of non-vegetated, consolidated substrate, associated with permanent or long-term dry pans.

28	Barren land	Sand Dunes (terrestrial)	*Non-vegetated*, naturally occurring inland (non-coastal) sand dunes, which are typically associated with arid, desert-like environments.
29	Barren land	Coastal Dunes & Beach Sand	Non-vegetated, naturally occurring coastal sands, typically associated with both coastal dunes and beach environments.
30	Barren land	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	Barren land	Other Bare	Other natural, semi-natural or man-created non-vegetated areas.
45	Barren land	Fallow Land & Old Fields (Bare)	Long-term, non-active, previously cultivated lands that are now predominately non-vegetated bare ground surfaces.

6.3 Approaches for determining land areas and land-use change data

South Africa covers an area of 123 564 kha and has a warm, temperate and dry climate. Land-cover[22] maps were developed for 1990 (DEA, 2016), 2013-14 (DEA, 2015a), 2018 (DEA, 2019) and more recently, 2020 (DFFE, 2021). The details of the processing and development of each of the maps is provided in the relevant reports and are summarised below.

A map for 2022 is currently being developed but had not been completed by the time this inventory was compiled and therefore is not included and data was extrapolated for 2021 and 2022 assuming the same rate of land change as seen between 2018 and 2020.

6.3.1 Database and data processing

6.3.1.1 SANLC 1990

The 1990 72 x class South African National Land-cover dataset was generated primarily from digital, multi-seasonal Landsat 5 multispectral imagery, acquired mainly between 1990 and 1991. In excess of 600 Landsat images were used to generate the land-cover information, based on an average of 8 different seasonal image acquisition dates, within each of the 76 x image frames required to cover South Africa. The land-cover dataset, which covered the whole of South Africa, was presented in a map-corrected, raster format, based on 30x30m cells equivalent to the image resolution of the source Landsat 8 multi-spectral imagery. Each data cell contains a single code representing the dominant land-cover class (by area) within that 30x30m unit, as determined from analysis of the multi-date imagery acquired over that image frame. The original land-cover dataset was processed in UTM (north) / WGS84 map projection format based on the standard Landsat map projection format provided by the USGS2. The final product is available in

[22] *The term 'land cover' is used loosely here as the classes are a combination of land cover and land use.*

UTM35(north) and (south), WGS84 map projections and Geographic Coordinates, WGS84.

The generation of the 1990 national land-cover dataset is based on the same mapping and modelling techniques developed for and used in the operational production of the 2013-14 South African national land-cover dataset and is described in the next section.

6.3.1.2 SANLC 2013-14

The primary imagery source used in the generation of the 2013-14 SA National Land-cover dataset (referred to as SANLC 2014 in this report) was 30m resolution Landsat 8 imagery, acquired between April 2013 and March 2014. Unfortunately, due to localised, prolonged cloud cover problems in some regions during this April 2013 - March 2014 period, there were gaps in the data. In these cases, Landsat 5 imagery was used as a substitute, but only if it was from a suitable seasonal period to compliment the Landsat 8 data, and was ± 100% cloud free.

All Landsat 8 and 5 imagery was standardised to 16-bit, Top-of-Atmosphere (ToA) reflectance values prior to land-cover modelling using a generic modelling approach. The original USGS generated UTM (north), WGS84 map projection format was retained without change or modification throughout all image-frame based modelling procedures. As far as possible only cloud free or image dates with limited cloud cover were used in the land-cover modelling (i.e. maximum ± 20% terrestrial cloud cover in any one date). Any cloud affected regions were corrected by merging cloud affected ToA corrected imagery with cloud free ToA corrected data from preferably the preceding or following overpass date; so that as far as possible, the final cloud-free merged imagery composite only represented a maximum difference of ± 16 days. Cloud masks were created using either using conventional pixel classification procedures (within analyst defined sub-image areas), or spectral based modelling using generic thermal and blue light reflectance thresholds; depending on cloud characteristics. This was deemed acceptable in terms of minimising any changes in local vegetation cover growth changes. Approximately 35% of the 616 x images used in the landcover modelling were cloud-masked composites. No external atmospheric correction was applied to the image data.

Derived spectral indices, generated from the ToA corrected imagery were used as the only inputs into the land-cover models. No original spectral (i.e. ToA reflectance) data was used as an input, although collectively, 5 out of the 8 available non-thermal spectral bands were used in the various spectral indices.

The same two step process as outlined below for the SANLC 2018 map was then followed to generate the land-cover dataset.

6.3.1.3 SANLC 2018

The 20m resolution, raster format SANLC 2018 dataset was generated from automated mapping models (as opposed to conventional image classification procedures), using multi-seasonal 20m resolution Sentinel 2 satellite imagery. The imagery used represents the full temporal range of available imagery acquired by Sentinel 2 during the period 01 January 2018 to 31 December 2018.

The automated land-cover mapping models and associated procedures utilise both cloud-based image archives and cloud-based geo-data computing capabilities; although the final compilation and merging of the different land-cover and land-use information components (i.e. water, mining extent, forest plantations etc.), were completed in a conventional desk-top environment, using automated modelling capabilities within commercial mapping software.

The generation of the automated land-cover data in the new, Sentinel 2 based procedure involved two separate, but sequential processing steps:

- Step 1: Fully automated image modelling procedures were used to generate what is referred to as the "spectrally-defined" base land-cover characteristics. These 'base' land-cover characteristics were the primary 'building blocks' which were used to describe the entire landscape in terms of primary cover characteristics such as woody vegetation, grass, bare or water dominated surfaces. A standardised set of spectral indices were identified from which the required foundation cover classes, namely (1) tree dominated, (2) bush dominated, (3) grass dominated, (4) water and (5) bare ground could be modelled, using pre-determined, generic spectral threshold values. The generic threshold values associated with each indices and cover type were tested over several landscapes and seasons before being confirmed and accepted as such. The spectral indices included both existing algorithms such as the Normalised Difference Vegetation Index (NDVI) and Normalised Difference Water Index (NDWI), as well as algorithms developed in-house specifically for the GTI land-cover modelling requirements. No attempt was made at this stage to define additional detail such as whether the tree cover is a natural forest, or a managed forest plantation.
- Step 2: Ancillary spatial datasets, referred to as 'geographical masks' (such as "Mines & Quarries", "Built-up"), were used to convert the base land-cover classes into more detailed sub-classes. The geographical masks define specific, pre-determined areas-of-interest within the South African landscape, within which the primary, spectrally-defined base classes were de-constructed into more specific land-cover and/or land-use sub-classes. In each case, a specific set of modification rules were used to either amalgamate, sub-divide or re-allocate the primary, base-level class(es) to the required sub-class detail. The primary objective and reason behind the use of these geographical masks is to facilitate the delineation of sub-classes that cannot be achieved using spectral data alone, since many unrelated

sub-classes can often share similar spectral characteristics, e.g. river water versus water-in-pans, or non-vegetated mine dumps and some natural rock exposures, or coastal dunes and sand-roads etc. The 'geographical masks' are described in detail in the SANLC 2018 report (DEA, 2019).

The automated land-cover mapping models and associated procedures used in the production of the SANLC 2018 dataset utilise both cloud-based image archives and cloud-based geo-data computing capabilities; although the final compilation and merging of the different land-cover and land-use information components (i.e. water, mining extent, forest plantations etc), has been completed in a conventional desk-top environment, using automated modelling capabilities within proprietary, i.e. commercial mapping software.

6.3.1.4 SANLC 2020

For the SANLC 2020 the entire workflow discusses for SANLC 2018 was migrated to cloud-based technologies and became a fully automated process termed "CALC" for Computer Automated Land-Cover". All future maps will be generated in this way.

6.3.2 Uncertainty

6.3.2.1 SANLC 1990 and 2014

No accuracy assessment was undertaken on the historical 1990 South African National Land-Cover dataset, because no suitable historical reference data was available in the same format as that used for the verification of the 2013-14 dataset. However, since exactly the same mapping and modelling procedures and image formats have been used in the generation of the 1990 land-cover data, the map accuracies determined for the 2013-14 dataset can be used as a reliable indication of the likely mapping accuracies achieved for the 1990 dataset.

The overall map accuracy for the 2013-14 South African National Land-Cover, modelled from multi-seasonal Landsat 8 imagery is 82.53%, with a mean land-cover / land-use class accuracy of 88.36 %. This was determined from 6415 sample points representing. The associated Kappa Index value of 80.87 indicates that these results are very unlikely to be the result of chance occurrence.

6.3.2.2 SANLC 2018

The overall map accuracy for the SANLC 2018 land-cover dataset, calculated on the 47 x class accuracy (detailed) legend is 90.14%, with a mean class accuracy of 89.63%, and 90% confidence limits of 89.65 – 90.62 %. The kappa index for this is 89.91.

6.3.2.3 SANLC 2020

The overall map accuracy for the SANLC 2020 land-cover dataset, calculated on the 47 x class accuracy (detailed) legend is 85.47%, with a mean class accuracy of 84.66%, and 90% confidence limits of 84.91 – 96.03 %. The kappa index for this is 85.13.

6.3.3 Comparison between Landsat and Sentinel maps

One of the key intentions behind the production of the new Sentinel land cover datasets was to expand the time-line of available South African national land-cover datasets in support of long-term environmental monitoring and change detection. To that end, the SANLC 2018 and 2020 datasets have been generated to provide as close as possible a repeat of the SANLC 1990 and SANLC 2014 data contents, format and landscape representations. However, improvements in landscape interpretation and mapping resulting from the improved spatial, spectral and temporal characteristics of Sentinel 2 imagery have resulted in changes between SANLC 2018 and the previous SANLC 1990 and SANLC 2014 datasets, which are not necessarily associated with true landscape changes, but rather improved interpretation and thus mapping quality. There has been no attempt to perpetuate both known and unknown errors from the SANLC 1990 and SANLC 2014 datasets into the SANLC 2018 and 2020 datasets if more accurate mapping could be achieved from the Sentinel 2 image interpretations, whilst retaining as far as possible the same class-based information content.

Generally, it can be assumed that comparisons between the current SANLC 2018 and both historical SANLC's will be more accurate in terms of documenting true land-use related changes, compared to land-cover related changes, as land-use features are typically associated with easily (image) detectable boundaries and/or unique (image) spectral characteristics. Mapping, and by association, change detection in natural landscapes, such as woodland, grassland and shrublands etc. are typically more challenging; since these landscape features typically do not have 'hard' boundaries, but rather gradients, within which a class boundary must be defined. This challenge is often compounded as a result of inter-annual seasonal differences, and associated differences in interpretable spectral/spatial image characteristics.

The end-result is that, if a user compares the current and historical SANLC datasets, many landscape differences will be correct, it is also likely that some of these differences, especially in natural vegetation landscape can be attributed to mapping errors in one or both land-cover input datasets. Although these are most likely to be associated with the historical Landsat generated SANLC's as a result of Landsat's poorer spatial, spectral and temporal characteristics, compared to Sentinel 2 imagery. The enhanced spectral, spatial and temporal characteristics associated with Sentinel 2 imagery, as well as enhancements to the content and integration of the geographical masks used in the latest SANLC 2018 and 2020 landcover modelling, are considered to have resulted in a more accurate SANLC 2018 landscape interpretation. This assumption is supported by the significantly higher woody class mapping accuracies reported for SANLC 2018 compared to those reported in the SANLC 2014 dataset (see Table 6.16).

Table 6.16: Comparison of mapping accuracies between SANLC 2014 and SANLC 2018.

SANLC 2014 Class Mapping Accuracies	User/Producer Accuracy (2014)	User/Producer Accuracy (2018)	SANLC 2018 Class Mapping Accuracies
Indigenous forest	72.60/94.64	98.90/84.11	Contiguous (indigenous) forest
		80.60/92.31	Contiguous low forest & thicket
Dense bush/Thicket	53.74/83.64	76.44/93.59	Dense forest & woodland
Woodland/Open bush	60.84/54.13	78.79/92.86	Open woodland
Grassland	84.56/69.82	85.90/87.58	Grassland
Shrubland (non-fynbos)	70.59/61.82	66.67/86.25	Shrubland (non-fynbos)

6.3.4 Land use change mapping

6.3.4.1 Data processing

Land-use changes were mapped using an Approach 2 method as described in 2006 IPCC Guidelines. The 1990-2014, 2014-2018 and 2018-2020 change maps were utilized in this inventory and data was extrapolated to 2022 assuming the same rate of change between 2018-2020. The key data processing steps used in Computer Automated Land Cover (CALC) system to generate any two-date SANLC change assessment 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 format 1990, 2013/14 and CALC generated SANLC datasets to a standardised Albers Equal Area map projection, including a single-step spatial resampling from 20 x 20 m to 30 x 30 m resolution for all CALC generated SANLC datasets, using nearest-neighbour class code allocation.
- Ensure pixel-to-pixel registration between all 30 m resolution Albers Equal Area map projection outcomes, using the CALC generated 2018 SANLC as the generic reference dataset against which the both the pre-CALC 1990 and 2013/14 datasets and all other CALC generated SANLC datasets are registered. This approach has been taken as the ortho-precision of the source Sentinel 2 imagery

from which all SANLC datasets are generated is considered superior to the Landsat imagery used in the compilation of the pre-CALC 1990 and 2013/14 SANLC datasets.

- Ensure pixel-level equivalent land-cover geographic coverage between all SANLC datasets, so that the change assessment results do not include a null class values as a result of differences in total mapped extent resulting from different boundary delineations and associated buffer zones.
- Generate a national 30 x 30 m resolution land-cover class-pair based change-reporting matrix for each two-year land-cover change assessment.

6.3.4.2 Land change maps and annual change data

Adjustments to 2014-2018 change map

A 2018 South African National Land Cover Change Assessments report (DEA, 2019a) was completed as part of the 2018 land cover mapping project to verify the natural land class changes between 1990/2014/2018. This assessment showed that most of the land changes between the natural land classes were not real changes. 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 2014-2018 land change data by making some assumptions (Table 6.17). The conversion areas where no conversion is considered to occur were reverted back to the 2018 land remaining land class as the 2018 areas were assumed to be more accurate. In addition to the changes based on the 1990/2014/2018 change assessment report, further corrections were made based on expert input in terms of unlikely changes. These are also documented in Table 6.17.

Table 6.17: Corrections made to 2014-2018 change matrix.

Conversion category	Correction	Assumption	Basis for correction
Indigenous forest to Thicket/Dense bush	95% of conversion area removed and allocated back to Thicket/dense bush	Assumption is that only 5% of the conversion of indigenous forest to thicket occurs and that the 2018 map is more accurate therefore 95% of the converted area is allocated back to the 2018 classification (Thicket/Dense bush).	The 2018 LC Assessment report (DEA 2019) 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. Data suggested there was no change but not all areas were assessed therefore to be more conservative it was assumed that 5% of change could have occurred.
Indigenous forest to Natural woodland	95% of conversion area removed and allocated back to Natural woodland	Assumption is that only 5% of the conversion of indigenous forest to natural woodland occurs and that the 2018 map is more accurate therefore 95% of the converted area is allocated back to the 2018 classification (Natural woodland).	The 2018 LC Assessment report (DEA 2019) 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	95% of the converted area is reverted back to Natural woodland	Assumption is that only 5% of the original conversion area is actually 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 (Natural woodland).	The 2018 LC Assessment report (DEA 2019) 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 95%, however this assumption will need to be investigated in more detail in future.

Thicket/Dense bush to Shrubland	85% of the converted area is reverted back to Shrubland	Assumption is that only 15% 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 (DEA 2019) 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 15% 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).
Indigenous forest to grassland	80% of conversion area removed and allocated back to grasslands	Assumption is that only 20% of the conversion of indigenous forest to grassland occurs and that the 2018 map is more accurate therefore 80% of the converted area is allocated back to the 2018 classification (Grassland).	The 2018 LC Assessment report (DEA 2019) compared the new 2018 Sentinel LC maps with the older 1990/2014 Landsat LC maps and the assessment showed that most of these conversions were due to a change in interpretation and not due to real change. There were, however some area that were indicated to be lot due to clearing of alien invasives and so instead of the lower 10% it was assumed that 20% of the conversion still occurred. Losses were also indicated to be due to fire, but fire losses are already included in the biomass loss calculations so do not need to be included in the area as this would be double counting. This loss of biomass and land-use change due to fire could be something that applies to other land categories and so this possible double counting will be investigated further in the next inventory.

Thicket/Dense bush to Grassland	95% of the converted area is reverted back to Grassland	Assumption is that only 5% of the original conversion area is actually 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 (DEA 2019) 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	95% of the conversion area removed and allocated back to Shrubland	Assumption is that only 5% of the original conversion of natural woodland 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 (DEA 2019) 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	95% of the converted area is reverted back to Grassland	Assumption is that only 5% of the original conversion area is actually 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 (DEA 2019) 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 5% of the original change may be due to actual change.
Shrubland to Natural woodland	95% of the conversion area removed and allocated back 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 (DEA 2019) 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	95% of the conversion area removed and allocated back to Natural woodland	Assumption is that 5% of the conversion of Shrubland to Natural woodland occurs and that the 2018 map is more accurate therefore 95% of the converted area is allocated back to the 2018 classification (Natural woodland).	The 2018 LC Assessment report (DEA 2019) 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	95% of conversion area removed and allocated back 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 (DEA 2019) 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	50% of conversion area removed and allocated back to grasslands	Assumption is that 50% of the conversion of Shrubland to grassland occurs and that the 2018 map is more accurate therefore 50% of the converted area is allocated back to the 2018 classification (Grassland).	The 2018 LC Assessment report (DEA 2019) compared the new 2018 Sentinel LC maps with the older 1990/2014 Landsat LC maps and the assessment showed that some of the conversions are due to seasonal change and others could be real change. Some of the changes are suggested to possibly be due to fire. Losses due to fire are incorporated in the biomass losses. It is therefore assumed that only 50% of the conversions actually occur but this can be investigated further in the next inventory and the overlay with burnt area assessed.
Settlements to mines	Assumed no conversion occurs, all areas allocated back to mines	These changes are "highly unlikely" so reverted back to the 2018 class as 2018 assumed to be more accurate.	Based on the presentation by Mark Thompson (GTI) titled "2020SANLC Technical Presentation), 2020 SANLC Data Launch, 29th June 2021.
Indigenous forest and thicket to plantation	Assumed no conversion occurs and the areas are allocated back to plantations	These changes are assumed highly unlikely so reverted to back to the 2018 land cover (plantations).	Based on discussions with forestry industry, also GTI presentation on the 2020 SANL map (2022) indicates this to be highly unlikely.

Wetlands, agricultural lands and settlements to plantation	Assumed no conversion occurs and the areas are allocated back to plantations	These changes are assumed highly unlikely so reverted to back to the 2018 land cover (plantations).	Based on discussions with forestry industry.
Conversions between natural land classes	Assumed only 5% of the conversion occurs and the other 95% is allocated back to land class in 2018.	Assumption is that 5% of the conversion of the class occurs and that the 2018 map is more accurate therefore the other 95% of the converted area is allocated back to the 2018 classification.	The 2018 LC Assessment report (DEA 2019) compared the new 2018 Sentinel LC maps with the older 1990/2014 Landsat LC maps and the assessment showed that conversions between natural vegetation classes were mostly due to an improved classification rather than actual change. There was no specific analysis on these land class changes in the report but based on the findings for the other natural land classes the same assumption (that 90% of the change was not real change but rather a change in classification) was applied.
Conversion of forest land to waterbodies	Assumes that a conversion of forest land to waterbody is highly unlikely therefore all the conversion area is allocated back to waterbody area	These changes are assumed highly unlikely so reverted to back to the 2018 land cover (waterbodies).	
Conversion of waterbodies to settlements	Assumes the conversion of waterbodies to settlements is highly unlikely therefore the conversion area is allocated back to settlements.	These changes are assumed highly unlikely so reverted to back to the 2018 land cover (settlements).	Based on the presentation by Mark Thompson (GTI) titled "2020SANLC Technical Presentation), 2020 SANLC Data Launch, 29th June 2021.
Conversion of settlements to cultivated land	Assumes the conversion of settlements to cultivated land is highly unlikely therefore the conversion area is allocated back to cultivated lands.	These changes are assumed highly unlikely so reverted to back to the 2018 land cover (cultivated lands).	Based on the presentation by Mark Thompson (GTI) titled "2020SANLC Technical Presentation), 2020 SANLC Data Launch, 29th June 2021.

Conversion of shrublands, grasslands, wetlands, cultivated land, and settlements to indigenous forests	Assumes that lower biomass land types cannot be converted to indigenous forest in 2 years therefore revert these changes back to original land types	These changes are logically not really possible due to the slow growth of trees	
Conversion of shrublands, grasslands, wetlands, cultivated land, and settlements to thicket	Assumes that lower biomass land types cannot be converted to thicket/dense bush in 4 years therefore revert these changes back to original land types	These changes are logically not really possible due to the slow growth of trees	

Adjustments to 2018-2020 change map

In the 2018 to 2020 change data only the unlikely changes mentioned in Table 6.17 were implemented. In an addition to this an attempt was made to make adjustments for seasonal changes, i.e. natural land areas that show changes but these are not permanent. This was done by taking the natural land class change areas from 2014-2018 and intersecting them with the opposite change areas in the 2018-2020 map. The areas that overlapped were assumed to be seasonal change and not permanent change and these areas were reverted back to the 2020 class. For example, the area of woodland converted to grassland in 2014-2018 was intersected with the area of grassland that was converted back to woodland in 2018-2020. The overlap area was assumed to therefore be non-permanent and the area was reverted back to the woodland class. The land change classes that were included in this analysis were Indigenous forests/Thickets, Thickets/Woodlands, Woodland/Grassland, Woodland/Low shrubland, Grassland/Low shrubland, Grassland/Barren land, and Low shrubland/Barren land.

As more maps become available this analysis and assessment of seasonal variation can be improved on.

Verification

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 and DFFE has started training the inventory team on this technique. Currently a targeted area of South Africa is being tested and then the validation process will be considered for inclusion in the development of maps going forward.

More frequent datasets would also provide further accuracy and DFFE 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.

Land use change matrix and annual change areas

The land change matrix for the most recent change map (2018-2020) before and after corrections are provided in Table 6.18 and Table 6.19, respectively. This rate of change was used to extrapolate the land areas in 2022.

Table 6.18: Land change (ha) matrix for South Africa between 2018 and 2020 prior to corrections.

Land categories		2018																			
		Indigenous Forest	Thicket / Dense Bush	Natural woodland	Planted Forest	Shrubland	Grassland	Waterbodies	Wetlands	Barren Land	Eroded Land	Cultivated Permanent	Cultivated Permanent	Annuals Pivot Irrigated	Annuals Non-Pivot	Cultivated Subsistence	Built-Up Residential All	Built-Up Smallholdings	Built-Up Commercial	Built-Up Industrial	Mines
2020	Indigenous Forest	425 300	4	1 775	978	142	4 145	54	158	67	0	0	0	0	4	0	192	2	1	0	48
	Thicket / Dense Bush	2	959 634	259 314	20	11 341	23 447	497	256	325	3	237	0	116	317	438	678	0	67	19	36
	Natural woodland	1 510	677 412	13 434 202	189	261 389	3 737 247	12 449	949	59 888	8 891	4 241	13	1 978	31 313	141 060	22 625	87	2 118	1 694	4 084
	Planted Forest	832	4 068	7 411	1 974 867	6 227	63 454	473	3 137	1 459	59	256	0	6	771	108	2 891	160	27	75	358
	Shrubland	120	9 855	95 376	3 191	27 608 050	2 206 915	7 821	447	1 775 487	20 632	38	39	189	2 388	14	21	0	2	12	6 749
	Grassland	4 820	155 742	2 622 842	62 302	2 578 791	30 128 218	29 468	10 496	239 662	49 786	241	13	993	14 076	15 500	340	18	5 749	6 370	32 585
	Waterbodies	32	312	8 922	413	13 484	17 022	2 063 968	6 598	18 891	378	35	13	50	1 231	109	392	82	15	98	3 446
	Wetlands	308	413	1 226	2 734	3 099	15 450	8 117	1 019 293	2 796	1	6	1	20	177	55	134	52	16	32	339
	Barren Land	168	2 559	34 946	1 114	1 697 277	218 837	26 530	753	10 574 723	31	11	1	16	156	109	35	0	3	46	981
	Eroded Land	0	4	3 464	86	20 977	56 047	460	1	778	354 137	0	0	2	3	66	0	0	0	0	46
	Cultivated Permanent Orchards	13	1 518	12 679	2 563	1 483	2 751	17	166	474	1	274 721	45	4 654	17 109	499	96	137	0	0	7
	Cultivated Permanent Vines	0	86	1 192	28	2 341	323	6	18	184	0	23	140 110	32	114	0	61	29	0	0	6
	Annuals Pivot Irrigated	1	1 431	11 051	210	2 481	13 891	39	389	338	48	303	94	829 476	41 055	232	55	72	0	0	129
	Annuals Non-Pivot	97	4 280	112 932	5 055	26 856	239 211	689	5 521	11 101	273	8 213	125	19 845	10 133 175	12 210	1 113	1 593	0	0	2 684
	Cultivated Subsistence	97	923	33 197	169	276	47 312	325	372	5 211	3 090	362	0	308	2 410	1 793 512	1 831	640	1	0	299

	Built-Up Residential All	616	3 973	35 572	1 980	1 218	16 039	490	149	1 645	126	12	0	45	958	4 030	2 908 277	96	124	14	1 365
	Built-Up Smallholdings	5	0	32	38	0	11	145	50	0	0	19	0	5	72	315	250	240 548	92	165	58
	Built-Up Commercial	0	22	890	15	20	3 525	13	12	59	0	4	0	0	0	3	68	53	75 906	1	75
	Built-Up Industrial	0	39	935	41	874	3 804	74	30	367	2	61	2	18	333	15	148	150	3	89 540	610
	Mines	74	18	1 909	826	10 062	19 573	2 693	369	1 476	114	8	4	211	4 439	442	737	26	50	406	245 783

Table 6.19: Land change (ha) matrix for South Africa between 2018 and 2020 after corrections.

Land categories		2018																			
		Indigenous Forest	Thicket / Dense Bush	Natural woodland	Planted Forest	Shrubland	Grassland	Waterbodies	Wetlands	Barren Land	Eroded Land	Cultivated Permanent	Cultivated Permanent	Annuals Pivot Irrigated	Annuals Non-Pivot	Cultivated Subsistence	Built-Up Residential All	Built-Up Smallholdings	Built-Up Commercial	Built-Up Industrial	Mines
2020	Indigenous Forest	426 167	0	1 775	978	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Thicket / Dense Bush	0	1 030 403	71 457	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Natural woodland	1 510	611 028	14 496 252	189	242 475	2 610 874	12 449	949	59 888	8 891	4 241	13	1 978	31 313	141 060	22 625	87	2 118	1 694	4 084
	Planted Forest	0	0	7 411	1 975 281	6 227	63 454	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Shrubland	120	9 855	52 891	3 191	28 788 948	570 022	7 821	447	1 001 743	20 632	38	39	189	2 388	14	21	0	2	12	6 749
	Grassland	4 820	155 742	1 800 058	62 302	2 189 423	33 037 083	29 468	10 496	0	49 786	241	13	993	14 076	15 500	340	18	5 749	6 370	32 585
	Waterbodies	0	0	0	0	13 484	17 022	2 065 714	6 598	18 891	378	35	13	50	1 231	109	392	82	15	98	3 446
	Wetlands	308	413	1 226	2 734	3 099	15 450	8 117	1 022 844	2 796	1	6	1	20	177	55	134	52	16	32	339
	Barren Land	168	2 559	34 946	1 114	936 145	100 831	26 530	753	11 589 979	31	11	1	16	156	109	35	0	3	46	981

	Eroded Land	0	4	3 464	86	20 977	56 047	460	1	778	354 199	0	0	2	3	66	0	0	0	0	46
	Cultivated Permanent Orchards	13	1 518	12 679	2 563	1 483	2 751	17	166	474	1	275 214	45	4 654	17 109	499	0	0	0	0	7
	Cultivated Permanent Vines	0	86	1 192	28	2 341	323	6	18	184	0	23	140 111	32	114	0	0	0	0	0	6
	Annuals Pivot Irrigated	1	1 431	11 051	210	2 481	13 891	39	389	338	48	303	94	829 599	41 055	232	0	0	0	0	129
	Annuals Non-Pivot	97	4 280	112 932	5 055	26 856	239 211	689	5 521	11 101	273	8 213	125	19 845	10 134 266	12 210	0	0	0	0	2 684
	Cultivated Subsistence	97	923	33 197	169	276	47 312	325	372	5 211	3 090	362	0	308	2 410	1 794 059	0	0	0	0	299
	Built-Up Residential All	616	3 973	35 572	1 980	1 218	16 039	0	149	1 645	126	12	0	45	958	4 030	2 915 931	96	124	14	1 365
	Built-Up Smallholdings	5	0	32	38	0	11	0	50	0	0	19	0	5	72	315	250	243 208	92	165	58
	Built-Up Commercial	0	22	890	15	20	3 525	0	12	59	0	4	0	0	0	3	68	53	76 052	1	75
	Built-Up Industrial	0	39	935	41	874	3 804	0	30	367	2	61	2	18	333	15	148	150	3	90 041	610
	Mines	74	18	1 909	826	10 062	19 573	2 693	369	1 476	114	8	4	211	4 439	442	0	0	0	0	246 225

Annual change by soil and land type

To determine the area of each land class in a particular soil type, the soil datasets (DEA, 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 remain the same over the entire time series and land areas also incorporated the 20-year default conversion period as described in section **Error! Reference source not found.**. S ince 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.

6.3.4.3 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.

This approach assumes that all the converted land is removed from the "land remaining" category which is unlikely to be true as the previously converted land could also be converted to another land use. To account for this the "land remaining" areas from 1990-2014 was overlaid with the "land remaining areas" between 2014-2018, and this was also done for 2018-2020. This provide the fraction by which the "land remaining" category was reduced and therefore what fraction of the converted area was from "land remaining" and therefore what fraction came from already converted land. On average about 35% of the land conversions in Forest lands, Grassland and Wetlands came from "land remaining", while this went up to about 47% for Cropland and Other lands. For Settlements the average was 57%, while the rest of the conversions came from already converted land areas. A fraction was therefore incorporated into the equation which indicated what fraction of the land conversion area was removed from "land remaining" category and, therefore, what fraction was removed from the "converted land" category. A fraction was included for the period 2014-2018 and another for 2018-2020.

Extrapolation to 2022

It was assumed that the annual change between 2018 and 2020 continued to 2022. This assumption will be corrected in the next inventory when the SANLC data for 2022 is available.

6.4 Forest land (4.A.)

6.4.1 Category description

Reporting in this category covers emissions and removals from above-ground and below-ground biomass, litter, deadwood 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. *Eucalyptus grandis* and *Other Eucalyptus* species were separated.

Changes in biomass included wood removal, fuelwood collection, and losses due to disturbance. Harvested wood was included for plantations, while fuelwood collection was estimated for all forest land and included under Woodlands as it was not possible to split it by forest type. All emissions from the burning of fuelwood for energy or heating purposes were reported as part of the energy sector. 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.

Emissions from *Harvested wood products* were included under 4.G.

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.

Biomass burning CH_4 and N_2O were also included here instead of being included under the *Biomass Burning* category (3C1) under *Aggregated and non-CO_2 emissions* (3C) in Agriculture as was the case in the previous inventory. This is to bring the inventory into alignment with the CRT tables required for reporting under the ETF.

6.4.2 Methodological issues

Carbon changes in the *Forest land* category were determined with a Tie 2 methodology for biomass, DOM and SOC for both the “land remaining” and the “converted land” categories. In the previous inventory Forest land remaining Forest land was identified as a key category and, based on the IPCC decision tree the Tier 2 approach is suitable for this category. A Gain-Loss approach was used for all forest land categories. The Stock-Difference approach was considered for plantations, but due to the fact that (a) detailed age-class population data from DFFE was only available from 2001 (therefore stock change data from 2002 only) and (b) land conversion losses were not fully incorporated into this methodology at this stage the Stock-Difference approach was used as verification and is discussed in more detail in section 6.4.5. Once these issues are resolved the Stock-Difference approach can be incorporated into the inventory.

6.4.2.1 Biomass

Carbon gains

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 6.20). 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 were 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 6.20 were applied and were assumed to grow until they reach their maximum biomass. Root to shoot ratios (Table 6.21) were utilized to include the below ground biomass. 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*.

Table 6.20: Biomass growth or accumulation rates for the forest land categories.

Land class	Forest type	Biomass growth rate (t C/ha/yr)	Data source	Other verification	IPCC default (t C/ha/yr)
Indigenous forest	Primary (undisturbed)	0	Glenday, 2007		0.42 – 0.85 (subtropical dry forest in Africa >20yrs)
	Secondary (disturbed)	1.39	Calculated (AGB/60yrs – as Glenday, 2007 indicates growth of 50-65yrs)	Glenday (2007) provided values between 1.14 and 1.84 tC/ha/yr)	0.56 – 1.18 (subtropical dry forest in Africa <20yrs)
Thicket/ dense bush	Primary (undisturbed)	0	Glenday, 2007		0.42 – 0.85 (subtropical dry forest in Africa >20yrs)
	Secondary (disturbed)	1.14	Glenday, 2007		0.56 – 1.18 (subtropical dry forest in Africa <20yrs)
Woodlands	Primary (undisturbed)	0	Glenday, 2007		0.42 – 0.85 (subtropical dry forest in Africa >20yrs)
	Secondary (disturbed)	0.9	Scholes & Walker, 1993 Hoffman & Franco, 2009		0.56 – 1.18 (subtropical dry forest in Africa <20yrs)

Table 6.21: Root:shoot ratios for the forest land categories.

Land class	Root:shoot ratio	Reference	Other verification	IPCC default
Indigenous forest	0.27	Glenday, 2007 Mangwale et al. 2017	FRA for South Africa (FAO, 2021) provided a value of 0.25	0.24 – 0.56 (subtropical dry forests, IPCC 2006)
Thicket/dense bush	0.38	Glenday, 2007 Mills et al., 2005 Powell, 2009 Mills & Cowling, 2006		0.24 – 0.56 (subtropical dry forests, IPCC 2006)
Woodlands	0.25	FAO, 2021	DEA, 2015 DEFF, 2020	

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) was used for calculating gains. Any excess mapped plantation area was allocated to woodlands. It should be noted that data for 2020 onwards was not available at the time of completing this inventory and these years were extrapolated using the IPCC extrapolation technique. The data will be corrected in future inventories once the data becomes available.

MAI curves were obtained from Forestry SA. The MAI at rotation age for each of the products (sawlogs, pulp, mining timber, poles and other uses) per each of the 5 plantations species (Pines, E.grandis, other Eucalyptus species, Wattle and other hardwood species) were weighted based on the area under production for each species and product. The overall MAI therefore varied slightly each year but data for 2022 is shown in Table 6.22.

The BCEFs values were calculated by using the equations given in Dovey et al. (2021) which estimates the BCEFs from the volume data. Stock volumes (m^3/ha) were determined from the MAI for each age class multiplied by the age of the stand. The BCEFi values were derived from the BCEFs data by analysing the 2006 IPCC Guideline default values and applying a ratio for BCERi to BCEFs. For softwood the BCEFi was determined to be 78% of the BCEFs, while for the other species it was 60%. The area weighted BCEFs and BCEFi for 2022 are provided in Table 6.22 but the values did vary slightly from year to year due to the changes in the areas of the different species and the areas of each age class. The root to shoot ratio was then applied to include the below-ground biomass.

Table 6.22: Factors applied for plantation data in 2022 with IPCC default values for comparison.

		Softwoods (e.g. Pines)	Eucalyptus grandis	Other Eucalyptus sp.	Acacia sp. (Wattles)	Other hardwood sp.

Mean annual increment (m3/ha/yr)	Sawlogs	15.2	17.5	17.8		17.8
	Pulp	16.6	17.9	18.4	9.8	18.9
	Mining timber		18.4	18.4	9.3	18.4
	Poles	17.0	17.9	15.4	9.3	18.9
	Weighted avg	15.5	17.9	18.3	9.9	18.5
	2019 Refinement default values	12 - 18	18 - 24	12-14 (general) 22-28 (E.nitens)	10 - 12	
BCEFs	Weighted avg	0.924	0.997	1.053	1.046	0.801
	2006 IPCC default (temperate)	0.6 – 1.0	0.8 – 2.6	0.8 – 2.6	0.7 – 1.9	0.7 – 1.9
BCEFi	Weighted avg	0.721	0.598	0.632	0.628	0.481
	2006 IPCC default (temperate)	0.6	1.3	1.3	0.9	0.9
$BCEF_R$	Weighted avg	0.595	0.713	0.705	0.990	0.671
	2006 IPCC default (temperate)	0.83	1.89	1.89	1.55	1.55
Ratio of below-ground biomass to above ground biomass		0.28	0.24	0.24	0.28	0.26

Carbon losses

<u>*Harvest losses*</u>

Loss of carbon from harvested wood was calculated for plantations only and followed the IPCC equation 2.12. Harvested wood data was obtained from Timber Statistics report from the Department of Forestry at DFFE and from Forestry SA (FSA, 2019). The industry conversion factors provided by FSA were used to convert between tonnes and m^3. The $BCEF_R$ (Table 6.22) were determined from the relationship between $BCEF_R$ and BCEFi provided in IPCC 2006 Guidelines. The harvested wood included 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 be harvested due to the longer harvest cycle.

<u>*Fuelwood collection losses*</u>

Loss of carbon from fuelwood removals was calculated using IPCC equation 2.13 (IPCC 2006 Guidelines). 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.

The amount of fuelwood collected was determined from the number of households using fuelwood for cooking and heating (Statistics SA, 2021). It was assumed that there was overlap between the houses that use wood for heating and cooking and so the higher value (households for heating) was 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 (Shackleton et al., 2022; Twine and Holdo, 2016) was 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. Data on which households have both electricity and fuelwood was not available but can be investigated further in the next inventory. Some of the fuelwood comes from plantations and this removal was 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 9 tons of wood are required to make 1 ton of charcoal (Garland et al., 2015). 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) was 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 household fuelwood consumption estimates showed a slight increase between 2000 and 2004, but then decline to 2016. The decline is attributed to the increased electrification, however from 2017 onwards household wood consumption starts to stabilise as even households that have electricity continue to use wood. There is an increase in charcoal production in 2003 and again in 2018 which leads to an increase in total fuelwood consumption data in these two years. The charcoal data is from FAO and, other than these two increases, remains level in the in-between years. These increases will need to be investigated in future and a better source of country specific charcoal production data needs to be identified to assist in the interpretation of the data.

Disturbance losses

The loss of carbon from disturbance was calculated following 2006 IPCC Equation 2.14. Only disturbance losses for fires was included, except for forest plantations where other disturbances were also included.

For fire disturbance losses the burnt area data is determined as described in section 6.1.3.6. Fire disturbance included both controlled and wildfire as there was no data to enable the split between the two. 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.

The above-ground biomass (B_W) of each forest land category was determined from published literature and are provided in Table 6.23. Literature provided biomass data for various forest types and the forest area data from the Vegetation Map of South Africa (Mucina and Rutherford, 2011) enabled an area weighted above ground biomass value to be determined for indigenous forests. Thickets have been shown to be degraded with degraded thickets having a lower carbon biomass. To incorporate this into the biomass estimates the fraction of thicket area that was intact, heavily degraded and moderately degraded was taken from Lloyd et al. (2002). Literature provided data on intact and degraded thicket biomass data and the degraded values were applied to the heavily degraded category, while the biomass for the moderately degraded area was taken to be an average of the intact and heavily degraded value. In the SANLC maps mangroves are included under thickets and biomass data was taken from Johnson eta al. (2020) and Steinke et al. (1995). An area weighted above ground biomass values was then determined for the thicket category. For Woodlands the SANLC data includes two classes, namely dense forest and woodland, and open woodland. Literature data was obtained for each category and an area weighted above ground biomass values was determined. The above-ground biomass data for forest plantations was determined from the age class and MAI data provided by Department of Forestry and the Forestry SA (FSA, 2019). This was combined with BCEFs data to estimate above ground biomass for each species each year. An area weighted biomass value was calculated, and this value varied slightly across the years due to changes in species composition and age structure.

Table 6.23: Above ground biomass for the various forest land categories.

Forest land category	Data applied in the inventory			IPCC default values
	Above ground biomass (t dm/ha)	SD	Reference	
Indigenous forests	175.1 (Southern Afrotemperate) 162.0 (Northern Afrotemperate) 253.5 (Southern Mistbelt) 218.8 (Northern Mistbelt) 103.4 (Scarp) 175.6 (Coastal) 80.0 (Sand)		Adie et al. 2013 Mensah et al. 2016 Glenday, 2007	35.1 – 65.2 (subtropical Africa, IPCC 2019 Refinement) 20 – 200 (Subtropical Africa, IPCC 2006)

	178.0 (Weighted average)	57.9		
Thickets	59.3 (Intact thickets) 17.6 (Degraded thickets) 121.2 (Mangroves) 28.2 (Weighted average)	12.2	Glenday, 2007 Van der Vyver et al., 2013 Powel, 2009 Van der Vyver & Cowling, 2019 Johnson et al. 2020 Steinke et al. 1995	
Woodlands	39.7 (Dense forest & woodland) 21.7 (Open woodland) 27.2 (Weighted average)	3.3	Glenday, 2007 Mograbi et al. 2015 Lembani, 2018 Wessels et al. 2013 Colgan et al. 2012 Scholes & Walker, 1993 Nickless et al., 2011 Cresswell et al., 1982 Shackleton & Scholes, 2011 Rutherford, 1079 Woomer, 1993 Gander, 1994	
Plantations	95.3 – 103.2 (Softwoods) 56.4 – 75.1 (E.grandis) 54.0 – 63.1 (Other Eucalyptus) 45.5 – 57.8 (Wattle sp.) 103.2 – 147.1 (Other hardwoods) 76.5 – 83.2 (Weighted average)		Calculated from Timber Statistics Reports (DAFF) and Forestry SA data (FSA, 2019)	15 – 70 (subtropical Africa, IPCC 2019 Refinement) 10 – 150 (Subtropical Africa, IPCC 2006)

There is no country specific data on the fraction of biomass lost (*fd*) during the fire disturbance, so the combustion fractions provided by 2019 Refinements of the 2006 IPCC Guidelines were used as a proxy. For indigenous forests and thickets the value of 0.45 for all other temperate forests was applied, while for woodlands the value was 0.56 (average of early and mid-season burns for savanna woodlands).

The fraction of biomass burnt for plantations was determined from actual forestry data (FSA, 2019; DAFF, 2021). This provided data on the area damaged during fire and other disturbances and the extent of the damage. Forest plantations were therefore the only category for which other disturbances losses were included. Disturbance matrices were developed for fire and other disturbances for both hardwoods and softwoods. FSA data reports on the severity of the disturbance, therefore disturbance matrices were developed for disturbances where there was (a) slight damage, (b) serious damage but where wood was salvaged and (c) severe damage where all biomass was lost. For slight damage it was assumed that half of the non-utilisable biomass would be burnt. The non-utilisable component was determined from the Dovey et al. (2021) equation for hardwoods and softwoods. In the case where there was serious damage but wood was salvaged it was assumed that all the non-utilisable biomass and an additional 10% was lost, while for severe damage with no recovery it was assumed all biomass was lost. The overall average fraction (*fd*) of plantation biomass lost to fires and other disturbances was 0.661 and 0.363, respectively. Losses due to disturbance were calculated for both the *Forest land remaining forest land* and *land converted to forest land* by applying the percentage disturbance area to each of the land sub-categories.

Gains and losses due to land conversions

The 2006 IPCC Guideline equations 2.15 and 20.16 were utilised for estimating emissions from biomass changes on converted land. The conversions also included conversions between forest types but then these losses were included under the "land remaining" category. 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 land converted from other land types to forest lands are calculated as for forest lands remaining forest lands (described above). Initial change in biomass carbon stocks on the converted land is added to the equation.

The carbon stocks on the land before conversion were determined from above- and below-ground biomass data provided in the relevant land category sections. Land being converted to plantations is assumed to be cleared and therefore the biomass values immediately after conversion were assumed to be zero. For land being converted to the natural forest land classes (indigenous forests, thickets and woodlands) it was assumed that there is no clearing and that the biomass slowly increases, at the annual growth rate for that forest, from the original land carbon stock to the final land carbon stock.

6.4.2.2 Deadwood and litter

Land remaining

A Tier 1 approach is applied to deadwood and litter for forest land where it is assumed there is no change in DOM in forest land remaining forest land. Change, however, did occur where one forest type was converted to another and these changes were included under "land remaining" but were estimated as described for land conversions.

Land conversions

For land that was converted to a forest land the initial DOM is given in the relevant land category section, and the final DOM for the forest land is shown in Table 6.24. Changes in DOM due to land conversions were estimated using 2006 IPCC Guidelines equation 2.23.

If there is a gain in DOM this is assumed to occur over the 20-year default period, while losses are assumed to occur within the year of conversion.

Table 6.24: Deadwood and litter biomass for forest lands.

	Data applied in the inventory		Comparison with other data	
	DOM (t C/ha)	Reference	DOM from updated NTCSA (t C/ha)	2006 IPCC Guidelines (t C/ha)
Indigenous forests	Deadwood: 6.37 Litter: 3.82	Glenday, 2007 (Area weighted average of coastal scarp, coastal lowland and dune forest)	4.67	Broadleaf litter: 2 – 3 Needleleaf litter: 4.1 (Subtropical values)
Thickets	Deadwood and litter (intact): 4.52 Deadwood and litter (degraded): 1.17 Weighted average: 1.35	Glenday, 2007 Mills et al., 2005 Powell, 2009 Van der Vyver, 2018	2.34	
Woodlands	Deadwood: 1.00 Litter: 2.10	Glenday, 2007 (average of wooded grassland and disturbed woodland)	1.01	
Plantations	Litter: 2.38	Dames et al., 1998	2.26	

6.4.2.3 Mineral soils

Soil emissions were calculated as explained in section 6.1.3.3. As soils are not a key category the 2006 IPCC Guideline default stock change factor of 1 was applied for all forest categories.

6.4.2.4 Non-CO_2 gases from biomass burning

Emissions from biomass burning were determined from burnt area data (see section 6.1.3.6), fuel load, combustion factor and an emission factor. The fuel load was the above-ground biomass and the DOM data for the relevant forest category, while the combustion factors were sourced from the 2006 IPCC Guidelines Table 2.6. The all "other" temperate forest value was applied to indigenous forests and thickets, while the average of the early and mid/late season factors for savanna woodlands was applied to the Woodland category. The *fd* factor for fire losses in plantations (described in section 6.4.2.1) was used as the combustion factor for forest plantations. Emission factors were taken from 2006

IPCC Guidelines Table 2.5. The extra tropical forest values were applied to indigenous forests, thickets and plantations, while the savanna values were applied to Woodlands.

6.4.3 Uncertainty

Activity data uncertainty

Uncertainty for the land areas were provided by the SANLC 2020 accuracy assessment (DFFE, 2021). The mapped areas of indigenous forests, thickets, woodlands and plantations have uncertainties of ±17%, ±22%, ±26% and ±6%, respectively. An additional 5% was added to this for indigenous forests, and 10% for woodlands and thickets to account for uncertainty on the corrections. The uncertainty for converted areas was taken to be the combined uncertainty (applying the propagation of errors as indicated in 2006 IPCC Guidelines) for the two land areas. The results of this approach indicate the converted lands have a slightly higher uncertainty than the individual land types, and this is considered to be reasonable.

Harvested wood uncertainty is around ±2% (expert opinion) as the forestry companies measure the harvested wood so it is fairly accurate data. The uncertainty lies in whether all the harvested wood is accounted for as not all small growers report to Forestry SA. The fuelwood removal data is very uncertain as it was determined from household statistics on number of households using wood (±5.6% uncertainty for rural households and ±32% for urban households based on Shackelton et al., 2022), a single wood density value (±5% based on data from IPCC, 2006) and an average household wood consumption value (±40% based on Shackelton et al., 2022). The burnt area data determined from MODIS collection 6 has an uncertainty of <6% (Boschetti et al., 2021) and the soil maps are estimated to have an uncertainty of ±10%. The overall activity data uncertainty for forest land remaining forest land was estimated at ±22.8% and ±17.3% for CO_2 emissions and non-CO_2 emissions, respectively. For land converted to forest land the uncertainty estimates were ±30.8% and ±26.7%, respectively.

Emission factor uncertainty

The uncertainty on biomass gains was estimated from uncertainties provided in the literature scientific literature mentioned in Table 6.20 on carbon accumulation and in Table 6.21 on root to shoot ratios. The BCEF were assumed to have the same uncertainty as the biomass accumulation data. Carbon fraction uncertainty is ±6% (IPCC, 2006). In terms of carbon losses, the wood density value is estimated to have an uncertainty of around 5% based on data provided in IPCC 2006. Since the DOM and SOC data have greater uncertainty than the biomass data an uncertainty of ±20% is assigned to these categories. The CO_2 emission factor uncertainty for forest lands remaining forest land was estimated at ±57%, while for land converted to forest lands it was ±62%. For CH_4 and N_2O uncertainties were ±35% and ±37% respectively for forest land remaining forest land.

6.4.4 Time-series consistency

The land change maps had some inconsistency in that different satellite data was used, however some corrections were made to bring these two datasets into alignment. The inconsistency was between 2014 and 2018. All other datasets were consistent through the time-series.

6.4.5 Category specific QA/QC and verification

All general QC listed 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 data

Plantation area and fuelwood consumption data was compared to FAO data.

Plantation emissions were estimated with the Stock-Difference approach for verification. Age class data for the 5 plantation species groups (Pines, Eucalyptus grandis, Other Eucalyptus species, Acia species, and Other hardwood species) was obtained from DFFE Timber Statistics reports. Data was available for 2021 to 2019. MAI curves for each species (obtained from Forestry SA) were used to determine MAI at each age. Stock volume was estimated from the MAI and age of the trees. The stock volume was combined with the BCEFs value (determine for each species and age class using the equation provided by Dovey et al., 2021) to estimate carbon biomass stock per age class. These were then added to determine the total carbon stock per year.

As the carbon stock is determined from area, it does not actually account for losses due to damage (fire or other disturbances). Disturbances losses, as determined for the Gain-Loss method, were therefore subtracted from the total carbon stock to get the overall carbon stock per species per year.

The change in carbon stock was then determined by subtracting the initial year carbon stock from the final year carbon stock. The area of plantations changes from year to year therefore an area correction[23], as described by IPCC, was applied. Ideally the area should be the same and then the carbon gains or losses due to land conversions in that area are accounted for. The area correction means that only the plantation area is being considered and so the gains and losses due to land conversion to/from other land classes is not accounted for. This is one area where the Gain-loss and Stock-difference approach applied in this inventory differ and is one of the reasons why the Gain-loss method was included in the inventory instead of the Stock-difference.

The carbon change determined by the Stock-Difference method had a similar trend to the estimates based on the Gain-Loss method, except that there were some variations between years (Figure 6.7). It is noted that between 2008 and 2016 there seems to be a mismatch in the years but there is no clear explanation for this. The Stock-difference method shows a sharp decline in carbon in 2012 and increase in 2013 which is not seen in the Gain-loss data. These peaks are due to large changes in TUP area. Effectively the carbon losses in the Stock-difference method are based on the area of TUP, whereas in the Gain-loss method the amount of wood harvested is taken into account. The Harvested wood and the TUP area show differing patterns which causes much of the variation between the Gain-loss and Stock-difference method.

Overall the two methods produce values in a similar range, but the differences will be explored further in the next inventory.

[23] *Area corrected carbon stock difference = ((Final carbon stock/Final plantation area) - (Initial carbon stock/Initial plantation area)) x Final plantation area.*

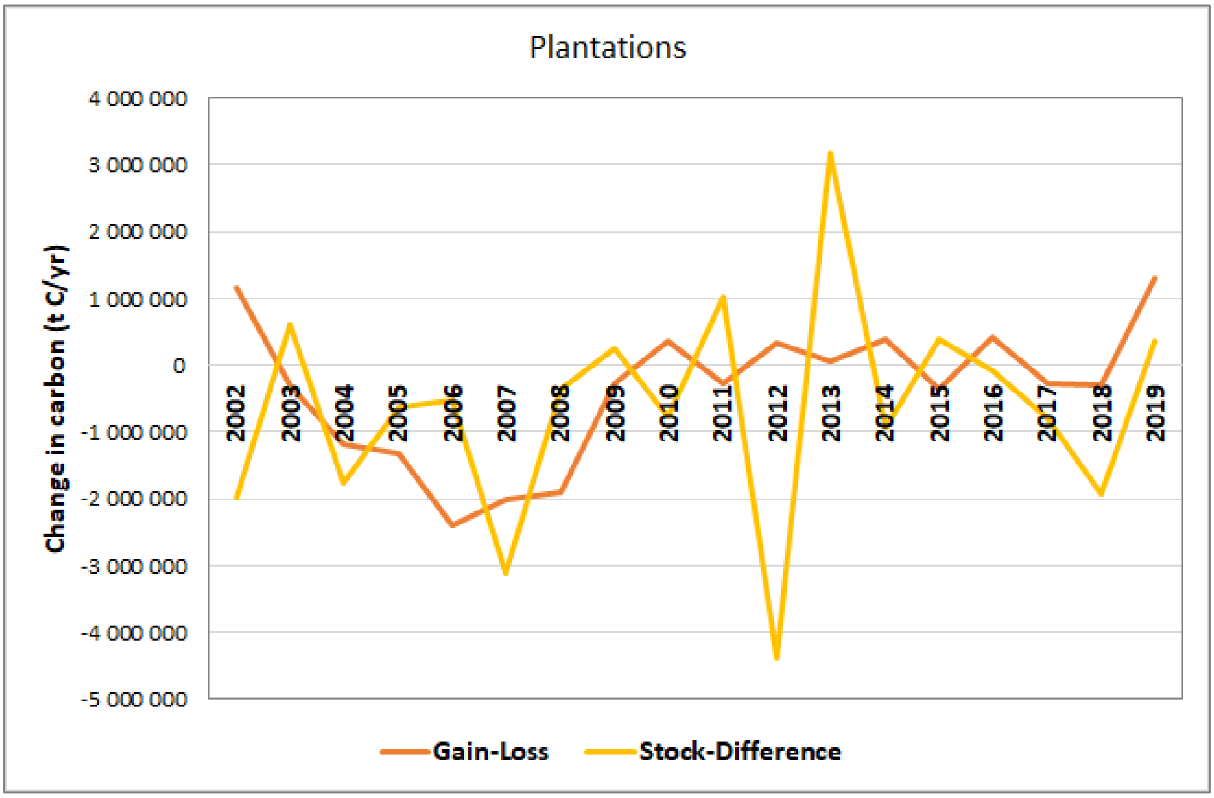

Figure 6.7: Carbon change for plantations estimated by the Gain-loss and Stock-difference methods.

6.4.6 Category-specific recalculations

The following main improvements led to a recalculation of the *Forest land* emissions:

- Inclusion of 1990-2014 and 2018-2020 land change maps
- Introduction of land area corrections for seasonal variation
- Updated biomass data
- Updated BCEF for plantations
- Inclusion of age class data for plantations
- Updated household fuelwood consumption factor
- Use of country specific biomass data for fuel loads
- Inclusion of non-CO_2 emissions from biomass burning

The improvements produced the same trends as the previous inventory but increased the sink 3-fold comparing the data in 2020. In the previous inventory the indigenous forest was a small source in most years, but with the improvements in this inventory the sink increased 2-fold and it is now a small sink in half of the years. The biggest sink being in 2016, as reflected in the previous inventory. The biggest changes were in thickets, as were to be expected, since thickets showed the largest changes and reclassification in the land cover maps. The improvements in the mapping and the updated biomass factors changed the original thicket source into a sink across all years. Thickets contributed 72.2% to the overall change in the 2020 estimate since the last inventory.

The inclusion of country specific BCEF factors and age class data also led to an increased sink in the forest plantations. The enhancement of the sink was greater between 2003 and 2010. In the previous inventory plantations were seen to be a source of emissions in most years, while in this inventory plantations show small increases and decreases around zero between 2009 and 2019. The sink is shown to increase from 2019 onwards, however this is extrapolated data due to plantation data only being available until 2019. This will be corrected in the next inventory.

Minor changes in biomass data were made to woodlands, therefore very little change was seen in woodlands, except the change in land cover map for 2018-2020 led to an increased sink in these years. In 2020 woodlands contributed 22.6% towards the 2020 recalculated value.

6.4.7 Category-specific planned improvements

The most critical factor in the LULUCF sector is the land use change data, particularly relating to thickets. The general land use change improvement plan will contribute significantly to improving this aspect of *Forest land*. Specific improvements for Forest land are to further assess the Stock-difference data for plantations and consider this for inclusion in the next inventory. Further data on litter for the various forest categories will be sought to start improving the DOM pool data as all pools are highlighted as being key for forest conversion.

6.5 Croplands (4.B)

6.5.1 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.

6.5.2 Methodological issues

In the previous inventory both the "Cropland remaining cropland" category and the "Land converted to Cropland" category were identified as key categories and carbon changes should, based on the IPCC decision tree, be calculated with a Tier 2 or 3 approach. For Cropland remaining cropland there is still insufficient data to determine biomass and litter changes for annual crops using a Tier 2 so a Tier 1 methodology was applied. For perennial crops country specific growth and loss factors were included to estimate biomass and litter emissions or removals with a Tier 2 approach. Soil emissions for all categories were estimated with a Tier 2 approach. The annual crops category has, therefore, been identified for improvement in the next inventory as a Tier 2 method should be applied to this category. Emissions and removals from all pools of the "converted land" category were estimated with a Tier 2 method which is suitable for this category. Where there were conversions between crop types (i.e. annual crop converted to a perennial crop) a Tier 2 "converted land" approach was applied but the emissions and removals were allocated to "Cropland remaining cropland".

6.5.2.1 Biomass

Carbon gains in land remaining

A Tier 1 approach was applied where annual crops were assumed to be in equilibrium, so biomass gains and losses were only accounted for in perennial crops. For gains the area of perennial crops was multiplied by a biomass accumulation rate (Table 6.25).

Carbon losses in land remaining

Losses accounted were those from biomass burning and harvest losses. For harvest losses the maturity cycle was 30 years and so the area was divided by 30 to divide the crops into age classes. Every year it was assumed then that the oldest age class was harvested. The only burning that was taken to occur in croplands is the pre-harvest burning of sugarcane. Sugarcane, however falls under the annual croplands and since equivalence was assumed for annual crops "land remaining" these CO_2 emissions did not need to be included. The non-CO_2 emissions from sugarcane burning are included under "Burning of Agricultural Residues".

Table 6.25: Biomass and growth factors for the various cropland categories.

	Inventory biomass data							Comparison to other data sets		Inventory growth data	
	AGB (t dm/ha)	SD	Reference	Root to shoot ratio	SD	Reference	Total biomass (t dm/ha)	IPCC default biomass (t dm/ha)	NTCSA (t dm/ha)	Biomass growth rate (t C/ha/yr)	References
Annual non-pivot crops	8.6		Area weighted average calculated from production, yield and harvest index data (DLRRD, 2022; Stats SA, 2021; DEA, 2015)	0.22		Varies slightly for each crop type (2019 IPCC 2006 Refinement) and this was an area weighted average	10.0	10.0 (annual crops, IPCC 2006 Table 5.9)	5.83	NA	
Annual pivot crops									9.94		
Subsistence crops	6.5		Assumed to be 75% of commercial				7.8		7.20		
Orchards	80.9		DEA, 2015	0.42		Scandellari et al., 2016	114.88	134.0 (temperate conditions, IPCC 2006 Table 5.1)	17.45	1.80	Carbon stock divided by 30 yr harvest cycle
Vineyards	29.8		DEA, 2015	0.42		Zhang et al., 2021	42.32		12.89	0.66	

Gains and losses due to land conversions

For "land converted to croplands" the 2006 IPCC Guideline equations 5.2 and 5.3 were applied. A tier 2 approach was adopted where the initial change in biomass carbon stocks on the converted land is added to the equation. 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. The carbon stocks on the croplands before conversion are the values associated with the initial vegetation type (Table 6.25). 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 time 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.

Where there was conversion between the various crop types the same approach as for "land converted to croplands" was applied, however the emissions are allocated to the "land remaining land" category.

6.5.2.2 Litter

Land remaining

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 2006 IPCC Guidelines equation 2.23 (stock-difference approach).

Converted land

For areas that are converted from another land to cropland, the litter carbon stock data from the initial (see relevant land category sections) and final land types (Table 6.26) was in the 2006 IPCC Guidelines equation 2.23. The litter data was sourced from the NTCSA (DEFF, 2020) which provided spatial carbon density maps. These maps were intersected with the SANLC data to provide an area averaged estimate of the litter for each crop type.

If there was a gain in litter carbon this was assumed to occur over the 20-year default period, while losses were assumed to occur within the year of conversion.

Table 6.26: Litter data applied in the inventory for the various cropland categories.

	Data applied in the inventory	
	Litter (t dm/ha)	Reference
Annual non-pivot crops	3.40	NTCSA (DEFF, 2020)
Annual pivot crops	2.72	
Subsistence crops	1.36	
Orchards	6.86	
Vineyards	9.80	

6.5.2.3 Mineral soils

Changes in mineral soil carbon were determined as described in section 6.1.3.3. *Cropland* stock change factors for management, input and land use were determined from data reported in Moeletsi et al. (2015) and Tongwane et al. (2016). Management and inputs differ between the crop types, therefore the data was weighted by crop area. Crop areas were obtained from DALRRD, national statistics (Statistics SA), Crop Estimates Committee, and FAO. The management and input data was combined with the 2019 Refinement of 2006 IPCC Guidelines default stock change factors and climate data to determine the stock change factors for each crop type (Table 6.27). The 2019 Refinement data was selected as it has greater disaggregation than the 2006 Guidelines. These factors were assumed to remain constant throughout the time period due to a lack of annual management data. The values applied in the inventory for the various crop types and land types is presented in Table 6.6.

Table 6.27: Stock change factors for the specific crops in South Africa.

Crop type	Stock change factors		
	Land use (F_{LU})	Management (F_{MG})	Inputs (F_I)
	Dry climate		
Barley	0.76	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

6.5.2.4 Non-CO_2 gases from biomass burning

Non-CO_2 emissions from croplands were not included here but rather under "Agricultural burning of Crop Residues" as the only burning that was considered to occur in croplands was the pre-harvest burning of sugarcane residues.

6.5.3 Uncertainty

Activity data uncertainty

Uncertainty for the land areas were provided by the SANLC 2020 accuracy assessment (DFFE, 2021). Cropland areas are determined from crop boundary data so uncertainty is low (±1% on perennials and ±7% on annual crops). The uncertainty for converted areas was taken to be the combined uncertainty (applying the propagation of errors as indicated in 2006 IPCC Guidelines) for the two land areas. The results of this approach indicate the converted lands have a slightly higher uncertainty than the individual land types, and this is considered to be reasonable. The soil maps are estimated to have an uncertainty of ±10%. The overall activity data uncertainty for cropland remaining cropland was estimated at ±9.9%. For land converted to cropland the uncertainty was estimated at ±19.8%.

Emission factor uncertainty

Biomass data was determined from actual yield and production data from commercial crops so has a small uncertainty for the individual crops (estimates at ±5%) but the average value overall crops had a slightly higher uncertainty (±10%). Litter and SOC data have greater uncertainty than the biomass data, particularly since they were derived from the NTCSA overlay, and therefore an uncertainty of ±20% was assumed for these categories. Emission factor uncertainty for CO_2 was estimated at ±22% for croplands.

6.5.4 Time-series consistency

The land change maps had some inconsistency in that different satellite data was used, however corrections were made to bring these two datasets into alignment. The inconsistency was between 2014 and 2018. All other datasets for *Croplands* were consistent across the time-series.

6.5.5 Category specific QA/QC and verification

The cropland planted area from agricultural statistics, which reports commercial crops only, was compared to the pivot and non-pivot annual crop area from the LC maps and it was found that the planted area (5.7 million ha in 2020) was much less than the total cropland area reported in the SANLC (11.5 million ha in 2020). On average the agricultural abstract area is 50% of that reported in the SANLC. The arable land area report by StatsSA Agricultural 2017 census was 7.6 million ha which is closer to the area report by the agricultural abstracts. The area reported by FAO very closely matches what is reported in the agricultural abstracts. On the other hand, the SANLC data is developed from crop boundary data and the SANLC crop area data is shown to have an uncertainty of 7% which is the second lowest (after perennial crops) of all the land types. The difference will need to be investigated in further detail with the DALRRD and will be incorporated as part of the land change improvement plan.

Dry mater yield calculated from area and production data were compared to estimates from the literature and in most cases the data matched well. The calculated yield values seemed to be overestimated for vegetables compared to the literature, but this may have been because the various vegetables were grouped together thereby creating high uncertainty for this category. In future, once data becomes available, the different types of vegetables could maybe be considered.

Country specific planted area, production and yield data were also compared to FAOStat data for South Africa.

6.5.6 Category-specific recalculations

The following main improvements led to a recalculation of the *Cropland* emissions:

- Inclusion of 1990-2014 and 2018-2020 land change maps
- Introduction of land area corrections for seasonal variation
- Updated biomass data (making use of harvest index data)
- Inclusion of a weighted average biomass accumulation rate which varied across the time-series due to variations in yield
- Inclusion of below-ground harvest losses
- Increase of harvest cycle from 25 to 30 years for orchards and vineyards due to updated information
- Assumption that no biomass burning occurs in agriculture except pre-harvest burning of sugarcane. These emissions were not included here but rather under burning of agricultural residue.

The improvements led to a doubling of the *Cropland* source between 2000 and 2014. Between 2015 and 2018 the source peaked around 12 000 Gg CO_2eq, but then declined again to levels shown between 2000 and 2014. The incorporation of the different land change maps was responsible for this change between 2015 and 2018. The main contributor to this source was an increase in conversion of perennial crops to annual (non-pivot) crops and the conversion of forest lands (mainly woodlands and plantations) to annual and subsistence crops.

Subsistence crops and annual non-pivot crops were found to be a source of emissions rather than a sink, while orchards were found to be a smaller sink. These were the main changes contributing to the increased source in *Croplands*.

6.5.7 Category-specific planned improvements

The inventory will be improved over time by sourcing more crop specific biomass data. The management system classification for the various crops will be improved by following the decision tree given in IPCC 2006 Guidelines, chapter 5, figure 5.1. Further the planned land change improvement plan will also lead to improvements for *Croplands*.

6.6 Grasslands (4.C)

6.6.1 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 of conversion.

Biomass burning CH_4 and N_2O were included here instead of being included under the Biomass Burning category (3C1) under Aggregated and non-CO_2 emissions (3C) in Agriculture as was the case in the previous inventory. This is to bring the inventory into alignment with the CRT tables required for reporting under the ETF.

6.6.2 Methodological issues

A Tier 1 approach was applied for Grasslands remaining grasslands. In the previous inventory this category was identified as a key category in the level assessment (at the bottom of the list) but not in the trend assessment. According to the methodology decision tree (2006 IPCC Guidelines, Figure 2.2) data should be collected to apply a Tier 2 for key categories. For grasslands this would require information on grassland management (such as degraded area, degree of degradation, area of improved grassland) and there is currently no sustainable source for this data, therefore the Tier 1 approach was applied.

6.6.2.1 Biomass

Carbon gains in land remaining

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. For low shrublands the accumulation rate is 1/20 of the carbon stock and therefore for “land remaining” it was assumed that this category has reached its equilibrium and therefore there is no more growth. The rule of equivalence was therefore also applied to low shrublands.

Carbon losses in land remaining

Only disturbance losses due to fire (wildfire and controlled fire) were included as there was no data on other disturbances. The carbon losses in annual grasses and low shrublands under "land remaining" was not reported, as the carbon released during combustion is assumed to be reabsorbed by the vegetation during the next growing season. Where there was land-use change between the grasslands and low shrublands, carbon stock changes were reported under *Grasslands remaining grasslands.* Fire disturbance losses were only accounted for in land converted to low shrubland using 2006 IPCC Guideline Equation 2.14. Above-ground and below-ground biomass were included in these losses and the fraction of biomass lost due to fire were taken to be the same fraction as the combustion factor (Table 6.31).

Gains and losses due to land conversions

Land converted to grassland was identified as a key category in the previous inventory with the level and trend assessment and therefore a Tier 2 approach (2006 IPCC Guideline equations 5.2 and 5.3) was applied. For *land converted to grasslands* only the biomass increase and losses 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.

Carbon gains and losses were calculated for the woody low shrubland component. The carbon stock change due to the removal of biomass from the initial land use (i.e. $\Delta C_{CONVERSION}$) was only calculated for the area of lands undergoing a conversion in a given year, and in subsequent years it was zero. The biomass values for the initial land types are given in the relevant land category sections, while biomass data for the grassland categories are provided in Table 6.28. For low shrublands, which consist of fynbos, succulent karoo and nama karoo vegetation, biomass data was obtained from the literature and then an area weighted average was obtained based on area data provided in the SANLC maps (15% fynbos, 17% succulent karoo, 43% nama karoo and 25% other shrublands). It was assumed that only croplands and plantations were cleared before being converted to a grassland, while all other conversions were slow transitions and not abrupt changes.

6.6.2.2 Litter

Land remaining

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 grassland category did not change, however, there were conversions between the various grassland categories so changes in litter were calculated for these areas using 2006 IPCC Guidelines equation 2.23 (stock-difference approach).

Converted land

For land converted to grasslands the changes in litter were determined from the litter data in the various land types (see the relevant land section) with the 2006 IPCC Guidelines equation 2.23. the litter stock in grasslands is provided in Table 6.29. As with the cropland litter data, this litter biomass data was sourced from the NTCSA (DEFF, 2020). It is assumed that the change occurs slowly over the 20-year default transition period.

Table 6.28: Above ground biomass factors for grassland categories.

	Data applied in the inventory							IPCC default
	AG biomass (t dm/ha)	SD	Reference	Root to shoot ratio	SD	Reference	Total biomass (t dm/ha)	
Grasslands	2.0 (Average)	0.24	Snyman, 2006 Snyman & Fouche, 1991 Snyman, 2005 Mills et al., 2005a O'Connor et al. 2001 Gander, 1994	2.6		Snyman, 2005	6.7	6.1 (warm temperate dry, IPCC 2006)
Low shrublands	8.7 (Weighted average)	0.61	Milton, 1990 Rutherford and Westfall, 1986 Rutherford, 1978 Van Wilgen, 1982 Mills et al, 2005a Anderson et al., 2010 Werger and Morris, 1991 O'Farrell, 2005	0.8		Mills et al., 2005a Malan and Snyman, 2008	15.8	NA
Eroded land	0		Assumed not to have biomass	NA			0	NA

Table 6.29: Litter data applied in the inventory for the grassland categories.

	Data applied in the inventory	
	Litter (t dm/ha)	Reference
Grasslands	1.55	NTCSA (DEFF, 2020)
Low shrublands	2.72	
Eroded land	0	Assumed to be zero

6.6.2.3 Mineral soils

A value of 1 was applied as the carbon stock change factor for *Grassland.* As in the previous inventory improved and degraded grasslands were incorporated. The 2018 and 2020 land cover maps do not have any division for grasslands in term of degradation, however the land cover maps for 1994/95 (Fairbanks et al., 2000) had degraded and improved lands incorporated. These maps indicated that 0.45% of grasslands were improved. Matsika (2007) researched degradation in grasslands and showed that 26.7% of grasslands had low degradation, 58.7% moderate degradation and 14.6% had high degradation. Unfortunately, spatial data for this could not be incorporated due to not all the data being available and also the maps were all for different years and scales making it hard to combine. Since the data was not spatial the percentage improved and degraded from Matsika (2007) was combined with the IPCC default stock change factors to obtain weighted average management stock change factor for grasslands (Table 6.30). The grassland management data is only once-off data therefore it was assumed, for now, that the amount improved and degraded has remained constant over the whole time-series.

Table 6.30: Stock change factors for grasslands in South Africa.

Grassland type	Stock change factors		
	Land use (F_{LU})	Management (F_{MG})	Inputs (F_I)
		WTD climate	
Grasslands	1	0.85	1
Low shrublands	1	1	1

6.6.2.4 Non-CO_2 gases from biomass burning

Emissions from biomass burning were determined from burnt area data (see section 6.1.3.6), fuel load, combustion factor and an emission factor. The fuel density (Table 6.31) was determined from the above-ground biomass and litter in the various grassland categories.

The combustion factor (C_f) for grasslands was determined from IPCC 2006 default values. Archibald et al. (2010) indicated that grassland burns are mainly in August with 80% of burning occurring at this time of the year. Therefore, the IPCC 2006 early and late season burn factors for sub-tropical grasslands were weighted based on this to get a weighted average C_f for grasslands. For low shrublands, IPCC 2006 provided a factor for fynbos and then the general shrubland factor was applied to other shrublands. In this way a weighted average was obtained by using the areas data as indicated for biomass.

Emission factors were taken from 2006 IPCC Guidelines Table 2.5.

Table 6.31: Fuel density and combustion fractions for the various grassland classes.

Vegetation class	Fuel density (t/ha)	Combustion factor		Fuel consumption (t/ha)	
		Value	Source	Value	IPCC default
Grasslands	3.5	0.88	Weighted average IPCC 2006 seasonal data	3.1	2.1 (early season burn) 5.2 (late season burn)
Low shrublands	11.4	0.91	Weighted average	10.4	12.9 for fynbos 14.3 (all shrublands)

6.6.3 Uncertainty

Activity data uncertainty

Uncertainty for the land areas were provided by the SANLC 2020 accuracy assessment (DFFE, 2021). Grasslands have the highest uncertainty (55%) followed by shrublands (225) and eroded land (13%). An additional 10% was added to this to account for uncertainty on the corrections. The uncertainty for converted areas was taken to be the combined uncertainty (applying the propagation of errors as indicated in 2006 IPCC Guidelines) for the two land areas. The burnt area data determined from MODIS collection 6 has an uncertainty of <6% (Boschetti et al., 2021) and the soil maps are estimated to have an uncertainty of ±10%. The overall activity data uncertainty for grasslands remaining grasslands was estimated at ±25.8%, while for converted lands it was ±19.1%.

Emission factor uncertainty

Uncertainty on growing stock was taken from the literature provided in Table 6.28 and were ±12%. Disturbance losses in industrialised countries have a default uncertainty of ±15%, so a ±20% uncertainty is assumed. Since the litter and SOC data have greater uncertainty than the biomass data an uncertainty of ±20% was assigned to these categories. Emission factor uncertainty for CO_2 was estimated at ±30.7%, while for CH_4 and N_2O it was ±39% and 48%, respectively. The non-CO_2 emission factor uncertainties were derived from the IPCC 2006 default values (IPCC, 2006).

6.6.4 Time-series consistency

The land change maps had some inconsistency in that different satellite data was used, however some corrections were made to bring these two datasets into alignment. The inconsistency was between 2014 and 2018. All other datasets were consistent through the time-series.

6.6.5 Category specific QA/QC and verification

The only category specific QA/QC checks that were undertaken for grasslands was the comparison of biomass data with the NTCSA (DFFE, 2020). The biomass data for low shrublands may be overestimated in the inventory as the values are higher than reported in the NTCSA, although they do still fall within the shrubland ranges reported in IPCC 2006. Further data will be required to improve this data.

6.6.6 Category-specific recalculations

The following main improvements led to a recalculation of the *Grassland* emissions:

- Inclusion of 1990-2014 and 2018-2020 land change maps
- Introduction of land area corrections for seasonal variation
- Updated biomass data
- Inclusion of non-CO_2 emissions from biomass burning

The improvements led to a reduced sink in the *Grasslands* category between 1990 and 2014, and this changed to a source from 2015 onwards. Part of this change was in land conversions, therefore improvements in other land category biomass data also contributed to changes in the *Grassland* category. Pure grasslands were indicated to be a source in this inventory rather than a sink (due mostly to the conversion of woodlands to grasslands), but the opposite was true for low shrublands. The largest contributor to the low shrubland sink was the conversion of bare ground to low shrublands. Both of these conversion categories, woodlands to grasslands and bare ground to shrublands, are subjected to large seasonal variations. These may therefore be improved in future with the land change improvement plan.

6.6.7 Category-specific planned improvements

Besides the planned improvements around the land cover maps and actual change detection (i.e. removal of seasonal variation changes), further biomass data for low shrublands will be sought to reduce the uncertainty on this dataset. Grasslands remaining grasslands are shown to be a key category and this category only includes the low shrubland data as pure grasslands are seen to be in equilibrium.

6.7 Wetlands (4.D)

6.7.1 Category description

Waterbodies and wetlands are the two sub-divisions in the wetland category and are defined in GTI (2015). Mangroves are not included under wetlands as these are within the thicket category. The wetland category is therefore only herbaceous (annual) vegetation. 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 and CH_4 emissions from wetlands were incorporated. Biomass burning CH_4 and N_2O were also included here instead of being included under the Biomass Burning category (3C1) under Aggregated and non-CO_2 emissions (3C) in Agriculture as was the case in the previous inventory. This is to bring the inventory into alignment with the CRT tables required for reporting under the ETF.

6.7.2 Methodological issues

Wetlands were not identified as a key category in the previous inventory, therefore a Tier 1 approach is suitable.

6.7.2.1 Biomass

Carbon gains and losses in land remaining

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 was a change from a waterbody with no vegetation to a wetland which has vegetation. In this case gains and losses were included and estimated as for land conversions.

Carbon gains and losses due to land conversions

For land conversions a Tier 2 approach (2006 IPCC Guideline equations 5.2 and 5.3) was applied. 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.

Wetland biomass data was sourced from the literature. An above ground biomass value of 14.2 t dm/ha were determined for salt marshes (Els, 2019) and 15.8 t dm/ha for macrophytes, reeds and sedges wetlands (Els, 2019; Glenday, 2007). A weighted average was determined (15.1 t dm/ha) by using an area based on the fraction of the two types of wetlands (DFFE, 2021). The root to shoot ratio of 0.96 provided in the IPCC Wetland Supplement (IPCC, 2014) was applied to determine below ground biomass.

For carbon losses due to fire disturbance the fraction burnt was taken to be 0.7 from the 2006 IPCC Guidelines Table 2.6 for tropical wetlands.

6.7.2.2 Litter

Land remaining

The Tier 1 assumption for the litter pool is that the stocks in *wetlands remaining wetlands* are not changing over time, therefore litter changes are reported to be zero. This was applied to areas where the *wetland category* did not change, however, there were conversions between *wetlands and waterbodies* so changes in litter were calculated for these areas using 2006 IPCC Guidelines Equation 2.23 which is the same as the approach for land conversions.

Land conversions

The litter stock for *Wetlands* was determined to be 2.34 t dm/ha. This was estimated from the overlay of the SANLC data with the NTCSA data (DFFE, 2020). For land converted to wetlands the changes in litter are determined from the litter data in the various land types (see the relevant land section) with the 2006 IPCC Guidelines equation 2.23. It was assumed that the change occurs slowly over the 20-year default transition period.

6.7.2.3 Mineral soils

Changes in mineral soil SOC in *Wetlands* was calculated as described in section 6.1.3.3.

6.7.2.4 CH_4 and N_2O emissions from wetlands

CH_4 emissions from *Wetlands* were calculated following equation 5.1. of the IPCC Wetland Supplement (IPCC, 2014; Chapter 5) where the wetland area was multiplied by the 2006 IPCC Guideline default CH_4 emission factor of 235 kg CH_4/ha/yr. This emission factor was much higher that the country-specific value 55.9 kg CH_4/ha/yr provided by Kruger et al. (2012). The country study indicated that the values was lower than found in other studies and could be due to the time of the year. A study by Otter et al. (2000) provided an emission factor of 255 kg CH_4/ha/yr which is much closer to the IPCC default value of 235 kg CH_4/ha/yr. As the Kruger et al. (2012) did not see to be representative of all wetlands and the Otter et al. (2000) data being much higher the default IPCC value was selected until more data is collected to validate these emission factors.

IPCC does not provide a method for estimating N_2O emissions from *Wetlands* so the same equation as used for CH_4 was applied. The only emission factor found was that from Kruger et al. (2012). Even though the data from this study does not appear to representative of all wetlands it is the only data available thus the emission factor of 1.4 kg N_2O/ha/yr (Kruger et al., 2012) but understanding that this value may be an underestimate. As more data becomes available this emission factor will be updated.

6.7.2.5 Non-CO_2 gases from biomass burning

Emissions from biomass burning were determined from burnt area data (see section 6.1.3.6), fuel load, combustion factor and an emission factor. The fuel density (18 t dm/ha) was determined from the above-ground biomass and litter, while the combustion factor (C_f) was assumed to be the same as grasslands. Emission factors were taken from 2006 IPCC Guidelines Table 2.5 and the grassland values were applied.

6.7.3 Uncertainty

Activity data uncertainty

Uncertainty for the land areas were provided by the SANLC 2020 accuracy assessment (DFFE, 2021). The burnt area data determined from MODIS collection 6 has an uncertainty of <6% (Boschetti et al., 2021) and the soil maps were estimated to have an uncertainty of ±10%. The overall activity data uncertainty for wetlands remaining wetlands was estimated to be ±11.6% and was ±21.5% for land converted to wetlands where the uncertainty was a combination of uncertainty of each land type.

Emission factor uncertainty

The uncertainty for biomass was estimated to be similar to *Grasslands*. Disturbance losses in industrialised countries have a default uncertainty of ±15%, so a ±20% uncertainty is assumed. Since the litter and SOC data have greater uncertainty than the biomass data an uncertainty of ±20% was assigned to these categories. Emission factor uncertainty for CO_2 was estimated at ±30%, while for CH_4 and N_2O it was ±39% and 48%, respectively. The non-CO_2 emission factor uncertainties were derived from the IPCC 2006 default values (IPCC, 2006).

6.7.4 Time-series consistency

The land change maps had some inconsistency in that different satellite data was used, however some corrections were made to bring these two datasets into alignment. The inconsistency was between 2014 and 2018. All other datasets were consistent through the time-series.

6.7.5 Category specific QA/QC and verification

No category specific checks were undertaken for *Wetlands*.

6.7.6 Category-specific recalculations

The main improvements for the *Wetlands* category that led to recalculations for the time series were:

- Inclusion of 1990-2014 and 2018-2020 land change maps
- Updated biomass data
- Updated CH_4 emission factor for emissions from saturated or flooded areas
- Inclusion of non-CO_2 emissions from biomass burning

The improvements caused a 4-fold increase in the sink and this was mainly due to the change in the CH_4 emission factor for wetland. The change in land cover areas and biomass data led to a reduction in emissions from *Wetlands remaining wetlands*, an increase in emissions from the conversion of forest lands to wetlands, and a reduction in the sink due to the conversion of grasslands to wetlands.

6.7.7 Category-specific planned improvements

There are no specific planned improvements for this category.

6.8 Settlements (4.E)

6.8.1 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:

- Residential
- Smallholdings
- Commercial
- Industrial and
- Mines

Residential and smallholdings were identified as either being vegetated (tree, bush or low shrub) or bare. Emissions and removals of CO_2 in the biomass, litter and mineral soil carbon pools for each of these categories was estimated, but dead wood was excluded due to insufficient data. Non-CO_2 emissions from biomass burning were also included for each category. Estimates are provided for both *Settlements remaining settlements* and *land converted to settlements*.

6.8.2 Methodological issues

Settlements remaining settlements were identified as a key category in the trend analysis in the previous inventory. There is insufficient data to carry out a Tier 2 on *Settlements remaining settlements*, however a more detailed categorisation was included to try to include more detail and reduce uncertainty.

6.8.2.1 Biomass

Carbon gains

To include more detail into this category the detailed SANLC classes, which identified areas covered with tree, bush, low shrubland and bare ground, was used. The change in biomass was only estimated for woody areas because for annual grasses the increase in biomass stocks in a single year is assumed to equal the biomass losses in that same year. Biomass gains were estimated using 2006 IPCC Guidelines Equation 2.9. Even though an area may have been identified as having trees, it was assumed that the density was not as great as in woodlands. Therefore, the lower carbon biomass from shrublands was applied to areas that had trees. Area with shrubs were assumed to have biomass that is half that of the areas with tree. Areas identified as having low shrubs or grasses were allocated the biomass value from grasslands. The carbon accumulation rate for wooded areas was estimated from the biomass and a 20 year growth cycle. Bare areas did not have any biomass. Based on this biomass data and the areas from the SANLC 2020, weighted average biomass values were estimated for the 5 settlement classes (Table 6.32). The values were compared to the data derived from the NTCSA (DFFE, 2020) and were found to be lower than the NTCSA, however the report did indicate that the settlement data may be overestimated as the LiDAR had difficulty distinguishing vegetation from buildings.

Carbon losses

The carbon losses from fire disturbance in settlements was estimated with 2006 IPCC Guidelines Equation 2.14. Where there was land-use change between the settlement categories, carbon stock changes were reported under Settlements remaining settlements. Losses were estimated from biomass data and a fraction of vegetation that was burnt. This fraction was taken to be 0.74 which is an average of fraction lost for grasslands and woodlands as settlements contain both grass and wood components.

Carbon gains and losses for land conversions

Land converted to Settlements was estimated using a Tier 2 approach (2006 IPCC Guideline equations 5.2 and 5.3). For *land converted to settlements* 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. The carbon stock change due to the removal of biomass from the initial land use (i.e. $\Delta C_{CONVERSION}$) was only calculated for the area of lands undergoing a conversion in a given year, and in subsequent years it was zero. The biomass values for the initial land types are given in the relevant land category sections, while biomass data for the settlement categories are provided in Table 6.32. It was assumed that only croplands and plantations were cleared before being converted to a grassland, while all other conversions were slow transitions and not abrupt changes.

Table 6.32: Biomass growth and accumulation rates for the various settlement categories.

Land class	Biomass (t C/ha)	Biomass accumulation rate (t C/ha/yr)	AG Biomass (DFFE, 2020) (t C/ha)
Residential	3.38	0.07	5.44
Smallholdings	4.00	0.11	4.77
Commercial	3.36	Non-woody so biomass accumulated in year	5.75
Industrial	3.36		6.23
Mines	0	0	2.53

6.8.2.2 Litter

Land remaining

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.

Land conversions

Changes in litter were calculated using 2006 IPCC Guidelines equation 2.23 and data provided in Table 6.33. Litter stocks for other land classes are provided in the relevant land category sections of this report. As mines were assumed not to have any vegetation, there is also no litter. It was also assumed that change occurred slowly over the 20-year default transition period.

Table 6.33: Litter data applied in the inventory for each of the settlement land classes.

	Litter (t dm/ha)	Reference
Residential	2.96	NTCSA (DFFE, 2020)
Smallholdings	2.4	
Commercial	2.35	
Industrial	4.3	

6.8.2.3 Mineral soils

Changes in mineral SOC were determined using the methods described in section 6.1.3.3. The *Settlement* mineral soil carbon stocks were assumed equal to the reference values (i.e. the stock change factors for management and input are equal to 1). This factor was assumed to remain constant for the period 2000 to 2020, and this can be improved in future inventories if data becomes available.

6.8.2.4 Non-CO_2 gases from biomass burning

Emissions from biomass burning were determined from burnt area data (see section 6.1.3.6), fuel load, combustion factor and an emission factor. The fuel density (18 t dm/ha) was determined from the above-ground biomass and litter, while the combustion factor (C_f) was assumed to be the same as for low shrublands and grasslands (Table 6.34). Emission factors were taken from 2006 IPCC Guidelines Table 2.5 and the grassland values were applied.

Table 6.34: Fuel density and combustion fractions for the various settlement classes.

Land class	Fuel density (t/ha)	Combustion factor		Fuel consumption (t/ha)	
		Value	Source	Value	IPCC default
Residential	5.73	0.89	Weighted average of low shrubland and grassland	5.10	2.1 – 14.3 for grasslands and shrublands
Smallholding	6.03	0.89		5.47	
Commercial	4.34	0.88	Same as grasslands	3.82	
Industrial	6.29	0.88	Same as grasslands	5.54	

6.8.3 Uncertainty

Activity data uncertainty

Uncertainty for the land areas were provided by the SANLC 2020 accuracy assessment (DFFE, 2021). The burnt area data determined from MODIS collection 6 has an uncertainty of <6% (Boschetti et al., 2021) and the soil maps were estimated (by expert opinion) to have an uncertainty of ±10%. The overall activity data uncertainty for settlements remaining settlements was ±38.0% and was ±105.3% for land converted to settlements where the uncertainty is a combination of uncertainty of each land type. The greatest uncertainty was land areas with residential areas having the highest uncertainty of ±21.7%, while smallholdings had an uncertainty of ±12.8%. Converted land obviously had higher uncertainty that the land remaining land categories and the conversion of grasslands to settlements had the highest uncertainty (±67.7).

Emission factor uncertainty

Growing stock or gains were indicated to have a ±30% uncertainty for non-industrialised countries. Disturbance losses in industrialised countries have a default uncertainty of ±15%, so a ±20% uncertainty is assumed. Since the litter and SOC data have greater uncertainty than the biomass data an uncertainty of ±20% is assigned to these categories. Emission factor uncertainty for CO_2 was estimated at ±31%, while for CH_4 and N_2O it was ±39% and 48%, respectively. The non-CO_2 emission factor uncertainties were derived from the IPCC 2006 default values (IPCC, 2006).

6.8.4 Time-series consistency

The land change maps had some inconsistency in that different satellite data was used, however some corrections were made to bring these two datasets into alignment. The inconsistency was between 2014 and 2018. All other datasets were consistent through the time-series.

6.8.5 Category specific QA/QC and verification

No category specific quality checks were completed for *Settlements*.

6.8.6 Category-specific recalculations

The main improvements for the *Settlement* category that led to recalculations for the time series were:

- Inclusion of 1990-2014 and 2018-2020 land change maps
- Inclusion of disaggregated settlement categories
- Updated biomass data
- Inclusion of non-CO_2 emissions from biomass burning

The improvements caused the *Settlements* to change from a slight sink to a slight source of emissions. The updated biomass factors are the main reason for the reduction in the *Settlement remaining settlement* sink. Between 2015 and 2018 there was an increase in the conversion of woodlands to settlements and during this time the source increased 5-fold, but emissions returned to the 2014 levels from 2019 onwards. These changes were directly related to the change in the land use maps.

6.8.7 Category-specific planned improvements

There are no specific planned improvements for this category.

6.9 Other lands (4.F)

6.9.1 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. Burning was assumed not to occur on bare ground therefore no non-CO_2 emissions were included for this category.

6.9.2 Methodological issues

6.9.2.1 Biomass

Carbon gains and losses in land remaining

Bare ground is void of vegetation, therefore there are no gains or losses for *Other lands remaining other lands*.

Carbon losses due to land conversions

The change in carbon stocks in biomass due to land conversions was estimated following the Tier 2 approach (2006 IPCC Guideline equations 5.2 and 5.3). 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. The initial biomass carbon stocks are found in the relevant land category sections.

6.9.2.2 Litter

Since there is no vegetation there is also no litter. On *Other lands remaining other lands*. Changes in litter were calculated using data provided in Table 6.33, as well as the litter stock for other lands (provided in the relevant land category sections) in the 2006 IPCC Guidelines equation 2.23.

6.9.2.3 Mineral soils

Changes in mineral SOC were determined using the methods described in section 6.1.3.3.

6.9.3 Uncertainty

Activity data uncertainty

Uncertainty for the land areas were provided by the SANLC 2020 accuracy assessment (DFFE, 2021). The soil maps were estimated (by expert opinion) to have an uncertainty of ±10%. The overall activity data uncertainty for other lands remaining other lands was ±27.3% and was ±34.5% for land converted to other lands where the uncertainty is a combination of uncertainty of each land type.

Emission factor uncertainty

There was a ±15% uncertainty on the soil data for *Other lands*, but no uncertainty for biomass or DOM as there is no vegetation on these lands.

6.9.4 Time-series consistency

The land change maps had some inconsistency in that different satellite data was used, however some corrections were made to bring these two datasets into alignment. The inconsistency was between 2014 and 2018. All other datasets were consistent through the time-series.

6.9.5 Category specific QA/QC and verification

No category specific quality checks were completed for *Other lands*.

6.9.6 Category specific recalculations

The main improvement to this category was the inclusion of 1990-2014, 2014-2018 and 2018-2020 land change maps. The recalculation of the emission estimates across the time-series led to a 27% increase in the source from this category between 2000 and 2014. Between 2018 and 2022 the emissions increased 3-fold compared to the previous inventory and this is due to the incorporation of the new land change maps.

6.9.7 Category specific planned improvements

There are no specific planned improvements for this category.

6.10 Harvested wood products (3.D.1)

6.10.1 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 harvested wood products (HWPs) to annual CO_2 emissions or removals. *HWPs* include all wood material that leaves harvest sites.

6.10.2 Methodological issues

6.10.2.1 Activity data

All the data on production was obtained from Forestry SA (FSA, 2018) from 1990 (Figure 6.8), while export data was obtained from FAOSTAT. 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). Data was only available up until 2019 so the last few years were extrapolated using a linear function.

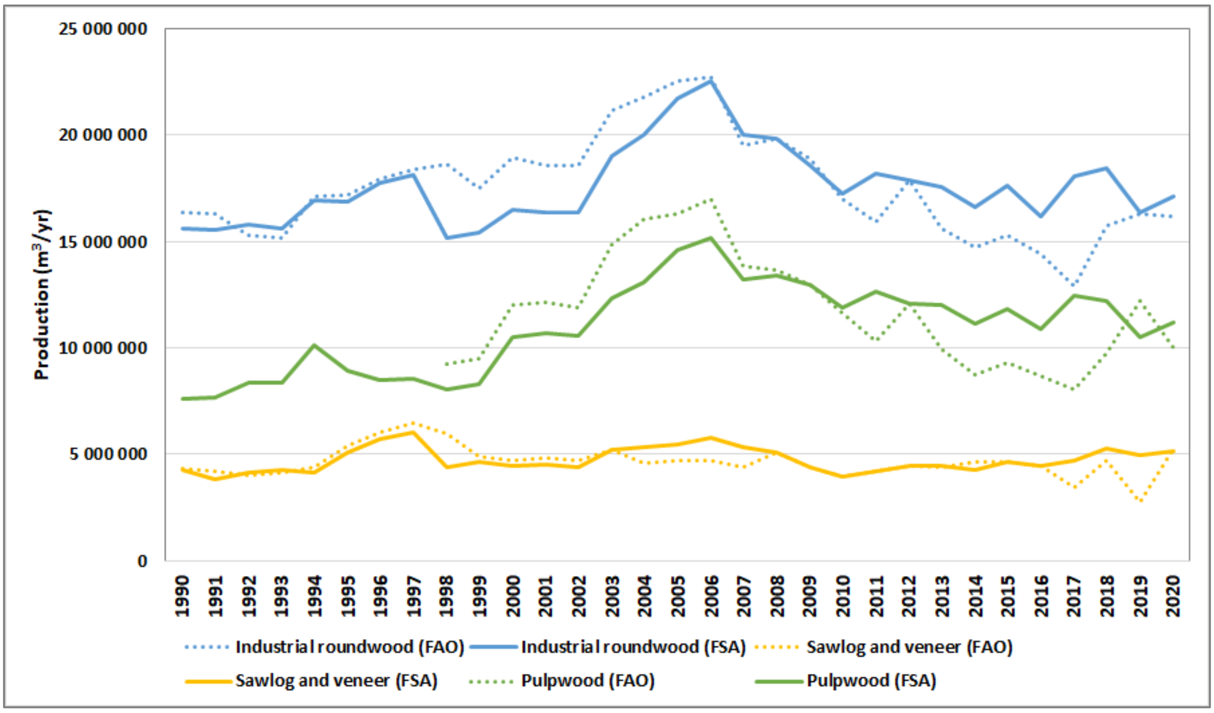

Figure 6.8: Production data from Forestry SA with comparison to FAO data.

6.10.2.2 Emission estimation method

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 2.8.1 and 2.8.2 in the 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. The resulting feedstock factors were applied to KP Supplement Equation 2.8.4 to estimate the HWP contribution of the aggregate commodities sawnwood, wood-based panels and paper and paperboard.

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 (Equation 12.1 in 2006 IPCC Guidelines) was applied to estimate the *HWP* contribution. 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 (this was taken to be 1990 (S.Ruter, pers. comm.)) and this steady state for each HWP commodity category is approximated using KP Supplement Equation 2.8.6.

6.10.3 Uncertainty

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.

6.10.4 Time-series consistency

All data sources were consistent across the time-series.

6.10.5 Category specific QA/QC and verification

Forestry production data was compared to the data on FAOSTAT. Both data sets had similar trends and in some years the data sets matched. FAO data between 1990 and 2008 were generally slightly higher than the Forestry data and from 2010 onwards the FAO data was slightly lower. Overall, the country specific data was deemed to be more accurate.

To verify the emissions from *HWP* the emissions were also calculated using the other 2006 IPCC methodologies, namely stock change, production, atmospheric flow and simple decay approach. The approach applied in this inventory is equivalent to a production approach. The Stock-change approach had exactly the same trend as the current inventory across the time series, but the method produced a sink that was twice as large as the current inventory (Figure 6.9). The Atmospheric approach produced a much larger sink, but again with the same trends. In this approach the sink was greater between 2000 and 2010, after which the sink was approximately 6-fold greater than the current inventory. The Production approach produced a greater sink between 2000 and

2009 (in between the stock change and atmospheric approach values) but matches the current values between 2009 and 2010. After 2010 the Simple decay approach produced values the same as the Stock change approach. The Simple decay approach produced the same values as the Production Approach.

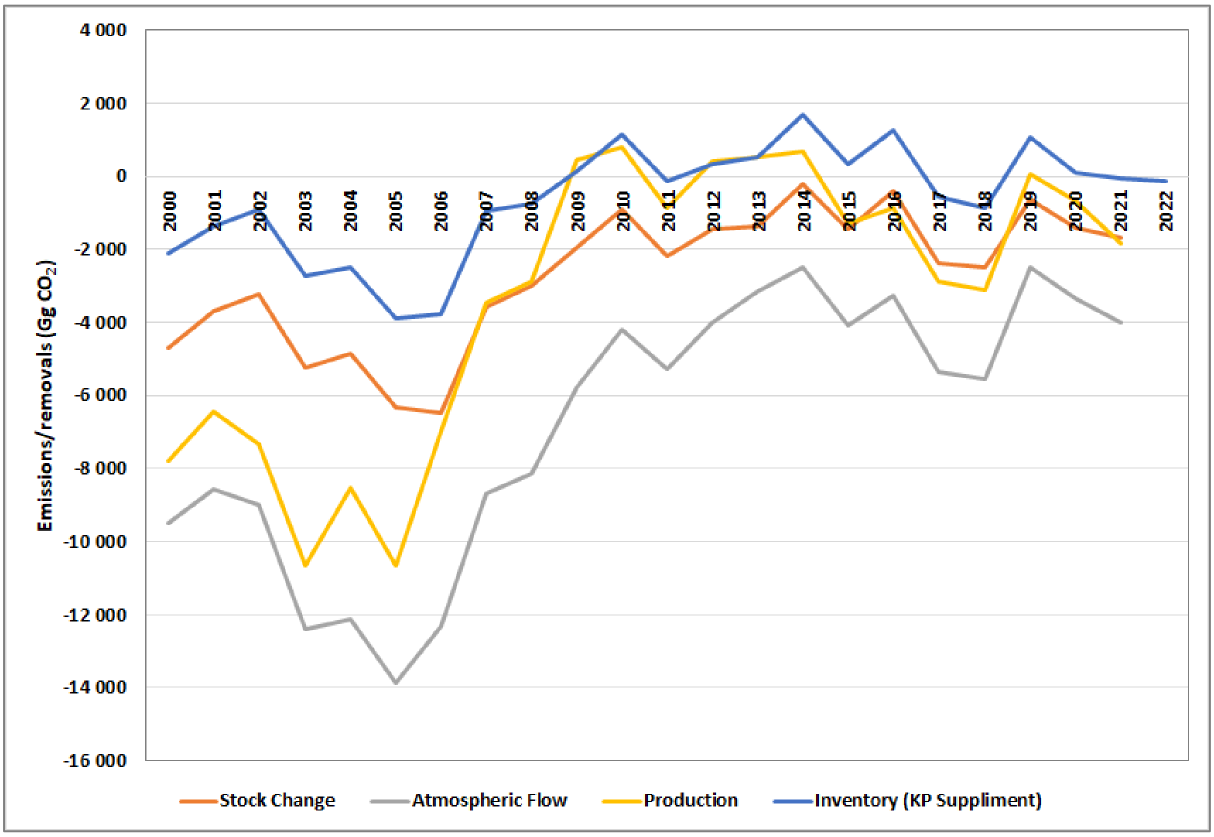

Figure 6.9: Comparison of HWP emissions estimated with the different IPCC methods.

In all cases the 2006 IPCC approaches had much larger sinks between 2000 and 2010, but one of the reasons for this is that the FAO datasets for some of the required data (such as fuel wood and other industrial round wood) were not complete and had some gaps during this time period. The data for the various approaches is more aligned between 2010 and 2022. The differences are also related to the implementation of the steady state at the initial time (in 1990) in the current inventory method.

The comparison suggests that the *HWP* sink could be underestimated, and this need further evaluation. This also supports the development of a project to conduct a more detailed assessment of the *HWP* pool.

6.10.6 Category specific recalculations

No recalculations were performed for this category.

6.10.7 Category specific planned improvements

As was stated in the previous inventory a more detailed assessment of *HWP* is required to include a wider range of products. This has not yet been done as funds would need to be made available for such a study. This is also supported by the verification process which highlighted the possible underestimate of the *HWP* sink.

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Chapter 7: Waste (CRT sector 5)

7.1 Sector overview

The waste sector covers greenhouse gas emissions from the following sources:

- *Solid Waste Disposal*
- *Biological Treatment of Solid Waste*
- *Open Burning of Waste*
- *Wastewater Treatment and Discharge*

7.1.1 Overview of shares and trends in emissions

The total emissions from the Waste sector for 2022 are shown in Table 7.1. The majority of Waste sector emissions are from wastewater treatment and discharge accounting for 45% of the emissions, followed by *Solid waste disposal* accounting for 42%. Emissions from *Biological treatment of solid waste* and *Open burning of waste* only contribute 12% and 2% respectively.

An overview of the Waste emissions trends for the period 2000-2022 can be seen in Figure 7. Waste sector emissions have increased by 44.1% since 2000.

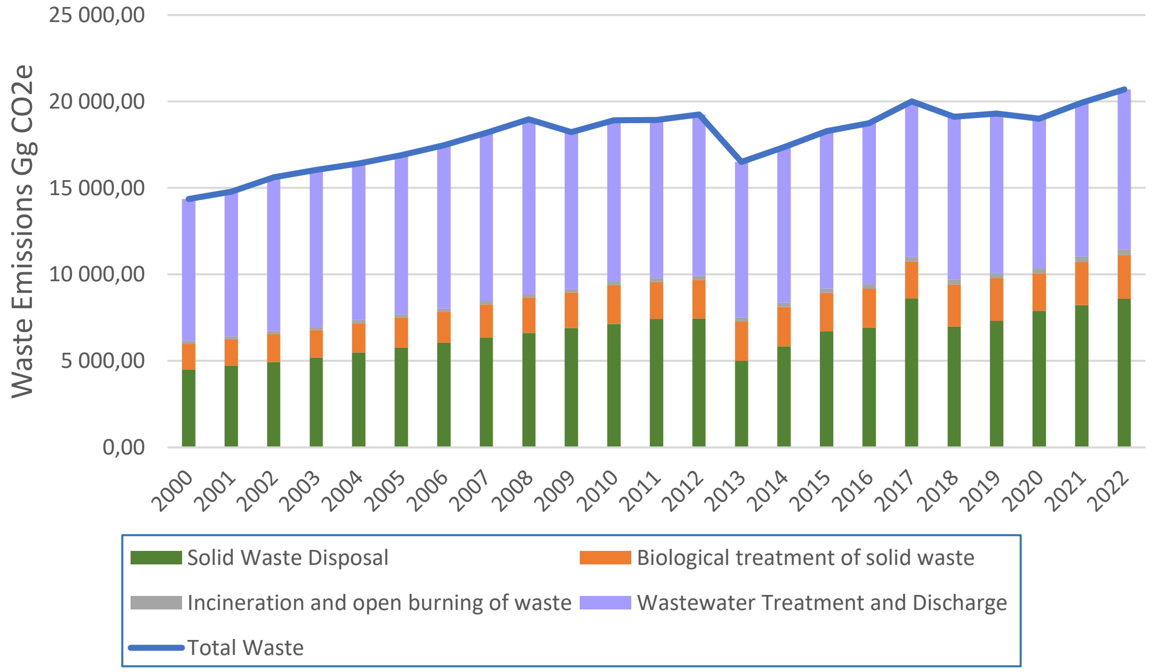

Figure 7.12: Trend in emissions from Waste sector, 2000 – 2022

Emissions from all waste categories have increased since 2000. For wastewater treatment and discharge while the overall emissions increased, emissions for industrial wastewater treatment and discharge have decreased by 8.6% as seen in Table 7.1.

Table 7.1: Summary of the change in emissions from South Africa's Waste sector between 2000 and 2022.

Source Categories	Emissions (Gg CO2e)		Change (%)
	2000	2022	2000-2022
5 - Waste	**14 362.7**	**20 698.4**	**44.1**
5A - Solid Waste Disposal	4 505.3	8 596.0	90.8
5B - Biological Treatment of Solid Waste	1 492.2	2 530.4	69.6
5C - Incineration and Open Burning of Waste	152.6	325.4	113.2
5C1 - Waste Incineration	NE	NE	NE
5C2 - Open Burning of Waste	152.6	325.4	113.2
5D - Wastewater Treatment and Discharge	8 212.6	9 246.7	12.6
5D1 - Domestic Wastewater Treatment and Discharge	2 723.5	4 231.2	55.4
5D2 - Industrial Wastewater Treatment and Discharge	5 489.1	5 015.5	-8.6
5E-Other (please specify)	NE	NE	NE

7.1.2 Overview of methodology and completeness

Table 7.2 shows a summary of methods and tier levels used for the waste inventory.

Table 7.2: Summary of methods and emission factors for the Waste sector and an assessment of the completeness of the Waste sector emissions.

GHG Source and sink category		CO_2		CH_4		N_2O		Details
		Method applied	Emission factor	Method applied	Emission factor	Method applied	Emission factor	
A	Solid waste disposal	NA	NA	T1	DF	NA	NA	Tier 1 FOD model was used.

B	Biological treatment of solid waste	NA	NA	T1		T1		2006 IPCC GL
C	Incineration and open burning of waste	T1	DF	T1	DF	T1	DF	2006 IPCC GL
D	Wastewater treatment and discharge	NA		T1	DF, CS	T1	DF	2006 IPCC GL

7.1.3 Improvements and recalculations

Recalculations were performed for the Waste sector because of the following reasons:

- Updated the population data with the latest Statistics South Africa data
- Change from SAR to AR5 GWPs
- Updated COD values for various industries by reverting back to IPCC defaults due to variability in country specific COD
- Correction of units for biological treatment of solid waste category

The recalculations show a change in the trend throughout the time series (Figure 7). The emissions are lower after the recalculations compared to the previous inventory.

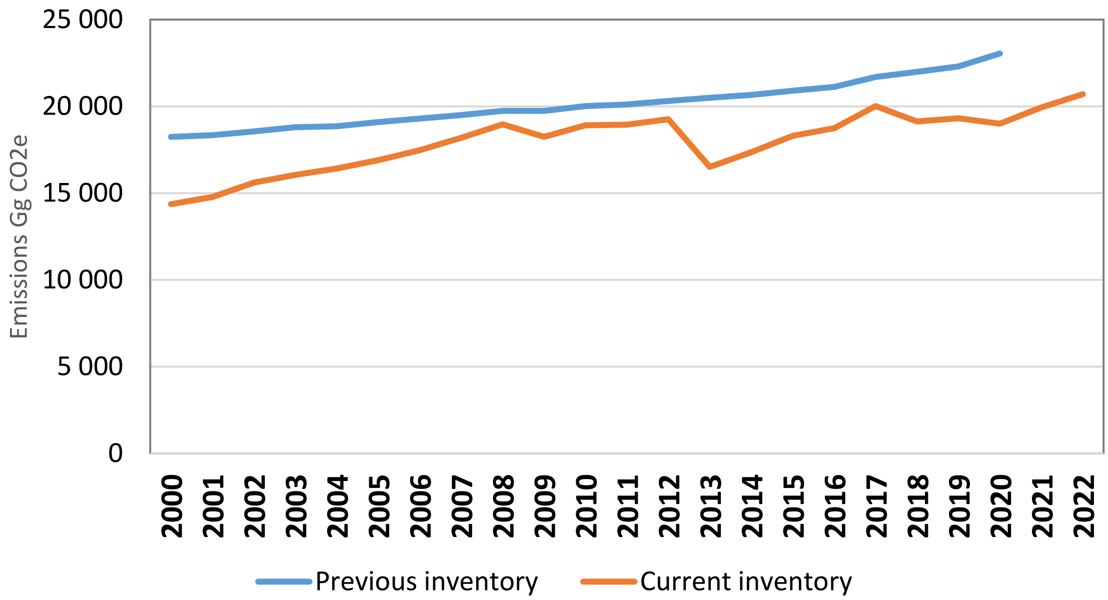

Figure 7.3: Change in Waste emission estimates due to recalculations since 2000 submission.

7.1.4 Key categories in the Waste sector

The key categories for the Waste sector as determined by level (L) and trend (T) assessment are shown in Table 7.3.

Table 7.3: Key categories in the Waste sector.

IPCC Code	Category	GHG	Criteria
5D2	Industrial Wastewater Treatment and Discharge	CH_4	L, T
5A	Solid Waste Disposal	CH_4	L, T

7.1.5 QA/QC process and verification

QA/QC measures in Table 7.4 below were used for the waste sector calculation files.

Table 7.4: General QA/QC checks completed for the Waste sector.

QA/QC principle	Check
Accuracy	Activity data source
Accuracy	Correct units
Accuracy	Unit carry through
Accuracy	Method validity
Accuracy	Calculations check
Accuracy	Uncertainties
Accuracy	Double counting
Accuracy	Correct GWP
Accuracy	Notation keys
Accuracy, Completeness, Consistency, Transparency	Trend check
Accuracy, Transparency	Emission factor applicability
Accuracy, Transparency, Consistency, Completeness	Recalculations
Completeness, Comparability	Sub-category completeness
Consistency	Time series consistency
Transparency	Documentation
Transparency, Completeness, Consistency, Accuracy	Colour coding
Accuracy, Comparability	Cross check data
Accuracy	Spot checks
Transparency, Consistency	Data source referencing
Transparency	Links to source data
Transparency	Raw primary data

QA/QC principle	Check
Accuracy	QA review

7.1.6 Planned improvements.

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:

- Obtain data on the quantities of waste disposed of into managed and unmanaged landfills including its composition.
- Improve the classification of landfill sites.
- Improve the reporting of economic data (e.g., annual growth) to include different population groups. The assumption that GDP growth is evenly distributed (using a computed mean) across all the population groups is highly misleading and leads to exacerbated margins of error.
- Obtain information on population distribution trends between rural and urban settlements as a function of income; and
- Conduct a study to trace waste streams and obtain more information on the bucket system which is still widely used in South Africa.
- Collect data on CH_4 recovery at SWDS based on metering data.

7.2 Solid Waste Disposal (5.A)

7.2.1 Category description

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 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.

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.

7.2.2 Methodological issues

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 CO2 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.

7.2.2.1 Activity data

Input data includes population data (StatsSA, 2023), 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 7.5).

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 2022, 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 2022 (StatsSA, 2023). Waste generation rates for industrial waste were estimated using GDP values sourced from the World Bank for period 2000 to 2022.

7.2.2.2 *Emission factors*

The emission factors for the FOD model are provided in Table 7.5.

Table 7.5: 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

7.2.3 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 (Table 7.6) 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.

Table 7.6: 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	

7.2.4 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 (StatsSA; 2023) provided consistent time-series activity data for solid waste disposal.

Time series consistency is ensured by use of consistent model parameters and datasets for the calculations of emissions estimates. Where changes in datasets or model parameters occur, a full time series recalculation is undertaken.

7.2.5 Category specific QA/QC and verification

General QA/QC measures in Table 7.4 were used for this category.

7.2.6 Category specific recalculations

The population data was updated from 2002 -2022 with the latest data from Statistics South Africa. The updated data led a slight increase in emissions by just over 1%.

7.2.7 Category specific planned improvements

Planned improvements include:

- Collection of actual quantities of waste disposed into landfill sites for period 2000 – 2022.
- 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.

7.3 Biological Treatment of Solid Waste (5.B)

7.3.1 Category description

Biological treatment of solid waste considers waste treated through composting and anaerobic digestion of organic waste. In this inventory only the emissions from *Biological treatment of Industrial Solid Waste* have been taken into account. *Biological treatment of Municipal Solid Waste* has been excluded due to lack of information.

7.3.2 Methodological issues

A tier 1 method, with default emission factors from the 2006 IPCC Guidelines was applied to calculate emissions for this category.

7.3.2.1 Activity data

The amount of waste treated by biological treatment of solid waste was obtained from a study that was done to by DFFE (Wastewater Treatment Pathways Study;2018)). Extrapolation was used to derive data for 2018-2022.

The activity data is shown in Table 7.7.

Table 7.7: Activity data for biological treatment systems.

Period	Biological Treatment System	Types of Waste	Total Annual amount treated by biological treatment facilities[3] (Gg)	CH_4 Recovered
2000	Composting	Industrial	2677	0
2001		Industrial	2781	0
2002		Industrial	2955	0
2003		Industrial	2866	0
2004		Industrial	3096	0
2005		Industrial	3215	0
2006		Industrial	3333	0
2007		Industrial	3622	0
2008		Industrial	3957	0
2009		Industrial	3803	0
2010		Industrial	4052	0
2011		Industrial	4156	0
2012		Industrial	4315	0
2013		Industrial	4386	0
2014		Industrial	4409	0
2015		Industrial	4335	0
2016		Industrial	4357	0
2017		Industrial	4099	0
2018		Industrial	4741	0
2019		Industrial	4842	0
2020		Industrial	4188	0
2021		Industrial	4896	0
2022		Industrial	4997	0
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
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

Period	Biological Treatment System	Types of Waste	Total Annual amount treated by biological treatment facilities[3] (Gg)	CH_4 Recovered
2018		Industrial	6078	11.5
2019		Industrial	6054	11.5
2020		Industrial	5752	10.9
2021		Industrial	5999	11.4
2022		Industrial	6005	11.4

7.3.2.2 Emission factors

The default emission factors for composting and anaerobic treatment at biogas facilities are shown in Table 7.8.

Table 7.8: 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

7.3.3 Uncertainty

The estimation of the uncertainties of methane emissions from *Biological treatment of solid waste* was carried out using the IPCC level 1 method (IPCC, 2006).

7.3.4 Time-series consistency

The time series for *Biological treatment of solid waste* is complete and consistent from 2000-2022.

7.3.5 Category specific QA/QC and verification

General QA/QC measures in Table 7.4 were used for this category.

7.3.6 Category specific recalculations

Recalculation were performed for this category as The QA process identified an incorrect emission factor discovered during the QA process was corrected. due to a comment that made during the review process where The QA process highlighted that the conversion of the emission factor from gCH_4/kg waste to $GgCH_4$/Gg waste was incorrect so this was updated and recalculations for the entire time-series was conducted. The recalculations led to a 0.2% increase in the emissions compared to the previous inventory.

7.3.7 Category specific planned improvements

In future inventories, it is planned to improve data collection of waste treated by biological treatment.

7.4 Incineration and open burning of waste (5.C)

7.4.1 Category description

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 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.

7.4.2 Methodological issues

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, chapter. 5; pg. 5.16).

7.4.2.1 Activity data

The activity data for the calculation of MSW are described in section 7.2.2. The fraction of population carrying out open-burning was estimated at 9% (Expert Judgement). CO2 emissions were calculated for the different waste types using the IPCC default breakdown.

7.4.2.2 Emission factors

The emission factors for *Open burning of waste* are provided in Table 7.9.

Table 7.9: Emission factors for estimating emissions from open burning of waste.

Sub-category	Value	Unit	Source
Dry matter content		fraction	IPCC 2006
Food	*0.4*		
Garden	*0.4*		
Paper	*0.9*		
Wood	*0.85*		
Textile	*0.8*		
Nappies	*0.4*		
Plastics, other inert	*0.9*		
Fraction of carbon in dry matter		fraction	IPCC 2006
Food	*0.38*		
Garden	*0.49*		
Paper	*0.46*		
Wood	*0.5*		
Textile	*0.5*		
Nappies	*0.7*		
Plastics, other inert	*0.03*		
Fraction of fossil C in total carbon		fraction	IPCC 2006
Food	*0*		
Garden	*0*		
Paper	*0.01*		
Wood	*0*		
Textile	*0.2*		

Sub-category	Value	Unit	Source
Nappies *Plastics, other inert*	*0.1* *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

7.4.3 Uncertainty

7.4.3.1 Activity data uncertainty

Uncertainties associated with CO_2 emission factors for *Open burning of waste* 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.

7.4.3.2 Emission factor uncertainty

Uncertainties on default N2O and CH4 emission factors have been estimated to be ±100%.

7.4.4 Time series consistency

The time series is consistent as the activity data source is the same throughout the time series.

7.4.5 Category specific QA/QC and verification

General QA/QC measures in Table 7.4 were used for this category.

7.4.6 Category specific recalculations

Recalculations for this category were done due to change in data source for the population data. The recalculations resulted in a decrease in emissions compared to the previous inventory.

7.4.7 Category specific planned improvements

An improvement planned for this category is collection of activity data on amounts of waste incinerated, by category of waste and the technologies used to incinerate waste in South Africa.

7.5 Wastewater Treatment and Discharge (5.D)

7.5.1 Domestic wastewater treatments and discharge (5.D.1)

7.5.1.1 Category description

Wastewater originates from a variety of domestic, commercial and industrial sources and may be treated on site (uncollected), sewered to a centralised plant (collected) or disposed untreated nearby or via an outfall. Domestic wastewater is defined as wastewater from household water use.

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.

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.

7.5.1.2 Methodological issues

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.

Activity data

The activity data for this category which is total amount of organically degradable material in the wastewater was calculated using population data from Statistics South Africa (Stats SA,2023) and IPCC default BOD.

IPCC default correction factor of 1 was used for the factor *I*.

Emission factors

Methane emissions from Domestic Wastewater Treatment

Default population distribution trends between rural and urban settlements as a function of income was 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.

The emissions factors for different wastewater treatment and discharge systems were taken from the 2006 IPCC Guidelines (Table 7.10) as was the data on distribution and utilization of different treatment and discharge systems (Table 7.11).

Table 7.10: 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 7.11: 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)	(Tij)
Rural	0.39	Septic tank	0.10
		Latrine – rural	0.28

		Sewer stagnant	0.10
		Other	0.04
		None	0.48
Urban high-income	0.12	Sewer closed	0.70
		Septic tank	0.15
		Other	0.15
Urban low-income	0.49	Latrine – urban low income	0.24
		Septic tank	0.17
		Sewer (open and warm)	0.34
		Sewer (flowing)	0.20
		Other	0.05

Nitrous oxide emissions from Domestic 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 the per capita protein consumption, a value of 27.96 kg/person/yr was applied throughout the time series (FAO, 2017).

7.5.1.3 Uncertainty

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 Statistics South Africa (StatsSA, 2023), the presumed constant country BOD production of about 37 g person-1 day-1 from 2001 to 2022, 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.

7.5.1.4 Time series consistency

The time series is complete and consistent from 2000-2022.

7.5.1.5 Category specific QA/QC and verification

General QA/QC measures in Table 7.4 were used for this category.

7.5.1.6 Category specific recalculations

Recalculations were performed for this category due to the following changes:

- change in data source for the population data. The recalculations were done for the entire time series.
- The factor was changed from 1.25 to 1 due to industrial wastewater being estimated separately therefore there is no commercial and industrial wastewater co discharged to domestic wastewater.

The recalculations resulted in a decrease in emissions compared to the previous inventory.

7.5.1.7 Category specific planned improvements

The following improvement is planned for this category:

- Collection of wastewater related activity data for period 2000 – 2022 taking into account different wastewater treatment pathways in South Africa.

7.5.2 Industrial wastewater treatment and discharge (5.D.2)

7.5.2.1 Category description

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).

7.5.2.2 Methodological issues

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 production tonnage per sector data for the period 2000 – 2017 was obtained from a study done by DFFE on the Sanitation Pathways for industrial wastewater.

For the period 2018-2022 the activity data was then extrapolated for the following sectors:

- Alcohol Refining
- Starch Production
- Beer and Malt
- Vegetable Oils
- Dairy Products
- Fish Processing
- Vegetables Fruits and Juices
- Meat and Poultry
- Organic Chemicals
- Petroleum Refining
- Plastic and Resins
- Soap and Detergents
- Wine and Vinegar

For the dairy products sector, data for the period 2018-2022 was obtained from Milk SA Lacto data report (Milk SA, 2023) which is published yearly. For the sugar industry, data for the period 2018-2022 was obtained from South Africa Sugar Association (SASA, 2023) and South African Sugar Technologists` Association (SASTA, 2023) on their production reports which are published yearly. For the Pulp and paper industry, data for the 2000-2015 and period 2019-2022 was obtained from the Paper Manufacturers Association of South Africa (PAMSA, 2023) and for the period 2016-2018 data was interpolated.

The COD data is a combination of IPCC defaults and country specific from the Sanitation Pathways study.

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 MCF values and emission factors applied are given in Table 7.12, while the COD values are provided in Table 7.13.

Table 7.12: 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

Table 7.13: Average COD values used to estimate CH_4 emissions from industrial wastewater.

Industry Type	Chemical Oxygen Demand
	(COD)
Alcohol Refining	11
Starch Production	10
Beer and Malt	2.9
Vegetable Oils	1
Dairy Products	2.7
Fish Processing	2.5
Vegetables Fruits and Juices	5
Meat and Poultry	4.1
Organic Chemicals	3

Petroleum Refining	1
Plastic and Resins	1.45
Soap and Detergents	0.85
Pulp and Paper	9
Sugar	6
Wine & vinegar	1.5

Emission factors

These are given in Table 7.12.

7.5.2.3 Uncertainty

The estimation of the uncertainties of methane emissions from industrial wastewater was carried out using the IPCC level 1 method (IPCC, 2006).

7.5.2.4 Time series consistency

The time series is complete and consistent from 2000-2022.

7.5.2.5 Category specific QA/QC and verification

General QA/QC measures in Table 7.4 were used for this category.

7.5.2.6 Category specific recalculations

Recalculations were done for industrial wastewater treatment due change of COD for the following industries:

- Starch Production
- Beer and Malt
- Pulp and Paper
- Vegetables Fruits and Juices
- Wine and Vinegar

The COD was changed to revert to IPCC defaults due to variability in the country specific COD.

The recalculations resulted in an increase on the emissions compared to the previous inventory.

7.5.2.7 Category specific 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.

7.6 References

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Appendix A: Key category analysis

Table A.1: Level assessment on emissions excluding LULUCF for South Africa (2000) with the key categories highlighted in green.

Code	Category Title	GHG	2000 Estimates	Level Assessment	Cumulative Total
1.A.1	Energy Industries - Solid Fuels	CO_2	185 027.4	0.379	38%
1.A.3.b	Road Transportation	CO_2	37 452.4	0.077	46%
1.A.1	Energy Industries - Liquid Fuels	CO_2	32 254.1	0.066	52%
1.A.2	Manufacturing Industries and Construction	CO_2	28 630.6	0.059	58%
1.B.3	Other emissions from energy production	CO_2	28 146.6	0.058	64%
3.A.1.a.ii	Non-dairy Cattle	CH_4	27 776.4	0.057	69%
1.A.4	Other Sectors - Solid Fuels	CO_2	22 051.8	0.045	74%
2.C.1	Iron and Steel Production	C	C	C	77%
1.A.5	Other (Not specified elsewhere) - Solid Fuels	CO_2	14 272.3	0.029	80%
5.A	Solid Waste Disposal	CH_4	14 056.0	0.029	83%
3.D.1	Direct N_2O Emissions From Managed Soils	N_2O	9 574.6	0.020	85%
3.A.2	Sheep	CH_4	8 121.1	0.017	87%
2.C.2	Ferroalloys Production	C	C	C	88%
1.A.4	Other Sectors - Liquid Fuels	CO_2	7 515.1	0.015	90%
5.D	Wastewater Treatment and Discharge - Industrial	CH_4	5 489.1	0.011	91%
3.A.1.a.i	Dairy Cattle	CH_4	3 884.1	0.008	92%
2.A.1	Cement Production	C	C	C	92%
1.B.1.a	Coal mining and handling	CH_4	3 117.4	0.006	93%
1.B.3	Other emissions from energy production	CH_4	2 949.5	0.006	94%
5.D	Wastewater Treatment and Discharge - Domestic	CH_4	2 601.5	0.005	94%
1.A.1	Energy Industries - Gaseous Fuels	CO_2	2 307.1	0.005	95%

Code	Category Title	GHG	2000 Estimates	Level Assessment	Cumulative Total
1.A.3.a	Domestic Aviation	CO_2	2 305.7	0.005	95%
3.A.4	Goats	CH_4	1 990.8	0.004	96%
1.A.5	Other (Not specified elsewhere) - Liquid Fuels	CO_2	1 908.0	0.004	96%
3.G	Liming	CO_2	1 820.0	0.004	96%
2.B.2	Nitric Acid Production	C	C	C	97%
2.C.3	Aluminium Production	C	C	C	97%
5.B	Biological Treatment of Solid Waste	CH_4	1 066.6	0.002	97%
3.D.2	Indirect N_2O Emissions From Managed Soils	N_2O	1 056.5	0.002	97%
2.C.3	Aluminium Production	C	C	C	97%
3.B.1.a.ii	Non-dairy Cattle	N_2O	818.5	0.002	98%
1.A.1	Energy Industries - Solid Fuels	N_2O	764.1	0.002	98%
1.B.2	Oil and Natural Gas	CO_2	752.0	0.002	98%
3.B.1.a.ii	Non-dairy Cattle	CH_4	701.8	0.001	98%
3.B.1.a.i	Dairy Cattle	CH_4	599.1	0.001	98%
3.B.4	Poultry	N_2O	557.3	0.001	98%
1.A.3.c	Railways	CO_2	555.5	0.001	98%
2.B.1	Ammonia Production	C	C	C	99%
5.D	Wastewater Treatment and Discharge - Domestic	N_2O	466.2	0.001	99%
1.A.3.b	Road Transportation	N_2O	466.0	0.001	99%
2.B.6	Titanium Dioxide Production	C	C	C	99%
2.A.2	Lime Production	C	C	C	99%
5.B	Biological Treatment of Solid Waste	N_2O	425.6	0.001	99%
1.A.4	Other Sectors - Biomass	N_2O	345.6	0.001	99%

Code	Category Title	GHG	2000 Estimates	Level Assessment	Cumulative Total
1.A.3.b	Road Transportation	CH_4	330.6	0.001	99%
3.H	Urea Application	CO_2	297.3	0.001	99%
3.B.5	Indirect N2O Emissions From Manure Management	N_2O	291.9	0.001	99%
1.A.4	Other Sectors - Biomass	CH_4	282.4	0.001	99%
3.B.3	Swine	CH_4	256.2	0.001	99%
3.B.1.a.i	Dairy Cattle	N_2O	230.0	0.000	99%
1.A.3.d	Domestic Navigation - Liquid Fuels	CO_2	209.8	0.000	99%
1.A.2	Manufacturing Industries and Construction	N_2O	194.1	0.000	100%
2.D.1	Non-energy Products from Fuels and Solvent Use - Lubricant use	CO_2	188.5	0.000	100%
3.B.2	Sheep	N_2O	159.2	0.000	100%
5.C	Incineration and Open Burning of Waste	CH_4	156.6	0.000	100%
2.B.8	Petrochemical and Carbon Black Production	C	C	C	100%
3.A.4	Horses	CH_4	136.1	0.000	100%
3.B.4	Poultry	CH_4	112.7	0.000	100%
3.B.2	Sheep	CH_4	108.8	0.000	100%
2.C.6	Zinc Production	C	C	C	100%
1.A.1	Energy Industries - Liquid Fuels	N_2O	97.7	0.000	100%
1.A.2	Manufacturing Industries and Construction	CH_4	95.2	0.000	100%
1.A.4	Other Sectors - Solid Fuels	N_2O	91.1	0.000	100%
2.B.1	Ammonia Production	C	C	C	100%
2.A.3	Glass Production	C	C	C	100%
1.B.1.c	Solid fuel transformation	CO_2	64.4	0.000	100%
3.B.4	Goats	N_2O	59.2	0.000	100%
1.A.5	Other (Not specified elsewhere) - Solid Fuels	N_2O	58.9	0.000	100%

Code	Category Title	GHG	2000 Estimates	Level Assessment	Cumulative Total
1.A.3.e	Railways	N_2O	56.4	0.000	100%
3.F	Field burning of agricultural residues	CH_4	55.5	0.000	100%
1.A.1	Energy Industries - Solid Fuels	CH_4	53.8	0.000	100%
3.A.3	Swine	CH_4	53.0	0.000	100%
1.B.1.c	Solid fuel transformation	CH_4	46.3	0.000	100%
3.A.4	Mules & Asses	CH_4	45.9	0.000	100%
5.C	Incineration and Open Burning of Waste	N_2O	34.2	0.000	100%
3.B.4	Goats	CH_4	33.7	0.000	100%
1.B.1.a	Coal mining and handling	CO_2	30.6	0.000	100%
3.B.3	Swine	N_2O	29.6	0.000	100%
5.C	Incineration and Open Burning of Waste	CO_2	18.6	0.000	100%
1.A.3.a	Domestic Aviation	N_2O	16.7	0.000	100%
1.A.1	Energy Industries - Liquid Fuels	CH_4	15.9	0.000	100%
2.C.5	Lead Production	C	C	C	100%
1.A.4	Other Sectors - Liquid Fuels	N_2O	13.9	0.000	100%
3.F	Field burning of agricultural residues	N_2O	13.6	0.000	100%
1.A.4	Other Sectors - Gaseous Fuels	CO_2	12.9	0.000	100%
1.A.4	Other Sectors - Liquid Fuels	CH_4	7.7	0.000	100%
2.D.2	Non-energy Products from Fuels and Solvent Use - Paraffin wax use	CO_2	7.4	0.000	100%
1.A.4	Other Sectors - Solid Fuels	CH_4	6.4	0.000	100%
2.C.2	Ferroalloys Production	C	C	C	100%
1.A.5	Other (Not specified elsewhere) - Solid Fuels	CH_4	4.2	0.000	100%
1.A.5	Other (Not specified elsewhere) - Liquid Fuels	N_2O	4.1	0.000	100%

Code	Category Title	GHG	2000 Estimates	Level Assessment	Cumulative Total
1.A.5	Other (Not specified elsewhere) - Liquid Fuels	CH_4	2.1	0.000	100%
2.B.5	Carbide Production	C	C	C	100%
1.A.3.d	Domestic Navigation - Liquid Fuels	N_2O	1.5	0.000	100%
1.A.1	Fuel combustion - Energy Industries - Gaseous Fuels	CH_4	1.1	0.000	100%
1.A.1	Fuel combustion - Energy Industries - Gaseous Fuels	N_2O	1.1	0.000	100%
1.B.1.c	Fugitive emissions from Solid Fuels - Solid fuel transformation	N_2O	0.9	0.000	100%
1.A.3.e	Railways	CH_4	0.9	0.000	100%
1.A.3.d	Domestic Navigation - Liquid Fuels	CH_4	0.6	0.000	100%
1.A.3.a	Domestic Aviation	CH_4	0.4	0.000	100%
2.B.8	Petrochemical and Carbon Black Production	C	C	C	100%
1.A.4	Other Sectors - Gaseous Fuels	CH_4	0.0	0.000	100%
1.A.4	Other Sectors - Gaseous Fuels	N_2O	0.0	0.000	100%
1.A.5	Other (Not specified elsewhere) - Gaseous Fuels	CO_2	0.0	0.000	100%
1.A.5	Other (Not specified elsewhere) - Gaseous Fuels	CH_4	0.0	0.000	100%
1.A.5	Other (Not specified elsewhere) - Gaseous Fuels	N_2O	0.0	0.000	100%
1.A.5	Other (Not specified elsewhere) - Biomass	CH_4	0.0	0.000	100%
1.A.5	Other (Not specified elsewhere) - Biomass	N_2O	0.0	0.000	100%
1.B.2	Oil and Natural Gas	CH_4	0.0	0.000	100%
1.B.2	Oil and Natural Gas	N_2O	0.0	0.000	100%
2.A.4	Other Process Uses of Carbonates	C	C	C	100%
2.B.5	Carbide Production	C	C	C	100%
2.B.7	Soda Ash Production	C	C	C	100%
2.B.10	Other	C	C	C	100%
2.B.10	Other	C	C	C	100%

Code	Category Title	GHG	2000 Estimates	Level Assessment	Cumulative Total
2.C.1	Iron and Steel Production	CH_4	0.0	0.000	100%
2.F.2	Foam Blowing Agents	F-gases	0.0	0.000	100%
2.F.3	Fire Protection	F-gases	0.0	0.000	100%
2.F.4	Aerosols	F-gases	0.0	0.000	100%
2.G	Other Product Manufacture and Use	CO_2	0.0	0.000	100%
2.B.2	Nitric Acid Production	C	C	C	100%
2.B.2	Nitric Acid Production	C	C	C	100%
2.B.8	Hydrogen Production	C	C	C	100%
2.C.2	Ferroalloys Production	C	C	C	100%
2.F.1.a	Refrigeration and Air conditioning - refrigeration and stationary ACs	CO_2e	0.0	0.000	100%
2.F.1.b	Refrigeration and Air conditioning - mobile ACs	CO_2e	0.0	0.000	100%

C=Confidential data

Table A.2: Level assessment on emissions including LULUCF for South Africa (2000) with the key categories highlighted in green.

Code	Category Title	GHG	2000 Estimates	Level Assessment	Cumulative Total
1.A.1	Energy Industries - Solid Fuels	CO_2	185 027,4	0,315	31%
1.A.4	Other Sectors - Solid Fuels	CO_2	43 592,2	0,074	39%
1.A.3.b	Road Transportation	CO_2	37 448,9	0,064	45%
1.A.1	Energy Industries - Liquid Fuels	CO_2	32 254,1	0,055	51%
1.B.3	Other emissions from energy production	CO_2	28 146,6	0,048	56%
3.A.1.a.ii	Non-dairy Cattle	CH_4	27 776,4	0,047	60%
4.A.2.b	Grassland converted to forest land – all pools	CO_2	-24 956,0	0,042	64%
4.A.1.a	Forest land remaining forest land – biomass (above and below)	CO_2	-18 241,8	0,031	68%
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CO_2	17 680,3	0,030	71%
2.C.1	Iron and Steel Production	C	C	C	73%
1.A.5	Other (Not specified elsewhere) - Solid Fuels	CO_2	12 737,8	0,022	75%
3.D.1	Direct N_2O Emissions From Managed Soils	N_2O	9 574,6	0,016	77%
4.C.2.e	Other land converted to Grassland – all pools	CO_2	-9 026,6	0,015	79%
4.C.2.a	Forest land converted to Grassland – all pools	CO_2	8 864,9	0,015	80%
3.A.2	Sheep	CH_4	8 121,1	0,014	81%
2.C.2	Ferroalloys Production	C	C	C	83%
4.D.1	Wetlands Remaining Wetlands	CH_4	6 990,6	0,012	84%
4.F.2.c	Grassland converted to other land – all pools	CO_2	6 879,7	0,012	85%
1.A.4	Other Sectors - Liquid Fuels	CO_2	6 259,8	0,011	86%
5.D	Wastewater Treatment and Discharge - Industrial	CH_4	5 489,1	0,009	87%
5.A	Solid Waste Disposal	CH_4	4 505,3	0,008	88%
3.A.1.a.i	Dairy Cattle	CH_4	3 884,1	0,007	89%
2.A.1	Cement Production	C	C	C	89%

Code	Category Title	GHG	2000 Estimates	Level Assessment	Cumulative Total
1.B.3	Other emissions from energy production	CH_4	2 949,5	0,005	90%
1.A.5	Other (Not specified elsewhere) - Liquid Fuels	CO_2	2 613,7	0,004	90%
4.A.2.a	Cropland converted to forest land – all pools	CO_2	-2 451,3	0,004	91%
1.A.3.a	Domestic Aviation	CO_2	2 315,9	0,004	91%
1.A.1	Energy Industries - Gaseous Fuels	CO_2	2 307,1	0,004	91%
5.D	Wastewater Treatment and Discharge - Domestic	CH_4	2 257,3	0,004	92%
4.B.2.b	Grassland converted to Cropland – all pools	CO_2	2 141,6	0,004	92%
4.G	Harvested Wood Products	CO_2	-2 106,2	0,004	92%
4(V)	Biomass Burning	CH_4	2 009,8	0,003	93%
3.A.4	Goats	CH_4	1 990,8	0,003	93%
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CO_2	1 976,7	0,003	93%
1.B.1.a	Coal mining and handling	CH_4	1 894,6	0,003	94%
3.G	Liming	CO_2	1 820,0	0,003	94%
4.B.2.a	Forest land converted to Cropland – all pools	CO_2	1 736,3	0,003	94%
4.C.2.b	Cropland converted to Grassland – all pools	CO_2	-1 699,5	0,003	95%
4.D.2	Land Converted to Wetlands	CH_4	1 655,1	0,003	95%
4.C.1.a	Grassland remaining Grassland – biomass (above and below)	CO_2	-1 531,4	0,003	95%
2.B.2	Nitric Acid Production	C	C	C	95%
4(V)	Biomass Burning	N_2O	1 321,7	0,002	96%
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	CO_2	1 289,7	0,002	96%
4.A.2.e	Other land converted to forest land – all pools	CO_2	-1 225,3	0,002	96%
2.C.3	Aluminium Production	C	C	C	96%
5.B	Biological Treatment of Solid Waste	CH_4	1 066,6	0,002	97%
3.D.2	Indirect N_2O Emissions From Managed Soils	N_2O	1 056,5	0,002	97%

Code	Category Title	GHG	2000 Estimates	Level Assessment	Cumulative Total
2.C.3	Aluminium Production	C	C	C	97%
4.A.2.c	Wetland converted to forest land – all pools	CO_2	-949,7	0,002	97%
3.B.1.a.ii	Non-dairy Cattle	N_2O	818,5	0,001	97%
4.F.2.a	Forest land converted to other land – all pools	CO_2	780,7	0,001	97%
1.A.1	Fuel combustion - Energy Industries - Solid Fuels	N_2O	764,1	0,001	97%
1.B.2	Oil and Natural Gas	CO_2	752,0	0,001	98%
4.E.2.a	Forest land converted to settlements – all pools	CO_2	707,6	0,001	98%
3.B.1.a.ii	Non-dairy Cattle	CH_4	701,8	0,001	98%
4.D.2	Land Converted to Wetlands	CO_2	616,1	0,001	98%
3.B.1.a.i	Dairy Cattle	CH_4	599,1	0,001	98%
3.B.4	Poultry	N_2O	557,3	0,001	98%
1.A.3.c	Railways	CO_2	555,5	0,001	98%
2.B.1	Ammonia Production	CO_2	485,3	0,001	98%
5.D	Wastewater Treatment and Discharge - Domestic	N_2O	466,2	0,001	98%
1.A.3.b	Road Transportation	N_2O	466,0	0,001	98%
1.A.4	Other Sectors - Solid Fuels	N_2O	449,5	0,001	99%
2.B.6	Titanium Dioxide Production	C	C	C	99%
1.A.3.d	Domestic Navigation - Liquid Fuels	CO_2	428,1	0,001	99%
4.D.1	Wetlands Remaining Wetlands	N_2O	426,4	0,001	99%
2.A.2	Lime Production	C	C	C	99%
5.B	Biological Treatment of Solid Waste	N_2O	425,6	0,001	99%
4.A.2.d	Settlements converted to forest land – all pools	CO_2	-424,4	0,001	99%
1.A.3.b	Road Transportation	CH_4	330,5	0,001	99%
1.A.5	Other (Not specified elsewhere) - Solid Fuels	N_2O	327,3	0,001	99%

Code	Category Title	GHG	2000 Estimates	Level Assessment	Cumulative Total
3.H	Urea Application	CO_2	297,3	0,001	99%
3.B.5	Indirect N_2O Emissions From Manure Management	N_2O	291,9	0,000	99%
4.E.1.a	Settlements remaining Settlements – biomass (above and below)	CO_2	-275,9	0,000	99%
3.B.3	Swine	CH_4	256,2	0,000	99%
4.B.1.a	Cropland remaining Cropland – biomass (above and below)	CO_2	248,5	0,000	99%
4.B.2.c	Wetland converted to Cropland – all pools	CO_2	246,3	0,000	99%
1.A.4	Other Sectors - Solid Fuels	CH_4	235,8	0,000	99%
3.B.1.a.i	Dairy Cattle	N_2O	230,0	0,000	99%
1.A.5	Other (Not specified elsewhere) - Solid Fuels	CH_4	220,7	0,000	99%
2.D.1	Non-energy Products from Fuels and Solvent Use - Lubricant use	CO_2	188,5	0,000	99%
4.E.2.c	Grassland converted to settlements – all pools	CO_2	177,0	0,000	100%
1.A.5	Other (Not specified elsewhere) - Gaseous Fuels	CO_2	175,7	0,000	100%
3.B.2	Sheep	N_2O	159,2	0,000	100%
4.C.2.c	Wetland converted to Grassland – all pools	CO_2	151,7	0,000	100%
2.B.8	Petrochemical and Carbon Black Production	C	C	C	100%
3.A.4	Horses	CH_4	136,1	0,000	100%
0	Wetlands converted to other land (all pools)	CO_2	134,2	0,000	100%
1.A.2	Manufacturing Industries and Construction - Solid Fuels	N_2O	130,0	0,000	100%
5.C	Incineration and Open Burning of Waste	CH_4	114,1	0,000	100%
3.B.4	Poultry	CH_4	112,7	0,000	100%
3.B.2	Sheep	CH_4	108,8	0,000	100%
2.C.6	Zinc Production	C	C	C	100%
4.D.2	Land Converted to Wetlands	N_2O	101,0	0,000	100%
1.A.1	Energy Industries - Liquid Fuels	N_2O	97,7	0,000	100%

forestry, fisheries & the environment

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Code	Category Title	GHG	2000 Estimates	Level Assessment	Cumulative Total
2.B.1	Ammonia Production	C	C	C	100%
2.A.3	Glass Production	C	C	C	100%
1.B.1.c	Solid fuel transformation	CO_2	64,4	0,000	100%
4.E.2.b	Cropland converted to settlements – all pools	CO_2	-61,3	0,000	100%
4.D.1	Wetlands Remaining Wetlands	CO_2	59,6	0,000	100%
3.B.4	Goats	N_2O	59,2	0,000	100%
1.A.3.e	Railways	N_2O	56,4	0,000	100%
3.F	Field burning of agricultural residues	CH_4	55,5	0,000	100%
1.A.1	Energy Industries - Solid Fuels	CH_4	53,8	0,000	100%
3.A.3	Swine	CH_4	53,0	0,000	100%
1.B.1.c	Solid fuel transformation	CH_4	49,6	0,000	100%
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CH_4	49,3	0,000	100%
3.A.4	Mules & Asses	CH_4	45,9	0,000	100%
4.A.1.b	Forest land remaining forest land – dead organic matter	CO_2	34,9	0,000	100%
3.B.4	Goats	CH_4	33,7	0,000	100%
3.B.3	Swine	N_2O	29,6	0,000	100%
4.C.2.d	Settlements converted to Grassland – all pools	CO2	-29,6	0,000	100%
5.C	Incineration and Open Burning of Waste	N_2O	24,9	0,000	100%
1.B.1.a	Coal mining and handling	CO_2	18,6	0,000	100%
4.B.1.c	Cropland remaining Cropland – soil (mineral)	CO_2	-17,8	0,000	100%
4.B.2.d	Settlements converted to Cropland – all pools	CO_2	17,4	0,000	100%
1.A.3.a	Domestic Aviation	N_2O	16,8	0,000	100%
1.A.1	Energy Industries - Liquid Fuels	CH_4	15,9	0,000	100%
2.C.5	Lead Production	C	C	C	100%

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Code	Category Title	GHG	2000 Estimates	Level Assessment	Cumulative Total
4.C.1.b	Grassland remaining Grassland – dead organic matter	CO_2	-14,9	0,000	100%
3.F	Field burning of agricultural residues	N_2O	13,6	0,000	100%
5.C	Incineration and Open Burning of Waste	CO_2	13,6	0,000	100%
1.A.4	Other Sectors - Gaseous Fuels	CO_2	12,9	0,000	100%
1.A.4	Other Sectors - Liquid Fuels	N_2O	12,9	0,000	100%
1.B.2	Oil and Natural Gas	CH_4	12,0	0,000	100%
4.B.2.e	Other land converted to Cropland – all pools	CO_2	-11,2	0,000	100%
4.E.2.e	Other land converted to settlements – all pools	CO_2	-9,8	0,000	100%
4.F.2.b	Cropland converted to other land – all pools	CO_2	9,2	0,000	100%
4.F.2.d	Settlements converted to other land – all pools	CO_2	8,7	0,000	100%
4.E.1.b	Settlements remaining Settlements – dead organic matter	CO_2	8,5	0,000	100%
2.D.2	Non-energy Products from Fuels and Solvent Use - Paraffin wax use	CO_2	7,4	0,000	100%
1.A.4	Other Sectors - Liquid Fuels	CH_4	6,9	0,000	100%
0	Wetlands converted to settlements (all pools)	CO_2	6,4	0,000	100%
1.A.5	Other (Not specified elsewhere) - Liquid Fuels	N_2O	5,3	0,000	100%
2.C.2	Ferroalloys Production	C	C	C	100%
4.B.1.b	Cropland remaining Cropland – dead organic matter (dead wood and litter)	CO_2	3,8	0,000	100%
1.A.5	Other (Not specified elsewhere) - Liquid Fuels	CH_4	2,9	0,000	100%
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	N_2O	2,6	0,000	100%
2.B.5	Carbide Production	C	C	C	100%
1.A.3.d	Domestic Navigation - Liquid Fuels	N_2O	1,5	0,000	100%
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	CH_4	1,4	0,000	100%
1.A.3.d	Domestic Navigation - Liquid Fuels	CH_4	1,1	0,000	100%
1.A.1	Energy Industries - Gaseous Fuels	CH_4	1,1	0,000	100%

Code	Category Title	GHG	2000 Estimates	Level Assessment	Cumulative Total
1.A.1	Energy Industries - Gaseous Fuels	N_2O	1,1	0,000	100%
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CH_4	1,0	0,000	100%
1.B.2	Oil and Natural Gas	N_2O	1,0	0,000	100%
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	N_2O	0,9	0,000	100%
1.B.1.c	Solid fuel transformation	N_2O	0,9	0,000	100%
1.A.3.e	Railways	CH_4	0,9	0,000	100%
1.A.3.a	Domestic Aviation	CH_4	0,4	0,000	100%
2.B.8	Petrochemical and Carbon Black Production	C	C	C	100%
1.A.5	Other (Not specified elsewhere) - Gaseous Fuels	CH_4	0,1	0,000	100%
1.A.5	Other (Not specified elsewhere) - Gaseous Fuels	N_2O	0,1	0,000	100%
1.A.4	Other Sectors - Gaseous Fuels	CH_4	0,0	0,000	100%
1.A.4	Other Sectors - Gaseous Fuels	N_2O	0,0	0,000	100%
2.A.4	Other Process Uses of Carbonates	CO_2	0,0	0,000	100%
2.B.5	Carbide Production	C	C	C	100%
2.B.7	Soda Ash Production	C	C	C	100%
2.B.10	Other	C	C	C	100%
2.B.10	Other	C	C	C	100%
2.C.1	Iron and Steel Production	C	C	C	100%
2.F.2	Foam Blowing Agents	F-gases	0,0	0,000	100%
2.F.3	Fire Protection	F-gases	0,0	0,000	100%
2.F.4	Aerosols	F-gases	0,0	0,000	100%
2.G	Other Product Manufacture and Use	CO_2	0,0	0,000	100%
2.B.2	Nitric Acid Production	C	C	C	100%
2.B.2	Nitric Acid Production	C	C	C	100%

Code	Category Title	GHG	2000 Estimates	Level Assessment	Cumulative Total
2.B.8	Hydrogen Production	C	C	C	100%
2.C.2	Ferroalloys Production	C	C	C	100%
2.F.1.a	Refrigeration and Air conditioning - refrigeration and stationary ACs	CO_2e	0,0	0,000	100%
2.F.1.b	Refrigeration and Air conditioning - mobile ACs	CO_2e	0,0	0,000	100%
4.A.1.c	Forest land remaining forest land – soil (mineral)	CO_2	0,0	0,000	100%
4.C.1.c	Grassland remaining Grassland – soil (mineral)	CO_2	0,0	0,000	100%
4.E.1.c	Settlements remaining Settlements – soil (mineral)	CO_2	0,0	0,000	100%
4.F.1.a	Other land remaining Other land – biomass (above and below)	CO_2	0,0	0,000	100%

C=Confidential data

Table A.3: Level assessment on emissions excluding LULUCF for South Africa (2022) with the key categories highlighted in green.

Code	Category Title	GHG	2022 Estimates	Level Assessment	Cumulative Total
1.A.1	Energy Industries - Solid Fuels	CO_2	191 064,0	0,399	40%
1.A.3.b	Road Transportation	CO_2	50 190,1	0,105	50%
1.A.1	Energy Industries - Liquid Fuels	CO_2	32 790,2	0,068	57%
3.A.1.a.ii	Non-dairy Cattle	CH_4	24 499,2	0,051	62%
1.B.3	Other emissions from energy production	CO_2	23 477,0	0,049	67%
1.A.5	Other (Not specified elsewhere) - Solid Fuels	CO_2	19 009,9	0,040	71%
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CO_2	18 424,4	0,038	75%
1.A.4	Other Sectors - Liquid Fuels	CO_2	13 710,5	0,029	78%
3.D.1	Direct N_2O Emissions From Managed Soils	N_2O	9 382,9	0,020	80%
5.A	Solid Waste Disposal	CH_4	8 596,0	0,018	82%
2.C.2	Ferroalloys Production	C	C	C	83%
3.A.2	Sheep	CH_4	6 377,5	0,013	85%
2.C.1	Iron and Steel Production	C	C	C	86%
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CO_2	5 415,7	0,011	87%
2.A.1	Cement Production	C	C	C	88%
5.D	Wastewater Treatment and Discharge - Industrial	CH_4	5 015,5	0,010	89%
1.A.4	Other Sectors - Solid Fuels	CO_2	4 381,2	0,009	90%
3.A.1.a.i	Dairy Cattle	CH_4	3 639,7	0,008	91%
5.D	Wastewater Treatment and Discharge - Domestic	CH_4	3 506,9	0,007	92%
2.F.1.a	Refrigeration and Air conditioning - refrigeration and stationary ACs	CO_2e	3 292,6	0,007	92%
1.B.3	Other emissions from energy production	CH_4	2 933,3	0,006	93%
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	CO_2	2 579,8	0,005	93%

Code	Category Title	GHG	2022 Estimates	Level Assessment	Cumulative Total
2.F.1.b	Refrigeration and Air conditioning - mobile ACs	CO_2e	2 544,3	0,005	94%
3.G	Liming	CO_2	1 860,7	0,004	94%
5.B	Biological Treatment of Solid Waste	CH_4	1 735,7	0,004	95%
1.B.1.a	Fugitive emissions from Solid Fuels - Coal mining and handling	CH_4	1 672,4	0,003	95%
3.A.4	Goats	CH_4	1 578,6	0,003	95%
2.C.3	Aluminium Production	C	C	C	96%
1.A.5	Other (Not specified elsewhere) - Liquid Fuels	CO_2	1 114,5	0,002	96%
3.D.2	Indirect N2O Emissions From Managed Soils	N_2O	995,2	0,002	96%
3.B.1.a.ii	Non-dairy Cattle	N_2O	927,2	0,002	96%
3.B.4	Poultry	N_2O	857,8	0,002	96%
2.B.6	Titanium Dioxide Production	C	C	C	97%
1.A.1	Energy Industries - Gaseous Fuels	CO_2	801,9	0,002	97%
5.B	Biological Treatment of Solid Waste	N_2O	794,7	0,002	97%
1.A.1	Energy Industries - Solid Fuels	N_2O	789,1	0,002	97%
5.D	Wastewater Treatment and Discharge - Domestic	N_2O	724,3	0,002	97%
2.A.2	Lime Production	C	C	C	97%
1.A.3.a	Domestic Aviation	CO_2	683,9	0,001	98%
3.B.1.a.ii	Non-dairy Cattle	CH_4	681,5	0,001	98%
1.A.3.b	Road Transportation	N_2O	646,5	0,001	98%
2.D.2	Non-energy Products from Fuels and Solvent Use - Paraffin wax use	CO_2	609,1	0,001	98%
3.H	Urea Application	CO_2	584,7	0,001	98%
3.B.1.a.i	Dairy Cattle	CH_4	561,4	0,001	98%
1.A.4	Other Sectors - Gaseous Fuels	CO_2	525,7	0,001	98%
2.D.1	Non-energy Products from Fuels and Solvent Use - Lubricant use	CO_2	515,7	0,001	98%

Code	Category Title	GHG	2022 Estimates	Level Assessment	Cumulative Total
1.A.5	Other (Not specified elsewhere) - Solid Fuels	N_2O	503,0	0,001	99%
1.A.3.d	Domestic Navigation - Liquid Fuels	CO_2	495,5	0,001	99%
2.B.2	Nitric Acid Production	C	C	C	99%
1.A.3.c	Railways	CO_2	361,6	0,001	99%
1.B.1.c	Solid fuel transformation	CO_2	349,1	0,001	99%
1.A.5	Other (Not specified elsewhere) - Solid Fuels	CH_4	340,9	0,001	99%
3.B.5	Indirect N2O Emissions From Manure Management	N_2O	325,2	0,001	99%
1.A.3.b	Road Transportation	CH_4	322,8	0,001	99%
1.B.1.c	Solid fuel transformation	CH_4	250,7	0,001	99%
5.C	Incineration and Open Burning of Waste	CH_4	243,3	0,001	99%
1.A.5	Other (Not specified elsewhere) - Gaseous Fuels	CO_2	227,2	0,000	99%
3.B.1.a.i	Dairy Cattle	N_2O	215,5	0,000	99%
2.B.1	Ammonia Production	C	C	C	99%
3.B.3	Swine	CH_4	208,9	0,000	99%
1.A.4	Other Sectors - Solid Fuels	N_2O	207,1	0,000	99%
2.A.3	Glass Production	C	C	C	99%
3.B.4	Poultry	CH_4	175,4	0,000	100%
3.A.4	Horses	CH_4	168,0	0,000	100%
1.A.4	Other Sectors - Solid Fuels	CH_4	161,8	0,000	100%
1.A.2	Manufacturing Industries and Construction - Solid Fuels	N_2O	150,0	0,000	100%
2.A.4	Other Process Uses of Carbonates	C	C	C	100%
3.B.2	Sheep	N_2O	143,5	0,000	100%
2.C.3	Aluminium Production	C	C	C	100%
2.B.1	Ammonia Production	C	C	C	100%

Code	Category Title	GHG	2022 Estimates	Level Assessment	Cumulative Total
1.A.1	Energy Industries - Liquid Fuels	N_2O	112,1	0,000	100%
2.B.8	Petrochemical and Carbon Black Production	C	C	C	100%
3.B.2	Sheep	CH_4	87,6	0,000	100%
2.F.3	Fire Protection	F-gases	87,5	0,000	100%
2.B.8	Hydrogen Production	C	C	C	100%
1.B.2	Oil and Natural Gas	CO_2	69,6	0,000	100%
2.G	Other Product Manufacture and Use	CO_2	65,7	0,000	100%
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CH_4	63,0	0,000	100%
1.A.1	Energy Industries - Solid Fuels	CH_4	55,6	0,000	100%
5.C	Incineration and Open Burning of Waste	N_2O	53,1	0,000	100%
3.B.4	Goats	N_2O	49,2	0,000	100%
3.F	Field burning of agricultural residues	CH_4	47,0	0,000	100%
3.A.4	Mules & Asses	CH_4	45,8	0,000	100%
3.A.3	Swine	CH_4	43,2	0,000	100%
1.A.1	Energy Industries - Liquid Fuels	CH_4	42,9	0,000	100%
2.B.5	Carbide Production	C	C	C	100%
1.A.3.e	Railways	N_2O	33,3	0,000	100%
5.C	Incineration and Open Burning of Waste	CO_2	28,9	0,000	100%
1.A.4	Other Sectors - Liquid Fuels	N_2O	27,4	0,000	100%
3.B.4	Goats	CH_4	27,1	0,000	100%
3.B.3	Swine	N_2O	24,2	0,000	100%
2.B.10	Other	C	C	C	100%
2.F.4	Aerosols	F-gases	18,3	0,000	100%
1.B.1.a	Coal mining and handling	CO_2	16,4	0,000	100%

Code	Category Title	GHG	2022 Estimates	Level Assessment	Cumulative Total
1.A.4	Other Sectors - Liquid Fuels	CH_4	14,8	0,000	100%
1.B.2	Oil and Natural Gas	CH_4	13,7	0,000	100%
3.F	Field burning of agricultural residues	N_2O	11,5	0,000	100%
1.B.2	Oil and Natural Gas	N_2O	11,0	0,000	100%
2.C.5	Lead Production	C	C	C	100%
2.B.7	Soda Ash Production	C	C	C	100%
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	N_2O	5,7	0,000	100%
1.A.3.a	Domestic Aviation	N_2O	5,0	0,000	100%
1.B.1.c	Solid fuel transformation	N_2O	4,7	0,000	100%
2.B.5	Carbide Production	C	C	C	100%
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CH_4	2,7	0,000	100%
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	CH_4	2,7	0,000	100%
2.B.2	Nitric Acid Production	C	C	C	100%
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	N_2O	2,6	0,000	100%
1.A.3.d	Domestic Navigation - Liquid Fuels	N_2O	2,5	0,000	100%
2.F.2	Foam Blowing Agents	F-gases	2,1	0,000	100%
2.B.2	Nitric Acid Production	C	C	C	100%
1.A.5	Other (Not specified elsewhere) - Liquid Fuels	N_2O	1,7	0,000	100%
1.A.3.d	Domestic Navigation - Liquid Fuels	CH_4	1,3	0,000	100%
1.A.5	Other (Not specified elsewhere) - Liquid Fuels	CH_4	1,0	0,000	100%
1.A.3.e	Railways	CH_4	0,6	0,000	100%
1.A.1	Energy Industries - Gaseous Fuels	CH_4	0,4	0,000	100%
1.A.1	Energy Industries - Gaseous Fuels	N_2O	0,4	0,000	100%
1.A.4	Other Sectors - Gaseous Fuels	CH_4	0,3	0,000	100%

Code	Category Title	GHG	2022 Estimates	Level Assessment	Cumulative Total
1.A.4	Other Sectors - Gaseous Fuels	N_2O	0,3	0,000	100%
1.A.3.a	Domestic Aviation	CH_4	0,1	0,000	100%
1.A.5	Other (Not specified elsewhere) - Gaseous Fuels	CH_4	0,1	0,000	100%
2.C.2	Ferroalloys Production	C	C	C	100%
1.A.5	Other (Not specified elsewhere) - Gaseous Fuels	N_2O	0,1	0,000	100%
2.B.8	Petrochemical and Carbon Black Production	C	C	C	100%
2.C.2	Ferroalloys Production	C	C	C	100%
2.B.10	Other	C	C	C	100%

C=Confidential data

Table A.4: Level assessment on emissions including LULUCF for South Africa (2022) with the key categories highlighted in green.

Code	Category Title	GHG	2022 Estimates	Level Assessment	Cumulative Total
1.A.1	Energy Industries - Solid Fuels	CO_2	191 064,0	0,297	30%
1.A.3.b	Road Transportation	CO_2	50 190,1	0,078	37%
4.A.2.b	Grassland converted to forest land – all pools	CO_2	-47 358,8	0,073	45%
4.A.1.a	Forest land remaining forest land – biomass (above and below)	CO_2	-33 242,4	0,052	50%
1.A.1	Energy Industries - Liquid Fuels	CO_2	32 790,2	0,051	55%
3.A.1.a.ii	Non-dairy Cattle	CH_4	24 499,2	0,038	59%
1.B.3	Other emissions from energy production	CO2	23 477,0	0,036	62%
1.A.5	Other (Not specified elsewhere) - Solid Fuels	CO_2	19 009,9	0,030	65%
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CO_2	18 424,4	0,029	68%
4.F.2.c	Grassland converted to other land – all pools	CO_2	18 120,9	0,028	71%
1.A.4	Other Sectors - Liquid Fuels	CO_2	13 710,5	0,021	73%
4.C.1.a	Grassland remaining Grassland – biomass (above and below)	CO_2	13 167,6	0,020	75%
4.C.2.a	Forest land converted to Grassland – all pools	CO_2	10 864,7	0,017	77%
4.C.2.e	Other land converted to Grassland – all pools	CO_2	-10 027,5	0,016	79%
3.D.1	Direct N2O Emissions From Managed Soils	N_2O	9 382,9	0,015	80%
5.A	Solid Waste Disposal	CH_4	8 596,0	0,013	81%
2.C.2	Ferroalloys Production	C	C	C	83%
3.A.2	Sheep	CH_4	6 377,5	0,010	84%
2.C.1	Iron and Steel Production	C	C	C	85%
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CO_2	5 415,7	0,008	85%
2.A.1	Cement Production	C	C	C	86%
5.D	Wastewater Treatment and Discharge - Industrial	CH_4	5 015,5	0,008	87%

Code	Category Title	GHG	2022 Estimates	Level Assessment	Cumulative Total
4.A.2.a	Cropland converted to forest land – all pools	CO_2	-4 993,1	0,008	88%
4.D.1	Wetlands Remaining Wetlands	CH_4	4 597,6	0,007	88%
1.A.4	Other Sectors - Solid Fuels	CO_2	4 381,2	0,007	89%
4.D.2	Land Converted to Wetlands	CH_4	4 099,3	0,006	90%
3.A.1.a.i	Dairy Cattle	CH_4	3 639,7	0,006	90%
5.D	Wastewater Treatment and Discharge - Domestic	CH_4	3 506,9	0,005	91%
2.F.1.a	Refrigeration and Air conditioning - refrigeration and stationary ACs	CO_2e	3 292,6	0,005	91%
1.B.3	Other emissions from energy production	CH_4	2 933,3	0,005	92%
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	CO_2	2 579,8	0,004	92%
2.F.1.b	Refrigeration and Air conditioning - mobile ACs	CO_2e	2 544,3	0,004	93%
4.C.2.b	Cropland converted to Grassland – all pools	CO_2	-2 297,8	0,004	93%
4(V)	Biomass Burning	CH_4	2 098,6	0,003	93%
4.B.2.b	Grassland converted to Cropland – all pools	CO_2	1 894,3	0,003	94%
3.G	Liming	CO_2	1 860,7	0,003	94%
5.B	Biological Treatment of Solid Waste	CH_4	1 735,7	0,003	94%
1.B.1.a	Fugitive emissions from Solid Fuels - Coal mining and handling	CH_4	1 672,4	0,003	94%
3.A.4	Goats	CH_4	1 578,6	0,002	95%
4.A.2.e	Other land converted to forest land – all pools	CO_2	-1 447,3	0,002	95%
4.B.2.a	Forest land converted to Cropland – all pools	CO_2	1 423,5	0,002	95%
4(V)	Biomass Burning	N_2O	1 328,6	0,002	95%
4.A.1.b	Forest land remaining forest land – dead organic matter	CO_2	-1 161,7	0,002	95%
2.C.3	Aluminium Production	C	C	C	96%
1.A.5	Other (Not specified elsewhere) - Liquid Fuels	CO_2	1 114,5	0,002	96%

Code	Category Title	GHG	2022 Estimates	Level Assessment	Cumulative Total
4.A.2.c	Wetland converted to forest land – all pools	CO_2	-1 073,4	0,002	96%
3.D.2	Indirect N_2O Emissions From Managed Soils	N_2O	995,2	0,002	96%
3.B.1.a.ii	Non-dairy Cattle	N_2O	927,2	0,001	96%
3.B.4	Poultry	N_2O	857,8	0,001	96%
2.B.6	Titanium Dioxide Production	C	C	C	97%
4.A.2.d	Settlements converted to forest land – all pools	CO_2	-805,6	0,001	97%
1.A.1	Energy Industries - Gaseous Fuels	CO_2	801,9	0,001	97%
5.B	Biological Treatment of Solid Waste	N_2O	794,7	0,001	97%
1.A.1	Energy Industries - Solid Fuels	N_2O	789,1	0,001	97%
4.F.2.a	Forest land converted to other land – all pools	CO_2	761,6	0,001	97%
5.D	Wastewater Treatment and Discharge - Domestic	N_2O	724,3	0,001	97%
2.A.2	Lime Production	C	C	C	97%
1.A.3.a	Domestic Aviation	CO_2	683,9	0,001	97%
3.B.1.a.ii	Non-dairy Cattle	CH_4	681,5	0,001	98%
1.A.3.b	Road Transportation	N_2O	646,5	0,001	98%
2.D.2	Non-energy Products from Fuels and Solvent Use - Paraffin wax use	CO_2	609,1	0,001	98%
3.H	Urea Application	CO_2	584,7	0,001	98%
3.B.1.a.i	Dairy Cattle	CH_4	561,4	0,001	98%
4.D.2	Land Converted to Wetlands	CO_2	544,8	0,001	98%
1.A.4	Other Sectors - Gaseous Fuels	CO_2	525,7	0,001	98%
4.E.2.a	Forest land converted to settlements – all pools	CO_2	525,5	0,001	98%
4.C.1.b	Grassland remaining Grassland – dead organic matter	CO_2	-518,3	0,001	98%
2.D.1	Non-energy Products from Fuels and Solvent Use - Lubricant use	CO_2	515,7	0,001	98%

Code	Category Title	GHG	2022 Estimates	Level Assessment	Cumulative Total
1.A.5	Other (Not specified elsewhere) - Solid Fuels	N_2O	503,0	0,001	98%
4.C.2.c	Wetland converted to Grassland – all pools	CO_2	-501,7	0,001	99%
1.A.3.d	Domestic Navigation - Liquid Fuels	CO_2	495,5	0,001	99%
4.E.1.a	Settlements remaining Settlements – biomass (above and below)	CO_2	-437,2	0,001	99%
2.B.2	Nitric Acid Production	C	C	C	99%
1.A.3.c	Railways	CO_2	361,6	0,001	99%
1.B.1.c	Solid fuel transformation	CO_2	349,1	0,001	99%
1.A.5	Other (Not specified elsewhere) - Solid Fuels	CH_4	340,9	0,001	99%
3.B.5	Indirect N_2O Emissions From Manure Management	N_2O	325,2	0,001	99%
1.A.3.b	Road Transportation	CH_4	322,8	0,001	99%
4.D.1	Wetlands Remaining Wetlands	N_2O	287,8	0,000	99%
4.E.2.c	Grassland converted to settlements – all pools	CO_2	268,5	0,000	99%
4.D.2	Land Converted to Wetlands	N_2O	256,6	0,000	99%
1.B.1.c	Solid fuel transformation	CH_4	250,7	0,000	99%
5.C	Incineration and Open Burning of Waste	CH_4	243,3	0,000	99%
4.B.2.c	Wetland converted to Cropland – all pools	CO_2	242,9	0,000	99%
1.A.5	Other (Not specified elsewhere) - Gaseous Fuels	CO_2	227,2	0,000	99%
3.B.1.a.i	Dairy Cattle	N_2O	215,5	0,000	99%
2.B.1	Ammonia Production	C	C	C	99%
3.B.3	Swine	CH_4	208,9	0,000	99%
1.A.4	Other Sectors - Solid Fuels	N_2O	207,1	0,000	99%
4.D.1	Wetlands Remaining Wetlands	CO_2	203,1	0,000	99%
2.A.3	Glass Production	C	C	C	99%

Code	Category Title	GHG	2022 Estimates	Level Assessment	Cumulative Total
4.G	Harvested Wood Products	CO_2	-181,4	0,000	99%
3.B.4	Poultry	CH_4	175,4	0,000	100%
3.A.4	Horses	CH_4	168,0	0,000	100%
1.A.4	Other Sectors - Solid Fuels	CH_4	161,8	0,000	100%
4.B.1.a	Cropland remaining Cropland – biomass (above and below)	CO_2	156,9	0,000	100%
1.A.2	Manufacturing Industries and Construction - Solid Fuels	N_2O	150,0	0,000	100%
2.A.4	Other Process Uses of Carbonates	C	C	C	100%
3.B.2	Sheep	N_2O	143,5	0,000	100%
0	Wetlands converted to other land (all pools)	CO_2	133,1	0,000	100%
2.C.3	Aluminium Production	F-gases	125,9	0,000	100%
2.B.1	Ammonia Production	CH_4	113,7	0,000	100%
1.A.1	Energy Industries - Liquid Fuels	N_2O	112,1	0,000	100%
4.C.2.d	Settlements converted to Grassland – all pools	CO_2	-110,2	0,000	100%
4.B.2.e	Other land converted to Cropland – all pools	CO_2	-106,6	0,000	100%
2.B.8	Petrochemical and Carbon Black Production	C	C	C	100%
3.B.2	Sheep	CH_4	87,6	0,000	100%
2.F.3	Fire Protection	F-gases	87,5	0,000	100%
4.E.2.b	Cropland converted to settlements – all pools	CO_2	-81,4	0,000	100%
2.B.8	Hydrogen Production	C	C	C	100%
1.B.2	Oil and Natural Gas	CO_2	69,6	0,000	100%
2.G	Other Product Manufacture and Use	CO_2	65,7	0,000	100%
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CH_4	63,0	0,000	100%
4.B.1.b	Cropland remaining Cropland – dead organic matter	CO_2	-61,0	0,000	100%

Code	Category Title	GHG	2022 Estimates	Level Assessment	Cumulative Total
1.A.1	Energy Industries - Solid Fuels	CH_4	55,6	0,000	100%
5.C	Incineration and Open Burning of Waste	N_2O	53,1	0,000	100%
3.B.4	Goats	N_2O	49,2	0,000	100%
3.F	Field burning of agricultural residues	CH_4	47,0	0,000	100%
3.A.4	Mules & Asses	CH_4	45,8	0,000	100%
3.A.3	Swine	CH_4	43,2	0,000	100%
1.A.1	Energy Industries - Liquid Fuels	CH_4	42,9	0,000	100%
2.B.5	Carbide Production	C	C	C	100%
1.A.3.e	Railways	N_2O	33,3	0,000	100%
5.C	Incineration and Open Burning of Waste	CO_2	28,9	0,000	100%
1.A.4	Other Sectors - Liquid Fuels	N_2O	27,4	0,000	100%
3.B.4	Goats	CH_4	27,1	0,000	100%
4.B.2.d	Settlements converted to Cropland – all pools	CO_2	-24,8	0,000	100%
3.B.3	Swine	N_2O	24,2	0,000	100%
2.B.10	Other	C	C	C	100%
2.F.4	Aerosols	F-gases	18,3	0,000	100%
1.B.1.a	Coal mining and handling	CO_2	16,4	0,000	100%
4.B.1.c	Cropland remaining Cropland – soil (mineral)	CO_2	-16,4	0,000	100%
4.E.2.e	Other land converted to settlements – all pools	CO_2	-15,8	0,000	100%
1.A.4	Other Sectors - Liquid Fuels	CH_4	14,8	0,000	100%
1.B.2	Oil and Natural Gas	CH_4	13,7	0,000	100%
3.F	Field burning of agricultural residues	N_2O	11,5	0,000	100%
1.B.2	Oil and Natural Gas	N_2O	11,0	0,000	100%

Code	Category Title	GHG	2022 Estimates	Level Assessment	Cumulative Total
4.E.1.b	Settlements remaining Settlements – dead organic matter	CO_2	-9,0	0,000	100%
0	Wetlands converted to settlements (all pools)	CO_2	7,9	0,000	100%
4.F.2.d	Settlements converted to other land – all pools	CO_2	7,5	0,000	100%
2.C.5	Lead Production	C	C	C	100%
2.B.7	Soda Ash Production	C	C	C	100%
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	N_2O	5,7	0,000	100%
1.A.3.a	Domestic Aviation	N_2O	5,0	0,000	100%
1.B.1.c	Solid fuel transformation	N_2O	4,7	0,000	100%
2.B.5	Carbide Production	C	C	C	100%
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CH_4	2,7	0,000	100%
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	CH_4	2,7	0,000	100%
2.B.2	Nitric Acid Production	C	C	C	100%
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	N_2O	2,6	0,000	100%
1.A.3.d	Domestic Navigation - Liquid Fuels	N_2O	2,5	0,000	100%
4.F.2.b	Cropland converted to other land – all pool	CO_2	2,2	0,000	100%
2.F.2	Foam Blowing Agents	F-gases	2,1	0,000	100%
2.B.2	Nitric Acid Production	C	C	C	100%
1.A.5	Other (Not specified elsewhere) - Liquid Fuels	N_2O	1,7	0,000	100%
1.A.3.d	Domestic Navigation - Liquid Fuels	CH_4	1,3	0,000	100%
1.A.5	Other (Not specified elsewhere) - Liquid Fuels	CH_4	1,0	0,000	100%
1.A.3.e	Railways	CH_4	0,6	0,000	100%
1.A.1	Energy Industries - Gaseous Fuels	CH_4	0,4	0,000	100%
1.A.1	Energy Industries - Gaseous Fuels	N_2O	0,4	0,000	100%

Code	Category Title	GHG	2022 Estimates	Level Assessment	Cumulative Total
1.A.4	Other Sectors - Gaseous Fuels	CH_4	0,3	0,000	100%
1.A.4	Other Sectors - Gaseous Fuels	N_2O	0,3	0,000	100%
1.A.3.a	Domestic Aviation	CH_4	0,1	0,000	100%
1.A.5	Other (Not specified elsewhere) - Gaseous Fuels	CH_4	0,1	0,000	100%
2.C.2	Ferroalloys Production	C	C	C	100%
1.A.5	Other (Not specified elsewhere) - Gaseous Fuels	N_2O	0,1	0,000	100%
2.B.8	Petrochemical and Carbon Black Production	C	C	C	100%
2.C.2	Ferroalloys Production	C	C	C	100%
2.B.10	Other	C	C	C	100%
2.C.1	Iron and Steel Production	C	C	C	100%
2.C.6	Zinc Production	C	C	C	100%
4.A.1.c	Forest land remaining forest land – soil (mineral)	CO_2	0,0	0,000	100%
4.C.1.c	Grassland remaining Grassland – soil (mineral)	CO_2	0,0	0,000	100%
4.E.1.c	Settlements remaining Settlements – soil (mineral)	CO_2	0,0	0,000	100%
4.F.1.a	Other land remaining Other land – biomass (above and below)	CO_2	0,0	0,000	100%

C=Confidential data

Table A.5: Trend assessment on emissions excluding LULUCF for South Africa (2000 - 2022) with the key categories highlighted in green.

Code	Category Title	GHG	2000 Estimates	2022 Estimates	Contribution to Trend	Cumulative Total
1.A.4	Other Sectors - Solid Fuels	CO_2	43 592,2	4381,207	31%	31%
1.A.3.b	Road Transportation	CO_2	37 448,9	50190,053	10%	42%
2.C.1	Iron and Steel Production	C	C	C	C	49%
1.A.4	Other Sectors - Liquid Fuels	CO_2	6 259,8	13710,545	6%	55%
1.A.5	Other (Not specified elsewhere) - Solid Fuels	CO_2	12 737,8	19009,890	5%	60%
1.A.1	Energy Industries - Solid Fuels	CO_2	185 027,4	191063,951	5%	65%
1.B.3	Other emissions from energy production	CO_2	28 146,6	23477,024	4%	68%
5.A	Solid Waste Disposal	CH_4	4 505,3	8596,000	3%	72%
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CO_2	1 976,7	5415,712	3%	74%
2.F.1.a	Refrigeration and Air conditioning - refrigeration and stationary ACs	CO_2e	0,0	3292,625	3%	77%
3.A.1.a.ii	Non-dairy Cattle	CH_4	27 776,4	24499,238	3%	80%
2.F.1.b	Refrigeration and Air conditioning - mobile ACs	CO_2e	0,0	2544,278	2%	82%
3.A.2	Sheep	CH_4	8 121,1	6377,534	1%	83%
1.A.3.a	Domestic Aviation	CO_2	2 315,9	683,915	1%	84%
1.A.1	Energy Industries - Gaseous Fuels	CO_2	2 307,1	801,878	1%	85%
1.A.5	Other (Not specified elsewhere) - Liquid Fuels	CO_2	2 613,7	1114,480	1%	87%
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	CO_2	1 289,7	2579,793	1%	88%
5.D	Wastewater Treatment and Discharge - Domestic	CH_4	2 257,3	3506,877	1%	89%
2.A.1	Cement Production	C	C	C	C	90%
2.B.2	Nitric Acid Production	C	C	C	C	90%
2.C.3	Aluminium Production	C	C	C	C	91%
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CO_2	17 680,3	18424,352	1%	92%

Code	Category Title	GHG	2000 Estimates	2022 Estimates	Contribution to Trend	Cumulative Total
1.B.2	Oil and Natural Gas	CO_2	752,0	69,565	1%	92%
5.B	Biological Treatment of Solid Waste	CH_4	1 066,6	1735,718	1%	93%
2.D.2	Non-energy Products from Fuels and Solvent Use - Paraffin wax use	CO_2	7,4	609,096	0%	93%
1.A.1	Energy Industries - Liquid Fuels	CO_2	32 254,1	32790,163	0%	94%
1.A.4	Other Sectors - Gaseous Fuels	CO_2	12,9	525,721	0%	94%
5.D	Wastewater Treatment and Discharge - Industrial	CH_4	5 489,1	5015,537	0%	95%
3.A.4	Goats	CH_4	1 990,8	1578,606	0%	95%
2.B.6	Titanium Dioxide Production	C	C	C	C	95%
5.B	Biological Treatment of Solid Waste	N_2O	425,6	794,658	0%	95%
2.D.1	Non-energy Products from Fuels and Solvent Use - Lubricant use	CO_2	188,5	515,689	0%	96%
3.B.4	Poultry	N_2O	557,3	857,768	0%	96%
3.H	Urea Application	CO_2	297,3	584,663	0%	96%
1.B.1.c	Solid fuel transformation	CO_2	64,4	349,124	0%	96%
2.B.1	Ammonia Production	C	C	C	C	97%
2.A.2	Lime Production	C	C	C	C	97%
5.D	Wastewater Treatment and Discharge - Domestic	N_2O	466,2	724,274	0%	97%
3.A.1.a.i	Dairy Cattle	CH_4	3 884,1	3639,745	0%	97%
1.A.4	Other Sectors - Solid Fuels	N_2O	449,5	207,055	0%	97%
1.B.1.a	Coal mining and handling	CH_4	1 894,6	1672,412	0%	98%
1.B.1.c	Solid fuel transformation	CH_4	49,6	250,689	0%	98%
1.A.3.c	Railways	CO_2	555,5	361,554	0%	98%
3.D.1	Direct N_2O Emissions From Managed Soils	N_2O	9 574,6	9382,894	0%	98%
1.A.3.b	Road Transportation	N_2O	466,0	646,549	0%	98%
1.A.5	Other (Not specified elsewhere) - Solid Fuels	N_2O	327,3	502,957	0%	98%

Code	Category Title	GHG	2000 Estimates	2022 Estimates	Contribution to Trend	Cumulative Total
2.A.4	Other Process Uses of Carbonates	C	C	C	C	98%
5.C	Incineration and Open Burning of Waste	CH_4	114,1	243,318	0%	99%
1.A.5	Other (Not specified elsewhere) - Solid Fuels	CH_4	220,7	340,897	0%	99%
2.A.3	Glass Production	C	C	C	C	99%
3.B.1.a.ii	Non-dairy Cattle	N_2O	818,5	927,249	0%	99%
2.C.6	Zinc Production	C	C	C	C	99%
2.F.3	Fire Protection	F-gases	0,0	87,504	0%	99%
2.B.8	Hydrogen Production	C	C	C	C	99%
1.A.4	Other Sectors - Solid Fuels	CH_4	235,8	161,810	0%	99%
1.A.3.d	Domestic Navigation - Liquid Fuels	CO_2	428,1	495,486	0%	99%
2.G	Other Product Manufacture and Use	CO_2	0,0	65,711	0%	99%
3.B.4	Poultry	CH_4	112,7	175,419	0%	99%
3.D.2	Indirect N_2O Emissions From Managed Soils	N_2O	1 056,5	995,231	0%	99%
1.A.5	Other (Not specified elsewhere) - Gaseous Fuels	CO_2	175,7	227,192	0%	99%
3.B.3	Swine	CH_4	256,2	208,933	0%	99%
2.C.3	Aluminium Production	C	C	C	C	99%
3.G	Liming	CO_2	1 820,0	1860,710	0%	99%
2.B.8	Petrochemical and Carbon Black Production	C	C	C	C	100%
3.B.1.a.i	Dairy Cattle	CH_4	599,1	561,405	0%	100%
2.B.5	Carbide Production	C	C	C	C	100%
3.B.5	Indirect N_2O Emissions From Manure Management	N_2O	291,9	325,159	0%	100%
3.A.4	Horses	CH_4	136,1	167,973	0%	100%
5.C	Incineration and Open Burning of Waste	N_2O	24,9	53,142	0%	100%
1.A.1	Energy Industries - Liquid Fuels	CH_4	15,9	42,852	0%	100%

Code	Category Title	GHG	2000 Estimates	2022 Estimates	Contribution to Trend	Cumulative Total
2.B.1	Ammonia Production	C	C	C	C	100%
1.A.1	Energy Industries - Solid Fuels	N_2O	764,1	789,069	0%	100%
1.A.3.e	Railways	N_2O	56,4	33,335	0%	100%
3.B.2	Sheep	CH_4	108,8	87,598	0%	100%
3.B.1.a.ii	Non-dairy Cattle	CH_4	701,8	681,523	0%	100%
1.A.2	Manufacturing Industries and Construction - Solid Fuels	N_2O	130,0	150,010	0%	100%
2.B.10	Other	C	C	C	C	100%
2.F.4	Aerosols	F-gases	0,0	18,255	0%	100%
1.B.3	Other emissions from energy production	CH_4	2 949,5	2933,252	0%	100%
3.B.2	Sheep	N_2O	159,2	143,505	0%	100%
5.C	Incineration and Open Burning of Waste	CO_2	13,6	28,909	0%	100%
1.A.4	Other Sectors - Liquid Fuels	N_2O	12,9	27,421	0%	100%
3.B.1.a.i	Dairy Cattle	N_2O	230,0	215,536	0%	100%
1.A.1	Energy Industries - Liquid Fuels	N_2O	97,7	112,053	0%	100%
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CH_4	49,3	62,980	0%	100%
1.A.3.a	Domestic Aviation	N_2O	16,8	4,953	0%	100%
1.B.2	Oil and Natural Gas	N_2O	1,0	11,010	0%	100%
3.B.4	Goats	N_2O	59,2	49,208	0%	100%
3.A.3	Swine	CH_4	53,0	43,218	0%	100%
3.F	Field burning of agricultural residues	CH_4	55,5	47,006	0%	100%
2.C.5	Lead Production	C	C	C	C	100%
1.A.4	Other Sectors - Liquid Fuels	CH_4	6,9	14,778	0%	100%
1.A.3.b	Road Transportation	CH_4	330,5	322,809	0%	100%
3.B.4	Goats	CH_4	33,7	27,052	0%	100%

Code	Category Title	GHG	2000 Estimates	2022 Estimates	Contribution to Trend	Cumulative Total
2.B.7	Soda Ash Production	C	C	C	C	100%
3.B.3	Swine	N_2O	29,6	24,169	0%	100%
2.B.5	Carbide Production	C	C	C	C	100%
2.C.2	Ferroalloys Production	C	C	C	C	100%
1.B.1.c	Solid fuel transformation	N_2O	0,9	4,671	0%	100%
1.A.5	Other (Not specified elsewhere) - Liquid Fuels	N_2O	5,3	1,703	0%	100%
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	N_2O	2,6	5,703	0%	100%
2.B.2	Nitric Acid Production	C	C	C	C	100%
1.B.1.a	Coal mining and handling	CO_2	18,6	16,430	0%	100%
2.F.2	Foam Blowing Agents	F-gases	0,0	2,104	0%	100%
3.F	Field burning of agricultural residues	N2O	13,6	11,534	0%	100%
1.A.5	Other (Not specified elsewhere) - Liquid Fuels	CH_4	2,9	0,987	0%	100%
1.A.1	Energy Industries - Solid Fuels	CH_4	53,8	55,582	0%	100%
1.B.2	Oil and Natural Gas	CH_4	12,0	13,691	0%	100%
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CH_4	1,0	2,735	0%	100%
2.B.2	Nitric Acid Production	C	C	C	C	100%
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	N_2O	0,9	2,588	0%	100%
2.C.2	Ferroalloys Production	C	C	C	C	100%
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	CH_4	1,4	2,706	0%	100%
1.A.3.d	Domestic Navigation - Liquid Fuels	N_2O	1,5	2,535	0%	100%
1.A.1	Energy Industries - Gaseous Fuels	CH_4	1,1	0,391	0%	100%
1.A.1	Energy Industries - Gaseous Fuels	N_2O	1,1	0,370	0%	100%
1.A.3.a	Domestic Aviation	CH_4	0,4	0,131	0%	100%
1.A.3.e	Railways	CH_4	0,9	0,602	0%	100%

Code	Category Title	GHG	2000 Estimates	2022 Estimates	Contribution to Trend	Cumulative Total
1.A.4	Other Sectors - Gaseous Fuels	CH_4	0,0	0,264	0%	100%
1.A.4	Other Sectors - Gaseous Fuels	N_2O	0,0	0,250	0%	100%
1.A.3.d	Domestic Navigation - Liquid Fuels	CH_4	1,1	1,321	0%	100%
3.A.4	Mules & Asses	CH_4	45,9	45,796	0%	100%
2.C.2	Ferroalloys Production	C	C	C	C	100%
2.B.10	Other	C	C	C	C	100%
1.A.5	Other (Not specified elsewhere) - Gaseous Fuels	CH_4	0,1	0,114	0%	100%
1.A.5	Other (Not specified elsewhere) - Gaseous Fuels	N_2O	0,1	0,108	0%	100%

C=Confidential data

Table A.6: Trend assessment on emissions including LULUCF for South Africa (2000 - 2022) with the key categories highlighted in green.

Code	Category Title	GHG	2000 Estimates	2022 Estimates	Contribution to Trend	Cumulative Total
1.A.4	Other Sectors - Solid Fuels	CO_2	43 592,2	4381,207	19%	19%
4.A.2.b	Grassland converted to forest land – all pools	CO_2	-24 956,0	-47358,835	11%	30%
4.A.1.a	Forest land remaining forest land – biomass	CO_2	-18 241,8	-33242,410	7%	37%
4.C.1.a	Grassland remaining Grassland – biomass	CO_2	-1 531,4	13167,621	7%	44%
1.A.3.b	Road Transportation	CO_2	37 448,9	50190,053	6%	50%
4.F.2.c	Grassland converted to other land – all pools	CO_2	6 879,7	18120,881	5%	56%
2.C.1	Iron and Steel Production	C	C	C	C	60%
1.A.4	Other Sectors - Liquid Fuels	CO_2	6 259,8	13710,545	4%	64%
1.A.5	Other (Not specified elsewhere) - Solid Fuels	CO_2	12 737,8	19009,890	3%	67%
1.A.1	Energy Industries - Solid Fuels	CO_2	185 027,4	191063,951	3%	70%
1.B.3	Other emissions from energy production	CO_2	28 146,6	23477,024	2%	72%
5.A	Solid Waste Disposal	CH_4	4 505,3	8596,000	2%	74%
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CO_2	1 976,7	5415,712	2%	76%
2.F.1.a	Refrigeration and Air conditioning - refrigeration and stationary ACs	CO_2e	0,0	3292,625	2%	77%
3.A.1.a.ii	Non-dairy Cattle	CH_4	27 776,4	24499,238	2%	79%
2.F.1.b	Refrigeration and Air conditioning - mobile ACs	CO_2e	0,0	2544,278	1%	80%
4.A.2.a	Cropland converted to forest land – all pools	CO_2	-2 451,3	-4993,079	1%	81%
4.D.2	Land Converted to Wetlands	CH_4	1 655,1	4099,344	1%	82%
4.D.1	Wetlands Remaining Wetlands	CH_4	6 990,6	4597,609	1%	84%
4.C.2.a	Forest land converted to Grassland – all pools	CO_2	8 864,9	10864,683	1%	85%
4.G	Harvested Wood Products	CO_2	-2 106,2	-181,444	1%	86%
3.A.2	Sheep	CH_4	8 121,1	6377,534	1%	86%

Code	Category Title	GHG	2000 Estimates	2022 Estimates	Contribution to Trend	Cumulative Total
1.A.3.a	Domestic Aviation	CO_2	2 315,9	683,915	1%	87%
1.A.1	Energy Industries - Gaseous Fuels	CO_2	2 307,1	801,878	1%	88%
1.A.5	Other (Not specified elsewhere) - Liquid Fuels	CO_2	2 613,7	1114,480	1%	89%
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	CO_2	1 289,7	2579,793	1%	89%
5.D	Wastewater Treatment and Discharge - Domestic	CH_4	2 257,3	3506,877	1%	90%
4.A.1.b	Forest land remaining forest land – dead organic matter	CO_2	34,9	-1161,677	1%	90%
2.A.1	Cement Production	C	C	C	C	91%
2.B.2	Nitric Acid Production	C	C	C	C	92%
4.C.2.e	Other land converted to Grassland – all pools	CO_2	-9 026,6	-10027,477	0%	92%
2.C.3	Aluminium Production	C	C	C	C	92%
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CO_2	17 680,3	18424,352	0%	93%
1.B.2	Oil and Natural Gas	CO_2	752,0	69,565	0%	93%
5.B	Biological Treatment of Solid Waste	CH_4	1 066,6	1735,718	0%	93%
4.C.2.c	Wetland converted to Grassland – all pools	CO_2	151,7	-501,689	0%	94%
2.D.2	Non-energy Products from Fuels and Solvent Use - Paraffin wax use	CO_2	7,4	609,096	0%	94%
4.C.2.b	Cropland converted to Grassland – all pools	CO_2	-1 699,5	-2297,795	0%	94%
1.A.1	Energy Industries - Liquid Fuels	CO_2	32 254,1	32790,163	0%	95%
1.A.4	Other Sectors - Gaseous Fuels	CO_2	12,9	525,721	0%	95%
4.C.1.b	Grassland remaining Grassland – dead organic matter	CO_2	-14,9	-518,338	0%	95%
5.D	Wastewater Treatment and Discharge - Industrial	CH_4	5 489,1	5015,537	0%	95%
3.A.4	Goats	CH_4	1 990,8	1578,606	0%	96%
4.A.2.d	Settlements converted to forest land – all pools	CO_2	-424,4	-805,639	0%	96%
2.B.6	Titanium Dioxide Production	C	C	C	C	96%
5.B	Biological Treatment of Solid Waste	N_2O	425,6	794,658	0%	96%

Code	Category Title	GHG	2000 Estimates	2022 Estimates	Contribution to Trend	Cumulative Total
2.D.1	Non-energy Products from Fuels and Solvent Use - Lubricant use	CO_2	188,5	515,689	0%	96%
4.B.2.a	Forest land converted to Cropland – all pools	CO_2	1 736,3	1423,508	0%	96%
3.B.4	Poultry	N_2O	557,3	857,768	0%	97%
3.H	Urea Application	CO_2	297,3	584,663	0%	97%
1.B.1.c	Fugitive emissions from Solid Fuels - Solid fuel transformation	CO_2	64,4	349,124	0%	97%
2.B.1	Ammonia Production	C	C	C	C	97%
2.A.2	Lime Production	C	C	C	C	97%
5.D	Wastewater Treatment and Discharge - Domestic	N_2O	466,2	724,274	0%	97%
4.B.2.b	Grassland converted to Cropland – all pools	CO_2	2 141,6	1894,320	0%	97%
3.A.1.a.i	Dairy Cattle	CH_4	3 884,1	3639,745	0%	97%
1.A.4	Other Sectors - Solid Fuels	N_2O	449,5	207,055	0%	98%
1.B.1.a	Coal mining and handling	CH_4	1 894,6	1672,412	0%	98%
4.A.2.e	Other land converted to forest land – all pools	CO_2	-1 225,3	-1447,324	0%	98%
1.B.1.c	Solid fuel transformation	CH_4	49,6	250,689	0%	98%
1.A.3.c	Railways	CO_2	555,5	361,554	0%	98%
3.D.1	Direct N_2O Emissions From Managed Soils	N_2O	9 574,6	9382,894	0%	98%
4.E.2.a	Forest land converted to settlements – all pools	CO_2	707,6	525,481	0%	98%
1.A.3.b	Road Transportation	N_2O	466,0	646,549	0%	98%
1.A.5	Other (Not specified elsewhere) - Solid Fuels	N_2O	327,3	502,957	0%	98%
4.E.1.a	Settlements remaining Settlements – biomass	CO_2	-275,9	-437,241	0%	98%
4.D.2	Land Converted to Wetlands	N_2O	101,0	256,582	0%	98%
2.A.4	Other Process Uses of Carbonates	CO_2	0,0	147,261	0%	99%
4.D.1	Wetlands Remaining Wetlands	CO_2	59,6	203,124	0%	99%
4.D.1	Wetlands Remaining Wetlands	N_2O	426,4	287,769	0%	99%

Code	Category Title	GHG	2000 Estimates	2022 Estimates	Contribution to Trend	Cumulative Total
5.C	Incineration and Open Burning of Waste	CH_4	114,1	243,318	0%	99%
4.A.2.c	Wetland converted to forest land – all pools	CO_2	-949,7	-1073,396	0%	99%
1.A.5	Other (Not specified elsewhere) - Solid Fuels	CH_4	220,7	340,897	0%	99%
2.A.3	Glass Production	C	C	C	C	99%
3.B.1.a.ii	Non-dairy Cattle	N_2O	818,5	927,249	0%	99%
2.C.6	Zinc Production	C	C	C	C	99%
4.B.2.e	Other land converted to Cropland – all pools	CO_2	-11,2	-106,553	0%	99%
4.B.1.a	Cropland remaining Cropland – biomass (above and below)	CO_2	248,5	156,878	0%	99%
4.E.2.c	Grassland converted to settlements – all pools	CO_2	177,0	268,546	0%	99%
4(V)	Biomass Burning	CH_4	2 009,8	2098,636	0%	99%
2.F.3	Fire Protection	F-gases	0,0	87,504	0%	99%
4.C.2.d	Settlements converted to Grassland – all pools	CO_2	-29,6	-110,166	0%	99%
2.B.8	Hydrogen Production	C	C	C	C	99%
1.A.4	Other Sectors - Solid Fuels	CH_4	235,8	161,810	0%	99%
4.D.2	Land Converted to Wetlands	CO_2	616,1	544,821	0%	99%
1.A.3.d	Domestic Navigation - Liquid Fuels	CO_2	428,1	495,486	0%	99%
2.G	Other Product Manufacture and Use	CO_2	0,0	65,711	0%	99%
4.B.1.b	Cropland remaining Cropland – dead organic matter	CO_2	3,8	-61,020	0%	99%
3.B.4	Poultry	CH_4	112,7	175,419	0%	100%
3.D.2	Indirect N_2O Emissions From Managed Soils	N_2O	1 056,5	995,231	0%	100%
1.A.5	Other (Not specified elsewhere) - Gaseous Fuels	CO_2	175,7	227,192	0%	100%
3.B.3	Swine	CH_4	256,2	208,933	0%	100%
2.C.3	Aluminium Production	C	C	C	C	100%
4.B.2.d	Settlements converted to Cropland – all pools	CO_2	17,4	-24,787	0%	100%

Code	Category Title	GHG	2000 Estimates	2022 Estimates	Contribution to Trend	Cumulative Total
3.G	Liming	CO_2	1 820,0	1860,710	0%	100%
2.B.8	Petrochemical and Carbon Black Production	C	C	C	C	100%
3.B.1.a.i	Dairy Cattle	CH_4	599,1	561,405	0%	100%
2.B.5	Carbide Production	C	C	C	C	100%
3.B.5	Indirect N_2O Emissions From Manure Management	N_2O	291,9	325,159	0%	100%
3.A.4	Horses	CH_4	136,1	167,973	0%	100%
5.C	Incineration and Open Burning of Waste	N_2O	24,9	53,142	0%	100%
1.A.1	Energy Industries - Liquid Fuels	CH_4	15,9	42,852	0%	100%
2.B.1	Ammonia Production	C	C	C	C	100%
1.A.1	Energy Industries - Solid Fuels	N_2O	764,1	789,069	0%	100%
1.A.3.e	Railways	N_2O	56,4	33,335	0%	100%
3.B.2	Sheep	CH_4	108,8	87,598	0%	100%
3.B.1.a.ii	Non-dairy Cattle	CH_4	701,8	681,523	0%	100%
4.E.2.b	Cropland converted to settlements – all pools	CO_2	-61,3	-81,417	0%	100%
1.A.2	Manufacturing Industries and Construction - Solid Fuels	N_2O	130,0	150,010	0%	100%
2.B.10	Other	C	C	C	C	100%
4.F.2.a	Forest land converted to other land – all pools	CO_2	780,7	761,614	0%	100%
2.F.4	Aerosols	F-gases	0,0	18,255	0%	100%
4.E.1.b	Settlements remaining Settlements – dead organic matter	CO_2	8,5	-8,964	0%	100%
1.B.3	Other emissions from energy production	CH_4	2 949,5	2933,252	0%	100%
3.B.2	Sheep	N_2O	159,2	143,505	0%	100%
5.C	Incineration and Open Burning of Waste	CO_2	13,6	28,909	0%	100%
1.A.4	Other Sectors - Liquid Fuels	N_2O	12,9	27,421	0%	100%
3.B.1.a.i	Dairy Cattle	N_2O	230,0	215,536	0%	100%

Code	Category Title	GHG	2000 Estimates	2022 Estimates	Contribution to Trend	Cumulative Total
1.A.1	Energy Industries - Liquid Fuels	N_2O	97,7	112,053	0%	100%
1.A.2	Manufacturing Industries and Construction - Solid Fuels	CH_4	49,3	62,980	0%	100%
1.A.3.a	Domestic Aviation	N_2O	16,8	4,953	0%	100%
1.B.2	Oil and Natural Gas	N_2O	1,0	11,010	0%	100%
3.B.4	Goats	N_2O	59,2	49,208	0%	100%
3.A.3	Swine	CH_4	53,0	43,218	0%	100%
3.F	Field burning of agricultural residues	CH_4	55,5	47,006	0%	100%
2.C.5	Lead Production	C	C	C	C	100%
1.A.4	Other Sectors - Liquid Fuels	CH_4	6,9	14,778	0%	100%
1.A.3.b	Road Transportation	CH_4	330,5	322,809	0%	100%
4.F.2.b	Cropland converted to other land – all pools	CO_2	9,2	2,240	0%	100%
4(V)	Biomass Burning	N_2O	1 321,7	1328,568	0%	100%
3.B.4	Goats	CH_4	33,7	27,052	0%	100%
2.B.7	Soda Ash Production	C	C	C	C	100%
4.E.2.e	Other land converted to settlements – all pools	CO_2	-9,8	-15,823	0%	100%
3.B.3	Swine	N_2O	29,6	24,169	0%	100%
2.B.5	Carbide Production	C	C	C	C	100%
2.C.2	Ferroalloys Production	C	C	C	C	100%
1.B.1.c	Solid fuel transformation	N_2O	0,9	4,671	0%	100%
1.A.5	Other (Not specified elsewhere) - Liquid Fuels	N_2O	5,3	1,703	0%	100%
4.B.2.c	Wetland converted to Cropland – all pools	CO_2	246,3	242,865	0%	100%
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	N_2O	2,6	5,703	0%	100%
2.B.2	Nitric Acid Production	C	C	C	C	100%
1.B.1.a	Coal mining and handling	CO_2	18,6	16,430	0%	100%

Code	Category Title	GHG	2000 Estimates	2022 Estimates	Contribution to Trend	Cumulative Total
2.F.2	Foam Blowing Agents	F-gases	0,0	2,104	0%	100%
3.F	Field burning of agricultural residues	N_2O	13,6	11,534	0%	100%
1.A.5	Other (Not specified elsewhere) - Liquid Fuels	CH_4	2,9	0,987	0%	100%
1.A.1	Fuel combustion - Energy Industries - Solid Fuels	CH_4	53,8	55,582	0%	100%
1.B.2	Oil and Natural Gas	CH_4	12,0	13,691	0%	100%
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	CH_4	1,0	2,735	0%	100%
2.B.2	Nitric Acid Production	C	C	C	C	100%
1.A.2	Manufacturing Industries and Construction - Gaseous Fuels	N_2O	0,9	2,588	0%	100%
0	Wetlands converted to settlements (all pools)	CO_2	6,4	7,901	0%	100%
2.C.2	Ferroalloys Production	C	C	C	C	100%
4.B.1.c	Cropland remaining Cropland – soil (mineral)	CO_2	-17,8	-16,351	0%	100%
1.A.2	Manufacturing Industries and Construction - Liquid Fuels	CO_2	1,4	2,706	0%	100%
4.F.2.d	Settlements converted to other land – all pools	CO_2	8,7	7,517	0%	100%
0	Wetlands converted to other land (all pools)	CO_2	134,2	133,120	0%	100%
1.A.3.d	Domestic Navigation - Liquid Fuels	N_2O	1,5	2,535	0%	100%
1.A.1	Fuel combustion - Energy Industries - Gaseous Fuels	CH_4	1,1	0,391	0%	100%
1.A.1	Fuel combustion - Energy Industries - Gaseous Fuels	N_2O	1,1	0,370	0%	100%
1.A.3.a	Domestic Aviation	CH_4	0,4	0,131	0%	100%
1.A.3.e	Railways	CH_4	0,9	0,602	0%	100%
1.A.4	Other Sectors - Gaseous Fuels	CH_4	0,0	0,264	0%	100%
1.A.4	Other Sectors - Gaseous Fuels	N_2O	0,0	0,250	0%	100%
1.A.3.d	Domestic Navigation - Liquid Fuels	CH_4	1,1	1,321	0%	100%
3.A.4	Mules & Asses	CH_4	45,9	45,796	0%	100%
2.C.2	Ferroalloys Production	C	C	C	C	100%

Code	Category Title	GHG	2000 Estimates	2022 Estimates	Contribution to Trend	Cumulative Total
2.B.10	Other	C	C	C	C	100%
1.A.5	Other (Not specified elsewhere) - Gaseous Fuels	CH_4	0,1	0,114	0%	100%
1.A.5	Other (Not specified elsewhere) - Gaseous Fuels	N_2O	0,1	0,108	0%	100%
2.B.8	Petrochemical and Carbon Black Production	C	C	C	C	100%
2.C.1	Iron and Steel Production	C	C	C	C	100%
4.A.1.c	Forest land remaining forest land – soil (mineral)	CO_2	0,0	0,000	0%	100%
4.C.1.c	Grassland remaining Grassland – soil (mineral)	CO_2	0,0	0,000	0%	100%
4.E.1.c	Settlements remaining Settlements – soil (mineral)	CO_2	0,0	0,000	0%	100%
4.F.1.a	Other land remaining Other land – biomass	CO_2	0,0	0,000	0%	100%

C=Confidential data

Appendix B: Uncertainty analysis

Table B.1: Overall uncertainty analysis including LULUCF for 2000 to 2022.

IPCC Category		Gas	Base year emissions/ removals (2000)	Year t emissions/ removals (2017)	Activity data uncertainty		Emission factor/estimation parameter uncertainty		Combined uncertainty		Contribution to variance in Year t		Uncertainty in trend in national emissions introduced by EF/ estimation parameter uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
			Gg CO2e	Gg CO2e	(-)%	(+)%	(-)%	(+)%	(-)%	(+)%	Lower (%)	Upper (%)	%	%	%
1A1a	Electricity and Heat Production	CO2	185 128.6	196 116.1	3.00%	5.00%	7.00%	7.00%	7.62%	8.60%	0.1174%	0.1498%	0.33%	3.00%	0.09%
1A1b	Petroleum Refining	CO2	4 005.3	1 078.7	3.00%	5.00%	7.00%	7.00%	7.62%	8.60%	0.0000%	0.0000%	0.04%	0.02%	0.00%
1A1c	Manufacture of Solid Fuels and Other Energy Industries	CO2	30 454.7	27 461.1	3.00%	5.00%	7.00%	7.00%	7.62%	8.60%	0.0023%	0.0029%	0.02%	0.42%	0.00%
1A1a	Electricity and Heat Production	CH4	53.9	61.3	3.00%	5.00%	75.00%	75.00%	75.06%	75.17%	0.0000%	0.0000%	0.00%	0.00%	0.00%
1A1b	Petroleum Refining	CH4	2.8	0.6	3.00%	5.00%	75.00%	75.00%	75.06%	75.17%	0.0000%	0.0000%	0.00%	0.00%	0.00%
1A1c	Manufacture of Solid Fuels and Other Energy Industries	CH4	14.2	36.9	3.00%	5.00%	75.00%	75.00%	75.06%	75.17%	0.0000%	0.0000%	0.00%	0.00%	0.00%
1A1a	Electricity and Heat Production	N2O	764.4	799.9	3.00%	5.00%	75.00%	75.00%	75.06%	75.17%	0.0002%	0.0002%	0.01%	0.01%	0.00%
1A1b	Petroleum Refining	N2O	4.2	0.8	3.00%	5.00%	75.00%	75.00%	75.06%	75.17%	0.0000%	0.0000%	0.00%	0.00%	0.00%
1A1c	Manufacture of Solid Fuels and Other Energy Industries	N2O	94.3	100.7	3.00%	5.00%	75.00%	75.00%	75.06%	75.17%	0.0000%	0.0000%	0.00%	0.00%	0.00%

1A2	Manufacturing Industries and Construction	CO2	20 946.7	26 419.9	5.00%	10.00%	7.00%	7.00%	8.60%	12.21%	0.0027%	0.0055%	0.10%	0.81%	0.01%
1A2	Manufacturing Industries and Construction	CH4	51.7	68.4	5.00%	10.00%	75.00%	75.00%	75.17%	75.66%	0.0000%	0.0000%	0.00%	0.00%	0.00%
1A2	Manufacturing Industries and Construction	N2O	133.5	158.3	5.00%	10.00%	75.00%	75.00%	75.17%	75.66%	0.0000%	0.0000%	0.01%	0.00%	0.00%
1A3a	Civil Aviation	CO2	2 315.9	683.9	5.00%	5.00%	1.50%	1.50%	5.22%	5.22%	0.0000%	0.0000%	0.00%	0.01%	0.00%
1A3b	Road Transport	CO2	37 448.9	50 190.1	5.00%	5.00%	2.00%	2.00%	5.39%	5.39%	0.0038%	0.0038%	0.06%	0.77%	0.01%
1A3c	Railways	CO2	555.5	361.6	5.00%	5.00%	2.00%	2.00%	5.39%	5.39%	0.0000%	0.0000%	0.00%	0.01%	0.00%
1A3d	Water-Borne Navigation	CO2	428.1	495.5	5.00%	5.00%	3.00%	3.00%	5.83%	5.83%	0.0000%	0.0000%	0.00%	0.01%	0.00%
1A3a	Civil Aviation	CH4	0.4	0.1	5.00%	5.00%	70.00%	70.00%	70.18%	70.18%	0.0000%	0.0000%	0.00%	0.00%	0.00%
1A3b	Road Transport	CH4	330.5	322.8	5.00%	5.00%	9.00%	9.00%	10.30%	10.30%	0.0000%	0.0000%	0.00%	0.00%	0.00%
1A3c	Railways	CH4	0.9	0.6	5.00%	5.00%	9.00%	9.00%	10.30%	10.30%	0.0000%	0.0000%	0.00%	0.00%	0.00%
1A3d	Water-Borne Navigation	CH4	1.1	1.3	5.00%	5.00%	50.00%	50.00%	50.25%	50.25%	0.0000%	0.0000%	0.00%	0.00%	0.00%
1A3a	Civil Aviation	N2O	16.8	5.0	5.00%	5.00%	70.00%	50.00%	70.18%	50.25%	0.0000%	0.0000%	0.00%	0.00%	0.00%
1A3b	Road Transport	N2O	466.0	646.5	5.00%	5.00%	70.00%	72.00%	70.18%	72.17%	0.0001%	0.0001%	0.03%	0.01%	0.00%
1A3c	Railways	N2O	56.4	33.3	5.00%	5.00%	70.00%	72.00%	70.18%	72.17%	0.0000%	0.0000%	0.00%	0.00%	0.00%
1A3d	Water-Borne Navigation	N2O	3.1	3.6	5.00%	5.00%	40.00%	140.00 %	40.31%	140.09%	0.0000%	0.0000%	0.00%	0.00%	0.00%
1A4a	Commercial/Institutional	CO2	20 516.6	12 037.7	5.00%	10.00%	7.00%	7.00%	8.60%	12.21%	0.0006%	0.0011%	0.11%	0.37%	0.00%
1A4b	Residential	CO2	26 941.0	3 495.5	5.00%	10.00%	7.00%	7.00%	8.60%	12.21%	0.0000%	0.0001%	0.33%	0.11%	0.00%
1A4c	Agriculture/Forestry/Fishing/Fish Farms	CO2	2 407.3	3 084.3	5.00%	10.00%	7.00%	7.00%	8.60%	12.21%	0.0000%	0.0001%	0.01%	0.09%	0.00%
1A4a	Commercial/Institutional	CH4	7.8	11.3	5.00%	10.00%	75.00%	75.00%	75.17%	75.66%	0.0000%	0.0000%	0.00%	0.00%	0.00%
1A4b	Residential	CH4	232.3	162.1	5.00%	10.00%	75.00%	75.00%	75.17%	75.66%	0.0000%	0.0000%	0.01%	0.00%	0.00%
1A4c	Agriculture/Forestry/Fishing/Fish Farms	CH4	2.6	3.5	5.00%	10.00%	75.00%	75.00%	75.17%	75.66%	0.0000%	0.0000%	0.00%	0.00%	0.00%

1A4a	Commercial/Institutional	N2O	79.8	27.7	5.00%	10.00%	75.00%	75.00%	75.17%	75.66%	0.0000%	0.0000%	0.01%	0.00%	0.00%
1A4b	Residential	N2O	376.9	200.2	5.00%	10.00%	75.00%	75.00%	75.17%	75.66%	0.0000%	0.0000%	0.03%	0.01%	0.00%
1A4c	Agriculture/Forestry/Fishing/Fish Farms	N2O	5.7	6.8	5.00%	10.00%	75.00%	75.00%	75.17%	75.66%	0.0000%	0.0000%	0.00%	0.00%	0.00%
1A5a	Stationary	CO2	15 527.3	20 351.6	3.00%	5.00%	7.00%	7.00%	7.62%	8.60%	0.0013%	0.0016%	0.09%	0.31%	0.00%
1A5a	Stationary	CH4	223.6	342.0	3.00%	5.00%	75.00%	75.00%	75.06%	75.17%	0.0000%	0.0000%	0.02%	0.01%	0.00%
1A5a	Stationary	N2O	332.7	504.8	3.00%	5.00%	75.00%	75.00%	75.06%	75.17%	0.0001%	0.0001%	0.03%	0.01%	0.00%
1B1a	Coal mining and handling	CO2	18.6	16.4	10.00%	10.00%	63.00%	63.00%	63.79%	63.79%	0.0000%	0.0000%	0.00%	0.00%	0.00%
1B1a	Coal mining and handling	CH4	1 894.6	1 672.4	10.00%	10.00%	63.00%	63.00%	63.79%	63.79%	0.0006%	0.0006%	0.02%	0.05%	0.00%
1B1c	Solid fuel transformation	CO2	64.4	349.1	10.00%	10.00%	63.00%	63.00%	63.79%	63.79%	0.0000%	0.0000%	0.04%	0.01%	0.00%
1B1c	Solid fuel transformation	CH4	49.6	250.7	10.00%	10.00%	63.00%	63.00%	63.79%	63.79%	0.0000%	0.0000%	0.03%	0.01%	0.00%
1B1c	Solid fuel transformation	N2O	0.9	4.7	10.00%	10.00%	63.00%	63.00%	63.79%	63.79%	0.0000%	0.0000%	0.00%	0.00%	0.00%
1B2a	Oil	CO2	752.0	69.6	25.00%	25.00%	75.00%	75.00%	79.06%	79.06%	0.0000%	0.0000%	0.10%	0.01%	0.00%
1B2a	Oil	CH4	12.0	13.7	25.00%	25.00%	75.00%	75.00%	79.06%	79.06%	0.0000%	0.0000%	0.00%	0.00%	0.00%
1B2a	Oil	N2O	1.0	11.0	25.00%	25.00%	75.00%	75.00%	79.06%	79.06%	0.0000%	0.0000%	0.00%	0.00%	0.00%
1B3	Other Emissions from Energy Production	CO2	28 146.6	23 477.0	25.00%	25.00%	75.00%	75.00%	79.06%	79.06%	0.1814%	0.1814%	0.50%	1.80%	0.03%
1B3	Other Emissions from Energy Production	CH4	2 949.5	2 933.3	25.00%	25.00%	75.00%	75.00%	79.06%	79.06%	0.0028%	0.0028%	0.02%	0.22%	0.00%
2A1	Cement Production	CO2	3 870.6	5 022.7	30.00%	30.00%	35.00%	35.00%	46.10%	46.10%	0.0028%	0.0028%	0.10%	0.46%	0.00%
2A2	Lime Production	CO2	426.1	693.7	30.00%	30.00%	6.00%	6.00%	30.59%	30.59%	0.0000%	0.0000%	0.00%	0.06%	0.00%
2A3	Glass Production	CO2	74.4	191.4	1.00%	3.00%	1.00%	3.00%	1.41%	4.24%	0.0000%	0.0000%	0.00%	0.00%	0.00%
2A4a	Ceramics	CO2	0.0	34.3	1.00%	85.00%	1.00%	5.00%	1.41%	85.15%	0.0000%	0.0000%	0.00%	0.01%	0.00%
2A4b	Other Uses of Soda Ash	CO2	0.0	31.5	1.00%	85.00%	1.00%	5.00%	1.41%	85.15%	0.0000%	0.0000%	0.00%	0.01%	0.00%
2A4d	Other	CO2	0.0	81.5	15.00%	85.00%	1.00%	5.00%	15.03%	85.15%	0.0000%	0.0000%	0.00%	0.02%	0.00%

2B1	Ammonia Production	CO2	485.3	209.4	2.00%	2.00%	2.00%	2.00%	2.83%	2.83%	0.0000%	0.0000%	0.00%	0.00%	0.00%
2B1	Ammonia Production	CH4	87.4	113.7	2.00%	2.00%	2.00%	2.00%	2.83%	2.83%	0.0000%	0.0000%	0.00%	0.00%	0.00%
2B2	Nitric Acid Production	CO2	0.0	1.7	2.00%	2.00%	2.00%	2.00%	2.83%	2.83%	0.0000%	0.0000%	0.00%	0.00%	0.00%
2B3	Nitric Acid Production	CH4	0.0	2.6	2.00%	2.00%	2.00%	2.00%	2.83%	2.83%	0.0000%	0.0000%	0.00%	0.00%	0.00%
2B2	Nitric Acid Production	N2O	1 405.8	364.3	2.00%	2.00%	2.00%	2.00%	2.83%	2.83%	0.0000%	0.0000%	0.00%	0.00%	0.00%
2B5	Carbide Production	CO2	2.0	37.4	5.00%	5.00%	10.00%	10.00%	11.18%	11.18%	0.0000%	0.0000%	0.00%	0.00%	0.00%
2B5	Carbide Production	CH4	0.0	4.6	5.00%	5.00%	10.00%	10.00%	11.18%	11.18%	0.0000%	0.0000%	0.00%	0.00%	0.00%
2B6	Titanium Dioxide Production	CO2	437.6	813.8	2.00%	2.00%	2.00%	2.00%	2.83%	2.83%	0.0000%	0.0000%	0.00%	0.00%	0.00%
2B7	Soda Ash Production	CO2	0.0	6.4	5.00%	5.00%	0.00%	0.00%	5.00%	5.00%	0.0000%	0.0000%	0.00%	0.00%	0.00%
2B8f	Carbon Black production	CO2	138.6	100.6	15.00%	15.00%	15.00%	15.00%	21.21%	21.21%	0.0000%	0.0000%	0.00%	0.00%	0.00%
2B8f	Carbon Black production	CH4	0.1	0.1	85.00%	85.00%	85.00%	85.00%	120.21 %	120.21%	0.0000%	0.0000%	0.00%	0.00%	0.00%
2B8g	Hydrogen Production	CO2	0.0	79.1	2.00%	2.00%	2.00%	2.00%	2.83%	2.83%	0.0000%	0.0000%	0.00%	0.00%	0.00%
2B10	Other	CO2	0.0	19.3	5.00%	5.00%	10.00%	10.00%	11.18%	11.18%	0.0000%	0.0000%	0.00%	0.00%	0.00%
2B10	Other	CH4	0.0	0.0	5.00%	5.00%	10.00%	10.00%	11.18%	11.18%	0.0000%	0.0000%	0.00%	0.00%	0.00%
2C1	Iron and Steel Production	CO2	15 334.4	6 307.2	5.00%	10.00%	25.00%	25.00%	25.50%	26.93%	0.0014%	0.0015%	0.44%	0.19%	0.00%
2C1	Iron and Steel Production	CH4	0.0	0.0	5.00%	10.00%	25.00%	25.00%	25.50%	26.93%	0.0000%	0.0000%	0.00%	0.00%	0.00%
2C2	Ferroalloys Production	CO2	8 079.1	8 080.6	5.00%	5.00%	5.00%	25.00%	7.07%	25.50%	0.0002%	0.0022%	0.03%	0.12%	0.00%
2C2	Ferroalloys Production	CH4	4.4	0.1	5.00%	5.00%	25.00%	25.00%	25.50%	25.50%	0.0000%	0.0000%	0.00%	0.00%	0.00%
2C2	Ferroalloys Production	N2O	0.0	0.1	5.00%	5.00%	25.00%	25.00%	25.50%	25.50%	0.0000%	0.0000%	0.00%	0.00%	0.00%
2C3	Aluminium Production	CO2	1 091.3	1 133.5	1.00%	1.00%	5.00%	5.00%	5.10%	5.10%	0.0000%	0.0000%	0.00%	0.00%	0.00%

2C3	Aluminium Production	PFCs	1 025.0	125.9	1.00%	1.00%	15.00%	15.00%	15.03%	15.03%	0.0000%	0.0000%	0.03%	0.00%	0.00%
2C5	Lead Production	CO2	15.1	7.2	10.00%	10.00%	50.00%	50.00%	50.99%	50.99%	0.0000%	0.0000%	0.00%	0.00%	0.00%
2C6	Zinc Production	CO2	108.4	0.0	10.00%	10.00%	50.00%	50.00%	50.99%	50.99%	0.0000%	0.0000%	0.01%	0.00%	0.00%
2D1	Lubricant Use	CO2	188.5	515.7	10.00%	20.00%	50.00%	50.00%	50.99%	53.85%	0.0000%	0.0000%	0.04%	0.03%	0.00%
2D2	Paraffin Wax Use	CO2	7.4	609.1	10.00%	20.00%	50.00%	50.00%	50.99%	53.85%	0.0001%	0.0001%	0.07%	0.04%	0.00%
2F1	Refrigeration and Air Conditioning	HFCs	0.0	5 836.9	25.00%	25.00%	25.00%	25.00%	35.36%	35.36%	0.0022%	0.0022%	0.32%	0.45%	0.00%
2F2	Foam Blowing Agents	HFCs	0.0	2.1	50.00%	50.00%	25.00%	25.00%	55.90%	55.90%	0.0000%	0.0000%	0.00%	0.00%	0.00%
2F3	Fire Protection	HFCs	0.0	87.5	25.00%	25.00%	25.00%	25.00%	35.36%	35.36%	0.0000%	0.0000%	0.00%	0.01%	0.00%
2F4	Aerosols	HFCs	0.0	18.3	25.00%	25.00%	25.00%	25.00%	35.36%	35.36%	0.0000%	0.0000%	0.00%	0.00%	0.00%
2G1	Use of Electrical equipment	SF6	0.0	65.7	25.00%	25.00%	25.00%	25.00%	35.36%	35.36%	0.0000%	0.0000%	0.00%	0.01%	0.00%
3A1	Enteric fermentation - cattle	CH4	31 660.5	28 139.0	17.19%	17.19%	13.82%	13.82%	22.06%	22.06%	0.0203%	0.0203%	0.05%	1.48%	0.02%
3A2	Enteric fermentation - sheep	CH4	8 121.1	6 377.5	13.07%	13.07%	30.80%	30.80%	33.46%	33.46%	0.0024%	0.0024%	0.09%	0.25%	0.00%
3A3	Enteric fermentation - swine	CH4	53.0	43.2	50.25%	50.25%	20.00%	20.00%	54.08%	54.08%	0.0000%	0.0000%	0.00%	0.01%	0.00%
3A4d	Enteric fermentation - goats	CH4	1 990.8	1 578.6	20.62%	20.62%	35.50%	35.50%	41.05%	41.05%	0.0002%	0.0002%	0.02%	0.10%	0.00%
3A4e	Enteric fermentation - horses	CH4	136.1	168.0	7.07%	7.07%	40.00%	40.00%	40.62%	40.62%	0.0000%	0.0000%	0.00%	0.00%	0.00%
3A4f	Enteric fermentation - mules and asses	CH4	45.9	45.8	11.18%	11.18%	40.00%	40.00%	41.53%	41.53%	0.0000%	0.0000%	0.00%	0.00%	0.00%
3A4h	Enteric fermentation - other game	CH4	0.0	0.0					0.00%	0.00%	0.0000%	0.0000%	0.00%	0.00%	0.00%

3B1	Manure management - cattle	CH4	1 300.9	1 242.9	17.19%	17.19%	12.00%	12.00%	20.97%	20.97%	0.0000%	0.0000%	0.00%	0.07%	0.00%
3B2	Manure management - sheep	CH4	108.8	87.6	13.07%	13.07%	16.00%	16.00%	20.66%	20.66%	0.0000%	0.0000%	0.00%	0.00%	0.00%
3B3	Manure management - swine	CH4	256.2	208.9	50.25%	50.25%	20.00%	20.00%	54.08%	54.08%	0.0000%	0.0000%	0.00%	0.03%	0.00%
3B4d	Manure management - goats	CH4	33.7	27.1	20.62%	20.62%	47.75%	47.75%	52.01%	52.01%	0.0000%	0.0000%	0.00%	0.00%	0.00%
3B4e	Manure management - horses	CH4	0.0	0.0	7.07%	7.07%	30.00%	30.00%	30.82%	30.82%	0.0000%	0.0000%	0.00%	0.00%	0.00%
3B4f	Manure management - mules and asses	CH4	0.0	0.0	11.18%	11.18%	30.00%	30.00%	32.02%	32.02%	0.0000%	0.0000%	0.00%	0.00%	0.00%
3B4g	Manure management - poultry	CH4	112.7	175.4	20.62%	20.62%	20.00%	20.00%	28.72%	28.72%	0.0000%	0.0000%	0.00%	0.01%	0.00%
3B4h	Manure management - other game	CH4	0.0	0.0					0.00%	0.00%	0.0000%	0.0000%	0.00%	0.00%	0.00%
3A2a	Manure management - cattle	N2O	1 048.5	1 142.8	43.20%	43.20%	50.00%	100.00 %	66.08%	108.93%	0.0003%	0.0008%	0.03%	0.15%	0.00%
3A2c	Manure management - sheep	N2O	159.2	143.5	32.95%	32.95%	50.00%	100.00 %	59.88%	105.29%	0.0000%	0.0000%	0.00%	0.01%	0.00%
3B3	Manure management - swine	N2O	29.6	24.2	59.37%	59.37%	50.00%	100.00 %	77.62%	116.30%	0.0000%	0.0000%	0.00%	0.00%	0.00%
3A2d	Manure management - goats	N2O	59.2	49.2	36.46%	36.46%	50.00%	100.00 %	61.88%	106.44%	0.0000%	0.0000%	0.00%	0.01%	0.00%

3B4e	Manure management - horses	N2O	0.0	0.0	31.22%	31.22%	50.00%	100.00 %	58.95%	104.76%	0.0000%	0.0000%	0.00%	0.00%	0.00%
3B4f	Manure management - mules and asses	N2O	0.0	0.0	32.08%	32.08%	50.00%	100.00 %	59.41%	105.02%	0.0000%	0.0000%	0.00%	0.00%	0.00%
3B4g	Manure management - poultry	N2O	557.3	857.8	44.16%	44.16%	50.00%	100.00 %	66.71%	109.32%	0.0002%	0.0005%	0.07%	0.12%	0.00%
3B4h	Manure management - other game	N2O							0.00%	0.00%	0.0000%	0.0000%	0.00%	0.00%	0.00%
3B5	Indirect N2O from manure management	N2O	291.9	325.2	89.47%	89.47%	100.00 %	101.00 %	134.18 %	134.93%	0.0001%	0.0001%	0.01%	0.09%	0.00%
3D1a	Inorganic fertilisers	N2O	1 732.1	1 713.6	15.00%	15.00%	100.00 %	120.00 %	101.12 %	120.93%	0.0016%	0.0023%	0.02%	0.08%	0.00%
3D1b	Organic fertilisers	N2O	643.4	775.6	41.18%	41.18%	100.00 %	120.00 %	108.15 %	126.87%	0.0004%	0.0005%	0.04%	0.10%	0.00%
3D1c	Urine and dund deposited by grazing animals	N2O	6 179.9	5 295.9	53.57%	53.57%	100.00 %	230.00 %	113.44 %	236.16%	0.0190%	0.0823%	0.26%	0.87%	0.01%
3D1d	Crop residues	N2O	426.9	977.7	91.24%	91.24%	100.00 %	120.00 %	135.37 %	150.75%	0.0009%	0.0011%	0.15%	0.27%	0.00%
3D1e	FSOM	N2O	592.2	620.1	5.00%	5.00%	100.00 %	230.00 %	100.12 %	230.05%	0.0002%	0.0011%	0.03%	0.01%	0.00%
3D2a	Atmospheric deposition	N2O	995.4	921.6	203.94 %	203.94 %	100.00 %	120.00 %	227.13 %	236.62%	0.0023%	0.0025%	0.00%	0.58%	0.00%
3D2b	Nitrogen leaching and runoff	N2O	61.1	73.6	58.45%	58.45%	100.00 %	82.00%	115.83 %	100.70%	0.0000%	0.0000%	0.00%	0.01%	0.00%
3F	Field burning of agricultural residues	CH4	55.5	47.0	21.21%	21.21%	40.00%	40.00%	45.28%	45.28%	0.0000%	0.0000%	0.00%	0.00%	0.00%
3F	Field burning of agricultural residues	N2O	13.6	11.5	21.21%	21.21%	27.00%	27.00%	34.34%	34.34%	0.0000%	0.0000%	0.00%	0.00%	0.00%
3G	Liming	CO2	1 820.0	1 860.7	75.00%	75.00%	50.00%	50.00%	90.14%	90.14%	0.0015%	0.0015%	0.02%	0.43%	0.00%

3H	Urea application	CO2	297.3	584.7	10.00%	10.00%	50.00%	50.00%	50.99%	50.99%	0.0000%	0.0000%	0.03%	0.02%	0.00%
4A1	Forest land remaining forest land	CO2	-18 206.9	-34 404.1	22.82%	22.82%	56.79%	56.79%	61.20%	61.20%	0.2334%	0.2334%	2.12%	2.40%	0.10%
4A2	Land converted to forest land	CO2	-30 006.8	-55 678.3	30.79%	30.79%	62.15%	62.15%	69.36%	69.36%	0.7852%	0.7852%	3.68%	5.25%	0.41%
4A1	Forest land remaining forest land	CH4	1 008.7	1 138.7	18.53%	18.53%	35.16%	35.16%	39.75%	39.75%	0.0001%	0.0001%	0.01%	0.06%	0.00%
4A2	Land converted to forest land	CH4	500.1	475.6	27.92%	27.92%	29.95%	29.95%	40.95%	40.95%	0.0000%	0.0000%	0.00%	0.04%	0.00%
4A1	Forest land remaining forest land	N2O	535.6	568.7	18.53%	18.53%	37.05%	37.05%	41.42%	41.42%	0.0000%	0.0000%	0.01%	0.03%	0.00%
4A2	Land converted to forest land	N2O	352.7	340.6	27.92%	27.92%	31.56%	31.56%	42.14%	42.14%	0.0000%	0.0000%	0.00%	0.03%	0.00%
4B1	Cropland remaining cropland	CO2	234.6	79.5	9.99%	9.99%	21.79%	21.79%	23.97%	23.97%	0.0000%	0.0000%	0.01%	0.00%	0.00%
4B2	Land converted to cropland	CO2	4 130.5	3 429.4	19.88%	19.88%	22.05%	22.05%	29.68%	29.68%	0.0005%	0.0005%	0.02%	0.21%	0.00%
4C1	Grassland remaining grassland	CO2	-1 546.3	12 649.3	28.10%	28.10%	30.72%	30.72%	41.64%	41.64%	0.0146%	0.0146%	0.94%	1.09%	0.02%
4C2	Land converetd to grassland	CO2	-1 739.2	-2 072.4	21.27%	21.27%	30.72%	30.72%	37.37%	37.37%	0.0003%	0.0003%	0.03%	0.13%	0.00%
4C1	Grassland remaining grassland	CH4	501.5	578.7	27.17%	27.17%	39.10%	39.10%	47.61%	47.61%	0.0000%	0.0000%	0.01%	0.05%	0.00%
4C2	Land converetd to grassland	CH4	77.6	127.2	20.40%	20.40%	39.10%	39.10%	44.10%	44.10%	0.0000%	0.0000%	0.00%	0.01%	0.00%
4C1	Grassland remaining grassland	N2O	433.3	500.0	27.17%	27.17%	47.60%	47.60%	54.81%	54.81%	0.0000%	0.0000%	0.01%	0.04%	0.00%
4C2	Land converetd to grassland	N2O	67.5	110.6	20.40%	20.40%	47.60%	47.60%	51.79%	51.79%	0.0000%	0.0000%	0.00%	0.01%	0.00%
4D1	Wetland remaining wetland	CO2	59.6	203.1	11.62%	11.62%	30.00%	30.00%	32.17%	32.17%	0.0000%	0.0000%	0.01%	0.01%	0.00%

4D2	Land converted to wetland	CO2	616.1	544.8	21.51%	21.51%	30.00%	30.00%	36.92%	36.92%	0.0000%	0.0000%	0.00%	0.04%	0.00%
4D1	Wetland remaining wetland	CH4	6 990.6	4 597.6	8.53%	8.53%	39.10%	39.10%	40.02%	40.02%	0.0018%	0.0018%	0.17%	0.12%	0.00%
4D2	Land converted to wetland	CH4	1 655.1	4 099.3	20.23%	20.23%	39.10%	39.10%	44.02%	44.02%	0.0017%	0.0017%	0.21%	0.25%	0.00%
4D1	Wetland remaining wetland	N2O	426.4	287.8	8.53%	8.53%	47.60%	47.60%	48.36%	48.36%	0.0000%	0.0000%	0.01%	0.01%	0.00%
4D2	Land converted to wetland	N2O	101.0	256.6	20.23%	20.23%	47.60%	47.60%	51.72%	51.72%	0.0000%	0.0000%	0.02%	0.02%	0.00%
4E1	Settlement remaining settlement	CO2	-267.4	-446.2	18.16%	18.16%	30.72%	30.72%	35.69%	35.69%	0.0000%	0.0000%	0.01%	0.02%	0.00%
4E2	Land converted to settlements	CO2	819.9	704.7	18.92%	18.92%	30.72%	30.72%	36.08%	36.08%	0.0000%	0.0000%	0.00%	0.04%	0.00%
4E1	Settlement remaining settlement	CH4	3.3	2.0	16.11%	16.11%	39.10%	39.10%	42.29%	42.29%	0.0000%	0.0000%	0.00%	0.00%	0.00%
4E2	Land converted to settlements	CH4	0.6	0.8	17.89%	17.89%	39.10%	39.10%	43.00%	43.00%	0.0000%	0.0000%	0.00%	0.00%	0.00%
4E1	Settlement remaining settlement	N2O	2.9	1.7	16.11%	16.11%	47.60%	47.60%	50.25%	50.25%	0.0000%	0.0000%	0.00%	0.00%	0.00%
4E2	Land converted to settlements	N2O	0.5	0.7	17.89%	17.89%	47.60%	47.60%	50.85%	50.85%	0.0000%	0.0000%	0.00%	0.00%	0.00%
4F1	Other land remaining other land	CO2	0.0	0.0	27.29%	27.29%	15.00%	15.00%	31.14%	31.14%	0.0000%	0.0000%	0.00%	0.00%	0.00%
4F2	Land converted to other land	CO2	7 812.5	19 025.4	34.45%	34.45%	15.00%	15.00%	37.57%	37.57%	0.0269%	0.0269%	0.38%	2.01%	0.04%
4G	Harvested wood products	CO2	-2 106.2	-181.4	10.00%	10.00%	10.00%	10.00%	14.14%	14.14%	0.0000%	0.0000%	0.04%	0.01%	0.00%
5A	Solid Waste Disposal	CH4	4 505.3	8 596.0	50.00%	50.00%	40.00%	40.00%	64.03%	64.03%	0.0159%	0.0159%	0.38%	1.32%	0.02%
5B	Biological Treatment of Solid Waste	CH4	1 066.6	1 735.7	50.00%	50.00%	50.00%	50.00%	70.71%	70.71%	0.0008%	0.0008%	0.08%	0.27%	0.00%

5B	Biological Treatment of Solid Waste	N2O	425.6	794.7	50.00%	50.00%	50.00%	50.00%	70.71%	70.71%	0.0002%	0.0002%	0.04%	0.12%	0.00%
5C2	Open Burning of Waste	CO2	13.6	28.9	50.00%	50.00%	40.00%	40.00%	64.03%	64.03%	0.0000%	0.0000%	0.00%	0.00%	0.00%
5C2	Open Burning of Waste	CH4	114.1	243.3	50.00%	50.00%	100.00 %	100.00 %	111.80 %	111.80%	0.0000%	0.0000%	0.03%	0.04%	0.00%
5C2	Open Burning of Waste	N2O	24.9	53.1	50.00%	50.00%	100.00 %	100.00 %	111.80 %	111.80%	0.0000%	0.0000%	0.01%	0.01%	0.00%
5D1	Domestic wastewater treatment and discharge	CH4	2 257.3	3 506.9	50.00%	50.00%	40.00%	40.00%	64.03%	64.03%	0.0027%	0.0027%	0.12%	0.54%	0.00%
5D1	Domestic wastewater treatment and discharge	N2O	466.2	724.3	50.00%	50.00%	90.00%	90.00%	102.96 %	102.96%	0.0003%	0.0003%	0.06%	0.11%	0.00%
5D2	Industrial wastewater treatment and discharge	CH4	5 489.1	5 015.5	50.00%	50.00%	40.00%	40.00%	64.03%	64.03%	0.0054%	0.0054%	0.01%	0.77%	0.01%
			462 205.4	435 827.7							1.46%	1.57%			0.80%
										Uncertainty in total inventory	12.08%	12.51%		**Trend uncertainty**	8.93%

C = Confidential

Appendix C: Summary emission tables for 2022

Table C.1: Summary emission table for South Africa for 2022.

IPCC 2006 category	Emissions and removals									
	Net CO_2	CH_4	N_2O	HFCs	PFCs	SF6	NOx	CO	NMVOC	Total GHGs
	(Gg)			(Gg CO_2e)			(Gg)			(Gg CO_2e)
Emissions (incl. LULUCF)	**335 992.1**	**2 652.2**	**73.4**	**5 944.8**	**125.9**	**65.7**	**106.6**	**2 241.9**	**211.3**	**435 827.7**
Emissions (excl. LULUCF)	**392 138.4**	**2 258.6**	**65.6**	**5 944.8**	**125.9**	**65.7**	**1.6**	**57.2**	**0.0**	**478 887.5**
1 - Energy	**365 688.0**	**210.0**	**9.4**							**374 072.4**
1.A - Fuel Combustion Activities	341 775.9	36.1	9.4				NE	NE	NE	345 274.5
1.B - Fugitive emissions from fuels	23 912.1	173.9	0.1				NE	NE	NE	28 797.9
1.C - Carbon dioxide Transport and Storage	NE									NE
2 - Industrial Processes and Product Use	**23 976.1**	**4.3**	**1.4**	**5 944.8**	**125.9**	**65.7**				**30 598.0**
2.A - Mineral Industry	6 055.1	NE								6 055.1
2.B - Chemical Industry	1 267.7	4.3	1.4							1 753.1
2.C - Metal Industry	15 528.5	0.0	0.0	NE	125.9					15 654.6
2.D - Non-Energy Products from Fuels and Solvent Use	1 124.8	NE	NE							1 124.8
2.E - Electronics Industry	NE		NE	NE	NE					NE
2.F - Product Uses as Substitutes for Ozone Depleting Substances	NE			5 944.8	NE					5 944.8
2.G - Other Product Manufacture and Use			NE	NE	NE	65.7				65.7
2.H - Other	NA	NA	NA							NA
3 - Agriculture	**2 445.4**	**1 362.2**	**48.8**				**1.6**	**57.2**		**53 518.7**
3.A – Enteric fermentation		1 298.3								36 352.1
3.B – Manure management		62.2	9.6							4 284.5
3.C – Rice cultivation		NO								NO
3.D – Agricultural soils		NA	39.2				NE	NE	NE	10 378.1
3.E – Prescribed burning of savannas		IE	IE				IE	IE	IE	IE

3.F – Field burning of agricultural residues		1.7	0.0				1.6	57.2	NE	58.5
3.G – Liming	1 860.7									1 860.7
3.H – Urea application	584.7									584.7
3.I – Other carbon-containing fertilisers	NE									NE
4 - LULUCF	**-56 146.3**	**393.6**	**7.8**				**105.1**	**2 184.7**	**211.3**	**-43 059.8**
4.A – Forest land	-90 082.4	57.7	3.4				57.7	1 421.2	150.1	-87 558.8
4.B - Cropland	3 508.9	IE	IE				IE	IE	IE	3 508.9
4.C - Grassland	10 576.8	25.2	2.3				42.8	713.2	55.3	11 893.4
4.D - Wetland	747.9	310.6	2.1				4.4	47.6	5.7	9 989.2
4.E - Settlements	258.5	0.1	0.0				0.2	2.7	0.2	263.6
4.F – Other land	19 025.4	NO	IE				NO	NO	NO	19 025.4
4.G – Harvested wood products	-181.4									-181.4
5 - Waste	**28.9**	**682.1**	**5.9**							**20 698.4**
5.A - Solid Waste Disposal		307.0	NE							8 596.0
5.B - Biological Treatment of Solid Waste		62.0	3.0							2 530.4
5.C - Incineration and Open Burning of Waste	28.9	8.7	0.2							325.4
5.D - Wastewater Treatment and Discharge		304.4	2.7							9 246.7
5.E – Other	NO	NO	NO							NO
Memo items										
International bunkers	**3 673.2**	**0.1**	**0.1**							**3 703.8**
International aviation	2 311.0	0.0	0.1							2 328.2
International water-borne transport	1 362.1	0.1	0.0							1 375.7
Multilateral operations	NA	NA	NA							NA

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

Table C.2: Summary Energy sector emission table for South Africa for 2022.

Categories	Emissions (Gg)							Emissions
	CO_2	CH_4	N_2O	NOx	CO	NMVOCs	SO_2	(Gg CO_2e)
1 - Energy	**365 688**	**210**	**9**	**0**	**0**	**0**	**0**	**374 061**
1.A - Fuel Combustion Activities	341 776	36	9	0	0	0	0	345 275
1.A.1 - Energy Industries	*224 656*	*4*	*3*	*0*	*0*	*0*	*0*	*225 656*
1.A.1.a - Main Activity Electricity and Heat Production	196 116	2	3	NE	NE	NE	NE	196 977
1.A.1.a.i - Electricity Generation	*196 116*	*2*	*3*	*NE*	*NE*	*NE*	*NE*	*196 977*
1.A.1.a.ii - Combined Heat and Power Generation (CHP)				*NE*	*NE*	*NE*	*NE*	0
1.A.1.a.iii - Heat Plants				*NE*	*NE*	*NE*	*NE*	0
1.A.1.b - Petroleum Refining	1 079	0	0	NE	NE	NE	NE	1 080
1.A.1.c - Manufacture of Solid Fuels and Other Energy Industries	27 461	1	0	NE	NE	NE	NE	27 599
1.A.1.c.i - Manufacture of Solid Fuels	*27 461*	*1*	*0*	*NE*	*NE*	*NE*	*NE*	*27 599*
1.A.1.c.ii - Other Energy Industries	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*	*NE*
1.A.2 - Manufacturing Industries and Construction	*26 420*	*2*	*1*	*0*	*0*	*0*	*0*	*26 647*
1.A.2.a - Iron and Steel	1 626	0	0	NE	NE	NE	NE	1 630
1.A.2.b - Non-Ferrous Metals	786	0	0	NE	NE	NE	NE	789
1.A.2.-ab - 1A2 Remainder	24 007	2	1	NE	NE	NE	NE	24 228
1.A.2.c - Chemicals	IE	IE	IE	NE	NE	NE	NE	IE
1.A.2.d - Pulp, Paper and Print	IE	IE	IE	NE	NE	NE	NE	IE
1.A.2.e - Food Processing, Beverages and Tobacco	IE	IE	IE	NE	NE	NE	NE	IE
1.A.2.f - Non-Metallic Minerals	IE	IE	IE	NE	NE	NE	NE	IE
1.A.2.g - Transport Equipment	IE	IE	IE	NE	NE	NE	NE	IE
1.A.2.h - Machinery	IE	IE	IE	NE	NE	NE	NE	IE
1.A.2.i - Mining (excluding fuels) and Quarrying	IE	IE	IE	NE	NE	NE	NE	IE
1.A.2.j - Wood and wood products	IE	IE	IE	NE	NE	NE	NE	IE
1.A.2.k - Construction	IE	IE	IE	NE	NE	NE	NE	IE

1.A.2.l - Textile and Leather	IE	IE	IE	NE	NE	NE	NE	IE
1.A.2.m - Non-specified Industry	IE	IE	IE	NE	NE	NE	NE	IE
1.A.3 - Transport	*51 731*	*12*	*3*	*0*	*0*	*0*	*0*	*52 744*
1.A.3.a - Civil Aviation	684	0	0	NE	NE	NE	NE	689
1.A.3.a.i - International Aviation (International Bunkers)	*2 311*	*0*	*0*	*NE*	*NE*	*NE*	*NE*	*2 328*
1.A.3.a.ii - Domestic Aviation	*684*	*0*	*0*	*NE*	*NE*	*NE*	*NE*	*689*
1.A.3.b - Road Transportation	50 190	12	2	NE	NE	NE	NE	51 159
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	362	0	0	NE	NE	NE	NE	395
1.A.3.d - Water-borne Navigation	495	0	0	NE	NE	NE	NE	500
1.A.3.d.i - International water-borne navigation (International bunkers)	*1 362*	*0*	*0*					*1 376*
1.A.3.d.ii - Domestic Water-borne Navigation	*495*	*0*	*0*	*NE*	*NE*	*NE*	*NE*	*500*
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	*18 617*	*6*	*1*	*0*	*0*	*0*	*0*	*19 029*
1.A.4.a - Commercial/Institutional	12 038	0	0	NE	NE	NE	NE	12 077
1.A.4.b - Residential	3 496	6	1	NE	NE	NE	NE	3 858
1.A.4.c - Agriculture/Forestry/Fishing/Fish Farms	3 084	0	0	NE	NE	NE	NE	3 095

1.A.4.c.i - Stationary	3 084	0	0	NE	NE	NE	NE	3 095
1.A.4.c.ii - Off-road Vehicles and Other Machinery	IE	IE	IE	NE	NE	NE	NE	NE
1.A.4.c.iii - Fishing (mobile combustion)	IE	IE	IE	NE	NE	NE	NE	NE
1.A.5 - Non-Specified	20 352	12	2	0	0	0	0	21 198
1.A.5.a - Stationary	20 352	12	2	NE	NE	NE	NE	21 198
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								
1.B - Fugitive emissions from fuels	23 912	174	0	0	0	0	0	28 787
1.B.1 - Solid Fuels	366	69		0	0	0	0	2 289
1.B.1.a - Coal mining and handling	16	60		NE	NE	NE	NE	1 689
1.B.1.a.i - Underground mines	16	60		NE	NE	NE	NE	1 689
1.B.1.a.i.1 - Mining	13	48		NE	NE	NE	NE	1 369
1.B.1.a.i.2 - Post-mining seam gas emissions	3	11		NE	NE	NE	NE	320
1.B.1.a.i.3 - Abandoned underground mines	NE	NE		NE	NE	NE	NE	NE
1.B.1.a.i.4 - Flaring of drained methane or conversion of methane to CO2	NE	NE		NE	NE	NE	NE	NE
1.B.1.a.ii - Surface mines	0	0		NE	NE	NE	NE	0
1.B.1.a.ii.1 - Mining	0	0		NE	NE	NE	NE	0
1.B.1.a.ii.2 - Post-mining seam gas emissions	0	0		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	349	9	0	NE	NE	NE	NE	NE
1.B.2 - Oil and Natural Gas	70	0	0	0	0	0	0	94
1.B.2.a - Oil	70	0	0	NE	NE	NE	NE	94
1.B.2.a.i - Venting				NE	NE	NE	NE	NE
1.B.2.a.ii - Flaring				NE	NE	NE	NE	NE
1.B.2.a.iii - All Other				NE	NE	NE	NE	0

1.B.2.a.iii.1 - Exploration				*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.a.iii.2 - Production and Upgrading				*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.a.iii.3 - Transport				*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.a.iii.4 - Refining				*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.a.iii.5 - Distribution of oil products				*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.a.iii.6 - Other				*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.b - Natural Gas				NE	NE	NE	NE	0
1.B.2.b.i - Venting				*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.b.ii - Flaring				*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.b.iii - All Other				*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.b.iii.1 - Exploration				*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.b.iii.2 - Production				*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.b.iii.3 - Processing				*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.b.iii.4 - Transmission and Storage				*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.b.iii.5 - Distribution				*NE*	*NE*	*NE*	*NE*	*0*
1.B.2.b.iii.6 - Other				*NE*	*NE*	*NE*	*NE*	*0*
1.B.3 - Other emissions from Energy Production	*23 477*	*105*	*0*	*0*	*0*	*0*	*0*	*26 410*
1.C - Carbon dioxide Transport and Storage	0			0	0	0	0	0
1.C.1 - Transport of CO2	*0*			*0*	*0*	*0*	*0*	*0*
1.C.1.a - Pipelines	NE			NE	NE	NE	NE	NE
1.C.1.b - Ships	NE			NE	NE	NE	NE	NE
1.C.1.c - Other (please specify)	NE			NE	NE	NE	NE	NE
1.C.2 - Injection and Storage	*0*			*0*	*0*	*0*	*0*	*0*
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 2022.

Categories	Emissions (Gg)										Emissions
	CO_2	CH_4	N_2O	HFCs	PFCs	SF6	NOx	CO	NMVOCs	SO_2	(Gg CO_2e)
2. Industrial processes and product use	**24 056.8**	**6.6**	**2.7**	**5 944.8**	**125.9**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**26 594.8**
2A Mineral Industry	**6 055.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**6 055.1**
2A1 Cement production	***5 022.7***						***NE***	***NE***	***NE***	***NE***	***5 022.7***
2A2 Lime production	***693.7***						***NE***	***NE***	***NE***	***NE***	***693.7***
2A3 Glass Production	***191.4***						***NE***	***NE***	***NE***	***NE***	***191.4***
2A4 Other Process Uses of Carbonates	***147.3***						***NE***	***NE***	***NE***	***NE***	***147.3***
2A4a Ceramics	34.3						NE	NE	NE	NE	34.3
2A4b Other Uses of Soda Ash	31.5						NE	NE	NE	NE	31.5
2A4c Non Metallurgical Magnesia Production	0						NE	NE	NE	NE	0
2A4d Other (please specify) (3)	81.5						NE	NE	NE	NE	81.5
2A5 Other (please specify) (3)							***NE***	***NE***	***NE***	***NE***	***NE***
2B Chemical Industry	**1 348.4**	**6.6**	**2.7**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**2 246.8**
2B1 Ammonia Production	***C***	***C***					***NE***	***NE***	***NE***	***NE***	***C***
2B2 Nitric Acid Production			***C***				***NE***	***NE***	***NE***	***NE***	***C***
2B3 Adipic Acid Production			***NE***				***NE***	***NE***	***NE***	***NE***	***NE***
2B4 Caprolactam. Glyoxal and Glyoxylic Acid Production			***NE***				***NE***	***NE***	***NE***	***NE***	***NE***
2B5 Carbide Production	***C***	***NE***					***NE***	***NE***	***NE***	***NE***	***C***
2B6 Titanium Dioxide Production	***C***						***NE***	***NE***	***NE***	***NE***	***C***
2B7 Soda Ash Production	***C***						***NE***	***NE***	***NE***	***NE***	***C***
2B8 Petrochemical and Carbon Black Production	***C***	***C***	***NE***	***NE***	***NE***	***NE***	***NE***	***NE***	***NE***	***NE***	***C***
2B8a Methanol	NO	NO					NO	NO	NO	NO	NO

2B8b Ethylene	NO	NO					NO	NO	NO	NO	NO
2B8c Ethylene Dichloride and Vinyl Chloride Monomer	NO	NO					NO	NO	NO	NO	NO
2B8d Ethylene Oxide	NO	NO					NO	NO	NO	NO	NO
2B8e Acrylonitrile	NO	NO					NO	NO	NO	NO	NO
2B8f Carbon Black	C	C					NE	NE	NE	NE	C
2B8g Hydrogen Production	C	NO					NE	NE	NE	NE	C
2B9 Fluorochemical Production	***NE***	***NE***	***NE***	***NE***	***NE***	***NE***	***NE***	***NE***	***NE***	***NE***	***NE***
2B9a By-product emissions (4)				NE			NE	NE	NE	NE	NE
2B9b Fugitive Emissions (4)							NE	NE	NE	NE	0.0
2B10 Other (Please specify) (3)							***NE***	***NE***	***NE***	***NE***	***0.0***
2C Metal Industry	**15 528.5**	**23.8**	**0.0**	**0.0**	**125.9**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**15 654.4**
2C1 Iron and Steel Production	***6 307.2***	***0.0***					***NE***	***NE***	***NE***	***NE***	***6 307.2***
2C2 Ferroalloys Production	***8 808.6***	***0.0***					***NE***	***NE***	***NE***	***NE***	***8 808.6***
2C3 Aluminium production	***1 133.5***				***125.9***		***NE***	***NE***	***NE***	***NE***	***1 259.3***
2C4 Magnesium production (5)	***0.0***					***NO***	***NO***	***NO***	***NO***	***NO***	***0.0***
2C5 Lead Production	***7.2***						***NE***	***NE***	***NE***	***NE***	***7.2***
2C6 Zinc Production	***0.0***						***NE***	***NE***	***NE***	***NE***	***0.0***
2C7 Other (please specify) (3)	***0.0***						***NE***	***NE***	***NE***	***NE***	***0.0***
2D Non-Energy Products from Fuels and Solvent Use (6)	**1 124.8**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**1 124.8**
2D1 Lubricant Use	***515.7***						***NE***	***NE***	***NE***	***NE***	***515.7***
2D2 Paraffin Wax Use	***609.1***						***NE***	***NE***	***NE***	***NE***	***609.1***
2D3 Solvent Use (7)							***NE***	***NE***	***NE***	***NE***	***0.0***
2D4 Other (please specify) (3). (8)							***NE***	***NE***	***NE***	***NE***	***0.0***
2E Electronics Industry	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
2E1 Integrated Circuit or Semiconductor (9)				***NE***	***NE***	***NE***	***NE***	***NE***	***NE***	***NE***	***NE***
2E2 TFT Flat Panel Display (9)					***NE***	***NE***	***NE***	***NE***	***NE***	***NE***	***NE***

2E3 Photovoltaics (9)					***NE***		***NE***	***NE***	***NE***	***NE***	***NE***
2E4 Heat Transfer Fluid (10)					***NE***		***NE***	***NE***	***NE***	***NE***	***NE***
2E5 Other (please specify) (3)							***NE***	***NE***	***NE***	***NE***	***NE***
2F Product Uses as Substitutes for Ozone Depleting Substances	**0.0**	**0.0**	**0.0**	**5 944.8**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**5 944.8**
2F1 Refrigeration and Air Conditioning	***0.0***	***0.0***	***0.0***	***5 836.9***	***NE***	***NE***	***NE***	***NE***	***NE***	***NE***	***5 836.9***
2F1a Refrigeration and Stationary Air Conditioning				3 292.6			NE	NE	NE	NE	3 292.6
2F1b Mobile Air Conditioning				2 544.3			NE	NE	NE	NE	2 544.3
2F2 Foam Blowing Agents				***2.1***			***NE***	***NE***	***NE***	***NE***	***2.1***
2F3 Fire Protection				***87.5***	***NE***		***NE***	***NE***	***NE***	***NE***	***87.5***
2F4 Aerosols				***18.3***			***NE***	***NE***	***NE***	***NE***	***18.3***
2F5 Solvents				***NE***	***NE***		***NE***	***NE***	***NE***	***NE***	***NE***
2F6 Other Applications (please specify) (3)				***NO***	***NO***		***NO***	***NO***	***NO***	***NO***	***NO***
2G Other Product Manufacture and Use	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**65.7**	**0.0**	**0.0**	**0.0**	**0.0**	**65.7**
2G1 Electrical Equipment	***NE***	***NE***	***NE***	***NE***	***NE***	***65.7***	***NE***	***NE***	***NE***	***NE***	***65.7***
2G1a Manufacture of Electrical Equipment					NE	NE	NE	NE	NE	NE	NE
2G1b Use of Electrical Equipment					NE	65.7	NE	NE	NE	NE	65.7
2G1c Disposal of Electrical Equipment					NE	NE	NE	NE	NE	NE	NE
2G2 SF6 and PFCs from Other Product Uses	***NE***	***NE***	***NE***	***NE***	***NE***	***NE***	***NE***	***NE***	***NE***	***NE***	***NE***
2G2a Military Applications					NE	NE	NE	NE	NE	NE	NE
2G2b Accelerators					NE	NE	NE	NE	NE	NE	NE
2G2c Other (please specify) (3)					NE	NE	NE	NE	NE	NE	NE
2G3 N2O from Product Uses	***NE***	***NE***	***NE***	***NE***	***NE***	***NE***	***NE***	***NE***	***NE***	***NE***	***NE***
2G3a Medical Applications			NE				NE	NE	NE	NE	NE

2G3b Propellant for pressure and aerosol products			NE				NE	NE	NE	NE	NE
2G3c Other (Please specify) (3)			NE				NE	NE	NE	NE	NE
2G4 Other (Please specify) (3)							***NE***	***NE***	***NE***	***NE***	***NE***
2H Other	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
2H1 Pulp and Paper Industry							***NE***	***NE***	***NE***	***NE***	***0.0***
2H2 Food and Beverages Industry							***NE***	***NE***	***NE***	***NE***	***0.0***
2H3 Other (please specify) (3)							***NE***	***NE***	***NE***	***NE***	***0.0***

Table C.4: Summary Agriculture sector emission table for South Africa for 2022.

	Emissions (Gg)						Total emissions (Gg CO_2e)
	CO_2	CH_4	N_2O	NOx	CO	NMVOCs	
3 - Agriculture	**2 445.4**	**1 385.3**	**50.7**	**671.9**	**32.6**	**38.9**	**53 518.67**
Livestock	**0.0**	**1 360.5**	**8.4**	**0.0**	**0.0**	**0.0**	**40 636.63**
3.A - Enteric Fermentation	0.0	1 298.3	0.0	0.0	0.0	0.0	***36 352.11***
3.A.1 - Cattle		1 005.0					28 139.0
3.A.1.a - Dairy Cows		130.0					3 639.7
3.A.1.b - Other Cattle		875.0					24 499.2
3.A.2 - Sheep		227.8					6 377.5
3.A.3 - Swine		1.5					43.2
3.A.4 – Other							
3.A.4.a- Buffalo		NO					NO
3.A.4.b - Camels		NO					NO
3.A.4.d - Goats		56.4					1 578.6
3.A.4.e - Horses		6.0					168.0
3.A.4.f - Mules and Asses		1.6					45.8
3.B - Manure Management	***0.0***	**62.2**	**8.4**	***0.0***	***0.0***	***0.0***	**4 284.5**
3.B.1 - Cattle		44.4	4.3				2 385.7
3.B.1.a - Dairy Cows		20.1	0.8				776.9
3.B.1.b - Other Cattle		24.3	3.5				1 608.8
3.B.2 - Sheep		3.1	0.5				87.6
3.B.3 - Swine		7.5	0.1				208.9
3.B.4 – Other							
3.B.4-a Buffalo		NO	NO				NO
3.B.4-b Camels		NO	NO				NO
3.B.4.d - Goats		1.0	0.2				27.1
3.B.4.e - Horses		NO	NO				NO
3.B.4.f - Mules and Asses		NO	NO				NO

3.B.4.g - poultry		6.3	3.2				175.4
3.B.5 – Indirect N_2O emissions			***1.2***				**325.2**
3.C - Rice cultivation	**NO**	**NO**	**NO**				**NO**
3.D - Agricultural soils	***0.0***	***39.2***	***2.7***	***1 093.9***	***47.7***	***53.4***	***10 378.1***
3.D.1-Direct N_2O Emissions from managed soils			35.4				9 382.9
3.D.2-Indirect N_2O Emissions from managed soils			3.8				995.2
3.E - Prescribed burning of savannas	**IE**	**IE**	**IE**				**IE**
3.F-Field burning of agricultural residues	**1.7**	**0.0**	**57.2**	**1.6**	**NO**	**1.7**	***58.5***
3.G - Liming	**1 860.7**						**1 860.7**
3.H - Urea application	**584.7**						**584.7**
3.I - Other carbon containing fertilisers	**NE**	**NE**	**NE**				***NE***
3.J - Other	**NO**	**NO**	***NO***				***NO***

Table C.5: Summary LULUCF sector emission table for South Africa for 2022.

	Emissions (Gg)						Total emissions (Gg CO_2e)
	CO_2	CH_4	N_2O	NOx	CO	NMVOCs	
4 - LULUCF	**-56 146.3**	**393.6**	**7.8**	**105.1**	**2 184.7**	**210.9**	**-43 059.8**
4.A - Forest land	**-90 082.4**	**57.7**	**3.4**	**57.7**	**1 421.2**	**150.1**	**-87 558.8**
4.A.1 - Forest land Remaining Forest land	-34 404.1	40.7	2.1	36.7	981.7	109.5	-32 696.7
4.A.2 - Land Converted to Forest land	-55 678.3	17.0	1.3	21.0	439.5	40.6	-54 862.1
4.A.2.a - Cropland converted to Forest Land	*-4 993.1*	*1.5*	*0.1*	*2.0*	*40.2*	*2.1*	*-4 918.5*
4.A.2.b - Grassland converted to Forest Land	*-47 358.8*	*14.0*	*1.1*	*17.6*	*363.1*	*34.7*	*-46 684.6*
4.A.2.c - Wetlands converted to Forest Land	*-1 073.4*	*0.6*	*0.0*	*0.6*	*15.5*	*1.8*	*-1 044.4*
4.A.2.d - Settlements converted to Forest Land	*-805.6*	*0.4*	*0.0*	*0.4*	*10.6*	*1.1*	*-785.9*
4.A.2.e - Other Land converted to Forest Land	*-1 447.3*	*0.4*	*0.0*	*0.5*	*10.0*	*1.0*	*-1 428.7*
4.B - Cropland	**3 508.9**	**IE**	**IE**	**IE**	**IE**	**IE**	**3 508.9**
4.B.1 - Cropland Remaining Cropland	79.5	IE	IE	IE	IE	IE	79.5
4.B.2 - Land Converted to Cropland	3 429.4	IE	IE	IE	IE	IE	3 429.4
4.B.2.a - Forest Land converted to Cropland	*1 423.5*	*IE*	*IE*	*IE*	*IE*	*IE*	*1 423.5*
4.B.2.b - Grassland converted to Cropland	*1 894.3*	*IE*	*IE*	*IE*	*IE*	*IE*	*1 894.3*
4.B.2.c - Wetlands converted to Cropland	*242.9*	*IE*	*IE*	*IE*	*IE*	*IE*	*242.9*
4.B.2.d - Settlements converted to Cropland	*-24.8*	*IE*	*IE*	*IE*	*IE*	*IE*	*-24.8*
4.B.2.e - Other Land converted to Cropland	*-106.6*	*IE*	*IE*	*IE*	*IE*	*IE*	*-106.6*
4.C - Grassland	**10 576.8**	**25.2**	**2.3**	**42.8**	**713.2**	**55.3**	**11 893.4**
4.C.1 - Grassland Remaining Grassland	12 649.3	20.7	1.9	35.0	584.0	45.8	13 728.0
4.C.2 - Land Converted to Grassland	-2 072.4	4.5	0.4	7.8	129.2	9.4	-1 834.6
4.C.2.a - Forest Land converted to Grassland	*10 864.7*	*2.5*	*0.2*	*4.3*	*71.9*	*4.9*	*10 997.5*
4.C.2.b - Cropland converted to Grassland	*-2 297.8*	*0.6*	*0.1*	*1.1*	*17.6*	*1.4*	*-2 265.2*
4.C.2.c - Wetlands converted to Grassland	*-501.7*	*0.2*	*0.0*	*0.4*	*6.2*	*0.5*	*-491.1*
4.C.2.d - Settlements converted to Grassland	*-110.2*	*0.1*	*0.0*	*0.2*	*3.6*	*0.3*	*-103.5*
4.C.2.e - Other Land converted to Grassland	*-10 027.5*	*1.1*	*0.1*	*1.8*	*29.9*	*2.3*	*-9 972.3*

4.D - Wetlands	**747.9**	**310.6**	**2.1**	**4.4**	**47.6**	**5.3**	**9 989.2**
4.D.1 - Wetlands Remaining Wetlands	203.1	164.2	1.1	2.3	38.6	3.0	5 088.5
4.D.2 - Land Converted to Wetlands	544.8	146.4	1.0	2.1	8.9	2.3	4 900.7
4.D.2.c.i - Forest Land converted to wetlands	*171.9*	*37.9*	*0.3*	*0.5*	*8.9*	*0.7*	*1 299.2*
4.D.2.c.ii - Cropland converted to wetlands	*-13.8*	*9.6*	*0.1*	*0.1*	*0.0*	*0.2*	*272.5*
4.D.2.c.iii - Grasslands converted to wetlands	*417.7*	*94.0*	*0.6*	*1.3*	*0.0*	*1.3*	*3 213.4*
4.D.2.c.iv - Settlements converted to wetlands	*8.5*	*2.3*	*0.0*	*0.0*	*0.0*	*0.0*	*76.3*
4.D.2.c.v - Other Land converted to wetlands	*-39.5*	*2.7*	*0.0*	*0.0*	*0.0*	*0.0*	*39.4*
4.E - Settlements	**258.5**	**0.1**	**0.0**	**0.2**	**2.7**	**0.2**	**263.6**
4.E.1 - Settlements Remaining Settlements	-446.2	0.1	0.0	0.1	2.0	0.1	-442.6
4.E.2 - Land Converted to Settlements	704.7	0.0	0.0	0.0	0.8	0.1	706.1
4.E.2.a - Forest Land converted to Settlements	*525.5*	*0.0*	*0.0*	*0.0*	*0.3*	*0.0*	*526.0*
4.E.2.b - Cropland converted to Settlements	*-81.4*	*0.0*	*0.0*	*0.0*	*0.1*	*0.0*	*-81.2*
4.E.2.c - Grassland converted to Settlements	*268.5*	*0.0*	*0.0*	*0.0*	*0.3*	*0.0*	*269.2*
4.E.2.d - Wetlands converted to Settlements	*7.9*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*7.9*
4.E.2.e - Other Land converted to Settlements	*-15.8*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*-15.8*
4.F - Other Land	**19 025.4**	**NO**	**NO**	**NO**	**NO**	**NO**	**19 025.4**
4.F.1 - Other land Remaining Other land	0	NO	NO	NO	NO	NO	0.0
4.F.2 - Land Converted to Other land	19025.37	NO	NO	NO	NO	NO	19 025.4
4.F.2.a - Forest Land converted to Other Land	*761.61443*	*NO*	*NO*	*NO*	*NO*	*NO*	*761.6*
4.F.2.b - Cropland converted to Other Land	*2.2401785*	*NO*	*NO*	*NO*	*NO*	*NO*	*2.2*
4.F.2.c - Grassland converted to Other Land	*18120.881*	*NO*	*NO*	*NO*	*NO*	*NO*	*18 120.9*
4.F.2.d - Wetlands converted to Other Land	*133.12041*	*NO*	*NO*	*NO*	*NO*	*NO*	*133.1*
4.F.2.e - Settlements converted to Other Land	*7.5173288*	*NO*	*NO*	*NO*	*NO*	*NO*	*7.5*
4.G - Harvested wood products	**-181.4**	**NA**	**NA**	**NA**	**NA**	**NA**	**-181.4**

Table C.6: Summary Land sector emission table for South Africa for 2022.

Categories	Activity Data		Net carbon stock change and CO2 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)	Net carbon stock change (Gg C)	Carbon stock change (Gg C)	Net carbon stock change (Gg C)	Net carbon stock change in mineral soils (2) (Gg C)	Carbon loss from drained organic soils (Gg C)	
4 - LULUCF	**123 562 851**	**NE**	**47 471.4**	**34 674.5**	**12 796.9**	**1 926.8**	**1 926.8**	**539.5**	**NE**	**-55 964.9**
4.A - Forest land	**27 756 880**	**NE**	**41 955.1**	**19 632.9**	**22 322.1**	**1 826.8**	**1 826.8**	**419.0**	**NE**	**-90 082.4**
4.A.1 - Forest land Remaining Forest land	16 848 814	NE	25 227.5	16 161.4	9 066.1	316.8	316.8	0.0	NE	-34 404.1
4.A.2 - Land Converted to Forest land	10 908 066	NE	16 727.6	3 471.5	13 256.0	1 509.9	1 509.9	419.0	NE	-55 678.3
4.A.2.a - Cropland converted to Forest Land	*1 005 784*	*NE*	*1 303.3*	*344.9*	*958.4*	*120.9*	*120.9*	*282.4*	*NE*	*-4 993.1*
4.A.2.b - Grassland converted to Forest Land	*9 229 456*	*NE*	*14 504.0*	*2 887.0*	*11 616.9*	*1 294.8*	*1 294.8*	*4.3*	*NE*	*-47 358.8*
4.A.2.c - Wetlands converted to Forest Land	*232 530*	*NE*	*334.7*	*95.3*	*239.5*	*30.1*	*30.1*	*23.1*	*NE*	*-1 073.4*
4.A.2.d - Settlements converted to Forest Land	*193 200*	*NE*	*263.8*	*70.0*	*193.8*	*25.9*	*25.9*	*0.0*	*NE*	*-805.6*

4.A.2.e - Other Land converted to Forest Land	*247 096*	*NE*	*321.8*	*74.4*	*247.4*	*38.2*	*38.2*	*109.1*	*NE*	*-1 447.3*
4.B - Cropland	**14 298 177**	**NE**	**1 824.9**	**2 150.7**	**-325.8**	**139.2**	**139.2**	**-770.4**	**NE**	**3 508.9**
4.B.1 - Cropland Remaining Cropland	11 303 557	NE	812.2	855.0	-42.8	16.6	16.6	4.5	NE	79.5
4.B.2 - Land Converted to Cropland	2 994 619	NE	1 012.7	1 295.7	-283.0	122.6	122.6	-774.8	NE	3 429.4
4.B.2.a - Forest Land converted to Cropland	*917 367*	*NE*	*388.6*	*599.3*	*-210.7*	*17.0*	*17.0*	*-194.6*	*NE*	*1 423.5*
4.B.2.b - Grassland converted to Cropland	*1 922 251*	*NE*	*573.4*	*650.3*	*-76.9*	*97.2*	*97.2*	*-537.0*	*NE*	*1 894.3*
4.B.2.c - Wetlands converted to Cropland	*80 563*	*NE*	*18.1*	*45.4*	*-27.3*	*4.2*	*4.2*	*-43.2*	*NE*	*242.9*
4.B.2.d - Settlements converted to Cropland	*34 990*	*NE*	*5.8*	*0.2*	*5.6*	*1.1*	*1.1*	*0.0*	*NE*	*-24.8*
4.B.2.e - Other Land converted to Cropland	*39 449*	*NE*	*26.9*	*0.7*	*26.2*	*3.0*	*3.0*	*-0.1*	*NE*	*-106.6*
4.C - Grassland	**61 859 432**	**NE**	**3 458.3**	**8 569.4**	**-5 111.0**	**293.8**	**293.8**	**1 932.7**	**NE**	**10 576.8**
4.C.1 - Grassland Remaining Grassland	49 110 515	NE	1 293.6	4 884.7	-3 591.2	141.4	141.4	0.0	NE	12 649.3

4.C.2 - Land Converted to Grassland	12 748 917	NE	2 164.8	3 684.6	-1 519.9	152.4	152.4	1 932.7	NE	-2 072.4
4.C.2.a - Forest Land converted to Grassland	*6 490 577*	*NE*	*460.6*	*3 278.5*	*-2 817.8*	*-142.2*	*-142.2*	*-3.1*	*NE*	*10 864.7*
4.C.2.b - Cropland converted to Grassland	*1 638 753*	*NE*	*161.3*	*46.0*	*115.3*	*11.4*	*11.4*	*499.9*	*NE*	*-2 297.8*
4.C.2.c - Wetlands converted to Grassland	*574 317*	*NE*	*58.8*	*68.4*	*-9.6*	*16.9*	*16.9*	*129.6*	*NE*	*-501.7*
4.C.2.d - Settlements converted to Grassland	*326 200*	*NE*	*23.6*	*4.6*	*18.9*	*11.4*	*11.4*	*-0.3*	*NE*	*-110.2*
4.C.2.e - Other Land converted to Grassland	*3 719 070*	*NE*	*1 460.5*	*287.1*	*1 173.4*	*254.9*	*254.9*	*1 306.5*	*NE*	*-10 027.5*
4.D - Wetlands	**3 100 156**	**NE**	**0.0**	**158.9**	**-158.9**	**15.1**	**15.1**	**-60.2**	**NE**	**747.9**
4.D.1 - Wetlands Remaining Wetlands	2 423 513	NE	0.0	45.9	-45.9	1.5	1.5	-11.0	NE	203.1
4.D.2 - Land Converted to Wetlands	676 643	NE	0.0	113.0	-113.0	13.6	13.6	-49.2	NE	544.8
4.D.2.c.i - Forest Land converted to wetlands	*14 549*	*NE*	*0.0*	*29.2*	*-29.2*	*2.2*	*2.2*	*-19.8*	*NE*	*171.9*
4.D.2.c.ii - Cropland converted to wetlands	*46 692*	*NE*	*0.0*	*3.9*	*-3.9*	*-0.2*	*-0.2*	*7.9*	*NE*	*-13.8*

4.D.2.c.iii - Grasslands converted to wetlands	*495 844*	*NE*	*0.0*	*78.7*	*-78.7*	*10.7*	*10.7*	*-45.9*	*NE*	*417.7*
4.D.2.c.iv - Settlements converted to wetlands	*24 695*	*NE*	*0.0*	*1.0*	*-1.0*	*0.2*	*0.2*	*-1.5*	*NE*	*8.5*
4.D.2.c.v - Other Land converted to wetlands	*94 862*	*NE*	*0.0*	*0.0*	*0.0*	*0.7*	*0.7*	*10.1*	*NE*	*-39.5*
4.E - Settlements	**3 644 453**	**NE**	**233.0**	**381.3**	**-148.2**	**37.1**	**37.1**	**40.6**	**NE**	**258.5**
4.E.1 - Settlements Remaining Settlements	2 465 619	NE	168.3	49.1	119.2	2.4	2.4	0.0	NE	-446.2
4.E.2 - Land Converted to Settlements	1 178 833	NE	64.7	332.2	-267.5	34.6	34.6	40.6	NE	704.7
4.E.2.a - Forest Land converted to Settlements	*387 473*	*NE*	*24.8*	*176.1*	*-151.3*	*8.0*	*8.0*	*0.0*	*NE*	*525.5*
4.E.2.b - Cropland converted to Settlements	*145 332*	*NE*	*7.7*	*26.0*	*-18.3*	*3.8*	*3.8*	*36.7*	*NE*	*-81.4*
4.E.2.c - Grassland converted to Settlements	*592 721*	*NE*	*30.8*	*125.5*	*-94.7*	*21.1*	*21.1*	*0.3*	*NE*	*268.5*
4.E.2.d - Wetlands converted to Settlements	*19 851*	*NE*	*0.5*	*4.4*	*-3.9*	*0.3*	*0.3*	*1.4*	*NE*	*7.9*
4.E.2.e - Other Land converted to Settlements	*33 457*	*NE*	*0.8*	*0.2*	*0.6*	*1.4*	*1.4*	*2.3*	*NE*	*-15.8*
4.F - Other Land	**12 903 753**	**NE**	**0.0**	**3 781.4**	**-3 781.4**	**-385.2**	**-385.2**	**-1 022.2**	**NE**	**19 025.4**

4.F.1 - Other land Remaining Other land	9 246 448	NE			0.0		0.0	0.0	NE	0.0
4.F.2 - Land Converted to Other land	3 657 305	NE	0.0	3 781.4	-3 781.4	-385.2	-385.2	-1 022.2	NE	19 025.4
4.F.2.a - Forest Land converted to Other Land	*176 235*	*NE*	*0.0*	*125.7*	*-125.7*	*-17.5*	*-17.5*	*-64.6*	*NE*	*761.6*
4.F.2.b - Cropland converted to Other Land	*38 226*	*NE*	*0.0*	*0.8*	*-0.8*	*-0.1*	*-0.1*	*0.3*	*NE*	*2.2*
4.F.2.c - Grassland converted to Other Land	*3 294 173*	*NE*	*0.0*	*3 649.5*	*-3 649.5*	*-367.4*	*-367.4*	*-925.1*	*NE*	*18 120.9*
4.F.2.d - Wetlands converted to Other Land	*148 183*	*NE*	*0.0*	*5.2*	*-5.2*	*-0.2*	*-0.2*	*-30.9*	*NE*	*133.1*
4.F.2.e - Settlements converted to Other Land	*487*	*NE*	*0.0*	*0.1*	*-0.1*	*0.0*	*0.0*	*-1.9*	*NE*	*7.5*

Table C.7: Summary Waste sector emission table for South Africa for 2022.

Categories	Emissions [Gg]							Total emissions
	CO_2	CH_4	N_2O	NOx	CO	NMVOCs	SO_2	(Gg CO_2e)
5 - Waste	**28.91**	**682.05**	**5.93**	**NE**	**NE**	**NE**	**NE**	**20 698.43**
5A - Solid Waste Disposal		307.00		NE	NE	NE	NE	8 596.00
5A1 - Managed Waste Disposal Sites		307.00		NE	NE	NE	NE	8 596.00
5A2 - Unmanaged Waste Disposal Sites		NE		NE	NE	NE	NE	NE
5A3 - Uncategorised Waste Disposal Sites		NE		NE	NE	NE	NE	NE
5B - Biological Treatment of Solid Waste		61.99	3.00	NE	NE	NE	NE	2 530.38
5C - Incineration and Open Burning of Waste	28.91	8.69	0.20	NE	NE	NE	NE	325.37
5C1 - Waste Incineration	NE	NE	NE	NE	NE	NE	NE	NE
5C2 - Open Burning of Waste	28.91	8.69	0.20	NE	NE	NE	NE	325.37
5D - Wastewater Treatment and Discharge	0.00	304.37	2.73	NE	NE	NE	NE	9 246.69
5D1 - Domestic Wastewater Treatment and Discharge		125.25	2.73	NE	NE	NE	NE	4 231.15
5D2 - Industrial Wastewater Treatment and Discharge		179.13		NE	NE	NE	NE	5 015.54
5E - Other (please specify)				NE	NE	NE	NE	NE

Appendix D: Reference and sectoral fuel consumption

The figures below show the comparison between the Reference and Sectoral Approach for 2000-2020 should this in line with the latest available data from the energy balance.

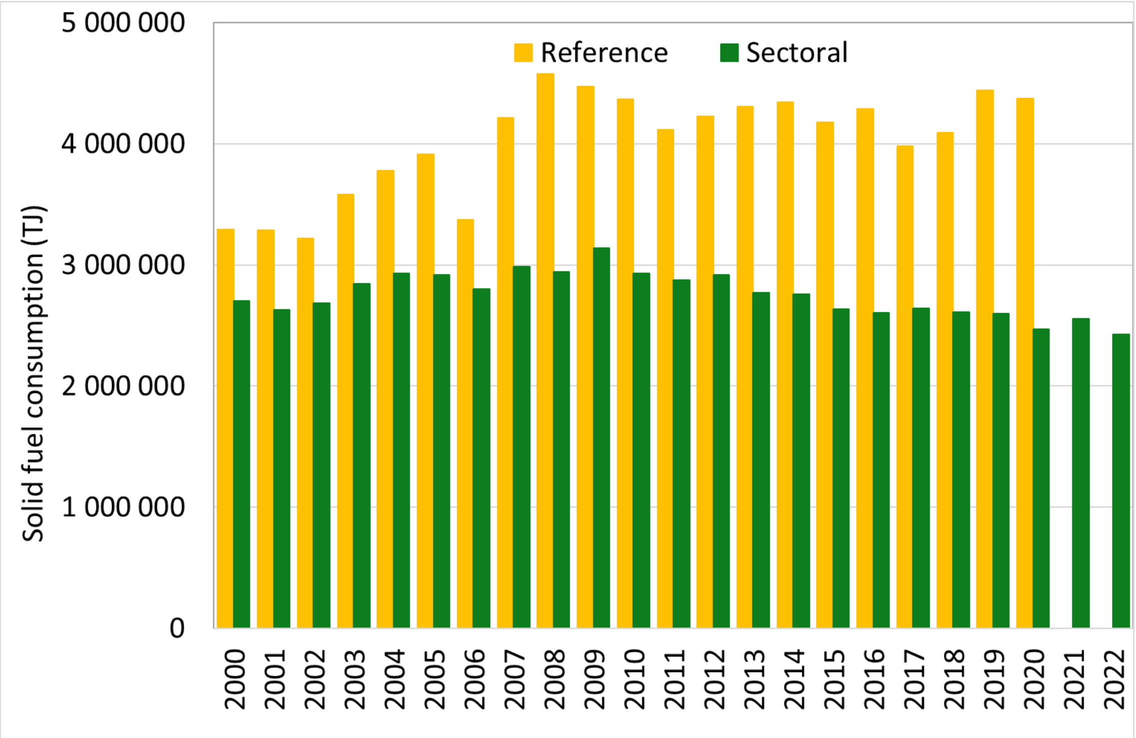

Figure D.1: Comparisons between the solid fuel consumption determined by the reference and sectoral approaches, 2000 – 2020.

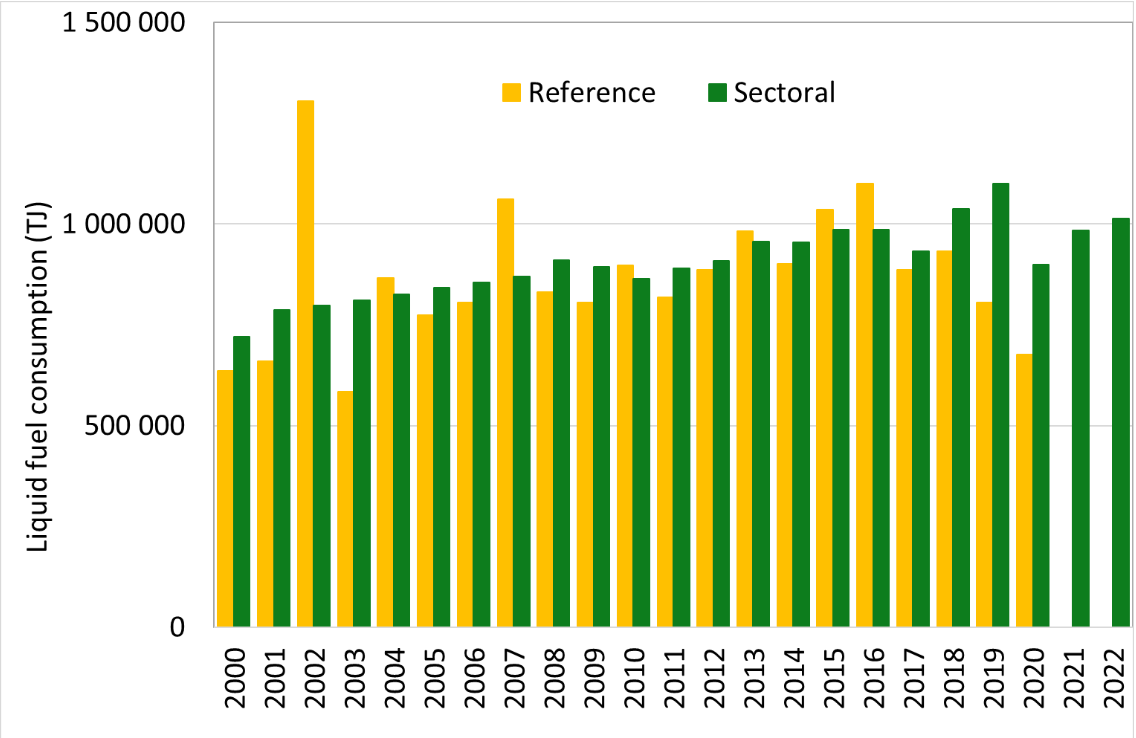

Figure D.2: Comparisons between the liquid fuel consumption determined by the reference and sectoral approaches, 2000 – 2020.

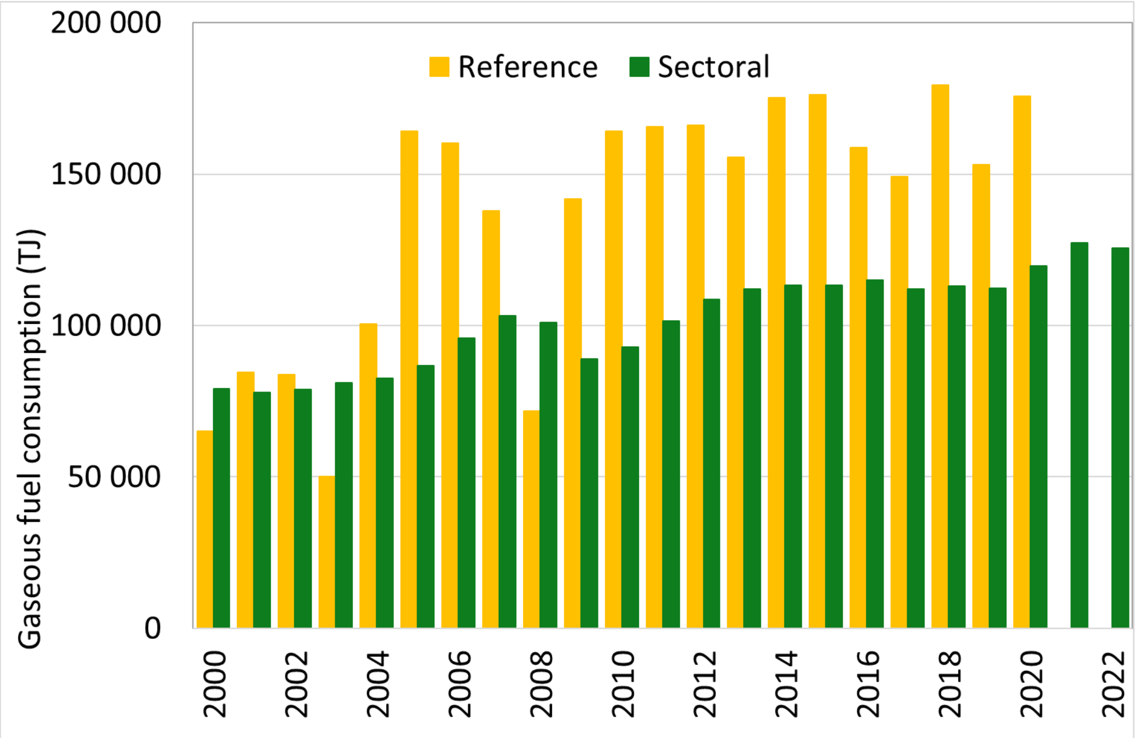

Figure D.3: Comparisons between the gaseous fuel consumption determined by the reference and sectoral approaches, 2000 – 2020.